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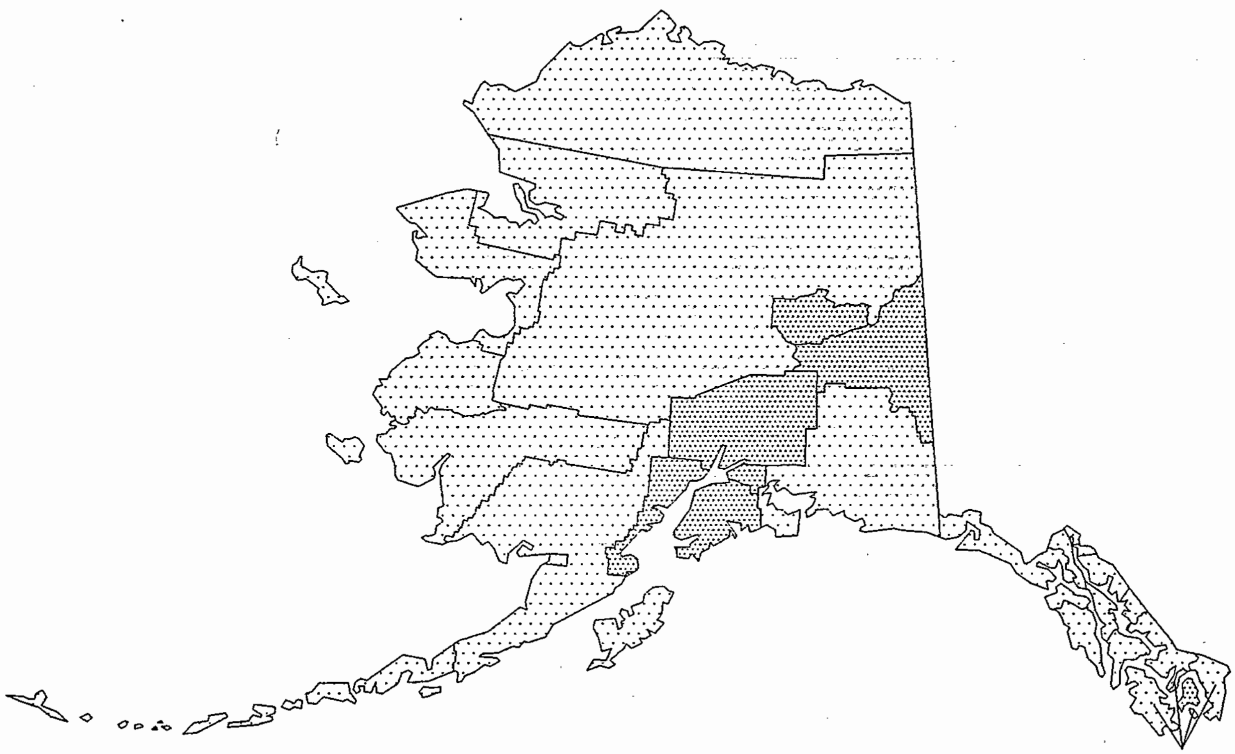
# EPA's Map of Radon Zones

## ALASKA



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# EPA'S MAP OF RADON ZONES
# ALASKA

## RADON DIVISION
## OFFICE OF RADIATION AND INDOOR AIR
## U.S. ENVIRONMENTAL PROTECTION AGENCY

SEPTEMBER, 1993

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## OVERVIEW

Sections 307 and 309 of the 1988 Indoor Radon Abatement Act (IRAA) direct EPA to identify areas of the United States that have the potential to produce elevated levels of radon. EPA, the U.S. Geological Survey (USGS), and the Association of American State Geologists (AASG) have worked closely over the past several years to produce a series of maps and documents which address these directives. The EPA Map of Radon Zones is a compilation of that work and fulfills the requirements of sections 307 and 309 of IRAA. The Map of Radon Zones identifies, on a county-by-county basis, areas of the U.S. that have the highest potential for elevated indoor radon levels (greater than 4 pCi/L).

The Map of Radon Zones is designed to assist national, State and local governments and organizations to target their radon program activities and resources. It is also intended to help building code officials determine areas that are the highest priority for adopting radon-resistant building practices. The Map of Radon Zones should not be used to determine if individual homes in any given area need to be tested for radon. **EPA recommends that all homes be tested for radon, regardless of geographic location or the zone designation of the county in which they are located.**

This document provides background information concerning the development of the Map of Radon Zones. It explains the purposes of the map, the approach for developing the map (including the respective roles of EPA and USGS), the data sources used, the conclusions and confidence levels developed for the prediction of radon potential, and the review process that was conducted to finalize this effort.

## BACKGROUND

Radon ($Rn^{222}$) is a colorless, odorless, radioactive gas. It comes from the natural decay of uranium that is found in nearly all soils. It typically moves through the ground to the air above and into homes and other buildings through cracks and openings in the foundation. Any home, school or workplace may have a radon problem, regardless of whether it is new or old, well-sealed or drafty, or with or without a basement. Nearly one out of every 15 homes in the U.S. is estimated to have elevated annual average levels of indoor radon.

Radon first gained national attention in early 1984, when extremely high levels of indoor radon were found in areas of Pennsylvania, New Jersey, and New York, along the Reading Prong-physiographic province. EPA established a Radon Program in 1985 to assist States and homeowners in reducing their risk of lung cancer from indoor radon.

Since 1985, EPA and USGS have been working together to continually increase our understanding of radon sources and the migration dynamics that cause elevated indoor radon levels. Early efforts resulted in the 1987 map entitled "Areas with Potentially High Radon Levels." This map was based on limited geologic information only because few indoor radon measurements were available at the time. The development of EPA's Map of Radon Zones and its technical foundation, USGS' National Geologic Radon Province Map, has been based on additional information from six years of the State/EPA Residential Radon Surveys, independent State residential surveys, and continued expansion of geologic and geophysical information, particularly the data from the National Uranium Resource Evaluation project.

Purpose of the Map of Radon Zones

EPA's Map of Radon Zones (Figure 1) assigns each of the 3141 counties in the United States to one of three zones:

- o Zone 1 counties have a predicted average indoor screening level > than 4 pCi/L
- o Zone 2 counties have a predicted average screening level ≥ 2 pCi/L and ≤ 4 pCi/L
- o Zone 3 counties have a predicted average screening level < 2 pCi/L

The Zone designations were determined by assessing five factors that are known to be important indicators of radon potential: indoor radon measurements, geology, aerial radioactivity, soil parameters, and foundation types.

The predictions of average screening levels in each of the Zones is an expression of radon potential in the lowest liveable area of a structure. This map is unable to estimate actual exposures to radon. EPA recommends methods for testing and fixing individual homes based on an estimate of actual exposure to radon. For more information on testing and fixing elevated radon levels in homes consult these EPA publications: *A Citizen's Guide to Radon, the Consumer's Guide to Radon Reduction and the Home Buyer's and Seller's Guide to Radon.*

EPA believes that States, local governments and other organizations can achieve optimal risk reductions by targeting resources and program activities to high radon potential areas. Emphasizing targeted approaches (technical assistance, information and outreach efforts, promotion of real estate mandates and policies and building codes, etc.) in such areas addresses the greatest potential risks first.

