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Radon in soil gas and soil radioactivity in Prince George's County, Maryland

by

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Introduction

Measurements of radon in soil gas and radioactivity of soils provide important clues to the radon potential of rocks and soils. When combined with other parameters such as permeability, soil moisture, and slope, natural radioactivity can provide a basis for mapping radon potential. A study of radon in soil gas and soil radioactivity was conducted across Prince George's County (Figure 1) as part of a larger study of the radon potential of rocks and soils in the county. Although aeroradioactivity data may be used in radon potential studies as a measure of the strength of the source term, Prince George's County has a limited aeroradioactivity dataset available (see discussion below).

Prince George's County is largely underlain by sedimentary rocks of the Atlantic Coastal Plain, although Precambrian crystalline rocks of the Piedmont are exposed in the lower part of stream valleys along the boundary between Prince George's County and Montgomery County (Figure 1). These sedimentary rocks include Cretaceous through late Tertiary restricted marine and fluvial-deltaic clay, siltstone, sandstone, and conglomerate. Locally abundant phosphate, marine and nonmarine fossils, glauconite, and diatomite occur in these sediments. Cretaceous and late Tertiary fluvial sediments are a major source of commercial gravel in Prince George's County. The phosphatic and glauconitic rocks are locally uraniferous. Some of the Tertiary sandstone is slightly enriched in uranium, possibly because of the presence of volcanic ash. Uranium is also locally enriched by geochemical processes along some unconformities between units. The stratigraphic nomenclature used throughout this report is that of Hack (1977) except where noted.

Previous work

Total-count aeroradioactivity measurements were made across Prince George's County as part of a study of the natural gamma radioactivity of the Baltimore-Washington area by Neuschel (1965). Neuschel shows that most of Prince George's County ranges from 200 to 300 counts per second (cps), however a triangular area enclosed by lines between Upper Marlboro, Bladensburg, and Old Bowie (Figure 1) gave readings ranging from 300 to 600 cps. This area of elevated radioactivity is underlain principally by the Aquia Formation (Ta) and the Chesapeake Group (Tc, principally the Calvert Formation) as mapped by Hack (1977). An additional linear zone of patchy high values (300-400 cps) extends from Upper Marlboro southward to the southeast corner of the county.

A spectral aeroradiometric survey of the Baltimore and Washington $1^{o}X2^{o}$ NTMS sheets was conducted as part of the National Uranium Resource Evaluation (NURE) program (Texas Instruments, 1978), however coverage of Prince George's County was restricted to about 45 miles along 8 flight lines spaced about 6 miles apart in the northernmost, southernmost, and east edge of the county.

