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BACKGROUND GAMMA RADIATION OF THE NEWCASTLE 1° x 2° QUADRANGLE, WYOMING AND SOUTH DAKOTA

by

Ray E. Harris

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Abstract

A study of the natural background gamma radiation intensity of the Newcastle 1°x 2° Quadrangle was conducted by the Geological Survey of Wyoming as part of an ongoing study of the natural gamma-ray background of Wyoming. A knowledge of background radiation intensity is useful since radiation intensity may indicate mineralization or affect land use.

Radiation intensity was measured 3 feet above ground level. Surface gamma radiation intensities are due to cosmic radiation and terrestrial radiation. Cosmic radiation intensity is a function of altitude. The decrease in cosmic radiation intensity with decreasing elevation is due to attenuation by the atmosphere. Cosmic radiation values in the Newcastle Quadrangle range from less than 0.007 mR/hr (milliroentgens per hour) to a high of 0.011 mR/hr.

Terrestrial radiation is proportional to the amount of uranium, thorium, and potassium in surface material. In the Newcastle Quadrangle, the highest terrestrial radiation intensity is found over the Oligocene White River Formation (average .025 mR/hr) and lower Miocene rocks (average 0.21 mR/hr). Slightly elevated intensity occurs over the Cretaceous Pierre, Belle Fourche, and Mowry Shales, and the Jurassic Morrison Formation (average .012-.013 mR/hr). The lowest intensity is found over the Mississippian Pahasapa and Permian Minnekahta Limestones (average .003-.004 mR/hr).

Variations in intensity within a rock unit are due to the syngenetic and/or diagenetic distribution of radioactive isotopes within each unit. An anomaly is a reading two times higher or lower than the average for the rock unit. Three positive and four negative gamma radiation anomalies were located in the Newcastle Quadrangle.

Introduction

Maps and tables accompanying this report (**Plates** 1 and 2 and **Tables** 1 and 2) present the natural background gamma radiation flux in the Newcastle 1°x 2° map area, Wyoming, South Dakota, and Nebraska. Gamma radiation is a primary component of natural radiation, a form of electromagnetic radiation characterized by wave lengths from 10^{-7} to 10^{-11} cm and frequencies of 10^{17} to 10^{21} sec^{-1} (Adams and Gasparini, 1970). This places gamma radiation at the short wave length and high frequency end of the electromagnetic radiation spectrum that includes radio waves, infrared and ultraviolet radiation, and visible light.

The other primary components of natural radiation, called alpha and beta, are much less energetic and penetrating. Alpha radiation, which consists of particles composed of two protons and two neutrons, can be stopped or shielded by a sheet of paper or plastic wrap. Beta radiation, which consists of particles called electrons, can be shielded by an inch of wood. Gamma radiation, however, can penetrate about three feet of concrete and about 0.25 inch of lead. Other types of ionizing radiation, including x-rays and neutron radiation, are a minor part of the background radiation flux at the surface.

A knowledge of the background radiation flux of an area may be useful to exploration geologists and land-use planners. Mineralized areas are often characterized by anomalous gamma radiation flux and the local radiation flux may affect a particular development or land use.

The purpose of this study is to provide a reference for expected radiation flux values. This report is the second of a planned series for each of the sixteen 1° x 2° quadrangles that cover Wyoming. The first, the Torrington 1° x 2° Quadrangle (Harris, 1985), adjoins the Newcastle Quadrangle to the south.

Maps showing gamma radiation flux were constructed for all of the 1° x 2° maps of Wyoming during the U.S. Department of Energy's National Uranium Resource Evaluation (NURE) program. However, these maps were plotted from information gathered by airborne detectors, which measured the radiation flux at altitudes of a few hundred feet. Terrestrial, atmospheric, and cosmic radiation are not separated on these maps. The NURE maps may be used to locate broad gamma radiation flux anomalies such as those associated with large bodies of high-background rock and uranium occurrences, but cannot be used as a guide to expected background radiation flux levels at the surface (GeoMetrics, 1979). Factors such as aircraft altitude, vegetation cover, area measured by the instrument, air pressure, humidity, and others, can be measured or estimated and then factored into the airborne measurements, as has been done in Canadian airborne surveys (Grasty and others, 1984), to give surface radiation flux values. Some of these factors were not considered during the NURE studies. Since the measurements of background radiation in this report were taken at ground level, these factors need not be considered. Cosmic radiation can be calculated and is plotted separately (Plate 1).

Non-natural gamma radiation has been released to the environment primarily by the atmospheric testing of nuclear weapons. In the Newcastle map area, the gamma-radiation flux from this fallout is now too small to detect. The reader is referred to Eisenbud (1987) for a complete discussion of fallout and its structure and distribution. Other non-natural sources of radiation over Wyoming have not produced amounts detectable by the instruments used in this study. Gamma radiation flux measurements were taken in Laramie, Wyoming by the author during the passage of the cloud of emissions from the Chernobyl meltdown in the Soviet Union in 1986 and no changes in the gamma radiation flux were observed.

Units of radiation

Values throughout this study are measurements of radiation flux (energy per unit time)[1] and are presented in milliroentgens per hour (mR/hr). These units relate directly to radiation dose rates (REMs). Radiation per unit time is flux, measured in units like milliroentgens per hour. Radiation per unit time in a given area is intensity and is measured in units like milliroentgens per hour per square centimeter (West and others, 1986). The use of the term intensity by most writers (and the American Geological Institute's *Glossary of Geology*) for measurements given in units of milliroentgens per hour is incorrect. Radiation intensity may be calculated from the radiation flux and the size of the detector. (See Appendix A for calculation of dose rates.)

Methods of obtaining data

The detectors used to measure radiation in the Newcastle 1° x 2° Quadrangle were a Precision Model 111 scintillator and a McPhar TV-1A spectrometer. The detectors were calibrated to a known radiation flux using a standard source of gamma radiation at each site. The standard sources were calibrated by the University of Wyoming Radiation Safety Office. One or two measurements were taken each day at base localities, and several sites were measured at different times to calibrate between the base localities. These correlations were done to check for variations in atmospheric and cosmic radiation flux. During this study, measurements at base stations varied less than ± 0.003 mR/hr. At each site, all measurements were taken 3 feet from an outcrop to ensure uniformity.

Sources of background gamma radiation

Cosmic radiation

Cosmic radiation is primary radiation that originates in outer space. This radiation, as detected by space probes above the Earth's atmosphere, consists of 87 percent protons, 11 percent alpha particles, and about one percent each of electrons and atomic nuclei of elements between and including beryllium (atomic number 4) and iron (atomic number 26). The interactions between these particles and nuclei of elements in the outer atmosphere of the Earth produce gamma rays and other types of radiation (Eisenbud, 1987). The gamma radiation so produced is a major source of gamma radiation at the surface of the Earth.

The gamma radiation flux from cosmic radiation is a function of altitude. The flux doubles with every 1 mile increase in altitude from sea level for altitudes below 20,000 feet (Eisenbud, 1987; Herbst, 1964), and increases to a maximum at altitudes between 52,000 and 78,000 feet (Lillie, 1986). The decrease in cosmic radiation with decreasing elevation is due to attenuation (partial shielding) of the radiation by the atmosphere. Some components of cosmic radiation such as x-rays are almost completely attenuated at low altitudes. Factors such as latitude, humidity, and air pressure affect the cosmic gamma radiation flux at the surface but in amounts less than the detection limits of the instruments used in this study. For this study, values calculated from the work of Herbst (1964) were plotted to the nearest 0.001 mR/hr (Plate 1). These values are comparable to the measurements of Lowder and Beck (1966) and O'Brien and McLaughlin (1972).

Terrestrial radiation

Terrestrial radiation is radiation originating in Earth materials. All Earth substances, including rock, soil, and water, contain trace amounts of radiogenic (radiation-producing) substances, which include the primary radiogenic isotopes uranium-238, uranium-235, thorium-232, and potassium-40 and their decay products. Very minor amounts of gamma radiation are produced by the naturally occurring but rare radioisotopes vanadium-50, lanthanum-138, and luthenium-176. The decay series of the isotopes of uranium and thorium are shown in **Figure 1**. Most of the total gamma radiation flux at the surface of the Earth comes from these isotopes in soil and rock and is a function of surface geology. Snow and the moisture content of the ground can affect the surface terrestrial radiation flux. Ground moisture was always low for this study, and readings were not taken over snow cover.

Thick soil cover can shield radiation produced by radioisotopes in the bedrock. Due to the shielding effect of soil and rocks, the gamma radiation flux that is measured at the surface is from radiogenic elements in the upper 8 to 12 inches of soil and rock. Weathering chemically removes uranium and potassium so soils usually contain a smaller amount of these elements than the parent rock (Grasty and others, 1984).

Water contains small amounts of the natural radioisotopes. Terrestrial gamma radiation is relatively low over large bodies of water (Herbst, 1964). Water bodies in the Newcastle map area are too small to have an effect on background gamma radiation levels in this area.

Atmospheric radiation

Atmospheric radiation is a minor but constant part of terrestrial gamma radiation flux measurements. Atmospheric gamma radiation is produced by the decay of radioisotopes in the atmosphere. In the decay series of uranium-238 and -235 and thorium-234, an isotope of radon is produced (**Figure 1**). The radon isotopes produced in the decay series of uranium-235 and thorium-234 have half lives (amount of time for half of the nuclei of each radioisotope to decay to the next isotope in the series) of less than a minute. However, radon-222, produced in the decay series from uranium-238, has a half life of almost four days. Radon is a noble gas (gaseous element that does not chemically combine with other elements to produce other compounds) and can be released to the atmosphere. The decay of other isotopes in the decay series of radon-222 produces gamma radiation, especially the decay of bismuth-214 (**Figure 1**). This is the primary source of atmospheric gamma radiation.