EPA also believes that the use of passive radon control systems in the construction of new homes in Zone 1 counties, and the activation of those systems if necessitated by follow-up testing, is a cost effective approach to achieving significant radon risk reduction.

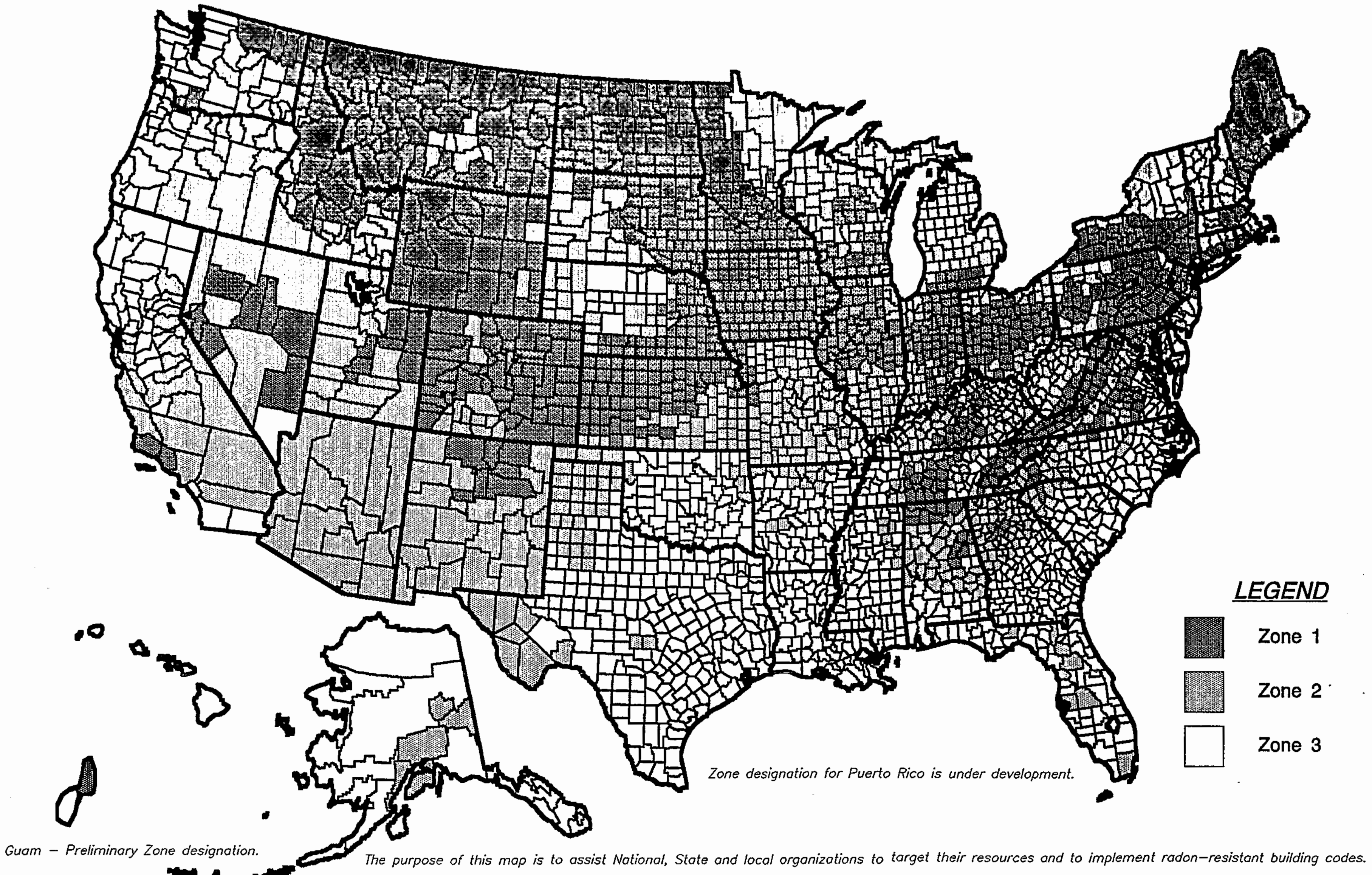
The Map of Radon Zones and its supporting documentation establish no regulatory requirements. Use of this map by State or local radon programs and building code officials is voluntary. The information presented on the Map of Radon Zones and in the supporting documentation is not applicable to radon in water.

Development of the Map of Radon Zones

The technical foundation for the Map of Radon Zones is the USGS Geologic Radon Province Map. In order to examine the radon potential for the United States, the USGS began by identifying approximately 360 separate geologic provinces for the U.S. The provinces are shown on the USGS Geologic Radon Province Map (Figure 2). Each of the geologic provinces was evaluated by examining the available data for that area: indoor radon measurements, geology, aerial radioactivity, soil parameters, and foundation types. As stated previously, these five factors are considered to be of basic importance in assessing radon