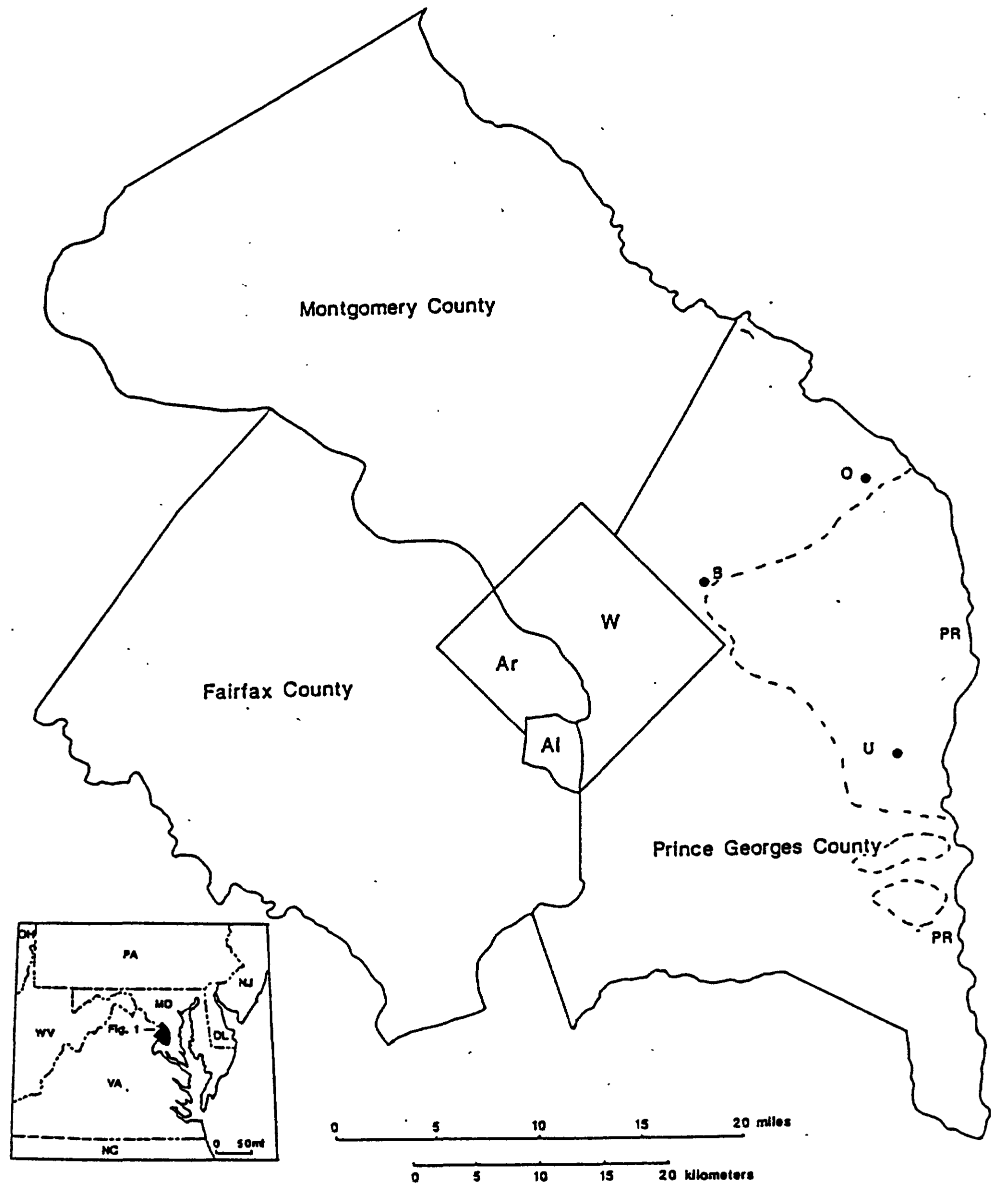

Figure 1- Location of Prince George's County, nearby jurisdictions, and selected towns within Prince George's County. W- Washington, D.C.; Ar- Arlington; Al- Alexandria; U- Upper Marlboro; O- Old Bowie; B- Bladensburg; PR- Patuxent River. Dashed lines outline areas of elevated radioactivity discussed in text.

The aircraft flew at about 400 feet above the ground's surface. About 90 percent of the gamma-ray signal received by the instruments in the aircraft comes from an area about 0.25 miles wide along the flight path of the aircraft. The position of the two northernmost flightlines from the Baltimore sheet was not possible to interpret from the index map and data from those two flightlines are not included here. Spectral radiometric surveys measure gamma rays from isotopes or decay products of potassium, uranium, and thorium independently and provide estimates of the content of these elements in the near-surface soils and rocks. Analyses of the flightline equivalent uranium (eU) data for units that underlie Prince George's County are shown in Table 1.

Soil-gas radon studies have been conducted in two nearby areas; Fairfax County, Virginia (Schumann and Owen, 1988) and Montgomery County, Maryland (Gundersen and others, 1988) (Figure 1). However, most of these two counties are underlain by Precambrian crystalline rocks of the Piedmont or sedimentary rocks of the Culpepper basin and little gas sampling was done on soils developed in Coastal Plain sediments.

Soil-gas samples along a 21 km traverse extending from Landover Hills to Hardesty in Prince George's County were analyzed for radon by Reimer (1988, 1990). Reimer's soil-gas radon values ranged from 100 to 2700 pCi/L. Highest readings were found in soils developed on the Aquia Formation (Ta) and the Calvert Formation (Tc).

Table 1. Estimated average equivalent uranium values for formations of interest for east-west flightlines crossing Prince George's County

[Kps- Potomac group sand, sandy clay, and gravel; Kpc- Potomac Group clay; TKb- Brightseat Formation and Monmouth Group; Tc- Chesapeake Group- principally the Calvert Formation; Tu- Upland deposits; Qt- river terrace deposits;derived from Texas Instruments, 1978]

Flightline Number	Location	Formation(s)	Equivalent Uranium(ppm)
24	College Park,	Kpc,Kps	1.3
	Bowie	TKb	2.0
25	Kidwell's Corner	Tc	2.4
26	East of Upper Marlboro	Qt	0.9
27	Lower Matta-poni Creek	Tc	2.2
28	Horsehead	Tc	1.7
	Magruder's Landing	Tu	1.4
29	Chalk Point	Tc	2.0

Methods

Soil-gas samples were collected from the soil at a depth of 0.75 m by means of a thin-walled, stainless steel probe pounded into the ground (Reimer, 1977). Soil-gas samples were withdrawn using a 20cc syringe inserted through a needle guide attached to the top of the probe. The gas sample is retained in the syringe for a minimum of 5 minutes to permit radon-220 (with a half-life of 55 seconds) to decay. The sample is then injected into an evacuated alpha scintillation (Lucas) cell (EDA Model RDA-200) and counted for 5 minutes. Background count for the cell (taken immediately before sample injection) is subtracted from the sample count and the radon level calculated from the net count using a calibration factor. This instrument has been calibrated against the radon chamber at the U.S. Bureau of Mines in Lakewood, Colorado.

Soil radioactivity was measured by two instruments; a Scintrex Gad-6 gamma spectrometer and a Geometrics Exploranium scintillometer. The gamma spectrometer was used for the early part of the study (the first 42 sample sites) until it developed instrumental problems. The scintillometer was then used for the rest of the sample sites except for the last one (PG89-226A-J). In both cases, the instrument was laid on the ground within 30 to 60 cm of the probe hole and measurements made concurrently with the drawing of the soil-gas sample. For the gamma spectrometer a five minute count was taken. For the scintillometer, the instrument was observed for several seconds and the range and median values estimated. Median values for the scintillometer count are reported here. The gamma spectrometer has been calibrated using Department of Energy calibration pads in Grand Junction, Colorado. Cosmic background for the spectrometer was determined by making measurements on Burke Lake in Fairfax County, Virginia.

During the course of the study, we made three vertical soil profiles in the south-central part of the county (Sample sites PG 89-14, PG 89-15, and PG 89-226) to determine the appropriateness of the sampling depth used (75 cm). Soil-gas samples were taken at 25, 50, 75, and 100 cm depths and a vertical radon profile constructed.

The primary criteria for selecting sample sites were ease of access and uniform geographic coverage. Sample sites were usually selected along road rights-of-way, school grounds, and park lands.

Results

Soil-gas radon and soil radioactivity were measured at 11 sites during the summer of 1988 and 226 sites during the summer and fall of 1989. Table 2 shows the sample location number, the date that the sample was collected, the map unit underlying the sample site, the radon measurement (all samples were taken at 75 cm depth unless otherwise noted), the gamma spectrometer data given in percent potassium and parts per million equivalent uranium and equivalent thorium, and the scintillometer data given in total counts per second. Sample locations are shown in Plate 1. Generalized geology from Hack (1977) also shows on Plate 1.