The amounts of radon-222 and its decay products in the atmosphere are not always uniform. Atmospheric inversions can increase the amount of atmospheric radiation by a factor of 10. The stagnant air in inversions continually receives radon-222 from the earth, so radon-222 and its decay products become more concentrated (Pitkin and others, 1964). Lowering barometric pressure increases the amount of radon-222 escaping from soil gas into the atmosphere, while increasing pressure decreases the amount escaping (Eisenbud, 1987). This change may be relatively minor. Measurement and calibration procedures used for this study would have detected significant changes in gamma radiation flux due to an atmospheric inversion or barometric pressure change.

The gamma radiation flux in an area increases significantly at the beginning of rain or snowfall but gradually returns to normal after a half hour or so of continuous precipitation. This is due to precipitation scavenging non-gaseous radioisotopes, particularly bismuth-214, from the atmosphere and returning them to the Earth's surface. The author has observed this effect during continuous background gamma radiation measurement at one site throughout the course of a rainstorm while conducting a surface background gamma radiation study of the northern Powder River Basin (Terry and others, 1974). Therefore, readings for this study were not taken during precipitation events.

Gamma radiation in the Newcastle 1° x 2° Quadrangle

Atmospheric inversions are rare in the Newcastle map area, due to the lack of large topographic depressions and to the prevalence of wind across the region. Any changes in atmospheric radiation were corrected by calibrating readings at standard locations at different times.

The cosmic gamma radiation flux in the mapped area (**Plate 1**) is less than 0.007 mR/hr on the east-central margin of the map area, where elevations less than 3,700 feet above sea level are found in the drainage of the Cheyenne River. The cosmic gamma radiation flux is greatest (0.011 mR/hr) at elevations above 6,400 feet in the Black Hills in the northeastern corner of the map area.

Terrestrial gamma radiation flux was measured at 275 locations (**Plate 2** and **Tables 1** and 2) in the Newcastle 1° x 2° Quadrangle. Measurements were made for every formation and(or) rock or sediment type in the area as mapped by Love and others (1987). **Table 2** presents the values of terrestrial radiation flux from **Table 1**, grouped according to the surface formation, rock type, or sediment type.

The average value of radiation flux from each unit is also shown on **Table 2.** The Cretaceous Inyan Kara Group and Jurassic Morrison Formation were mapped together by Love and others (1987) but because the Inyan Kara group has a significantly lower background gamma-radiation flux than the Morrison Formation, these units are differentiated in this report. The average value for lower Miocene rocks, which are only found in small areas adjacent to the Torrington 1° x 2° Quadrangle, was taken from the Torrington 1° x 2° report (Harris, 1985). Terrestrial radiation flux values for each site were corrected for altitude by subtracting the expected cosmic radiation flux value calculated by Herbst (1964).

The variability of gamma radiation flux from place to place within a geologic formation and(or) rock or sediment type is due to the distribution of radioactive isotopes within each unit, which can be a function of (1) depositional environment or mode of origin or (2) diagenesis, which can produce radioactive isotope depletions or concentrations. Mapped geologic formations and(or) rock or sediment type units may include many different rock types. A good example is the Fort Union Formation, which is composed of sandstones, siltstones, shales, and coal. This and other heterogenous units have variable background radiation. A large number of measurements were taken for such units to obtain an average flux rate for the unit. **Table 1** shows the lithology of such units at the site of each measurement.

Some mapped units, such as Quaternary alluvium (Qal), have their sources in different rock types. Their background radioactivity, while not locally variable, changes from area to area and appears in this quadrangle to equal or be slightly less than the adjacent bedrock. The background gamma radiation flux of landslide debris and terrace gravel deposits are dependent upon the type of rock material within each deposit, so no values are given for these units in this report.

The rock unit that emits the highest background gamma-ray flux in the Newcastle 1° x 2° Quadrangle area is the White River Formation (Oligocene). This unit is composed of sediments reworked from air-transported volcanic ash of acidic chemical composition, which contains greater than average amounts of potassium-40, uranium, and thorium. The White River Formation is also considered by some (for example Love, [1952]) to be the source of uranium for the sandstone-hosted redox deposits in Wyoming. Lower Miocene rocks also have a significant acidic volcanic component (Love and others, 1987) and are the next highest unit in background radiation flux. Bentonitic beds in the Cretaceous Belle Fourche and Mowry Shales have a higher gamma ray flux than the average for the quadrangle. Since bentonite is altered acidic volcanic material, this higher flux was expected. The bentonite beds have a significantly higher flux than the rest of their host unit, as determined from gamma signatures on downhole gamma-ray logs. The Jurassic Morrison Formation, partly composed of volcanic material, emits slightly more gamma radiation than the average rock unit in the map area. The Wasatch Formation emits more gamma radiation than the Fort Union Formation. This may be due to a greater proportion of arkosic material (containing more potassium-40) or to some effect of uranium transport related to uranium ore formation.

The lowest gamma radiation flux is found over the Mississippian Pahasapa and lower Pennsylvanian Englewood Formations of Love and others (1987). These units are principally carbonates and contain little uranium, thorium, potassium-40, and their decay products.

The expected background radiation flux for any location on the Newcastle 1° x 2° Quadrangle may be predicted by summing the terrestrial radiation flux values for the rock unit at the location (from **Plate 2** and **Table 2**) and the cosmic radiation flux at the location (from **Plate 1**). This value is the expected total background gamma radiation flux. Significant discrepancies (2 times greater or less than this calculated value) constitute an anomaly. Seven anomalies were detected during the course of this study. These are listed in **Table 3**. Known anomalous areas, such as those near past or present uranium mines, were not measured for this study.

Most of the anomalies from **Table 3** are due to the presence of gypsum, carbonaceous shale, and clinker (baked and fused rock). Gypsum contains very few radioisotopes. Clinker beds in both the Wasatch and Fort Union Formations have a significantly higher gamma radiation flux than the other formations. Carbonaceous shale absorbs uranium from ground water during diagenesis and weathering and has a greater gamma radiation flux than the rest of the unit in which it is found. However, coal beds are not more radioactive than the remainder of the Fort Union or Wasatch Formations.

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Appendix A

Radiation dose rates

Dose rates can also be calculated from A.P.I. units. Counts per second (c.p.s.) units are a function of detector design and size and cannot be correlated between individual brands of detectors. Reports on radiation flux should never use counts per second for units of radiation except when comparative values are desired.

Radiation doses and dose rates can be calculated from the radiation flux. One Roentgen (R) is the quantity of radiation that produces one electrostatic unit of charge in one milliliter of air at standard temperature and pressure. The dose may be calculated from the Roentgen by the following formula:

$$\text{dose rate } (D) = .869R$$

where D is measured in RADs (radiation absorbed dose). The dose in REMs is calculated from the dose in RADs:

$$D(\text{REMs}) = \text{RBE} \cdot D(\text{RADs})$$

where RBE is the relative biological effectiveness of the tissues in question to specific types of radiation. For human tissue, and for effectiveness due to gamma and X-radiation, the RBE is one so the dose in REMs is the same as the dose in RADs (Grasty and others, 1984). The dose rate is the dose per unit time as given from radiation flux measurements.