Figure 1

# EPA Map of Radon Zones

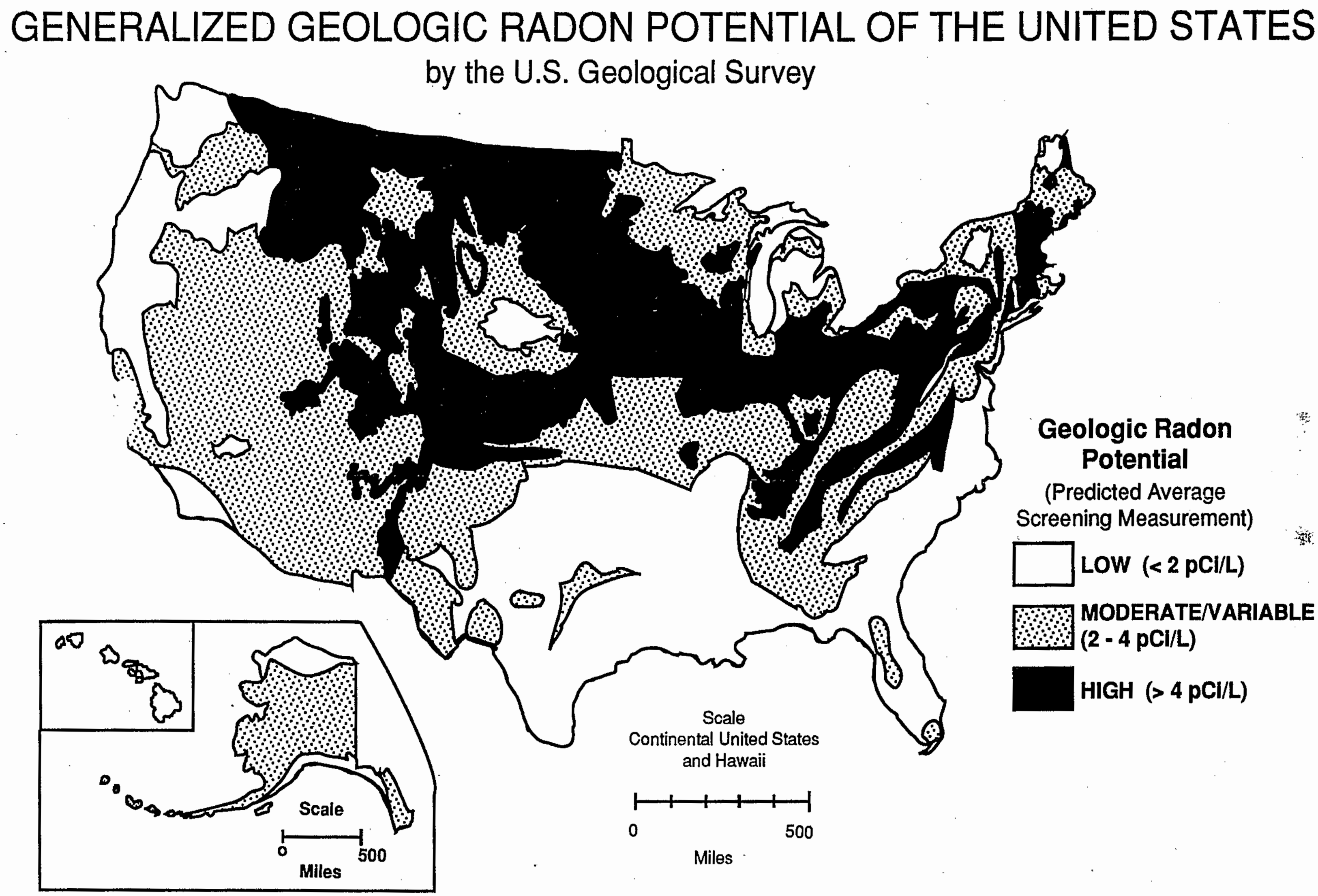



*The purpose of this map is to assist National, State and local organizations to target their resources and to implement radon–resistant building codes.*

*This map is not intended to be used to determine if a home in a given zone should be tested for radon. Homes with elevated levels of radon have been found in all three zones. All homes should be tested, regardless of geographic location.*

*IMPORTANT: Consult the EPA Map of Radon Zones document (EPA–402–R–93–071) before using this map. This document contains information on radon potential variations within counties. EPA also recommends that this map be supplemented with any available local data in order to further understand and predict the radon potential of a specific area.*

Figure 2


GENERALIZED GEOLOGIC RADON POTENTIAL OF THE UNITED STATES
by the U.S. Geological Survey
Geologic Radon Potential
(Predicted Average Screening Measurement)
LOW (< 2 pCI/L)
MODERATE/VARIABLE (2 - 4 pCI/L)
HIGH (> 4 pCI/L)
Scale
Continental United States and Hawaii
0
500
Miles
Scale
0
500
Miles

potential and some data are available for each of these factors in every geologic province. The province boundaries do not coincide with political borders (county and state) but define areas of general radon potential. The five factors were assigned numerical values based on an assessment of their respective contribution to radon potential, and a confidence level was assigned to each contributing variable. The approach used by USGS to estimate the radon potential for each province is described in Part II of this document.

EPA subsequently developed the Map of Radon Zones by extrapolating from the province level to the county level so that all counties in the U.S. were assigned to one of three radon zones. EPA assigned each county to a given zone based on its provincial radon potential. For example, if a county is located within a geologic province that has a predicted average screening level greater than 4 pCi/L, it was assigned to Zone 1. Likewise, counties located in provinces with predicted average screening levels $\geq$ 2 pCi/L and $\leq$ 4 pCi/L, and less than 2 pCi/L, were assigned to Zones 2 and 3, respectively.

If the boundaries of a county fall in more than one geologic province, the county was assigned to a zone based on the predicted radon potential of the province in which most of the area lies. For example, if three different provinces cross through a given county, the county was assigned to the zone representing the radon potential of the province containing most of the county's land area. (In this case, it is not technically correct to say that the predicted average screening level applies to the entire county since the county falls in multiple provinces with differing radon potentials.)

Figures 3 and 4 demonstrate an example of how EPA extrapolated the county zone designations for Nebraska from the USGS geologic province map for the State. As figure 3 shows, USGS has identified 5 geologic provinces for Nebraska. Most of the counties are extrapolated "straight" from their corresponding provinces, but there are counties "partitioned" by several provinces -- for example, Lincoln County. Although Lincoln county falls in multiple provinces, it was assigned to Zone 3 because most of its area falls in the province with the lowest radon potential.

**It is important to note that EPA's extrapolation from the province level to the county level may mask significant "highs" and "lows" within specific counties. In other words, within-county variations in radon potential are not shown on the Map of Radon Zones. EPA recommends that users who may need to address specific within-county variations in radon potential (e.g., local government officials considering the implementation of radon-resistant construction codes) consult USGS' Geologic Radon Province Map and the State chapters provided with this map for more detailed information, as well as any locally available data.**

Map Validation

The Map of Radon Zones is intended to represent a preliminary assessment of radon potential for the entire United States. The factors that are used in this effort --indoor radon data, geology, aerial radioactivity, soils, and foundation type -- are basic indicators for radon potential. It is important to note, however, that the map's county zone designations are not "statistically valid" predictions due to the nature of the data available for these 5 factors at the county level. In order to validate the map in light of this lack of statistical confidence, EPA conducted a number of analyses. These analyses have helped EPA to identify the best situations in which to apply the map, and its limitations.