The two vertical radon profiles taken in soils developed on the Calvert Formation (Tc, PG 89-14 and PG 89-226F, Fig. 2) show a progressive increase in radon content with the 75 cm depth recording either the maximum radon reading or about 95 percent of the maximum reading. The variation between the 75 and 100 cm readings in both of these sites is probably within the sampling and analytical error of the technique. This suggests that for these soils (sand and silt loams), the 75 cm sampling depth approaches the maximum value for soils at the sites. We conclude that 75 cm is an acceptable operational sampling depth for this area.

A third vertical radon profile was taken at sample site PG 89-15 (Fig. 2), a site where thin soils have formed on recently disturbed gravel beds adjacent to an abandoned gravel mining operation. Values measured on August 11 increase from 25 cm to 50 cm, drop at 75 cm, then continue to increase at 100 cm. A previous single measurement on July 18 at 75 cm at this site showed a value intermediate between the 50 and 100 cm values of August 11. Note that the U content of these soils is very low, 0.4 ppm eU. These data suggest that for gravels, especially soils formed on disturbed gravels, measurements taken at 75 cm may not adequately characterize the radon content of the soil gas that might be available to the foundation zone surrounding a home. This may be because the depth of sampling is inadequate to escape the effects of the surface, or because sampling in gravelly soils sometimes produces poor seals between the exterior of the probe and the soil, thus permitting atmospheric dilution of the sample.

There is a systematic variation in the range and average soil-gas radon readings for soils on the various mapped rock formations in the county. The measured soil-gas values for the various rock units mapped in the county were tabulated using the stratigraphic nomenclature of Hack (1977). Although other mapping with different nomenclature was available for parts of the county, Hack's map provided the only countywide nomenclature available to us. Table 3 summarizes soil-gas radon data for soils on the rock formations sampled.

Soil radioactivity also varies systematically from one formation to another. The radioactivity data are summarized in Tables 4-7. Equivalent uranium values (Table 4) were highest for the Severn Formation (part of TKb of Hack, 1977, but not mapped separately by him), however all values were from the same locality (PG89-226), thus these high values do not necessarily represent the Severn Formation or TKb. The presence of phosphate minerals and phosphatic fossil material at this locality is likely a factor in the elevated equivalent uranium observed as uranium is often adsorbed by or coprecipitated with phosphate in shallow restricted marine environments. The next highest average equivalent uranium value was for Tc (the Chesapeake Group, principally the Calvert Formation and hereafter referred to as the Calvert Formation). Equivalent uranium values for the Calvert Formation (Tc) at locality PG89-226 lie in the upper 10 percent of Calvert Formation (Tc) equivalent uranium values. At this locality the Calvert

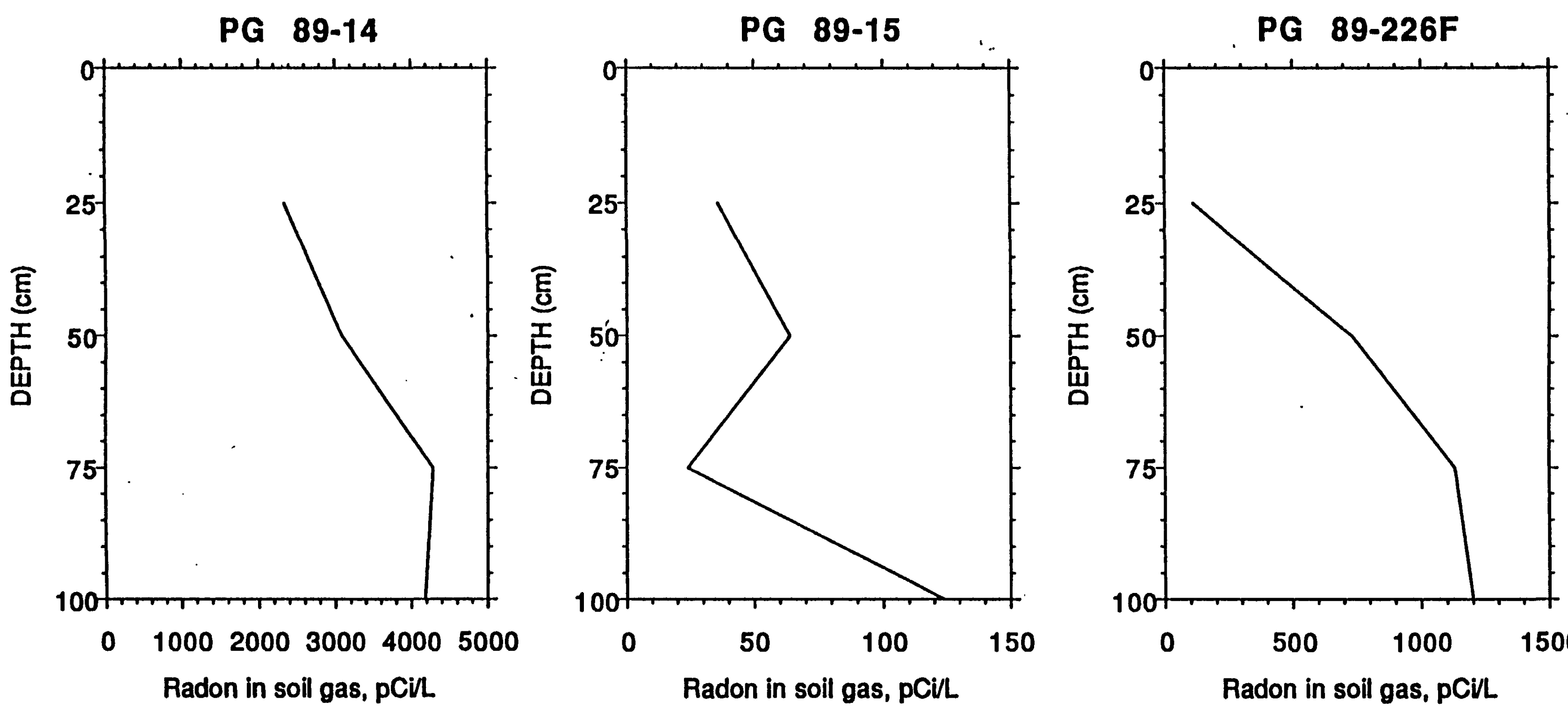

Figure 2. Vertical radon profiles for three soil sample locations in Prince George's County, Maryland. See Plate 1 for locations.