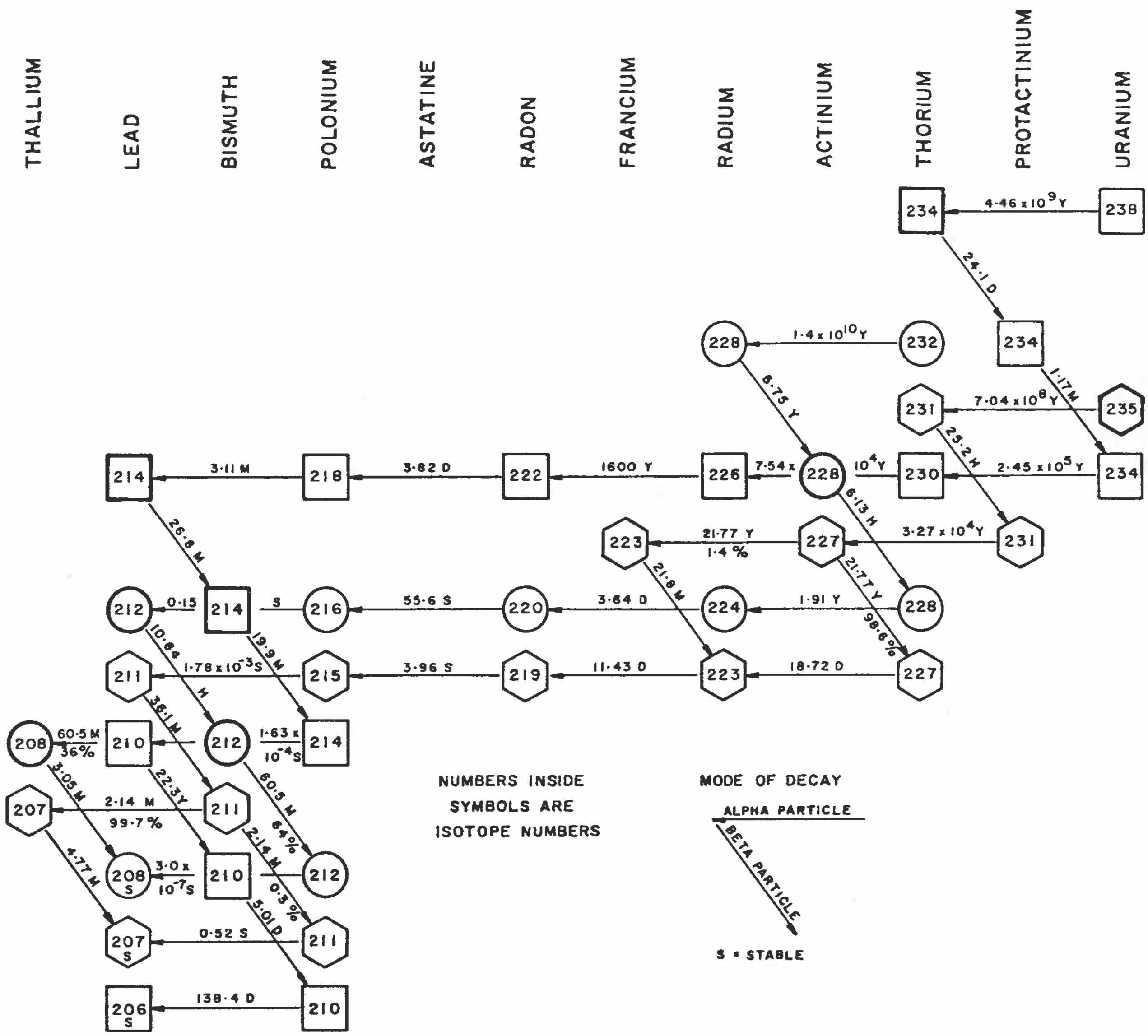


Figure caption:

Figure 1. Diagram showing natural decay series of uranium-238 (squares), uranium-235 (hexagons) and thorium-232 (circles). Isotopes with heavy outlines emit gamma rays that are detected by field and laboratory instruments. Number along mode of decay lines indicate half lives (y = years, d = days, m = minutes, s = seconds) and the percentages of isotopes that follow that particular mode of decay (after Heath, 1986; Adams and Gasparini, 1970).

Table 1. Terrestrial gamma radiation flux readings, Newcastle 1° x 2° Quadrangle.

Site no.[1]	Location	Rock unit[2]	Measured background (corrected) (mR/hr)[3]	Site elevation	Cosmic radiation at site (mR/hr)	Terrestrial radiation at site (mR/hr)
1	SWSE sec. 1, T.35N., R.74W.	Tw	.023	5,380	.009	.014
2	SENW sec. 22, T.36N., R.74W.	Tw	.018	5,780	.010	.008
3	SESW sec. 35, T.37N., R.74W.	Tw	.019	5,570	.009	.010
4	NWNW sec. 36, T.38N., R.74W.	Tw	.019	5,200	.009	.010
5	NWSE sec. 34, T.39N., R.74W.	Tw	.026	5,280	.009	.017
6	NWNW sec. 17, T.39N., R.74W.	Tw	.018	5,180	.009	.009
7	SWNW sec. 31, T.40N., R.74W.	Tw	.036	5,120	.009	.027
8	SENW sec. 22, T.40N., R.75W.	Tw	.026	5,340	.009	.017
9	SWNW sec. 31, T.41N., R.75W.	Tw	.018	5,440	.009	.009
10	SENE sec. 23, T.41N., R.76W.	Tw	.025	5,600	.010	.015
11	SESW sec. 31, T.42N., R.75W.	Tw	.023	5,510	.009	.014
12	SWNE sec. 24, T.42N., R.75W.	Tw	.019	5,450	.009	.010
13	NWNE sec. 29, T.43N., R.74W.	Tw	.021	5,340	.009	.012
14	SWNW sec. 31, T.44N., R.74W.	Tw	.021	5,220	.009	.012
15	SWNW sec. 15, T.43N., R.75W.	Tw	.022	5,640	.010	.012
16	SWNW sec. 15, T.43N., R.75W.	Tw	.023	5,840	.010	.013
17	SWNW sec. 15, T.43N., R.75W.	Tw	.023	5,900	.010	.013
18	NWSW sec. 15, T.43N., R.75W.	Twr	.034	5,900	.010	.024
19	SWSW sec. 15, T.43N., R.75W.	Twr	.026	6,000	.010	.016
20	NESW sec. 15, T.43N., R.75W.	Twr	.042	5,920	.010	.032
21	SESW sec. 15, T.43N., R.75W.	Twr	.036	5,980	.010	.026
22	NENW sec. 22, T.43N., R.75W.	Twr	.038	5,930	.010	.028
23	SWNW sec. 15, T.43N., R.75W.	Twr	.024	5,920	.010	.014
24	SWNW sec. 21, T.44N., R.75W.	Tw	.025	5,320	.009	.016
25	SESE sec. 23, T.45N., R.75W.	Tw	.019	5,120	.009	.010
26	NENW sec. 3, T.45N., R.75W.	Tw	.019	4,870	.009	.010
27	NESE sec. 7, T.45N., R.75W.	Tw	.021	4,960	.009	.012
28	NESE sec. 26, T.45N., R.76W.	Tw	.022	5,100	.009	.013
29	SWSE sec. 33, T.45N., R.76W.	Tw	.018	4,910	.009	.009
30	SWSW sec. 20, T.46N., R.74W.	Tw	.018	5,110	.009	.009
31	SESW sec. 35, T.47N., R.74W.	Tw	.018	5,100	.009	.009
32	SWNW sec. 15, T.35N., R.73W.	Tw	.020	5,320	.009	.011
33	SWSW sec. 22, T.36N., R.73W.	Tw	.018	5,520	.009	.009
34	SWSW sec. 12, T.36N., R.73W.	Tw	.018	5,410	.009	.009
35	NENW sec. 14, T.36N., R.72W.	Tw	.017	5,340	.009	.008
36	SWSW sec. 21, T.36N., R.71W.	Qal Box Creek	.014	4,900	.009	.005
37	SWSW sec. 21, T.36N., R.71W.	Tw	.020	4,910	.009	.011
38	SESE sec. 36, T.36N., R.71W.	Tw	.017	5,040	.009	.008
39	NWSW sec. 33, T.36N., R.70W.	Tw	.016	4,910	.009	.007
40	NWNW sec. 34, T.37N., R.70W.	Tw	.017	4,820	.009	.008
41	NWNW sec. 34, T.38N., R.70W.	Tw	.018	4,710	.009	.009
42	NENE sec. 36, T.38N., R.70W.	Tw	.018	4,650	.009	.009
43	NENE sec. 16, T.38N., R.69W.	Tfl	.017	4,760	.009	.008
44	NWNW sec. 34, T.39N., R.69W.	Tfl	.020	4,700	.009	.011
45	SESE sec. 10, T.39N., R.69W.	Tfl	.015	4,700	.009	.006
46	SWNE sec. 2, T.39N., R.69W.	Tfl clinker	.033	4,570	.008	.025
47	NESE sec. 36, T.40N., R.69W.	Tfl	.015	4,460	.008	.007
48	NWNW sec. 25, T.40N., R.68W.	Tfl	.019	4,420	.008	.011
49	NWNW sec. 4, T.40N., R.67W.	Tft	.017	4,380	.008	.009
50	NWNE sec. 28, T.41N., R.67W.	Qal Cheyenne River	.018	4,190	.008	.010
51	SENW sec. 33, T.42N., R.67W.	Tft	.019	4,550	.008	.011
52	SWSE sec. 6, T.41N., R.66W.	Tft	.016	4,420	.008	.008
53	SWNW sec. 2, T.41N., R.66W.	Tft	.018	4,350	.008	.010
54	SWSW sec. 30, T.42N., R.65W.	Qal Black Thunder Cr.	.017	4,080	.008	.009
55	NWNW sec. 32, T.42N., R.65W.	Kl	.019	4,120	.008	.011
56	SWNW sec. 6, T.41N., R.64W.	Kl	.020	4,130	.008	.012
57	SESE sec. 35, T.42N., R.64W.	Kl	.019	4,220	.008	.011
58	SENE sec. 8, T.41N., R.63W.	Kl	.019	4,180	.008	.011

Table 1. Continued.