Figure 3

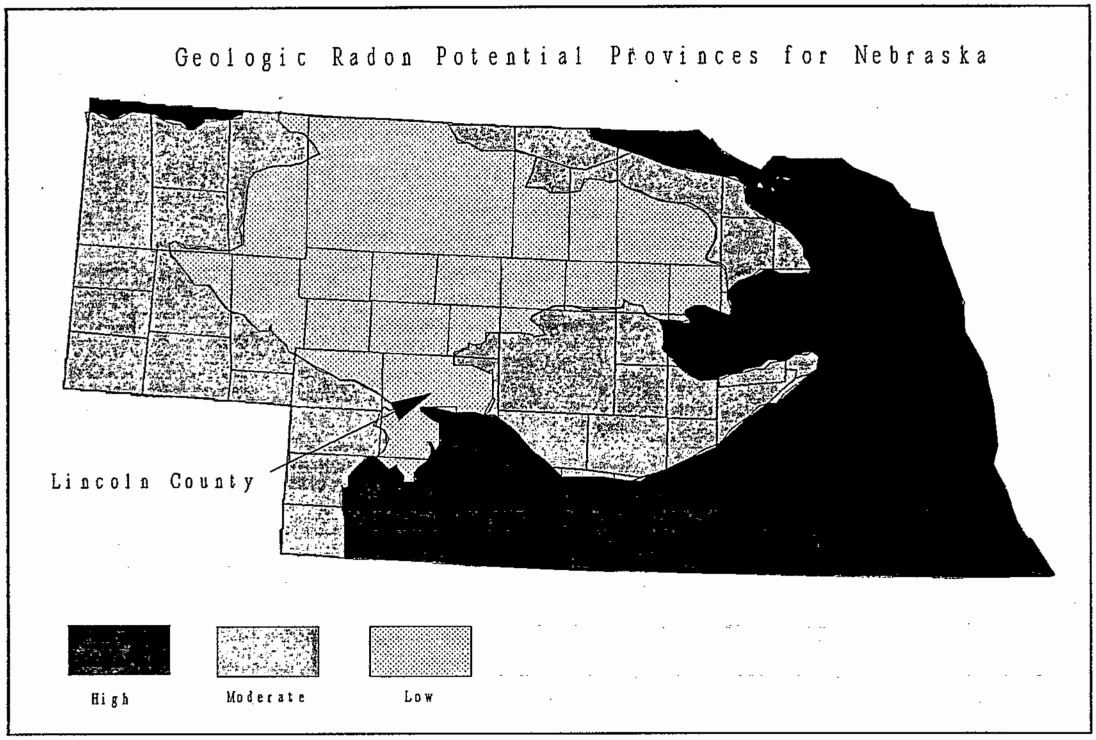
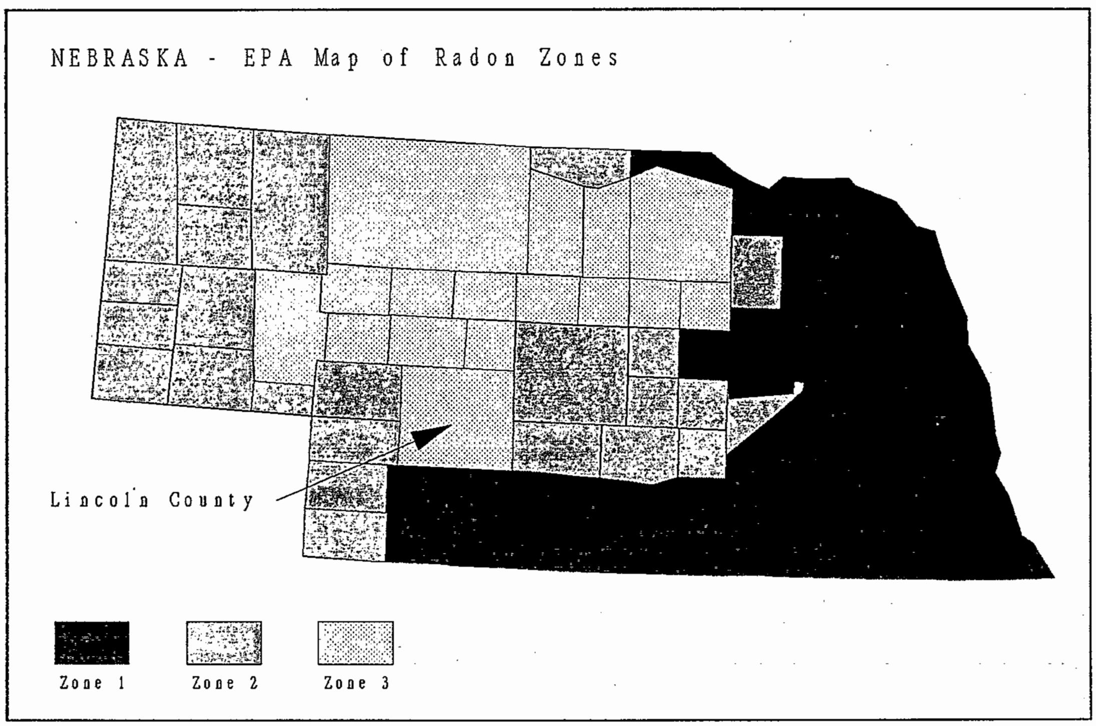



Figure 4



One such analysis involved comparing county zone designations to indoor radon measurements from the State/EPA Residential Radon Surveys (SRRS). Screening averages for counties with at least 100 measurements were compared to the counties' predicted radon potential as indicated by the Map of Radon Zones. EPA found that 72% of the county screening averages were correctly reflected by the appropriate zone designations on the Map. In all other cases, they only differed by 1 zone.

Another accuracy analysis used the annual average data from the National Residential Radon Survey (NRRS). The NRRS indicated that approximately 6 million homes in the United States have annual averages greater than or equal to 4 pCi/L. By cross checking the county location of the approximately 5,700 homes which participated in the survey, their radon measurements, and the zone designations for these counties, EPA found that approximately 3.8 million homes of the 5.4 million homes with radon levels greater than or equal to 4 pCi/L will be found in counties designated as Zone 1. A random sampling of an equal number of counties would have only found approximately 1.8 million homes greater than 4 pCi/L. In other words, this analysis indicated that the map approach is three times more efficient at identifying high radon areas than random selection of zone designations.

Together, these analyses show that the approach EPA used to develop the Map of Radon Zones is a reasonable one. In addition, the Agency's confidence is enhanced by results of the extensive State review process -- the map generally agrees with the States' knowledge of and experience in their own jurisdictions. However, the accuracy analyses highlight two important points: the fact that elevated levels will be found in Zones 2 and 3, and that there will be significant numbers of homes with lower indoor radon levels in all of the Zones. For these reasons, users of the Map of Radon Zones need to supplement the Map with locally available data whenever possible. Although all known "hot spots", i.e., localized areas of consistently elevated levels, are discussed in the State-specific chapters, accurately defining the boundaries of the "hot spots" on this scale of map is not possible at this time. Also, unknown "hot spots" do exist.

The Map of Radon Zones is intended to be a starting point for characterizing radon potential because our knowledge of radon sources and transport is always growing. Although this effort represents the best data available at this time, EPA will continue to study these parameters and others such as house construction, ventilation features and meteorology factors in order to better characterize the presence of radon in U.S homes, especially in high risk areas. These efforts will eventually assist EPA in refining and revising the conclusions of the Map of Radon Zones. And although this map is most appropriately used as a targeting tool by the aforementioned audiences -- **the Agency encourages all residents to test their homes for radon, regardless of geographic location or the zone designation of the county in which they live. Similarly, the Map of Radon Zones should not to be used in lieu of testing during real estate transactions.**

## Review Process

The Map of Radon Zones has undergone extensive review within EPA and outside the Agency. The Association of American State Geologists (AASG) played an integral role in this review process. The AASG individual State geologists have reviewed their State-specific information, the USGS Geologic Radon Province Map, and other materials for their geologic content and consistency.