Table 2- Soil-gas radon and soil radioactivity measurements at sites in Prince George's County, Maryland (K is given in percent, U and Th in ppm equivalent, d- damp, w- wet, NS-No sample, sample depths different than 75cm are indicated next to location number)

Location number (see Plate 1)	Date	Map unit	Radon (pCi/L)	Soil radioactivity K	U	Th	Cps
PG 88-1	9/8	Tu	480	0.92	3.2	9.7	
	9/8	Replicate		0.98	2.5	9.5	
PG 88-2	9/8	Tu	710	0.75	2.7	7.7	
PG 88-3	9/8	Tc	2020	0.74	2.1	6.2	
PG 88-4	9/8	Qt	830	0.79	1.7	6.7	
PG 88-5	9/8	Tn	660	0.80	2.9	7.6	
PG 88-6	9/8	Tc	2760	0.76	3.1	8.4	
PG 88-7	9/8	Tu	860	0.88	1.8	8.9	
PG 88-8	9/8	Tu	390	0.81	2.7	9.5	
PG 88-9	9/8	Tu	100	0.28	0.5	4.0	
PG 88-10	9/8	Tu	140	0.59	1.9	6.2	
PG 88-11	9/8	Tc	1040	0.64	2.2	5.6	
PG 89-1	7/12	Qt	1980	0.87	3.5	7.4	
PG 89-2	7/12	Tc	1950	0.63	3.0	6.6	
PG 89-3 (d)	7/12	Tu	NS	0.85	3.1	8.6	
PG 89-4	7/12	Tc	2760	0.22	0.9	3.4	
PG 89-5	7/12	Tn	2640	0.28	1.0	3.3	
PG 89-6	7/12	Tc	2950	0.76	2.6	7.2	
PG 89-7	7/12	Tn	2060	0.63	1.7	4.8	
PG 89-8	7/12	Qg	490	0.30	1.1	1.7	
PG 89-9	7/12	Tu	830	0.55	1.8	4.4	
PG 89-10	7/12	Tu	120	0.27	0.8	3.9	
PG 89-11	7/12	Tc	1780	0.53	1.8	5.3	
PG 89-12	7/12	Tc	485	0.40	1.6	5.8	
PG 89-13	7/12	Tc	810	0.32	1.2	3.9	
PG 89-14	7/18	Tc	4100	0.81	3.0	7.1	
PG 89-14 profile							
25cm	8/11		2340				
50cm	8/11		3090				
75cm	8/11		4290				
100cm	8/11		4180				
PG 89-15	7/18	Tu	80	0.22	0.4	1.6	
PG 89-15 profile							
25cm	8/11		36				
50cm	8/11		64				
75cm	8/11		24				
100cm	8/11		124				
PG 89-16A	7/18	Tn	970	0.38	2.2	4.3	
PG 89-16B	7/18	Tc	1290	0.50	3.2	5.2	
PG 89-16C	7/18	Tc	3100	0.48	2.4	4.8	
PG 89-16D	7/18	Tc	560	0.31	1.6	3.6	
PG 89-17	7/18	Tc	3800	0.69	3.4	7.2	
PG 89-18	7/18	Tc	690	0.23	0.8	2.2	

Table 2 (continued)

Location number (see Plate 1)	Date	Map unit	Radon (pCi/L)	Soil radioactivity K	U	Th	Cps
PG 89-19	7/18	Tc	5000	0.45	2.6	5.2	
PG 89-20	7/18	Tu	310	0.38	0.9	2.9	
PG 89-21	7/18	Tc	2710	0.58	2.0	6.7	
PG 89-22	7/21	Tn?	2020	1.24	3.4	6.8	
PG 89-23	7/21	Tc?	3550	0.85	2.3	6.9	
PG 89-24	7/21	Tc	4030	0.84	2.5	9.2	
PG 89-25 (w)	7/21	Tc?	4060	0.72	3.6	7.8	
PG 89-26	7/21	Tc	1230	0.67	2.7	4.9	
PG 89-27 (w)	7/21	Tc	NS	0.56	2.6	5.0	
PG 89-28	7/21	Tc	2920	0.79	4.3	9.3	
PG 89-29	7/21	Tc	3500	0.79	2.8	6.6	
PG 89-30	7/21	Tmb	1300	1.38	2.1	10.1	
PG 89-31 (w)	7/21	Ta	1700	1.00	1.9	3.5	
PG 89-32	7/28	Tc	2125				27
PG 89-33	7/28	Ta	1250				27
PG 89-34	7/28	Ta	1800				20
PG 89-35	7/28	Ta	500				24
PG 89-36	7/28	Kmo	260				21
PG 89-37	7/28	TKb	970				35
PG 89-38	7/28	Tc?	6990				32
PG 89-39	7/28	Ta	3020				41
PG 89-40	7/28	TKb	1540				39
PG 89-41	7/28	TKb?	1350				43
PG 89-42	7/28	Ta?	7180				45
PG 89-43	7/28	Ta	1850				44
PG 89-44	7/28	Tc	1910				41
PG 89-45	8/1	TKb?	2020				37
PG 89-46	8/1	Tmb?	2000				41
PG 89-47	8/1	TKb?	970				40
PG 89-48	8/1	Kpc	NS				32
PG 89-49	8/1	Kps	2180				30
PG 89-50	8/1	Kps?	2120				39
PG 89-51	8/1	Kpc	900				25
PG 89-52(45cm)	8/1	Kpc	1070				33
PG 89-53	8/1	TKb	1210				38
PG 89-54	8/1	Ta	1760				26
PG 89-55	8/1	Ta	3330				33
PG 89-56A	8/1	Ta	2510				34
PG 89-56B	8/4	TKb	2910				34
PG 89-57	8/4	Ta	2330				41
PG 89-58	8/4	Tc	1680				30
PG 89-59	8/4	TKb	1060				35
PG 89-60	8/4	Tc	2440				26
PG 89-61	8/4	TKb	1850				29
PG 89-62	8/4	Tc	850				25
PG 89-63	8/4	Tc	940				24
PG 89-64	8/4	Tu	1320				35
PG 89-65 (d)	8/4	Tu	490				19
PG 89-66	8/4	Tc	5510				36

