PREPARED IN COOPERATION WITH THE
COUNTY OF FAIRFAX

Location map

INTRODUCTION

Since 1984, indoor radon has gained national attention as a significant health hazard in the United States. Radon is a colorless, odorless, radioactive gas derived from uranium by radioactive decay. The U.S. Environmental Protection Agency (EPA) now projects that 5,000 to 20,000 lung-cancer deaths per year may be attributed to the long-term exposure to indoor radon and its radioactive decay products. Indoor radon had been previously recognized as a health hazard associated with uranium-bearing mill tailings or building materials, but it was not until December 1984 that some natural soils and rocks were found to be sources of indoor radon at levels comparable to those in uranium mines. It is now suspected that elevated indoor radon levels are far more widespread than initially thought. The EPA considers 4 picoCuries of radon per liter of air (pCi/L) as the level (in a year-round measurement) at which action ought to be taken to lower the concentration of indoor radon.

All soils and rocks contain measurable amounts of uranium, which generate measurable amounts of radon. Certain soils and rocks, however, have a greater potential to cause indoor radon problems than others because (1) they have a higher uranium content and thus can generate higher levels of radon in soil gas (gas that occupies the pores of the soil), and (2) the permeability of the soil or rock is sufficiently high that radon-bearing soil gas can flow freely and move indoors through the foundation of the structure.

This study was designed to demonstrate the correlation between the geologic environment and indoor radon levels and to demonstrate a method of assessment that could be used by other informed workers in areas of their interest. A parallel study by Gundersen and others (1988) of the radon potential of rocks and soils in Montgomery County, Md., used somewhat different methods of assessment because the data available for an assessment of Montgomery County differed.

METHODOLOGY USED TO CREATE THE MAP

It would be ideal to have detailed maps of the radon content and the permeability of soils throughout Fairfax County in order to define the radon potential. Such information does not exist, however, and it is expensive to obtain. Data that are available include (1) geologic maps of Fairfax County, (2) soil surveys of Fairfax County, and some detailed studies of soil properties for the various mapped soil types, (3) an aeroradioactivity map of Fairfax County, (4) limited soil-gas radon and surface radioactivity measurements in parts of the county, and (5) indoor radon data from a study conducted by the Fairfax County Department of Health during the winter of 1986-87. We used these data to develop this radon-potential assessment in the ways described below. Data from a study of indoor radon in Fairfax County and other areas by Douglas Mose of the Geology Department of George Mason University were also available (Douglas Mose, George Mason University, written commun., 1987, 1988); however, these data were not used in this assessment.

Geology

The geologic map of Fairfax County (Drake and others, 1979; also see figure 1) shows that various igneous, sedimentary, and metamorphic rocks occur across the county. These rocks occur within three physiographic provinces: the Coastal Plain, the Piedmont, and the early Mesozoic Culpeper basin (informally referred to as the Triassic basin or Triassic Lowland). Geochemical analysis of rocks for several decades has led geoscientists to expect the uranium content of various types of rock, including those found in Fairfax County, to be predictable within certain limits. The geologic map of the county shows several rock types that, if typical, would have high (greater than 3 parts per million [ppm]), intermediate (1.5 to 3 ppm), or low (less than 1.5 ppm) uranium content. Rocks having expected low uranium content include diabase in the Culpeper basin and ultramafic rocks in the Piedmont. Rocks having expected high uranium content include siltstone in the Culpeper basin, some of the schist and phyllite in the Piedmont, and some of the granite in the Piedmont.

Figure 1.--Geologic sketch map of Fairfax County and vicinity showing physiographic provinces.

High concentrations of uranium (to several tens of parts per million) occur in areas north and south of Fairfax County in the zone where sandstone and siltstone of the Culpeper basin intertongue. Although such high concentrations of uranium have not been found in Fairfax County, there is a strong likelihood that they do occur. If so, and if structures are sited on such occurrences, then some localized severe levels of indoor radon (greater than 200 pCi/L) may occur.

Soils

Soil surveys show the distribution of and describe the physical, chemical, and morphological properties of various types of soils. The properties most often described are those that are important to the agricultural and engineering uses of the soil. The important physical properties with respect to radon migration through soils are gas permeability and soil moisture. Higher soil-gas permeabilities increase the ability of radon to migrate by either gaseous diffusion or convective flow. Although modest amounts of soil moisture (8-15 percent) increase the amount of radon that escapes from mineral matter, higher levels of soil moisture retard gaseous diffusion and convective flow as water progressively blocks the pore spaces. Thus higher permeabilities and lower soil moisture tend to enhance radon potential.