In addition to each State geologist providing technical comments, the State radon offices were asked to comment on their respective States' radon potential evaluations. In particular, the States were asked to evaluate the data used to assign their counties to specific zones. EPA and USGS worked with the States to resolve any issues concerning county zone designations. In a few cases, States have requested changes in county zone designations. The requests were based on additional data from the State on geology, indoor radon measurements, population, etc. Upon reviewing the data submitted by the States, EPA did make some changes in zone designations. These changes, which do not strictly follow the methodology outlined in this document, are discussed in the respective State chapters.

EPA encourages the States and counties to conduct further research and data collection efforts to refine the Map of Radon Zones. EPA would like to be kept informed of any changes the States, counties, or others make to the maps. Updates and revisions will be handled in a similar fashion to the way the map was developed. States should notify EPA of any proposed changes by forwarding the changes through the Regional EPA offices that are listed in Part II. Depending on the amount of new information that is presented, EPA will consider updating this map periodically. The State radon programs should initiate proper notification of the appropriate State officials when the Map of Radon Zones is released and when revisions or updates are made by the State or EPA.

# THE USGS/EPA RADON POTENTIAL ASSESSMENTS: AN INTRODUCTION

*by*
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## BACKGROUND

The Indoor Radon Abatement Act of 1988 (15 U.S.C. 2661-2671) directed the U.S. Environmental Protection Agency (EPA) to identify areas of the United States that have the potential to produce harmful levels of indoor radon. These characterizations were to be based on both geological data and on indoor radon levels in homes and other structures. The EPA also was directed to develop model standards and techniques for new building construction that would provide adequate prevention or mitigation of radon entry. As part of an Interagency Agreement between the EPA and the U.S. Geological Survey (USGS), the USGS has prepared radon potential estimates for the United States. This report is one of ten booklets that document this effort. The purpose and intended use of these reports is to help identify areas where states can target their radon program resources, to provide guidance in selecting the most appropriate building code options for areas, and to provide general information on radon and geology for each state for federal, state, and municipal officials dealing with radon issues. *These reports are not intended to be used as a substitute for indoor radon testing, and they cannot and should not be used to estimate or predict the indoor radon concentrations of individual homes, building sites, or housing tracts. Elevated levels of indoor radon have been found in every State, and EPA recommends that all homes be tested for indoor radon.*

Booklets detailing the radon potential assessment for the U.S. have been developed for each State. USGS geologists are the authors of the geologic radon potential booklets. Each booklet consists of several components, the first being an overview to the mapping project (Part I), this introduction to the USGS assessment (Part II), including a general discussion of radon (occurrence, transport, etc.), and details concerning the types of data used. The third component is a summary chapter outlining the general geology and geologic radon potential of the EPA Region (Part III). The fourth component is an individual chapter for each state (Part IV). Each state chapter discusses the state's specific geographic setting, soils, geologic setting, geologic radon potential, indoor radon data, and a summary outlining the radon potential rankings of geologic areas in the state. A variety of maps are presented in each chapter—geologic, geographic, population, soils, aerial radioactivity, and indoor radon data by county. Finally, the booklets contain EPA's map of radon zones for each state and an accompanying description (Part V).

Because of constraints on the scales of maps presented in these reports and because the smallest units used to present the indoor radon data are counties, some generalizations have been made in order to estimate the radon potential of each area. Variations in geology, soil characteristics, climatic factors, homeowner lifestyles, and other factors that influence radon concentrations can be quite large within any particular geologic area, so these reports cannot be used to estimate or predict the indoor radon concentrations of individual homes or housing tracts. Within any area of a given geologic radon potential ranking, there are likely to be areas where the radon potential is lower or higher than that assigned to the area as a whole, especially in larger areas such as the large counties in some western states.

In each state chapter, references to additional reports related to radon are listed for the state, and the reader is urged to consult these reports for more detailed information. In most cases the best sources of information on radon for specific areas are state and local departments of health, state departments responsible for nuclear safety or environmental protection, and U.S. EPA regional offices. More detailed information on state or local geology may be obtained from the state geological surveys. Addresses and telephone numbers of state radon contacts, geological surveys, and EPA regional offices are listed in Appendix C at the end of this chapter.

## RADON GENERATION AND TRANSPORT IN SOILS

Radon ($^{222}Rn$) is produced from the radioactive decay of radium ($^{226}Ra$), which is, in turn, a product of the decay of uranium ($^{238}U$) (fig. 1). The half-life of $^{222}Rn$ is 3.825 days. Other isotopes of radon occur naturally, but, with the exception of thoron ($^{220}Rn$), which occurs in concentrations high enough to be of concern in a few localized areas, they are less important in terms of indoor radon risk because of their extremely short half-lives and less common occurrence. In general, the concentration and mobility of radon in soil are dependent on several factors, the most important of which are the soil's radium content and distribution, porosity, permeability to gas movement, and moisture content. These characteristics are, in turn, determined by the soil's parent-material composition, climate, and the soil's age or maturity. If parent-material composition, climate, vegetation, age of the soil, and topography are known, the physical and chemical properties of a soil in a given area can be predicted.

As soils form, they develop distinct layers, or horizons, that are cumulatively called the soil profile. The A horizon is a surface or near-surface horizon containing a relative abundance of organic matter but dominated by mineral matter. Some soils contain an E horizon, directly below the A horizon, that is generally characterized by loss of clays, iron, or aluminum, and has a characteristically lighter color than the A horizon. The B horizon underlies the A or E horizon. Important characteristics of B horizons include accumulation of clays, iron oxides, calcium carbonate or other soluble salts, and organic matter complexes. In drier environments, a horizon may exist within or below the B horizon that is dominated by calcium carbonate, often called caliche or calcrete. This carbonate-cemented horizon is designated the K horizon in modern soil classification schemes. The C horizon underlies the B (or K) and is a zone of weathered parent material that does not exhibit characteristics of A or B horizons; that is, it is generally not a zone of leaching or accumulation. In soils formed in place from the underlying bedrock, the C horizon is a zone of unconsolidated, weathered bedrock overlying the unweathered bedrock.

The shape and orientation of soil particles (soil structure) control permeability and affect water movement in the soil. Soils with blocky or granular structure have roughly equivalent permeabilities in the horizontal and vertical directions, and air and water can infiltrate the soil relatively easily. However, in soils with platy structure, horizontal permeability is much greater than vertical permeability, and air and moisture infiltration is generally slow. Soils with prismatic or columnar structure have dominantly vertical permeability. Platy and prismatic structures form in soils with high clay contents. In soils with shrink-swell clays, air