Table 2 (continued)

Location number (see Plate 1)	Date	Map unit	Radon (pCi/L)	Soil radioactivity K	U	Th	Cps
PG 89-67	8/4	Tn	2450				39
PG 89-68	8/4	Tc	3960				ND
PG 89-69	8/8	gn	580				41
PG 89-70	8/8	gn	630				ND
PG 89-71	8/8	Kps	1230				36
PG 89-72	8/8	gn	2460				28
PG 89-73	8/8	Tu	950				20
PG 89-74	8/8	Tu	360				23
PG 89-75(60cm)	8/8	Tu	340				31
PG 89-76(65cm)	8/8	Tu	350				29
PG 89-77	8/8	Kps	530				23
PG 89-78	8/8	Kps	780				30
PG 89-79	8/8	Kps?	420				19
PG 89-80	8/8	Kps	890				32
PG 89-81	8/8	Kps	240				22
PG 89-82	8/9	Kpc	580				37
PG 89-83	8/9	Kpc	810				37
PG 89-84(60cm)	8/9	Kpc	360				38
PG 89-85	8/9	Kpc	350				27
PG 89-86	8/9	Kpc	3550				31
PG 89-87	8/9	Kps	1780				30
PG 89-88	8/9	Kpc	930				23
PG 89-89	8/9	Kps	340				23
PG 89-90	8/9	Kpc	1670				31
PG 89-91	8/9	Kps	640				25
PG 89-92(w)	8/10	Kps	280				15
PG 89-93	8/10	Kpc	540				27
PG 89-94	8/10	Kpc	2050				28
PG 89-95	8/10	Kps	730				19
PG 89-96	8/10	Kpc	630				24
PG 89-97	8/10	Kpc	850				26
PG 89-98	8/10	Kps	590				18
PG 89-99	8/10	Kpc	1400				32
PG 89-100	8/10	Kps	100				16
PG 89-101	8/10	Kpc	85				36
PG 89-102	8/10	Kps	720				26
PG 89-103	8/15	Kps	750				42
PG 89-104	8/15	Kps?	380				41
PG 89-105	8/15	TKb	320				39
PG 89-106	8/15	Ta	3120				47
PG 89-107	8/15	Kpc	1650				29
PG 89-108	8/15	Kps?	790				19
PG 89-109	8/15	Kps	630				26
PG 89-110	8/15	Kps	460				25
PG 89-111	8/15	Kps	410				25
PG 89-112	8/15	Kpc	870				21
PG 89-113(65cm)	8/15	Kps	1000				23
PG 89-114	8/17	Qt	810				35
PG 89-115	8/17	Qc/Tn	1780				24

Table 2 (continued)

Location number (see Plate 1)	Date	Map unit	Radon (pCi/L)	Soil radioactivity K	U	Th	Cps
PG 89-116	8/17	Tb	1090				33
PG 89-117	8/17	Qc	500				24
117R	8/17		680				
PG 89-118(50cm)	8/17	Tb	250				35
PG 89-119	8/17	Tb	740				32
PG 89-120	8/17	Tb	320				25
PG 89-121A	8/17	Tb	570				28
PG 89-121B	8/17	Tc?	1170				40
PG 89-122	8/17	Qc/Tc	700				31
PG 89-123	8/17	Qt	550				12
PG 89-124	8/17	Tc	7340				25
PG 89-125	8/17	Tc	2200				33
PG 89-126	8/22	Qc/Tc	1360				29
PG 89-127(60cm)	8/22	Tb	200				33
PG 89-128	8/22	Tc?	2030				29
PG 89-129	8/22	Tn	1140				22
PG 89-130	8/22	Tb	230				33
PG 89-131	8/22	Tc	1580				27
PG 89-132	8/22	Tb	180				19
PG 89-133	8/22	Qc/Tc	1020				28
PG 89-134	8/22	Tc	3640				25
PG 89-135(w)	8/22	Tc	NS				22
PG 89-136	8/22	Tb	210				17
PG 89-137	8/22	Tc	960				32
PG 89-138(55cm)	8/22	Tb	580				ND
PG 89-139	8/29	Kpc	710				30
PG 89-140	8/29	Kpc	NS				35
PG 89-141	8/29	Kps	460				26
PG 89-142	8/29	Kpc	140				23
PG 89-143(60cm)	8/29	Kpc	540				37
PG 89-144	8/29	Kpc	80				16
PG 89-145	8/29	Kpc	1080				28
PG 89-146	8/29	Kpc	620				28
PG 89-147	8/29	Kpc	360				37
PG 89-148	8/29	TKb	860				22
PG 89-149	8/29	TKb	760				46
PG 89-150(65cm)	9/1	Tu	320				25
PG 89-151(60cm)	9/1	Tu	640				27
PG 89-152A (w)	9/1	Tc	780				36
PG 89-152B	9/1	Ta	3040				39
PG 89-152C	9/1	TKb?	1900				32
PG 89-153(55cm)	9/1	Tu	320				36
PG 89-154	9/1	Tc?	460				30
PG 89-155	9/1	Ta	760				35
PG 89-156	9/1	Qc/Tc	360				22
PG 89-157A	9/1	Tc	8220				33
PG 89-157A	12/5	Retake	6790				
		Replicate	7480				
PG 89-157B	9/1	Tc?	3060				32