Gas permeability is not normally measured in soil studies; however, water permeability is, and it can be used as an approximation of gas permeability. Soil moisture is not normally measured in soil surveys; nevertheless, soil moisture is related to the permeability, slope, topographic position, and clay content of the soil. Highly permeable soils and soils on steep slopes tend to be well drained and therefore drier. Soils with high clay content tend to retain soil moisture. Soils in topographic lows tend to have higher soil moisture. For this study, we decided to classify soils on the basis of permeability alone, making the assumption that the general inverse relation between soil permeability and soil moisture in Fairfax County would allow us to evaluate the effect of soil moisture also. As we looked at the soil moisture characteristics of the soils that fell into our three classes of permeability we concluded that this approach was justified.

In soils characterization work, percolation rate (in inches per hour in a standardized test) is a commonly used means of measuring water permeability. We selected three permeability ranges as significant in estimating radon potential from soils maps: high, more than 6.0 inches per hour (in./hr); moderate, 0.2-6.0 in./hr; and low, less than 0.2 in./hr. The boundary between the moderate and high ranges was selected at the approximate point where radon migration through soils changes from movement mainly by relatively slow gaseous diffusion to transport by convective flow. For soils having low average moisture content--for example, well-drained soils on hillslopes--this point corresponds to a permeability of about 6 in./hr or 10^{-7} cm^2 (Sextro and others, 1987). The lower boundary of the moderate range was selected at the permeability value that separates soils described by soil scientists as "slow" in permeability from soils of higher permeability. Slowly permeable soils, in addition to transmitting radon at a low rate through air-filled pores, commonly are characterized by high seasonal or perched water tables in areas of relatively high rainfall such as Fairfax County. Water-saturated soils have severely limited radon movement and lowered radon potential.

We evaluated soils shown on the soil maps of Fairfax County (Porter and others, 1963) and compared their described physical properties with more recent and complete information on permeability developed by the Soils Science Office of the Fairfax County Department of Extension and Continuing Education. We then ranked the mapped soil types into high, moderate, and low permeability classes using the criteria described above. Using individual air photo plates from the 1963 map folio, the distribution of soils of high, moderate, and low permeability was traced on overlays. Soils developed on flood plains were not considered in the evaluation because homes typically are not located in these areas. These overlays were then reduced to the scale of the assessment map (1:48,000), and areas dominated by high, moderate, and low permeability soils were outlined to produce a soil permeability worksheet.

We found that several soil types in Fairfax County are typically high in overall permeability: Manor, Galestown, and Louisburg. Of these three, only the Manor and the Louisburg are common soil types. Manor soils are widespread on moderate to steep slopes underlain by the Peters Creek Schist, Sykesville Formation, and phyllite near stream drainages in the Piedmont. Louisburg soils have formed on moderate to steep slopes adjacent to stream drainages underlain by granite and granite gneiss in the Piedmont. Soils that are typically low in permeability are the Calverton, Colfax, Croton, Elbert, Elkton, Iredell-Mecklenburg, Kelly, Lenoir, Orange, and Worsham. These low-permeability soils have formed over the diabase and siltstone in the Culpeper basin and over the ultramafic rocks in the Piedmont, and over the clayey sediments in the Coastal Plain--especially marine clays of Cretaceous age. All other soils in the county were judged to be moderate in permeability.

Aeroradioactivity

Aeroradioactivity of surface materials in Fairfax County was measured during a survey conducted in 1975 and 1976 (U.S. Geological Survey, 1980). During the survey, total-count gamma data were acquired by low-flying aircraft on a flightline spacing of 0.5 mile across most of the county. Total-count gamma measurements record the combined gamma activity (in counts per second) of potassium-40 (an isotope of potassium), bismuth-214 (a radioactive decay product of radon-222 and uranium-238), and thallium-208 (a radioactive decay product of thorium-232). Aerial gamma measurements record the gamma rays from materials at the surface to depths of about 12 in. In many types of rocks and soils the potassium, uranium, and thorium contents vary similarly; thus rocks having high potassium content often have elevated uranium and thorium contents. This would suggest that, in general, variation in total count also would reflect variation in the uranium content of the surface materials.