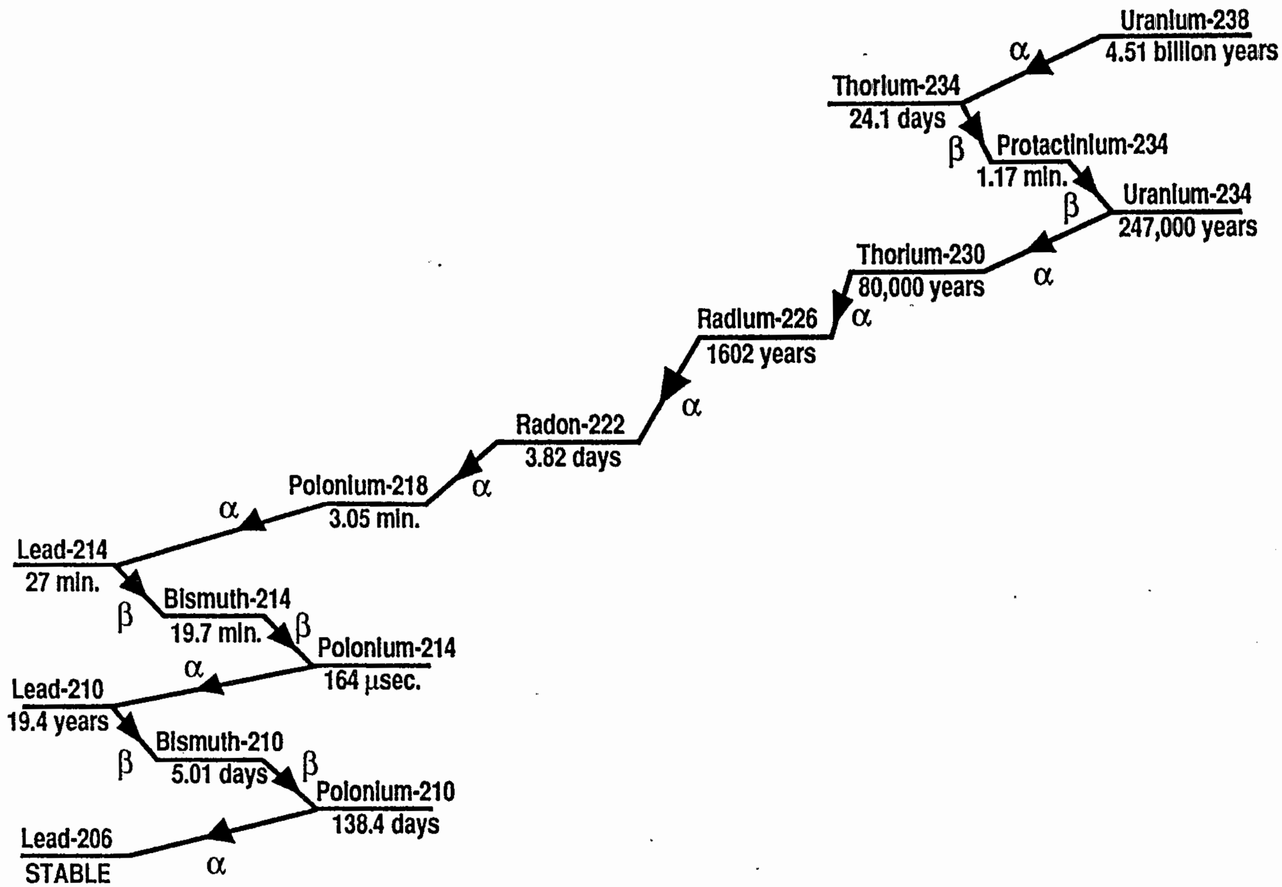


Figure 1. The uranium-238 decay series, showing the half-lives of elements and their modes of decay (after Wanty and Schoen, 1991). $\alpha$ denotes alpha decay, $\beta$ denotes beta decay.

and moisture infiltration rates and depth of wetting may be limited when the cracks in the surface soil layers swell shut. Clay-rich B horizons, particularly those with massive or platy structure, can form a capping layer that impedes the escape of soil gas to the surface (Schumann and others, 1992). However, the shrinkage of clays can act to open or widen cracks upon drying, thus increasing the soil's permeability to gas flow during drier periods.

Radon transport in soils occurs by two processes: (1) diffusion and (2) flow (Tanner, 1964). Diffusion is the process whereby radon atoms move from areas of higher concentration to areas of lower concentration in response to a concentration gradient. Flow is the process by which soil air moves through soil pores in response to differences in pressure within the soil or between the soil and the atmosphere, carrying the radon atoms along with it. Diffusion is the dominant radon transport process in soils of low permeability, whereas flow tends to dominate in highly permeable soils (Sextro and others, 1987). In low-permeability soils, much of the radon may decay before it is able to enter a building because its transport rate is reduced. Conversely, highly permeable soils, even those that are relatively low in radium, such as those derived from some types of glacial deposits, have been associated with high indoor radon levels in Europe and in the northern United States (Akerblom and others, 1984; Kunz and others, 1989; Sextro and others, 1987). In areas of karst topography formed in carbonate rock (limestone or dolomite) environments, solution cavities and fissures can increase soil permeability at depth by providing additional pathways for gas flow.

Not all radium contained in soil grains and grain coatings will result in mobile radon when the radium decays. Depending on where the radium is distributed in the soil, many of the radon atoms may remain imbedded in the soil grain containing the parent radium atom, or become imbedded in adjacent soil grains. The portion of radium that releases radon into the pores and fractures of rocks and soils is called the emanating fraction. When a radium atom decays to radon, the energy generated is strong enough to send the radon atom a distance of about 40 nanometers (1 nm = $10^{-9}$ meters), or about $2 \times 10^{-6}$ inches—this is known as alpha recoil (Tanner, 1980). Moisture in the soil lessens the chance of a recoiling radon atom becoming imbedded in an adjacent grain. Because water is more dense than air, a radon atom will travel a shorter distance in a water-filled pore than in an air-filled pore, thus increasing the likelihood that the radon atom will remain in the pore space. Intermediate moisture levels enhance radon emanation but do not significantly affect permeability. However, high moisture levels can significantly decrease the gas permeability of the soil and impede radon movement through the soil.

Concentrations of radon in soils are generally many times higher than those inside of buildings, ranging from tens of pCi/L to more than 100,000 pCi/L, but typically in the range of hundreds to low thousands of pCi/L. Soil-gas radon concentrations can vary in response to variations in climate and weather on hourly, daily, or seasonal time scales. Schumann and others (1992) and Rose and others (1988) recorded order-of-magnitude variations in soil-gas radon concentrations between seasons in Colorado and Pennsylvania. The most important factors appear to be (1) soil moisture conditions, which are controlled in large part by precipitation; (2) barometric pressure; and (3) temperature. Washington and Rose (1990) suggest that temperature-controlled partitioning of radon between water and gas in soil pores also has a significant influence on the amount of mobile radon in soil gas.

Homes in hilly limestone regions of the southern Appalachians were found to have higher indoor radon concentrations during the summer than in the winter. A suggested cause for this phenomenon involves temperature/pressure-driven flow of radon-laden air from subsurface solution cavities in the carbonate rock into houses. As warm air enters solution cavities that are higher on the hillslope than the homes, it cools and settles, pushing radon-laden air from lower in the cave or cavity system into structures on the hillslope (Gammage and others, 1993). In contrast, homes built over caves having openings situated below the level of the home had higher indoor radon levels in the winter, caused by cooler outside air entering the cave, driving radon-laden air into cracks and solution cavities in the rock and soil, and ultimately, into homes (Gammage and others, 1993).