Table 2 (continued)

Location number (see Plate 1)	Date	Map unit	Radon (pCi/L)	Soil radioactivity K	U	Th	Cps
PG 89-157C	9/1	Tc?	3260				29
PG 89-158	9/15	Ta	2470				44
PG 89-159	9/15	Ta	3120				28
PG 89-160	9/15	Ta	1670				43
PG 89-161	9/15	Ta?	270				22
PG 89-162	9/15	Ta?	580				29
PG 89-163	9/15	Ta	1100				34
PG 89-164	9/15	Ta	1090				32
PG 89-165	9/15	Tc	1110				39
PG 89-166	9/15	Tc	760				33
PG 89-167	9/15	Ta	590				37
PG 89-168	9/15	Ta	340				30
PG 89-169	9/15	Ta	440				42
PG 89-170	9/25	Tu	420				25
PG 89-171	9/25	Tu	760				33
PG 89-172	9/25	Tu	230				19
PG 89-173	9/25	Ta	1690				47
PG 89-174	9/25	Tc	4930				26
PG 89-175	9/25	Tc	3920				33
PG 89-176	9/25	Tc	1460				32
PG 89-177	9/25	Tc	2620				31
PG 89-178	9/25	Tc	3240				29
PG 89-179	9/25	Tu	1150				30
PG 89-180	9/25	Tu	970				31
PG 89-181	9/25	Tc	2370				26
PG 89-182	10/08	Tu	1260				30
PG 89-183A	10/08	Tu	640				25
PG 89-183B	10/08	Qc/Tc	300				22
PG 89-184	10/08	Tu	1090				12
PG 89-185	10/08	Tu	2430				29
PG 89-186(w)	10/08	Tu/Tc	1740				30
PG 89-187	10/08	Qc/Tc	600				24
PG 89-188	10/08	Ta	3260				42
PG 89-189(w)	10/08	Tu	NS				37
PG 89-190(w)	10/08	Tu	NS				ND
PG 89-191	10/08	Tu	660				29
PG 89-192	10/13	Ta	2120				30
PG 89-193	10/13	Qal	470				23
PG 89-194A	10/13	TKb	1920				46
PG 89-194B(d)	10/13	Ta	NS				28
PG 89-194C	10/13	Qc/Tc	820				25
PG 89-195	10/13	Tu	730				30
PG 89-196	10/13	Qc/TKb	680				19
PG 89-197	10/13	Qc/TKb	940				25
PG 89-198	10/13	Tc	500				28
PG 89-199(w)	10/13	Qc/Ta	1450				20
PG 89-200	10/13	Qc/Tc	670				22
PG 89-201	10/25	Tc	1470				26
PG 89-202	10/25	Tu	910				25

Table 2 (continued)

Location number (see Plate 1)	Date	Map unit	Radon (pCi/L)	Soil radioactivity K	U	Th	Cps
PG 89-203	10/25	Tc	2010				26
PG 89-204	10/25	Tc	4660				38
PG 89-205(d)	10/25	Tc	NS				32
PG 89-206	10/25	Tc	2960				25
PG 89-207(45cm)	10/25	Tu	1260				29
PG 89-208(w)	10/25	Tu	NS				24
PG 89-209(w)	10/25	Tu	NS				ND
PG 89-210(w)	10/25	Tu	2130				27
PG 89-211(w,70cm)	10/25	Tu	2110				27
PG 89-212(w)	11/2	Tu	860				28
PG 89-213(w)	11/2	Tu	NS				33
PG 89-214(w)	11/2	Tu	NS				29
PG 89-215(d)	11/2	Tu	NS				33
PG 89-216(w)	11/2	Tu	1830				22
PG 89-217(d)	11/2	Tu	NS				ND
PG 89-218(d)	11/2	Qc/Tc	230				22
PG 89-219	11/2	Tc	1860				31
PG 89-220A	11/2	Tc	660				30
PG 89-220B	11/2	Tc	740				30
PG 89-221(w)	11/2	Tu	2030				22
PG 89-222	11/2	Tu	190				20
PG 89-223	11/2	Tc	1370				26
PG 89-224	11/2	Tc	6580				36
PG 89-225	11/2	Tu	1860				42
PG 89-226A(25cm)	12/5	Ks	NS	1.98	4.6	12.5	
PG 89-226B	12/5	Ks		1.74	5.4	11.2	
PG 89-226C	12/5	Ks		1.60	6.2	14.0	
PG 89-226D	12/5	Tc/Ks		0.89	10	10.1	
PG 89-226E	12/5	Tc		1.38	6.2	9.0	
PG 89-226F	12/5	Tc		1.61	3.6	12.2	
PG 89-226F profile							
25cm			110				
50cm			730				
75cm			1130				
100cm			1200				
PG 89-226G	12/5	Tb		0.42	2.2	7.2	
PG 89-226H	12/5	Kpc		0.36	2.5	7.7	
PG 89-226I	12/5	Kpc		0.29	2.0	9.2	
PG 89-226J	12/5	Ks	1640				