Site no.[1]	Location	Rock unit[2]	Measured background (corrected) (mR/hr)[3]	Site elevation	Cosmic radiation at site (mR/hr)	Terrestrial radiation at site (mR/hr)
59	NENE sec. 23, T.41N., R.63W.	Kl	.019	3,950	.008	.011
60	SWNW sec. 17, T.41N., R.62W.	Kfh	.018	4,040	.008	.010
61	SENE sec. 21, T.41N., R.62W.	Kfh	.016	4,030	.008	.008
62	SWSW sec. 14, T.41N., R.62W.	Kp	.021	3,830	.008	.013
63	NENW sec. 21, T.41N., R.61W.	Kp	.022	3,850	.008	.014
64	NWNW sec. 23, T.41N., R.61W.	Kp	.020	3,810	.008	.012
65	SWSW sec. 14, T.41N., R.61W.	Kn	.019	3,810	.008	.011
66	SESW sec. 14, T.41N., R.61W.	Kcl	.022	3,840	.008	.014
67	SESW sec. 14, T.41N., R.61W.	Kg	.015	3,830	.008	.007
68	SWSW sec. 13, T.41N., R.61W.	Kb	.023	3,750	.008	.015
69	NWSE sec. 13, T.41N., R.61W.	Km	.020	3,760	.008	.012
70	NWNW sec. 18, T.41N., R.60W.	Qal Beaver Creek	.019	3,670	.007	.012
71	SWNW sec. 15, T.41N., R.60W.	Km	.020	3,840	.008	.012
72	NESW sec. 17, T. 6S., R. 1E	Kb	.023	3,740	.008	.015
73	SESE sec 9, T. 6S., R. 1E.	Ksc	.019	3,870	.008	.011
74	NWSE sec. 15, T.35N., R.65W.	Kp	.018	4,490	.008	.010
75	NWNW sec. 6, T.35N., R.65W.	Kfh	.014	4,500	.008	.006
76	SESW sec. 36, T.36N., R.66W.	Kl	.020	4,540	.008	.012
77	NWSW sec. 35, T.36N., R.66W.	Tft	.020	4,770	.009	.012
78	NENW sec. 5, T.35N., R.65W.	Twr	.052	4,400	.008	.044
79	SESW sec. 5, T.38N., R.73W.	Tw	.018	5,140	.009	.009
80	SENW sec. 23, T.39N., R.73W.	Tw	.023	5,120	.009	.014
81	SENE sec. 5, T.39N., R.72W.	Tw	.020	4,800	.009	.011
82	NESW sec. 36, T.40N., R.72W.	Tfl	.018	4,820	.009	.009
83	NESW sec. 33, T.40N., R.71W.	Tw	.017	5,060	.009	.008
84	SWSE sec. 6, T.38N., R.68W.	Tfl	.024	4,910	.009	.015
85	NENW sec. 4, T.38N., R.68W.	Tfl	.017	4,900	.009	.008
86	NESW sec. 31, T.39N., R.67W.	Tfl	.020	4,520	.008	.012
87	SWSW sec. 36, T.39N., R.67W.	Tft	.017	4,450	.008	.009
88	NWSE sec. 3, T.38N., R.66W.	Tft	.018	4,390	.008	.010
89	NENE sec. 20, T.38N., R.65W.	Kl	.018	4,120	.008	.010
90	NWNW sec. 26, T.38N., R.65W.	Kl	.018	4,100	.008	.010
91	SESW sec. 6, T.38N., R.64W.	Kl	.014	4,220	.008	.006
92	SWNW sec. 23, T.39N., R.64W.	Kl	.022	4,210	.008	.014
93	NESW sec. 21, T.39N., R.63W.	Kl	.018	4,110	.008	.010
94	NESW sec. 1, T.38N., R.63W.	Qal Lance Creek	.017	3,780	.008	.009
95	SESW sec. 29, T.38N., R.62W.	Kfh	.023	4,130	.008	.015
96	NWNW sec. 27, T.38N., R.62W.	Kfh	.016	3,900	.008	.008
97	NWNE sec. 26, T.38N., R.62W.	Kp	.020	3,970	.008	.012
98	NENE sec. 1, T.38N., R.61W.	Kp	.019	4,190	.008	.011
99	SWSW sec. 31, T.39N., R.60W.	Kn	.018	4,100	.008	.010
100	SWSW sec. 19, T.39N., R.60W.	Kcl	.018	4,090	.008	.010
101	SESE sec. 12, T.39N., R.61W.	Kcl	.021	3,940	.008	.013
102	NWSE sec. 1, T.39N., R.61W.	Kg	.016	3,870	.008	.008
103	NENW sec. 31, T.40N., R.60W.	Kb	.020	3,690	.007	.013
104	SENW sec. 27, T.40N., R.60W.	Kb	.017	3,610	.007	.010
105	NENE sec. 19, T. 7S., R. 1E.	Qs	.013	3,600	.007	.006
106	SWNE sec. 28, T. 7S., R. 1E.	Qs	.014	3,560	.007	.007
107	SESW sec. 26, T.40N., R.61W.	Kb	.019	3,780	.008	.011
108	NESE sec. 27, T.40N., R.61W.	Kg	.016	3,760	.008	.008
109	NWSE sec. 27, T.40N., R.61W.	Kcl	.019	3,760	.008	.011
110	SESW sec. 27, T.40N., R.61W.	Kn	.019	3,750	.008	.011
111	SWSW sec. 28, T.40N., R.60W.	Kp	.017	3,770	.008	.009
112	SENW sec. 19, T.36N., R.62W.	Twr	.028	4,160	.008	.020
113	SENW sec. 15, T.36N., R.62W.	Twr	.026	4,320	.008	.018
114	SENW sec. 14, T.36N., R.62W.	Kb	.021	4,320	.008	.013
115	NESW sec. 14, T.36N., R.62W.	Kg	.020	4,370	.008	.012
116	NWNE sec. 13, T.36N., R.62W.	Kcl	.022	4,290	.008	.014
117	SESW sec. 6, T.36N., R.61W.	Kn	.017	4,240	.008	.009

Table 1. *Continued.*

Site no.[1]	Location	Rock unit[2]	Measured background (corrected) (mR/hr)[3]	Site elevation	Cosmic radiation at site (mR/hr)	Terrestrial radiation at site (mR/hr)
118	SWNE sec. 6, T.36N., R.61W.	Kn	.021	4,220	.008	.013
119	SENW sec. 9, T.36N., R.61W.	Kp	.019	4,480	.008	.011
120	SESE sec. 17, T.36N., R.60W.	Kp	.021	4,200	.008	.013
121	NWSE sec. 19, T.11S., R. 1E.	Kp	.020	4,240	.008	.012
122	NWNE sec. 4, T.12S., R. 1E.	Kp	.019	4,130	.008	.011
123	SWNE sec. 9, T.36N., R.62W.	Jsg	.014	4,240	.008	.006
124	SWNW sec. 9, T.36N., R.62W.	Jsg	.017	4,280	.008	.009
125	SESE sec. 8, T.36N., R.62W.	Jm[5]	.025	4,440	.008	.017
126	NWNW sec. 16, T.36N., R.62W.	Kik Lakota[5]	.013	4,400	.008	.005
127	NWNW sec. 16, T.36N., R.62W.	Kik Fuson[5]	.021	4,430	.008	.013
128	SWNW sec. 16, T.36N., R.62W.	Kik Fall River[5]	.018	4,430	.008	.010
129		No reading taken				
130	NWNE sec. 20, T.36N., R.62W.	Jm[5]	.027	4,180	.008	.019
131	NWNW sec. 2, T.35N., R.63W.	Twr	.028	4,260	.008	.020
132	SENE sec. 36, T.36N., R.64W.	Kp	.026	4,440	.008	.018
133	NWNW sec. 27, T.36N., R.64W.	Kp	.021	4,440	.008	.013
134	NWNE sec. 21, T.36N., R.64W.	Kfh	.018	4,500	.008	.010
135	SESW sec. 9, T.36N., R.64W.	Kl	.015	4,590	.008	.007
136	NWNE sec. 16, T.46N., R.63W.	Km	.020	4,320	.008	.012
137	NWNE sec. 16, T.46N., R.63W.	Km	.024	4,330	.008	.016
138	NENW sec. 17, T.46N., R.63W.	Kb	.022	4,130	.008	.014
139	NWSE sec. 18, T.46N., R.63W.	Kg	.018	4,130	.008	.010
140	NENE sec. 24, T.46N., R.64W.	Kcl	.020	4,110	.008	.012
141	SWNW sec. 24, T.46N., R.64W.	Kn	.021	4,040	.008	.013
142	SWNW sec. 24, T.46N., R.64W.	Qal Beaver Creek	.020	4,050	.008	.012
143	SENW sec. 22, T.46N., R.64W.	Kp	.017	4,250	.008	.009
144	NWSE sec. 20, T.46N., R.64W.	Kfh	.018	4,330	.008	.010
145	NWSW sec. 24, T.46N., R.65W.	Kl	.021	4,200	.008	.013
146	NWSE sec. 21, T.46N., R.65W.	Kl	.018	4,320	.008	.010
147	SWNW sec. 30, T.46N., R.65W.	Kl	.021	4,720	.009	.013
148	NWNW sec. 35, T.46N., R.66W.	Kl	.020	4,780	.009	.012
149	NWNW sec. 16, T.45N., R.66W.	Tft	.019	4,540	.008	.011
150	NWNW sec. 16, T.45N., R.66W.	Road Surface[4]	.025	4,530	.008	.017
151	NWNE sec. 24, T.45N., R.67W.	Tft	.020	4,610	.009	.011
152	NWNE sec. 12, T.45N., R.68W.	Tft	.020	4,770	.009	.011
153	SWNW sec. 16, T.45N., R.67W.	Tft	.023	4,750	.009	.014
154	NENW sec. 26, T.43N., R.72W.	Tw	.023	5,040	.009	.014
155	NWNE sec. 27, T.43N., R.72W.	Tw clinker[6]	.027	5,090	.009	.018
156	NWNE sec. 28, T.43N., R.72W.	Tw coal[6]	.018	5,080	.009	.009
157	NWSW sec. 25, T.43N., R.73W.	Tw	.022	5,040	.009	.013
158	NENE sec. 5, T.42N., R.73W.	Tw	.022	5,280	.009	.013
159	NWSW sec. 10, T.42N., R.74W.	Tw	.024	5,300	.009	.015
160	NENW sec. 4, T.41N., R.76W.	Tw	.025	5,020	.009	.016
161	NWSE sec. 21, T.42N., R.61W.	Qal Beaver Creek	.020	3,730	.008	.012
162	NWSE sec. 21, T.43N., R.61W.	Kp	.021	3,920	.008	.013
163	NWSE sec. 21, T.44N., R.61W.	Kp	.020	4,120	.008	.012
164	SESW sec. 3, T.44N., R.61W.	Kcl	.020	4,230	.008	.012
165	NWSE sec. 3, T.44N., R.61W.	Kcl	.017	4,320	.008	.009
166	SWNE sec. 3, T.44N., R.61W.	Kg	.017	4,310	.008	.009
167	SWSE sec. 34, T.45N., R.61W.	Kb	.021	4,310	.008	.013
168	SWSW sec. 35, T.45N., R.61W.	Km	.022	4,400	.008	.014
169	NWSW sec. 35, T.45N., R.61W.	Knc	.017	4,410	.008	.009
170	NWSW sec. 35, T.45N., R.61W.	Kik Fall River	.015	4,410	.008	.007
171	SESW sec. 26, T.45N., R.61W.	Jm[5]	.017	4,420	.008	.009
172	SWSE sec. 19, T.45N., R.60W.	₨Ps	.018	4,500	.008	.010
173	SWNE sec. 31, T.45N., R.60W.	₨Ps	.016	4,400	.008	.008
174	NWSE sec. 31, T.45N., R.60W.	₨Ps	.013	4,400	.008	.005
175	NWSE sec. 31, T.45N., R.60W.	₨Ps gypsum[6]	.012	4,400	.008	.004
176	NENE sec. 6, T.44N., R.60W.	Jsg	.014	4,420	.008	.006
177	SWSE sec. 6, T.44N., R.60W.	Jm5	.018	4,360	.008	.010