The published version of the aeroradioactivity map (U.S. Geological Survey, 1980) shows contoured data at a scale of 1:48,000. In this study we used a color-shaded version of that map. The color-shaded map showed 15 intervals of total count. We selected the top five intervals as high (325 to 450 counts per second [cps]), the middle five as moderate (200 to 325 cps), and the lower five as low (from less than 100 to 200 cps) in radioactivity.

Diabase, ultramafic rocks, conglomerates of the Culpeper basin, Coastal Plain sediments, the granitoid complex, and the Occoquan Granite persistently showed low aeroradiometric signatures. We expected the Occoquan Granite to be higher because biotite-muscovite granites commonly contain elevated uranium contents. A study by Daniels (1980) suggested that the Occoquan had been leached of uranium and potassium in the surface soil horizons and that this was responsible for the unexpectedly low aeroradiometric count (see discussion in the following section). The siltstone of the Culpeper basin and the Peters Creek Schist in the Piedmont persistently showed high aeroradiometric counts. Isolated high values also occurred over Coastal Plain sediments in parts of Hybla Valley.

Soil-gas and surface radioactivity measurements

During the spring of 1987, we gathered additional data for several rock types in the county by measuring radon in soil gas and surface radioactivity at several sites (Schumann and Owen, 1988). This sampling was conducted along highway rights-of-way, at one school site, and at one home site. We measured radon in soil gas by driving a hollow, stainless-steel probe 0.75 meter (2.5 feet) into the ground, extracting a soil-gas sample through the probe, and injecting the sample into an evacuated alpha-particle counting device. We measured the radioactivity of bismuth-214 (a radioactive decay product of uranium-238 and radon-222) using a gamma spectrometer. Assuming radioactive equilibrium between bismuth-214 and its uranium parent, we then calculated the uranium content of the surface layer of soil. This calculated uranium content is referred to as equivalent uranium.

Highest average levels of radon in soil gas and of equivalent uranium measured during this study occur in the sandstone-siltstone transition zone in the Culpeper basin (1582 pCi/L), in the siltstone of the Culpeper basin (1028 pCi/L), and in the Peters Creek Schist in the Piedmont (1076 pCi/L). A metagraywacke phase of the Peters Creek Schist yielded average levels of radon similar to those for the Peters Creek Schist (1022 pCi/L). Lowest average levels of radon in soil gas were measured at sites on the conglomerate in the Culpeper basin (458 pCi/L) and at the few sites on sediments in the Coastal Plain (500 pCi/L). Low average levels of radon in soil gas were observed at sites on the Sykesville Formation (483 pCi/L). Sampling at several sites on the Occoquan Granite confirmed the relatively low surface radiometric signatures noted in the aeroradiometric data (average equivalent uranium 1.9 ppm), but showed that the average soil-gas radon content was among the highest of the rock types sampled (1425 pCi/L). Because of this, we ranked the Occoquan Granite higher than the aeroradioactivity and soil permeability data alone would suggest. Two sites on diabase showed higher-than-expected levels of equivalent uranium (about 3 ppm); a third site on diabase showed a higher-than-expected level of radon in soil gas (1875 pCi/L). These sites were near contacts with sedimentary rocks that had been intruded by the diabase. Examination of trenches and foundation cuts in the diabase near or along some of our sample traverses showed that inclusions of sedimentary rocks are common within the diabase. These inclusions are the most likely source of the elevated levels of equivalent uranium and soil-gas radon at the sites we sampled. Because of this, we ranked the diabase higher than otherwise.

Elevated levels of radon in soil gas (975 and 1300 pCi/L) and low levels of equivalent uranium (average 1.7 ppm) were measured at the two sampled sites on ultramafic rocks. Because the sites were within a shear zone, however, higher-than-normal levels of radon could be expected (see discussion of radon associated with sheared rocks, in Gundersen and others [1988]). We do not consider these sites typical of the ultramafic rock, and we rank the ultramafic rock low based on the permeability of its soils and its low aeroradioactivity. The data from the sites sampled during our study suggest that the potential of the ultramafic rocks may locally be higher near contacts or shear zones.