Table 3. Summary data for radon in soil gasby formation

[Values in pCi/L; gn-Precambrian gneiss; Kps- Potomac group sand, sandy clay, and gravel; Kpc- Potomac Group clay; TKb- Brightseat Formation and Monmouth Group; Ta- Aquia Formation; Tmb- Marlboro clay member of theNanjemoy Formation; Tn- upper member of the NanjemoyFormation; Tc- Chesapeake Group- principally theCalvert Formation; Tu- Upland deposits; Qt- river terrace deposits; Qal- river alluvium]

Formation	N	Range	Average and standard deviation
gn	3	580-2460	1223±1071
Kps	26	100-2180	841±602
Kpc	24	80-3550	909±757
TKb	17	320-2910	1347±639
Ta	27	270-3330	1747±995
Tmb	2	1300-2000	1650
Tn	7	970-2640	1865±624
Tc	71	230-8220	2418±1886
Tu	43	80-2430	798±622
Qt	4	490-1980	958±696
Qal	1	470	470

Table 4. Summary data for equivalent uranium (eU) in soils by formation

[Values in ppm; Kpc- - Potomac Group clay;Ks- Severn Formation, part of TKb; Ta- Aquia Formation; Tmb- Marlboro clay member of theNanjemoy Formation; Tn- upper member of the NanjemoyFormation; Tc- Chesapeake Group- principally theCalvert Formation; Tu- Upland deposits;Qt- river terrace deposits]

Formation	N	eU Range	Average and standard deviation
Kpc	2	2.0-2.5	2.3
Ks	4	4.6-10	6.6±2.4
Ta	1	1.9	1.9
Tmb	1	2.1	2.1
Tn	5	1.0-3.4	2.2±1.0
Tc	26	0.8-4.3	2.6±1.1
Tu	12	0.8-3.2	1.8±1.0
Qt	3	1.1-3.5	2.1±1.3

Table 5. Summary data for potassium in soilsby formation [Values in percent; gn-Precambrian gneiss; Kps- Potomac group sand, sandy clay and gravel; Kpc- Potomac Group clay; TKb- Brightseat Formation and Monmouth Group; Ta- Aquia Formation; Tmb- Marlboro clay member of theNanjemoy Formation; Tn- upper member of the NanjemoyFormation; Tc- Chesapeake Group- principally theCalvert Formation; Tu- Upland deposits; Qt- river terrace deposits; Qal- river alluvium]

Formation	N	K Range	Average and standard deviation
Kpc	2	0.29-0.36	0.33
Ks	3	1.60-1.98	1.77±0.19
Ta	1	1.00	1.00
Tmb	1	1.38	1.38
Tn	5	0.28-1.24	0.67±0.38
Tc	26	0.22-1.61	0.68±0.31
Tu	11	0.22-0.92	0.55±0.26
Qt	3	0.30-0.87	0.65±0.31

Table 6. Summary data for equivalent thorium in soils by formation
[Values in parts per million; gn-Precambrian gneiss; Kps- Potomac group sand, sandy clay and gravel; Kpc- Potomac Group clay; TKb- Brightseat Formation and Monmouth Group; Ta- Aquia Formation; Tmb- Marlboro clay member of theNanjemoy Formation; Tn- upper member of the NanjemoyFormation; Tc- Chesapeake Group- principally theCalvert Formation; Tu- Upland deposits; Qt- river terrace deposits; Qal- river alluvium]

Formation	N	eTh Range	Average and standard deviation
Kpc	2	7.7-9.2	8.5
Ks	3	11.2-14.0	12.6±1.4
Ta	1	3.5	3.5
Tmb	1	10.1	10.1
Tn	5	3.3-7.6	5.4±1.8
Tc	27	3.4-12.2	6.5±2.2
Tu	12	1.6-9.7	6.2±2.8
Qt	3	1.7-7.4	5.3±3.1

Table 7. Summary data for total gamma count in soils by formation

[Values in counts per second; gn-Precambrian gneiss; Kps- Potomac group sand, sandy clay and gravel; Kpc- Potomac Group clay; TKb- Brightseat Formation and Monmouth Group; Ta- Aquia Formation; Tmb- Marlboro clay member of theNanjemoy Formation; Tn- upper member of the NanjemoyFormation; Tc- Chesapeake Group- principally theCalvert Formation; Tu- Upland deposits; Qt- river terrace deposits; Qal- river alluvium]

Formation	N	Gamma Range	Average and standard deviation
gn	2	28-41	35
Kps	24	15-42	26±8
Kpc	26	16-38	30±6
TKb	14	22-46	37±6
Ta	27	20-47	35±8
Tmb	1	41	41
Tn	2	22-39	31
Tc	40	22-41	30±5
Tu	44	12-42	28±6
Qt	16	12-35	24±5
Qal	1	23	23

Formation (Tc) may have incorporated significant amounts of material from the underlying Severn Formation (Ks). The Calvert Formation (Tc) rests with erosional unconformity on Severn Formation (Ks) at this locality; the basal contact is irregular and marked by a gravel bed.

Average values for the Potomac Group clay (Kpc), the Marlboro clay member of the Nanjemoy Formation (Tmb), the upper member of the Nanjemoy Formation (Tn), and river terrace deposits (Qt) were slightly over 2 ppm eU, however these units were sparsely sampled. The upland deposits (Tu) and the Aquia Formation (Ta) averaged slightly under 2 ppm.