Table 1. Continued.

Site no.[1]	Location	Rock unit[2]	Measured background (corrected) (mR/hr)[3]	Site elevation	Cosmic radiation at site (mR/hr)	Terrestrial radiation at site (mR/hr)
178	SWSE sec. 6, T.44N., R.60W.	Kik Lakota[5]	.014	4,350	.008	.006
179	SWSE sec. 6, T.44N., R.60W.	Kik Fuson[5]	.016	4,340	.008	.008
180	SWSE sec. 6, T.44N., R.60W.	Kik Fall River[5]	.015	4,340	.008	.007
181	SWSE sec. 6, T.44N., R.60W.	Ksc	.019	4,330	.008	.011
182	NWNE sec. 21, T.44N., R.60W.	TRPs gypsum[6]	.012	4,560	.008	.004
183	NWNE sec. 21, T.44N., R.60W.	TRPs	.018	4,560	.008	.010
184	NWSE sec. 19, T. 3S., R. 1E.	Pmo Opeche[5]	.018	4,570	.008	.010
185	NWSE sec. 19, T. 3S., R. 1E.	Pmo Minnekahta[5]	.012	4,560	.008	.004
186	NENE sec. 18, T. 3S., R. 1E.	Pmo Opeche[5]	.018	4,740	.009	.009
187	SESE sec. 7, T. 3S., R. 1E.	Pmo Minnekahta[5]	.012	4,800	.009	.003
188	SWSW sec. 33, T. 2S., R. 1E.	PPm	.017	5,190	.009	.008
189	SENE sec. 20, T. 2S., R. 1E.	PPm	.014	5,630	.010	.004
190	SENE sec. 8, T. 2S., R. 1E.	PPm	.015	6,090	.010	.005
191	NESW sec. 33, T. 1S., R. 1E.	PPm	.017	6,280	.010	.007
192	SWNE sec. 21, T. 1S., R. 1E.	PPm	.014	6,460	.011	.003
193	SESE sec. 4, T. 1S., R. 1E.	PPm	.017	6,600	.011	.006
194	SWNW sec. 29, T. 1S., R. 1E.	Mpe	.013	5,960	.010	.003
195	SWNW sec. 30, T. 1S., R. 1E.	Mpe	.013	5,680	.010	.003
196	SESE sec. 28, T.46N., R.60W.	PPm	.015	5,370	.009	.006
197	NWNW sec. 32, T.46N., R.60W.	PPm	.015	5,050	.009	.006
198	SENW sec. 32, T.46N., R.60W.	Pmo Minnekahta[5]	.013	4,940	.009	.004
199	SWNE sec. 31, T.46N., R.60W.	TRPs	.015	4,740	.009	.006
200	SWNE sec. 31, T.46N., R.60W.	TRPs gypsum[6]	.013	4,740	.009	.004
201	SENE sec. 26, T.45N., R.62W.	Kp	.019	4,180	.008	.011
202	NWSE sec. 34, T.45N., R.62W.	Qal Oil Creek	.019	4,050	.008	.011
203	SWSE sec. 4, T.44N., R.62W.	Qal Skull Creek	.019	4,090	.008	.011
204	SWSW sec. 4, T.44N., R.62W.	Kp	.019	4,000	.008	.011
205	SWSE sec. 12, T.44N., R.63W.	Qal Beaver Creek	.021	3,900	.008	.013
206	NWNW sec. 13, T.44N., R.63W.	Kp	.018	3,960	.008	.010
207	NWNW sec. 21, T.44N., R.63W.	Kfh	.018	4,040	.008	.010
208	NESE sec. 24, T.44N., R.64W.	Kl	.019	4,240	.008	.011
209	SESE sec. 28, T.44N., R.64W.	Kl	.019	4,220	.008	.010
210	SENE sec. 2, T.43N., R.65W.	Kl	.021	4,420	.008	.013
211	SWNE sec. 16, T.43N., R.65W.	Qal Lodgepole Creek	.019	4,160	.008	.011
212	NESE sec. 18, T.43N., R.65W.	Kl	.020	4,340	.008	.012
213	NWNE sec. 20, T.43N., R.66W.	Tft	.018	4,440	.008	.010
214	SESE sec. 23, T.43N., R.67W.	Tft	.017	4,410	.008	.009
215	NWSW sec. 27, T.43N., R.67W.	Tft	.019	4,340	.008	.011
216	SESE sec. 35, T.43N., R.68W.	Tfl	.019	4,380	.008	.011
217	SESE sec. 25, T.43N., R.69W.	Tfl	.018	4,460	.008	.010
218	NESE sec. 30, T.43N., R.69W.	Tfl	.019	4,560	.008	.011
219	NESE sec. 1, T.42N., R.70W.	Tfl	.018	4,680	.008	.010
220	NENE sec. 9, T.42N., R.70W.	Tw	.021	4,850	.009	.012
221	SESW sec. 2, T.42N., R.71W.	Tw	.020	4,880	.009	.011
222	SWSW sec. 31, T.43N., R.71W.	Tw	.019	4,900	.009	.010
223	SESE sec. 25, T.46N., R.72W.	Tw	.021	4,650	.008	.013
224	SWSW sec. 34, T.46N., R.71W.	Tw	.020	4,860	.009	.011
225	SWSW sec. 34, T.46N., R.71W.	Tw clinker[6]	.021	5,050	.009	.012
226	SWSW sec. 1, T.45N., R.71W.	Q playa lake[6]	.021	4,710	.009	.012
227	NENW sec. 7, T.45N., R.70W.	Tw	.020	4,720	.009	.011
228	NWNE sec. 9, T.45N., R.70W.	Tw clinker[7]	.028	4,760	.009	.019
229	SWSW sec. 3, T.45N., R.70W.	Tw	.019	4,810	.009	.010
230	SWSE sec. 10, T.45N., R.70W.	Tw	.020	4,860	.009	.011
231	SENW sec. 23, T.45N., R.70W.	Tfl	.018	4,830	.009	.009
232	SESE sec. 24, T.45N., R.70W.	Tfl	.018	4,860	.009	.009
233	SESE sec. 24, T.45N., R.70W.	Tfl	.017	4,860	.009	.008
234	NESE sec. 25, T.46N., R.72W.	Qal Belle Fourche R.	.020	4,610	.009	.011
235	NWSE sec. 9, T.46N., R.63W.	Km	.019	4,350	.008	.011
236	NENW sec. 10, T.46N., R.63W.	Knc	.018	4,350	.008	.010
237	SWSE sec. 3, T.46N., R.63W.	Knc	.023	4,370	.008	.015

Table 1. Continued.