Indoor radon data

In response to growing public concern over indoor radon in Fairfax County, county personnel began a two-year indoor radon survey during the winter of 1986-87 (Fairfax County Radon Task Force, 1987). Participants in the study included individuals who volunteered their homes and those whose homes were selected for study by county personnel. This sampling was thus nonrandom and tended to favor the western and central parts of the county where the highest indoor radon levels were anticipated. Short-term, wintertime screening measurements were made following EPA recommendations (U.S. Environmental Protection Agency and U.S. Centers for Disease Control, 1986). The data set used in this radon-potential assessment consisted of readings from slightly more than a thousand homes.

In the county study, the highest percentage of homes having indoor radon levels greater than 4 pCi/L were in areas underlain by the Peters Creek Schist, phyllite, and the Occoquan Granite. The highest percentage of homes having indoor radon levels less than 4 pCi/L were in areas underlain by ultramafic rocks, diabase, and Coastal Plain sediments.

Radon-potential assessment procedure

Overlaying the geologic map, the aeroradioactivity map, and the soil permeability worksheet, we subjectively ranked the radon potential of various areas of the county into six categories, making modifications for some of the areas based on the soil-gas and equivalent-uranium measurements taken in them. Areas having high surface aeroradioactivity and high permeability were generally ranked in categories 5 or 4. Areas having low aeroradioactivity and low permeability were ranked in categories 1 or 2. Contacts between ranked areas were typically drawn along contacts between rock types, or, in areas where one rock type showed considerable variability, between zones of varying aeroradioactivity and permeability. Once a preliminary map was drawn, we laid the indoor radon map over it, and tabulated data and calculated statistics for the various ranked categories. It was immediately obvious that there was no difference in mean, median, and percent values over 4 pCi/L between areas initially ranked in categories 1 and 2. We therefore combined categories 1 and 2, reduced the number of categories to five, and retabulated the data. A closer analysis of these retabulated data suggested that we had ranked many of the areas underlain by the Peters Creek Schist and most of the areas underlain by the Occoquan Granite too low. For example, using the median and the percentage of homes having a radon level greater than 4 pCi/L, we could not discriminate between areas of Peters Creek Schist ranked in category 4 and those ranked in category 5. We then reranked the areas appropriately, retabulated the data, and recalculated the indoor radon information for the five categories. No areas required adjustment of more than one category in this second step. The mean and median values and the percentages of homes having indoor radon levels greater than or equal to 4 pCi/L in each of these categories are reported in table 1. Histograms of the indoor radon data for each of the categories are shown in figure 2.

GUIDELINES FOR USE OF THE RADON-POTENTIAL MAP

The radon-potential assessment is presented in table 1 and on the map. Areas on the map are labeled to show their radon-potential ranking, physiographic province, and dominant rock type (see explanation). Descriptions and comments are in table 1.

The following points should be considered when using the table and the map:

1. All boundaries between the ranked areas are approximately located. This is the result of the imprecise nature of geologic, aeroradiometric, and soil mapping at the scale of this map and the typically gradational nature of changes in the physical properties of rocks and soils at the surface.

2. Small, localized areas of higher or lower radon potential are likely to be present within any given area of a specific ranking. Areas of higher radon potential may be associated with shear zones within the Piedmont. Shear zones are common near contacts between rock types. The scale of the map and the limited detail of the available information preclude identification of the radon potential on a site-by-site basis. The assessment suggests that if detailed data of the type used here are available for smaller parcels of land, then estimates of the radon potential could be made for them.

3. This map should not be used as the sole source of information for predicting indoor radon levels. Other factors, such as house structural characteristics, local climate, and use patterns of the residents, strongly affect the indoor radon levels. For a discussion of radon entry points and methods of radon reduction in structures see U.S. Environmental Protection Agency (1987).

4. The reported percentages of homes in each of the five ranked categories having indoor radon levels greater than 4 pCi/L (see table 1) are data from the first year of the Fairfax County Radon Project (Fairfax County Radon Task Force, 1987). These data were the result of a three-day charcoal canister test made in the lowest liveable area of the house. *Average annual* indoor radon levels are likely to be lower than this in most homes across the county because radon levels in other seasons of the year are lower in most homes.

5. EPA's health-risk estimates are based on an exposure for 75 percent of the time for 70 years at the measured level of indoor radon. The *average annual* indoor radon level comes closest to approximating what the long-term exposure would be for a given structure. The indoor radon data reported here are short-term measurements; thus these data and the radon-potential assessment reported here cannot be used directly to estimate absolute health risks for citizens in Fairfax County. For a discussion of health risks associated with radon, see U.S. Environmental Protection Agency and U.S. Centers for Disease Control (1986).