## RADON ENTRY INTO BUILDINGS

A driving force (reduced atmospheric pressure in the house relative to the soil, producing a pressure gradient) and entry points must exist for radon to enter a building from the soil. The negative pressure caused by furnace combustion, ventilation devices, and the stack effect (the rising and escape of warm air from the upper floors of the building, causing a temperature and pressure gradient within the structure) during cold winter months are common driving forces. Cracks and other penetrations through building foundations, sump holes, and slab-to-foundation wall joints are common entry points.

Radon levels in the basement are generally higher than those on the main floor or upper floors of most structures. Homes with basements generally provide more entry points for radon, commonly have a more pronounced stack effect, and typically have lower air pressure relative to the surrounding soil than nonbasement homes. The term "nonbasement" applies to slab-on-grade or crawl space construction.

## METHODS AND SOURCES OF DATA

The assessments of radon potential in the booklets that follow this introduction were made using five main types of data: (1) geologic (lithologic); (2) aerial radiometric; (3) soil characteristics, including soil moisture, permeability, and drainage characteristics; (4) indoor radon data; and (5) building architecture (specifically, whether homes in each area are built slab-on-grade or have a basement or crawl space). These five factors were evaluated and integrated to produce estimates of radon potential. Field measurements of soil-gas radon or soil radioactivity were not used except where such data were available in existing, published reports of local field studies. Where applicable, such field studies are described in the individual state chapters.

### GEOLOGIC DATA

The types and distribution of lithologic units and other geologic features in an assessment area are of primary importance in determining radon potential. Rock types that are most likely to cause indoor radon problems include carbonaceous black shales, glauconite-bearing sandstones, certain kinds of fluvial sandstones and fluvial sediments, phosphorites, chalk, karst-producing carbonate rocks, certain kinds of glacial deposits, bauxite, uranium-rich granitic rocks, metamorphic rocks of granitic composition, silica-rich volcanic rocks, many sheared or faulted rocks, some coals, and certain kinds of contact metamorphosed rocks. Rock types least likely to cause radon problems include marine quartz sands, non-carbonaceous shales and siltstones, certain kinds of clays, silica-poor metamorphic and igneous rocks, and basalts. Exceptions exist within these general lithologic groups because of the occurrence of localized uranium deposits, commonly of the hydrothermal type in crystalline rocks or the "roll-front" type in sedimentary rocks. Uranium and radium are commonly sited in heavy minerals, iron-oxide coatings on rock and soil grains, and organic materials in soils and sediments. Less common are uranium associated with phosphate and carbonate complexes in rocks and soils, and uranium minerals.

Although many cases of elevated indoor radon levels can be traced to high radium and (or) uranium concentrations in parent rocks, some structural features, most notably faults and shear zones, have been identified as sites of localized uranium concentrations (Deffeyes and MacGregor, 1980) and have been associated with some of the highest reported indoor radon levels (Gundersen, 1991). The two highest known indoor radon occurrences are associated with sheared fault zones in Boyertown, Pennsylvania (Gundersen and others, 1988a; Smith and others, 1987), and in Clinton, New Jersey (Henry and others, 1991; Muessig and Bell, 1988).

## NURE AERIAL RADIOMETRIC DATA

Aerial radiometric data are used to quantify the radioactivity of rocks and soils. Equivalent uranium (eU) data provide an estimate of the surficial concentrations of radon parent materials (uranium, radium) in rocks and soils. Equivalent uranium is calculated from the counts received by a gamma-ray detector from the 1.76 MeV (mega-electron volts) emission energy corresponding to bismuth-214 ($^{214}Bi$), with the assumption that uranium and its decay products are in secular equilibrium. Equivalent uranium is expressed in units of parts per million (ppm). Gamma radioactivity also may be expressed in terms of a radium activity; 3 ppm eU corresponds to approximately 1 picocurie per gram (pCi/g) of radium-226. Although radon is highly mobile in soil and its concentration is affected by meteorological conditions (Kovach, 1945; Klusman and Jaacks, 1987; Schery and others, 1984; Schumann and others, 1992), statistical correlations between average soil-gas radon concentrations and average eU values for a wide variety of soils have been documented (Gundersen and others, 1988a, 1988b; Schumann and Owen, 1988). Aerial radiometric data can provide an estimate of radon source strength over a region, but the amount of radon that is able to enter a home from the soil is dependent on several local factors, including soil structure, grain size distribution, moisture content, and permeability, as well as type of house construction and its structural condition.

The aerial radiometric data used for these characterizations were collected as part of the Department of Energy National Uranium Resource Evaluation (NURE) program of the 1970s and early 1980s. The purpose of the NURE program was to identify and describe areas in the United States having potential uranium resources (U.S. Department of Energy, 1976). The NURE aerial radiometric data were collected by aircraft in which a gamma-ray spectrometer was mounted, flying approximately 122 m (400 ft) above the ground surface. The equivalent uranium maps presented in the state chapters were generated from reprocessed NURE data in which smoothing, filtering, recalibrating, and matching of adjacent quadrangle data sets were performed to compensate for background, altitude, calibration, and other types of errors and inconsistencies in the original data set (Duval and others, 1989). The data were then gridded and contoured to produce maps of eU with a pixel size corresponding to approximately 2.5 x 2.5 km (1.6 x 1.6 mi).