Site no.[1]	Location	Rock unit[2]	Measured background (corrected) (mR/hr)[3]	Site elevation	Cosmic radiation at site (mR/hr)	Terrestrial radiation at site (mR/hr)
238	SWSE sec. 3, T.46N., R.63W.	Knc bentonite[6]	.025	4,370	.008	.017
239	NESE sec. 2, T.46N., R.63W.	Ksc	.019	4,500	.008	.011
240	SENE sec. 2, T.46N., R.63W.	Qal	.020	4,560	.008	.012
241	SESW sec. 9, T.45N., R.62W.	Kp	.019	4,220	.008	.011
242	NENW sec. 9, T.45N., R.62W.	Kn	.016	4,260	.008	.008
243	NESW sec. 4, T.45N., R.62W.	Kik Fall River[5]	.018	4,260	.008	.010
244	SWNE sec. 4, T.45N., R.62W.	Kik Lakota	.015	4,280	.008	.007
245	NENE sec. 4, T.45N., R.62W.	Jm[5]	.019	4,300	.008	.011
246	SESE sec. 5, T. 4S., R. 1E.	₮Ps	.017	4,720	.009	.008
247	SESE sec. 5, T. 4S., R. 1E.	₮Ps gypsum[6]	.014	4,720	.009	.005
248	SWNW sec. 4, T. 4S., R. 1E.	Pmo Minnekahta	.013	4,690	.009	.004
249	SWNW sec. 8, T.44N., R.60W.	Jsg	.018	4,440	.008	.010
250	NWNW sec. 28, T.45N., R.61W.	Km	.021	4,420	.008	.013
251	NWNW sec. 28, T.45N., R.61W.	Knc	.017	4,460	.008	.009
252	NWNW sec. 28, T.45N., R.61W.	Knc	.020	4,460	.008	.012
253	SWSW sec. 21, T.45N., R.61W.	Ksc	.020	4,500	.008	.012
254	NWNW sec. 28, T.45N., R.61W.	Knc lignite[6]	.031	4,460	.008	.023
255	SENW sec. 4, T.45N., R.61W.	Kik Fuson[5]	.017	5,140	.009	.005
256	NESE sec. 33, T.46N., R.61W.	Kik Lakota[5]	.015	5,210	.009	.006
257	NWSE sec. 28, T.46N., R.61W.	Jsg	.017	4,960	.009	.008
258	SWNE sec. 28, T.46N., R.61W.	Jsg	.017	4,870	.009	.008
259	SWNE sec. 28, T.46N., R.61W.	Jsg	.016	4,890	.009	.007
260	SESE sec. 8, T.46N., R.61W.	Jsg	.020	5,070	.009	.011
261	NENW sec. 9, T.46N., R.61W.	Jsg gypsum[6]	.013	5,160	.009	.004
262	NWNW sec. 3, T.46N., R.61W.	₮Ps	.021	5,280	.009	.012
263	SESE sec. 2, T.44N., R.62W.	Kp	.018	4,090	.008	.010
264	NWNE sec. 36, T.44N., R.62W.	Kp	.018	3,980	.008	.010
265	SESW sec. 35, T.43N., R.62W.	Kp	.019	3,890	.008	.011
266	NENE sec. 17, T.42N., R.62W.	Kfh	.018	4,100	.008	.010
267	NWNW sec. 20, T.40N., R.61W.	Kp	.019	3,660	.007	.012
268	NWNE sec. 36, T.40N., R.62W.	Kfh	.018	3,710	.008	.010
269	NENE sec. 5, T.39N., R.62W.	Kl	.023	4,010	.008	.015
270	SENE sec. 5, T.39N., R.62W.	Kl	.016	3,980	.008	.008
271	SWSW sec. 35, T.40N., R.63W.	Kl	.020	3,900	.008	.012
272	SWSW sec. 35, T.40N., R.63W.	Kl	.019	3,860	.008	.011
273	NWSW sec. 2, T.39N., R.63W.	Qal Cheyenne River	.019	3,760	.008	.011
274	NWSE sec. 24, T.40N., R.64W.	Kl	.018	3,820	.008	.010
275	SWNE sec. 23, T.39N., R.64W.	Qal Cheyenne River	.019	3,830	.008	.011
276	NESW sec. 33, T.39N., R.64W.	Kl	.019	4,260	.008	.011

[1] Plotted on Figure 1.

[2] Explanation of Rock Unit abbreviations.

Qal	Alluvial deposits	Kp	Pierre Shale	Jm	Morrison Formation
Ws	Windblown sand	Kn	Niobrara Formation	Jsg	Sundance and Gypsum Spring Formations
Tml	Lower Miocene rocks	Kcl	Carlile Shale	₮Ps	Spearfish Formation
Twr	White River Formation	Kg	Greenhorn Formation	Pmo	Minnekahta Limestone and Opeche Shale
Tw	Wasatch Formation	Kb	Belle Fourche Shale	PPm	Minnelusa Formation
Tfl	Lebo Member, Fort Union Formation	Km	Mowry Formation	Mpe	Pahasapa and Englewood Formations
Tft	Tullock Member, Fort Union Formation	Knc	Newcastle Sandstone		
Kl	Lance Formation	Ksc	Skull Creek Shale		
Kfh	Fox Hills Sandstone	Kik	Inyan Kara Group		

[3] Actual site measurement corrected for daily variations.

[4] Highway surfaced with clinker aggregate, probably from Tft.

[5] Formations distinguishable lithologically and radiometrically at outcrop; mapped together by Love and others (1987).

[6] Rock types within Formations distinguishable lithologically and radiometrically.

[7] Not mapped by Love and others (1987).

Table 2. Terrestrial gamma radiation flux measurements grouped by formation and(or) rock or sediment type. (See Table 1 for explanation of unit symbols.)

Unit	Site no.	Terr. Rad.[1]
Qal	36	.005
	50	.010
	54	.009
	70	.012
	94	.009
	142	.012
	150	.017
	161	.012
	202	.011
	203	.011
	205	.013
	211	.011
	234	.011
	240	.012
	273	.011
	275	.011
	AVERAGE	.011
Qs	105	.006
	106	.007
	AVERAGE	.007
Q playa lake	226	.012
Tml	AVERAGE	.021[2]
Twr	18	.024
	19	.016
	20	.032
	21	.026
	22	.028
	23	.014
	78	.044
	112	.020
	113	.026
	131	.020
	AVERAGE	.025
Tw	1	.014
	2	.008
	3	.010
	4	.010
	5	.017
	6	.009
	7	.027
	8	.017
	9	.009
	10	.015
	11	.014
	12	.010
	13	.012
	14	.012
	15	.012
	16	.013
	17	.013
	24	.016
	25	.010
	26	.010
	27	.012
	28	.013
	29	.009
	30	.009
Tw cont.	31	.009
	32	.011
	33	.009
	34	.009
	35	.008
	37	.011
	38	.008
	39	.007
	40	.008
	41	.009
	42	.009
	79	.009
	80	.014
	81	.011
	83	.008
	154	.014
	155	.018
	156	.009
	157	.013
	158	.013
	159	.015
	160	.016
	220	.012
	221	.011
	222	.010
	223	.013
	224	.011
	225	.012
	227	.011
	228	.019
	229	.010
	230	.011
	AVERAGE	.013
Tfl	43	.008
	44	.011
	45	.006
	46	.025
	47	.007
	48	.011
	82	.009
	84	.015
	85	.008
	86	.012
	216	.011
	217	.010
	218	.011
	219	.010
	231	.009
	232	.009
	233	.008
	AVERAGE	.010
Tft	49	.009
	51	.011
	52	.008
	53	.010
	77	.012
	87	.009
	88	.010
	149	.011
	151	.011
	152	.011
Tft cont.	153	.013
	213	.020
	214	.009
	215	.011
	AVERAGE	.010
Kl	55	.011
	56	.012
	57	.011
	58	.011
	59	.011
	76	.012
	89	.010
	90	.010
	91	.006
	92	.014
	93	.010
	135	.007
	145	.013
	146	.010
	147	.013
	148	.012
	208	.011
	209	.010
	210	.013
	212	.012
	269	.015
	270	.008
	271	.012
	272	.011
	274	.010
	276	.011
	AVERAGE	.011
Kfh	60	.010
	61	.008
	75	.006
	95	.015
	96	.008
	134	.010
	144	.010
	207	.010
	266	.010
	268	.010
	AVERAGE	.010
Kp	62	.013
	63	.014
	64	.012
	74	.010
	97	.012
	98	.011
	111	.009
	119	.011
	120	.013
	121	.012
	122	.011
	132	.018
	133	.013
	143	.009
	162	.013
	163	.012
	201	.011
	204	.011
	206	.010

[1] Terrestrial radiation at site (mR/hr).

[2] Value from Harris (1985).

Unit	Site no.	Terr. Rad.[1]
Kp cont.	241	.011
	263	.010
	264	.010
	265	.011
	267	.012
	AVERAGE	.012
Kn	65	.011
	99	.010
	110	.011
	117	.009
	118	.013
	141	.013
	242	.008
	AVERAGE	.011
Kcl	66	.014
	100	.010
	101	.013
	109	.011
	116	.014
	140	.012
	164	.012
	165	.009
	AVERAGE	.009
Kg	67	.007
	102	.008
	108	.008
	115	.012
	139	.010
	166	.009
	AVERAGE	.009
Kb	68	.015
	72	.015
	103	.013
	104	.010
	107	.011
	114	.013
	138	.014
	167	.013
	AVERAGE	.013
Km	69	.012
	71	.012
	136	.012
	137	.016
	168	.014
	235	.011
	250	.013
	AVERAGE	.013
Knc	169	.009
	236	.010
	237	.015
	238	.017
	251	.009
	252	.012
	254	.023
	AVERAGE	.011
Ksc	73	.011
	181	.011
	239	.011
	253	.012
	AVERAGE	.011
Kik	126	.005
	127	.013
	128	.010
	170	.007
	178	.006
	179	.008
	180	.007
	243	.010
	244	.007
	255	.008
	256	.009
	AVERAGE	.008
Jm	125	.017
	130	.019
	171	.009
	177	.010
	245	.011
	AVERAGE	.013
Jsg	123	.006
	124	.009
	176	.006
	249	.010
	257	.008
	258	.008
	259	.007
	260	.011
	261	.004
	AVERAGE	.008
ꞦPs	172	.010
	173	.008
	174	.005
	175	.004
	182	.004
	183	.010
	199	.006
	200	.004
	246	.008
	247	.005
	262	.012
	AVERAGE	.008
Pmo	184	.010
	185	.004
	186	.009
	187	.003
	198	.004
	248	.004
	AVERAGE	.006
PIPm	188	.008
	189	.004
	190	.005
	191	.007
	192	.003
	193	.006
	196	.006
	197	.006
	AVERAGE	.006
Mpe	194	.003
	195	.003
	AVERAGE	.003

[1] Terrestrial radiation at site (mR/hr).