The average eU values in Table 4 for Kpc (2.3 ppm), Tc (2.6 ppm), Qt (2.1 ppm) and Tu (1.8 ppm) are persistently higher than the eU values recorded by the various NURE flightlines (Table 1, Kpc/Kps- 1.3 ppm; Tc- 2.4, 2.2, 1.7, and 2.0 ppm; Qt- 0.9 ppm; and Tu- 1.4 ppm). This discrepancy is not unexpected as the measurements of soil radioactivity and the measurements of aeroradioactivity covered different areas of the county and were taken under different conditions.

Highest potassium values were reported for the Severn Formation (Ks, 1.5-2.0 percent, Table 5). This likely reflects the presence of glauconite and vivianite in the outcrop studied (Sample locality PG89-226). Single high potassium values (1.00 percent or greater) were recorded for Ta and Tmb, and Tn and Tc each had 1 or 2 potassium values over 1.00. The two elevated potassium values in the Calvert Formation (Tc) are all from locality PG89-226 and suggest further that material from the underlying Severn Formation (Ks) is incorporated in Calvert Formation (Tc) at this locality. The Aquia Formation (Ta) and the upper member of the Nanjemoy Formation (Tn) are known to be glauconitic, thus the high potassium values are not unexpected. The Marlboro clay member of the Nanjemoy Formation (Tmb) is generally not glauconitic thus the elevated potassium value is surprising unless the unit is mismapped at this locality or slumped material from overlying glauconitic units overlies the Marlboro clay (Tmb) at the sampled locality.

The highest average equivalent thorium value (12.6 ppm, Table 6) also came from the Severn Formation (Ks) at locality PG89-226 and, similar to uranium and potassium, thorium values for the Calvert Formation (Tc) from this locale are elevated. Average thorium values are about 5-6 ppm for most other units (Tu, Qt, Tn) and for most of the Calvert Formation (Tc).

Average total counts (Table 7) show variation from 23 (single value for Qal) to 41 (a single value for Tmb). Ta, TKb, and gn cluster around 36 cps; Kpc, Tn, and Tc cluster around 30 cps; and Kps, Tu, and Qt range from 24-28 cps. Ta and TKb are known to have higher contents of uranium, thorium, and potassium due to the presence of phosphate, glauconite, and clay. Uranium, thorium, and potassium tend to associate with clays, glauconite, and phosphatic material found in the formations deposited in restricted marine environments. Gneiss (gn) in nearby Montgomery County is also known for elevated radioactivity (Gundersen and others, 1988). All the low total-count values are associated with formations characterized by sandy sediments deposited by stream flow. Fluvial sediment in this area is enriched in quartz and chert grains which are typically low in radionuclides.

Discussion and Conclusions

Although elevated indoor radon levels (>4 pCi/L) can occur anywhere in the county, soil-gas radon levels across Prince George's County are locally high enough to suggest that elevated indoor radon levels are more likely to occur in homes sited on soils formed on the Calvert (Tc) and Aquia Formations (Ta). Thirty-five of 71 soil-gas readings (49 percent) on the Calvert Formation (Tc) and 14 of 27 soil-gas readings (52 percent) on the Aquia Formation (Ta) exceed 2000 pCi/L. This level has been used by various workers as an indication of significantly increased radon potential; see, for example, Gundersen and others (1988). Elevated indoor radon levels are also likely on the gneiss (gn) and on the Marlboro clay member (Tmb) and upper member of the Nanjemoy Formation (Tn), however far fewer soil-gas radon data are available for these units, thus the conclusion is less reliable. With the exception of the gneiss, these units crop out principally in the eastern parts of the county.

Elevated indoor radon levels are less likely to occur in homes sited on the Potomac Group (Kps and Kpc) or Tertiary upland (Tu) deposits, where less than 10 percent of the soil-gas values exceed 2000 pCi/L. However, all of the Tertiary upland deposit (Tu) values that exceed 2000 pCi/L occur in southeastern Prince

George's County where they overlie the Calvert Formation (Tc). It seems likely that Tertiary upland deposits (Tu) have eroded and incorporated part of the underlying Calvert Formation (Tc), thus the potential for elevated indoor radon levels in soils developed in Tertiary upland deposits in this part of the county may be higher than elsewhere.

The spectral soil radioactivity data were too sparse for most of the formations, except the Calvert Formation (Tc) and the Tertiary upland deposits (Tu), to draw any conclusions other than those noted above.

The total-count soil radioactivity data are not entirely consistent with the picture suggested for the soil-gas radon data. Average total gamma count for the Calvert Formation (Tc) is 30 cps, whereas the Aquia Formation (Ta) averages 35 cps, yet soil-gas radon levels appear to be significantly higher for the Calvert Formation. It seems likely that the higher potassium content expected for the Aquia Formation (Ta) because of the presence of glauconite is contributing to the higher total gamma count. It may also be that the emanating fraction for Calvert Formation (Tc) soils is higher than that for Aquia Formation (Ta) soils, therefore more radon is being generated by the radium present.

Further evaluation of the radon potential in Prince George's County will require examination of other factors such as soil moisture, permeability, and drainage. Comparison of the geologic factors to available indoor radon data may also permit a definition of the expected indoor radon levels for various areas of the county.

By themselves, soil-gas radon data, soil radioactivity data, and aeroradiometric data do not provide site-specific evaluations of radon potential, except in those cases where extreme values occur over specific rock types or at specific locations. When this occurs, elevated indoor radon levels are likely, however predictions of expected indoor values are still imprecise.

The significant variation in uranium and potassium radiometric data for soils formed on the various rock units suggests that uranium and potassium values may be used as a field indicator of what unit is present below the soil profile. However, it must be remembered that gamma detection equipment generally receive 90 percent of their signal from the upper 40 cm of the soil profile. On hillslopes, sediment may be displaced downslope by slumping. Where there is a good contrast in the radioactivity of the units involved, the soil radiometric signature may be a good indicator of the extent of slumped areas.

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