6. The geologic assessment suggests that, no matter where one may live in the county, there is some likelihood that indoor radon levels will be above 4 pCi/L (EPA's lowest level for which action is recommended) in a wintertime screening measurement.

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EXPLANATION

Map-unit labels

Radon-potential category, from 1 (low) to 5 (high); see table 1

Physiographic province (A, early Mesozoic Culpeper basin; B, Piedmont; C, Coastal Plain)

4Ba — Dominant rock type within physiographic province; see table 1

Boundary between areas of different radon potential; dashed where inferred

Numbered grid-squares represent Fairfax County tax-map grid

Figure 2.--Histograms showing results of indoor radon study conducted by Fairfax County Radon Task Force during the winter of 1986-87 (see text discussion; also see comments section of table 1).

Table 1.--*Radon potential of rocks and soils in Fairfax County*

RADON POTENTIAL	PHYSIOGRAPHIC PROVINCE and dominant rock types associated with the five radon-potential categories			COMMENTS
	A- Early Mesozoic Culpeper basin	B- Piedmont	C- Coastal Plain	
5- High		a- Peters Creek Schist b- Phyllite		These areas occur mostly in the central part of the county. Soils have elevated radon in soil gas, high aeroradioactivity, and moderate to high permeability. These areas also have significant topographic relief. In the Fairfax County study, 53 percent of 137 homes situated in areas within this radon-potential category had indoor radon levels that were greater than or equal to 4 pCi/L. The median reading was 4.1 pCi/L and the mean was 7.8 pCi/L. The highest reading was 203 pCi/L.
4- Moderate to high	a- Sandstone-siltstone facies transition. This area may also contain local uranium occurrences; if so, severe indoor radon levels (greater than 200 pCi/L) may occur	a- Peters Creek Schist b- Phyllite c- Occoquan Granite d- Sykesville Formation f- Graywacke/schist		These areas occur mostly in the northwestern two-thirds of the county. Soils have moderate to high aeroradioactivity, moderate to high permeability, and locally elevated radon in soil gas. In the Fairfax County study, 43 percent of 350 homes situated in areas within this radon-potential category had indoor radon levels that were greater than or equal to 4 pCi/L. The median reading was 3.5 pCi/L and the mean was 5.0 pCi/L.
3- Moderate	b- Siltstone	a- Peters Creek Schist b- Phyllite c- Occoquan Granite d- Sykesville Formation e- Granitoid complex f- Graywacke/schist		These areas occur mostly in the northwestern two-thirds of the county. Soils have moderate aeroradioactivity and moderate to locally high permeability. Most soils over siltstones in the west have high radioactivity, and high radon in soil gas, but very low permeability. In the Fairfax County study, 38 percent of 216 homes situated in areas within this radon-potential category had indoor radon levels that were greater than or equal to 4 pCi/L. The median reading was 2.8 pCi/L and the mean was 3.6 pCi/L.
2- Moderate to low	e- Diabase	a- Peters Creek Schist d- Sykesville Formation	a- Undifferentiated sediments (moderate aeroradioactivity, low to moderate permeability)	These areas are scattered across the entire county. Soils show moderate to low aeroradioactivity and moderate to low permeability. Soils over the diabase have low aeroradioactivity and low permeability, but diabase contains abundant inclusions of sedimentary rock having higher radon potential. In the Fairfax County study, 19 percent of 122 homes situated in areas within this radon-potential category had indoor radon levels greater than or equal to 4 pCi/L. The median reading was 1.9 pCi/L and the mean was 2.7 pCi/L.
1- Low	c- Sandstone (proximal facies) d- Conglomerate	e- Granitoid complex h- Ultramafic rocks	a- Undifferentiated sediments (low aeroradioactivity, low to moderate permeability)	These areas occur mostly in the southeastern third of the county, and are scattered elsewhere. Soils have low aeroradioactivity and low to moderate permeability. In the Fairfax County study, 9 percent of 180 homes situated in areas within this radon-potential category had indoor radon levels greater than or equal to 4 pCi/L. The median reading was 1.2 pCi/L and the mean was 2.1 pCi/L.

MAP SHOWING RADON POTENTIAL OF ROCKS AND SOILS IN FAIRFAX COUNTY, VIRGINIA

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