[2] Value from Harris (1985).

Table 3. Gamma radiation flux anomalies, Newcastle 1° x 2° Quadrangle.

Site no[1]	Location[1]	Measured radio-activity (mR/hr)	Background radioactivity for unit[2] (mR/hr)	Measured radio-activity as a function of the normal background radiation[3]
007	SWSW sec. 31, T.40N., R.74W.	.027	.013 (Tw)	2.1X
046	SWNE sec. 2, T.39N., R.69W.	.025	.010 (Tfl)	2.5X[4]
175	NWSE sec. 31, T.45N., R.60W.	.004	.008 (TRPs)	-2.0X[6]
182	NWNE sec. 21, T.44N., R.60W.	.004	.008 (TRPs)	-2.0X[6]
200	SWNE sec. 31, T.46N., R.61W.	.004	.008 (TRPs)	-2.0X[6]
254	NWNW sec. 28, T.45N., R.61W.	.023	.011 (Knc)	2.1X[5]
261	NENW sec. 9, T.46N., R.61W.	.004	.008 (Jsg)	-2.0X[6]

1 See Plate 1 and Table 1.

2 For explanation of formation abbreviations, see Table 1.

3 Anomalies are 2 times the average for the unit or greater.

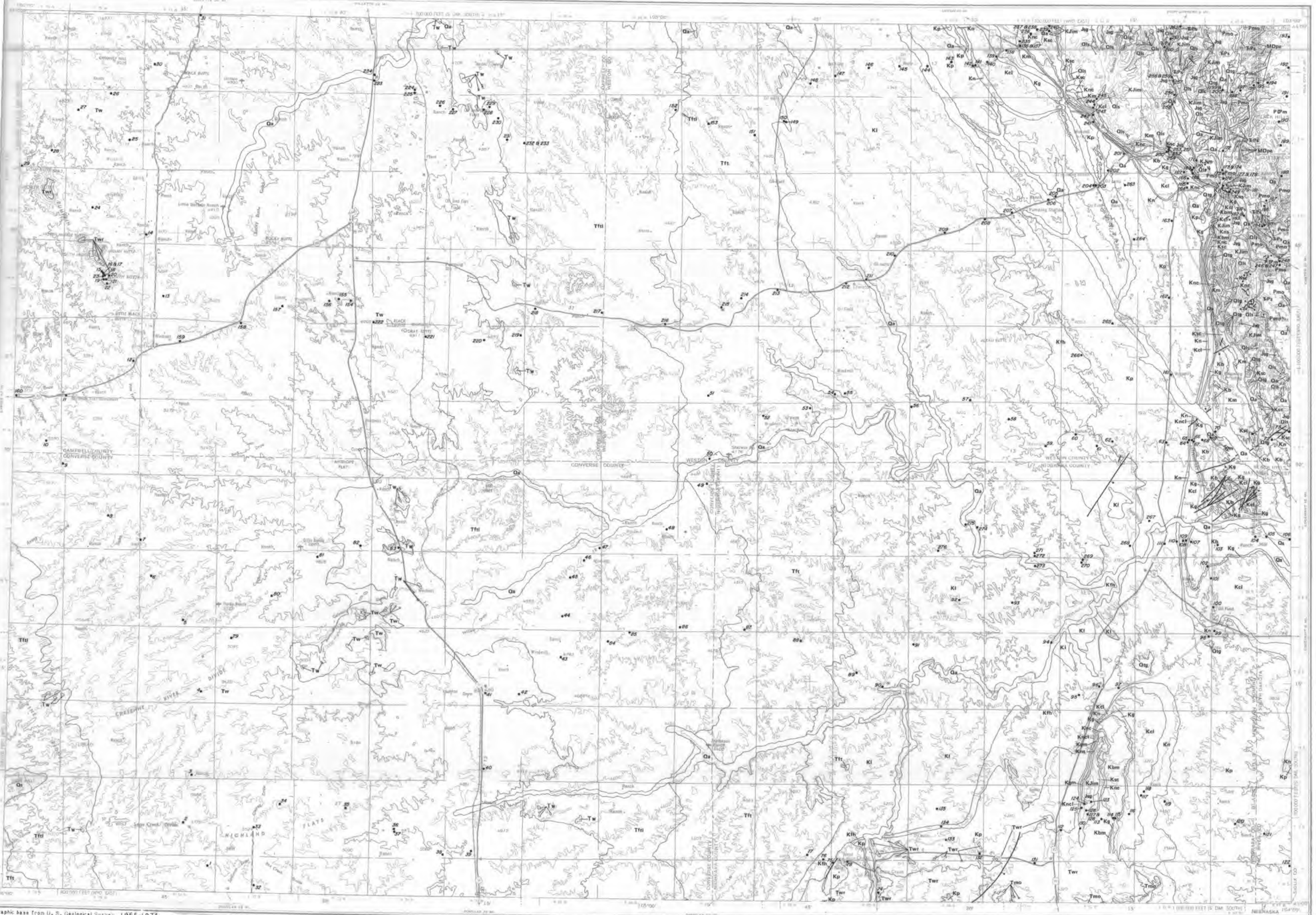
4 Clinker

5 Carbonaceous shale

6 Gypsum

GEOLOGICAL SURVEY OF WYOMING
Gary B. Glass, State Geologist

OPEN FILE REPORT 89-3



Topographic base from U. S. Geological Survey, 1955-1974.
Geologic base from Love, J. D., Christiansen, A. C., and McGrew, L. W., 1987. Geologic map of the Newcastle 1° X 2° quadrangle, northeastern Wyoming and western South Dakota: Geological Survey of Wyoming Map Series 25L, scale 1:250,000.

This map has not been reviewed for conformity with the editorial standards of The Geological Survey of Wyoming.

CONTOUR INTERVAL 200 FEET
TRANSVERSE MERCATOR PROJECTION

TERRESTRIAL RADIATION LEVELS, BACKGROUND GAMMA RADIATION OF THE NEWCASTLE 1° BY 2° QUADRANGLE, WYOMING AND SOUTH DAKOTA

by

Ray E. Harris 1989

EXPLANATION

—— CONTACT

FAULT--Dotted where concealed or inferred. Bar and ball on downthrown side

BACKGROUND GAMMA RADIATION LEVELS (milliroentgens per hour)

- 0.050 mR/hr or greater
- 0.040 - 0.049 mR/hr
- 0.030 - 0.039 mR/hr
- 0.020 - 0.029 mR/hr
- 0.010 - 0.019 mR/hr
- 0.009 mR/hr or less

No patterns or colors are used on this Open File map. The map may be hand-colored, however, by coloring each formation and rock type in accordance with the mean background gamma radiation tabulated below.

DESCRIPTION OF MAP UNITS AND MEAN BACKGROUND GAMMA RADIATION LEVEL
in milliroentgens per hour (mR/hr)

Qa (.011) ALLUVIAL DEPOSITS (HOLOCENE AND PLEISTOCENE)--Unconsolidated and poorly consolidated clay, silt, sand, and gravel, mainly in flood plains and terraces

Qtg (varies) TERRACE GRAVEL (HOLOCENE AND PLEISTOCENE)--May include some high-level deposits of Tertiary age

Qs (.007) WINDBLOWN SAND (HOLOCENE AND PLEISTOCENE)--Chiefly quartz sand. Includes active and dormant sand dunes

Ql (varies) LANDSLIDE DEPOSITS (HOLOCENE AND PLEISTOCENE)--Unsized and unsorted rock debris emplaced by mass movement

Tml (.021) LOWER MIOCENE ROCKS -- Light-gray to buff fine-grained poorly bedded sandstone containing abundant magnetite grains; some siltstone, limestone, and tuff; lenticular conglomerate near base. Chiefly Arikaree Formation (Denson and Horn, 1975). Thickness 0-61 m (0-200 ft)

Twr (.025) WHITE RIVER FORMATION (OLIGOCENE)--White, pink, green, and brown tuffaceous claystone and siltstone; lenticular conglomerates near base; thin beds of ash and limestone. Thickness (0-152 m (0-500 ft)

Tw (.013) WASATCH FORMATION (EOCENE)--Buff arkosic sandstone, lenticular conglomerates, drab siltstone, carbonaceous shale, and many coal beds; upper part contains much variegated claystone in northwestern part. Thickness 0-914 m (0-3,000 ft); the upper 305 m (1,000 ft) occurs only in the northwestern corner of the map area

FORT UNION FORMATION (PALEOCENE)

Tfl (.010) Lebo Member--Fine-grained drab to gray sandstone, finely conglomeratic in part, interbedded with drab siltstone, claystone, shale, and thin coal beds. Thickness 0-762 m (0-2,500 ft)

Tft (.010) Tullock Member--Has a drab appearance and contains massive sandstones, whereas the Lebo Member is lighter colored and contains more shale and claystone. Thickness 0-457 m (0-1,500 ft)

Kl (.010) LANCE FORMATION (UPPER CRETACEOUS)--Somber shale and drab massive lenticular concretionary sandstone; many thin coal beds in lower half. Thickness 610-762 m (2,000-2,500 ft)

Kfh FOX HILLS SANDSTONE (UPPER CRETACEOUS) -- White to light-gray sandstone and gray sandy shale containing marine fossils. Thickness 46-61 m (150-200 ft)

Kp (.012) PIERRE SHALE (UPPER CRETACEOUS)--Dark-gray to black concretionary marine shale. Includes Kara Bentonitic Member in upper part; Red Bird Silty Member in Middle part; Mitten Member and its Pedro Bentonite Bed in lower part; Sharon Springs Member and its Ardmore Bentonite Bed near base; and Gammon Ferruginous Member. Thickness 610-945 m (2,000-3,100 ft)

Kn (.011) NIOBRARA FORMATION (UPPER CRETACEOUS)--Light-gray to yellow chalky marl and limestone and gray to yellow limy speckled shale. Thickness 46-84 m (150-275 ft)

Kcl (.009) CARLILE SHALE (UPPER CRETACEOUS)--Dark-gray to black soft sandy shale. Sage Breaks Member at top; Turner Sandy Member in middle. Thickness 137-229 m (450-750 ft)

Kncl NIOBRARA FORMATION AND CARLILE SHALE

Kg (.009) GREENHORN FORMATION (UPPER CRETACEOUS)--Light-colored marl, limestone, and limy sandstone interbedded with gray concretionary shale. Thickness 61-107 m (200-350 ft)

Kb (.013) BELLE FOURCHE SHALE (UPPER CRETACEOUS)--Black soft bentonitic concretionary shale. Thickness 107-152 m ((350-500 ft)

Km (.013) MOWRY SHALE (LOWER CRETACEOUS)--Black hard siliceous shale; weathers silvery gray. Thickness 55-61 m (180-200 ft)

Kgm GREENHORN FORMATION AND BELLE FOURCHE AND MOWRY SHALES

Kbm BELLE FOURCHE AND MOWRY SHALES

Knc (.011) NEWCASTLE SANDSTONE (LOWER CRETACEOUS)--Gray sandstone, sandy shale, and siltstone; some bentonite and coal. Thickness 0-30 m (0-100 ft)

Ksc (.011) SKULL CREEK SHALE (LOWER CRETACEOUS)--Black soft fissile shale. Thickness 61-76 m (200-250 ft)

Kns NEWCASTLE SANDSTONE AND SKULL CREEK SHALE

KJim (.008) INYAN KARA GROUP AND MORRISON FORMATION
Inyan Kara Group (Lower Cretaceous)
Fall River Formation -- Brown sandstone, siltstone, and shale. Thickness 46-61 m (150-200 ft)
Fuson and Lakota Formations--Intertongued variegated claystone and sandstones underlain by gray conglomeratic sandstone. Thickness 61-76 m (200-250 ft)
(.013) Morrison Formation (Upper Jurassic)--Dully variegated siliceous claystone containing nodular limestone and gray silty sandstone lenses. Thickness 15-30 m (50-100 ft)

Jsg (.008) SUNDANCE AND GYPSUM SPRING FORMATIONS
Sundance Formation (Upper and Middle Jurassic)--Greenish-gray glauconitic sandstone and shale underlain by red and gray nonglauconitic sandstone and shale. Thickness 107-122 m (350-400 ft)
Gypsum Spring Formation (Middle Jurassic)--Massive white gypsum. Thickness 0-7 m (0-20 ft)

TrPs (.008) SPEARFISH FORMATION (TRIASSIC AND PERMAIN)--Red shale, red siltstone, and white gypsum beds. Thickness 46-168 m (150-550 ft)

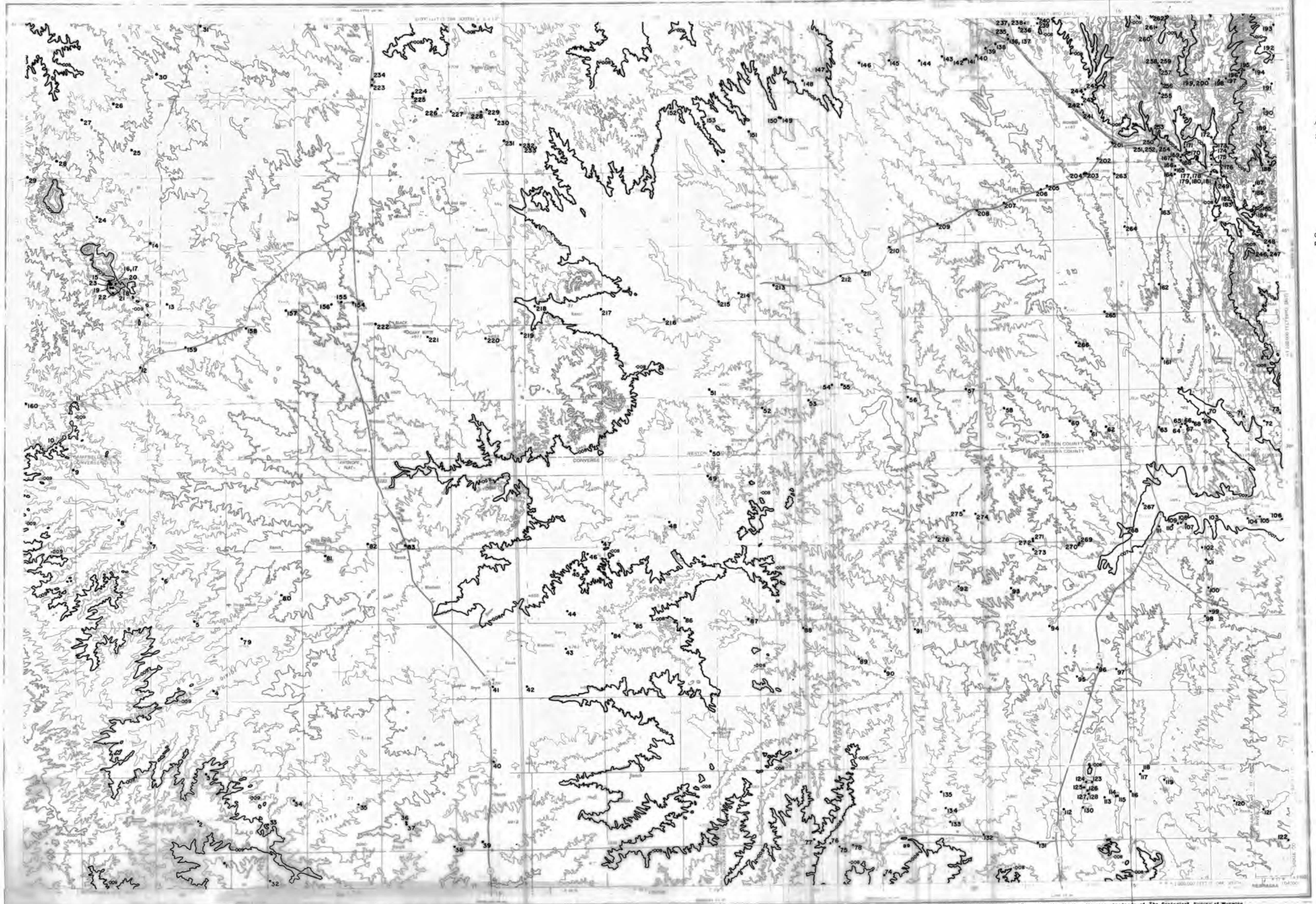
Pmo (.006) MINNEKAHTA LIMESTONE AND OPECHE SHALE (LOWER PERMIAN)
Minnekahta Limestone -- Gray, slabby, hard. Thickness about 12 m (40 ft)
Opeche Shale -- Red, sandy, soft. Thickness 23-49 m (75-160 ft)

PPm (.008) MINNELUSA FORMATION (LOWER PERMIAN AND PENNSYLVANIAN)--Light-gray and red sandstone, breccia that merges with anhydrite in subsurface, thin limestone and dolomites, and red and black shale. Thickness 274-396 m (900-1,300 ft)

Mpe (.003) PAHASAPA AND ENGLEWOOD (PART) FORMATIONS (LOWER MISSISSIPPIAN)
Pahasapa Limestone--Gray, massive, locally cavernous, dolomitic. Thickness 91-183 m (300-600 ft)
Englewood Formation (part)--Pink slabby dolomitic limestone. Thickness 15-18 m (50-60 ft)

GEOLOGICAL SURVEY OF WYOMING
Gary B. Glass, State Geologist

OPEN FILE REPORT 89-3 NK 13-2



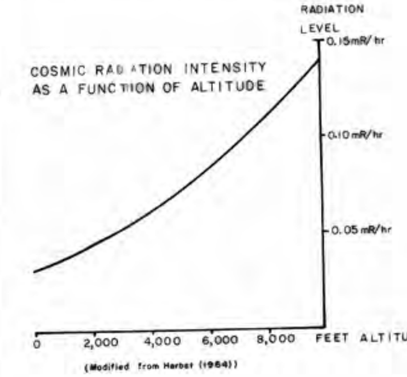
EXPLANATION

.012 Cosmic radiation background (milliroentgens per hour)

32 Sample locality

Note- sample locality numbers are not in sequence

Cosmic radiation levels calculated from Herbst (1964), plotted to the nearest 200-foot contour line:



(Modified from Herbst (1964))

This map has not been reviewed for conformity with the editorial standards of The Geological Survey of Wyoming

COSMIC RADIATION LEVELS AND SAMPLE LOCALITIES, BACKGROUND RADIATION OF THE NEWCASTLE 1° by 2° QUADRANGLE, WYOMING AND SOUTH DAKOTA

by
Ray E. Harris

1989

N

Topographic base from U. S. Geological Survey, 1955-1974.