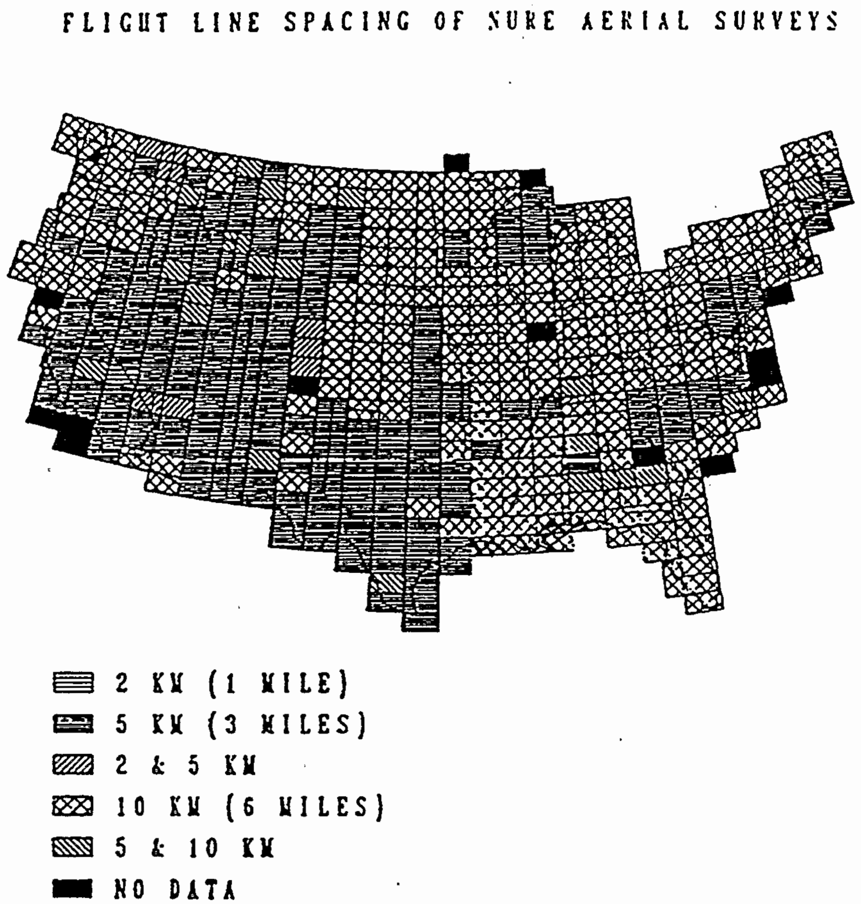


Figure 2. Nominal flightline spacings for NURE aerial gamma-ray surveys covering the contiguous United States (from Duval and others, 1990). Rectangles represent 1°x2° quadrangles.

Figure 2 is an index map of NURE 1° x 2° quadrangles showing the flight-line spacing for each quadrangle. In general, the more closely spaced the flightlines are, the more area was covered by the aerial gamma survey, and thus, more detail is available in the data set. For an altitude of 400 ft above the ground surface and with primary flightline spacing typically between 3 and 6 miles, less than 10 percent of the ground surface of the United States was actually measured by the airborne gamma-ray detectors (Duval and others, 1989), although some areas had better coverage than others due to the differences in flight-line spacing between areas (fig. 2). This suggests that some localized uranium anomalies may not have been detected by the aerial surveys, but the good correlations of eU patterns with geologic outcrop patterns indicate that, at relatively small scales (approximately 1:1,000,000 or smaller) the National eU map (Duval and others, 1989) gives reasonably good estimates of average surface uranium concentrations and thus can assist in the prediction of radon potential of rocks and soils, especially when augmented with additional geologic and soil data.

The shallow (20-30 cm) depth of investigation of gamma-ray spectrometers, either ground-based or airborne (Duval and others, 1971; Durrance, 1986), suggests that gamma-ray data may sometimes underestimate the radon-source strength in soils in which some of the radionuclides in the near-surface soil layers have been transported downward through the soil profile. In such cases the concentration of radioactive minerals in the A horizon would be lower than in the B horizon, where such minerals are typically concentrated. The concentration of radionuclides in the C horizon and below may be relatively unaffected by surface solution processes. Under these conditions the surface gamma-ray signal may indicate a lower radon source concentration than actually exists in the deeper soil layers, which are most likely to affect radon levels in structures with basements. The redistribution of radionuclides in soil profiles is dependent on a combination of climatic, geologic, and geochemical factors. There is reason to believe that correlations of eU with actual soil radium and uranium concentrations at a depth relevant to radon entry into structures may be regionally variable (Duval, 1989; Schumann and Gundersen, 1991). Given sufficient understanding of the factors cited above, these regional differences may be predictable.

## SOIL SURVEY DATA

Soil surveys prepared by the U.S. Soil Conservation Service (SCS) provide data on soil characteristics, including soil-cover thickness, grain-size distribution, permeability, shrink-swell potential, vegetative cover, generalized groundwater characteristics, and land use. The reports are available in county formats and State summaries. The county reports typically contain both generalized and detailed maps of soils in the area.

Because of time and map-scale constraints, it was impractical to examine county soil reports for each county in the United States, so more generalized summaries at appropriate scales were used where available. For State or regional-scale radon characterizations, soil maps were compared to geologic maps of the area, and the soil descriptions, shrink-swell potential, drainage characteristics, depth to seasonal high water table, permeability, and other relevant characteristics of each soil group noted. Technical soil terms used in soil surveys are generally complex; however, a good summary of soil engineering terms and the national distribution of technical soil types is the "Soils" sheet of the National Atlas (U.S. Department of Agriculture, 1987).

Soil permeability is commonly expressed in SCS soil surveys in terms of the speed, in inches per hour (in/hr), at which water soaks into the soil, as measured in a soil percolation test. Although in/hr are not truly units of permeability, these units are in widespread use and are referred to as "permeability" in SCS soil surveys. The permeabilities listed in the SCS surveys are for water, but they generally correlate well with gas permeability. Because data on gas permeability of soils is extremely limited, data on permeability to water is used as a substitute except in cases in which excessive soil moisture is known to exist. Water in soil pores inhibits gas transport, so the amount of radon available to a home is effectively reduced by a high water table. Areas likely to have high water tables include river valleys, coastal areas, and some areas overlain by deposits of glacial origin (for example, loess).

Soil permeabilities greater than 6.0 in/hr may be considered high, and permeabilities less than 0.6 in/hr may be considered low in terms of soil-gas transport. Soils with low permeability may generally be considered to have a lower radon potential than more permeable soils with similar radium concentrations. Many well-developed soils contain a clay-rich B horizon that may impede vertical soil gas transport. Radon generated below this horizon cannot readily escape to the surface, so it would instead tend to move laterally, especially under the influence of a negative pressure exerted by a building.

Shrink-swell potential is an indicator of the abundance of smectitic (swelling) clays in a soil. Soils with a high shrink-swell potential may cause building foundations to crack, creating pathways for radon entry into the structure. During dry periods, desiccation cracks in shrink-swell soils provide additional pathways for soil-gas transport and effectively increase the gas permeability of the soil. Soil permeability data and soil profile data thus provide important information for regional radon assessments.

## INDOOR RADON DATA

Two major sources of indoor radon data were used. The first and largest source of data is from the State/EPA Residential Radon Survey (Ronca-Battista and others, 1988; Dziuban and others, 1990). Forty-two states completed EPA-sponsored indoor radon surveys between 1986 and 1992 (fig. 3). The State/EPA Residential Radon Surveys were designed to be comprehensive and statistically significant at the state level, and were subjected to high levels of quality assurance and control. The surveys collected screening indoor radon measurements, defined as 2-7 day measurements using charcoal canister radon detectors placed in the lowest livable area of the home. The target population for the surveys included owner-occupied single family, detached housing units (White and others, 1989), although attached structures such as duplexes, townhouses, or condominiums were included in some of the surveys if they met the other criteria and had contact with the ground surface. Participants were selected randomly from telephone-directory listings. In total, approximately 60,000 homes were tested in the State/EPA surveys.

The second source of indoor radon data comes from residential surveys that have been conducted in a specific state or region of the country (e.g. independent state surveys or utility company surveys). Several states, including Delaware, Florida, Illinois, New Hampshire, New Jersey, New York, Oregon, and Utah, have conducted their own surveys of indoor radon. The quality and design of a state or other independent survey are discussed and referenced where the data are used.

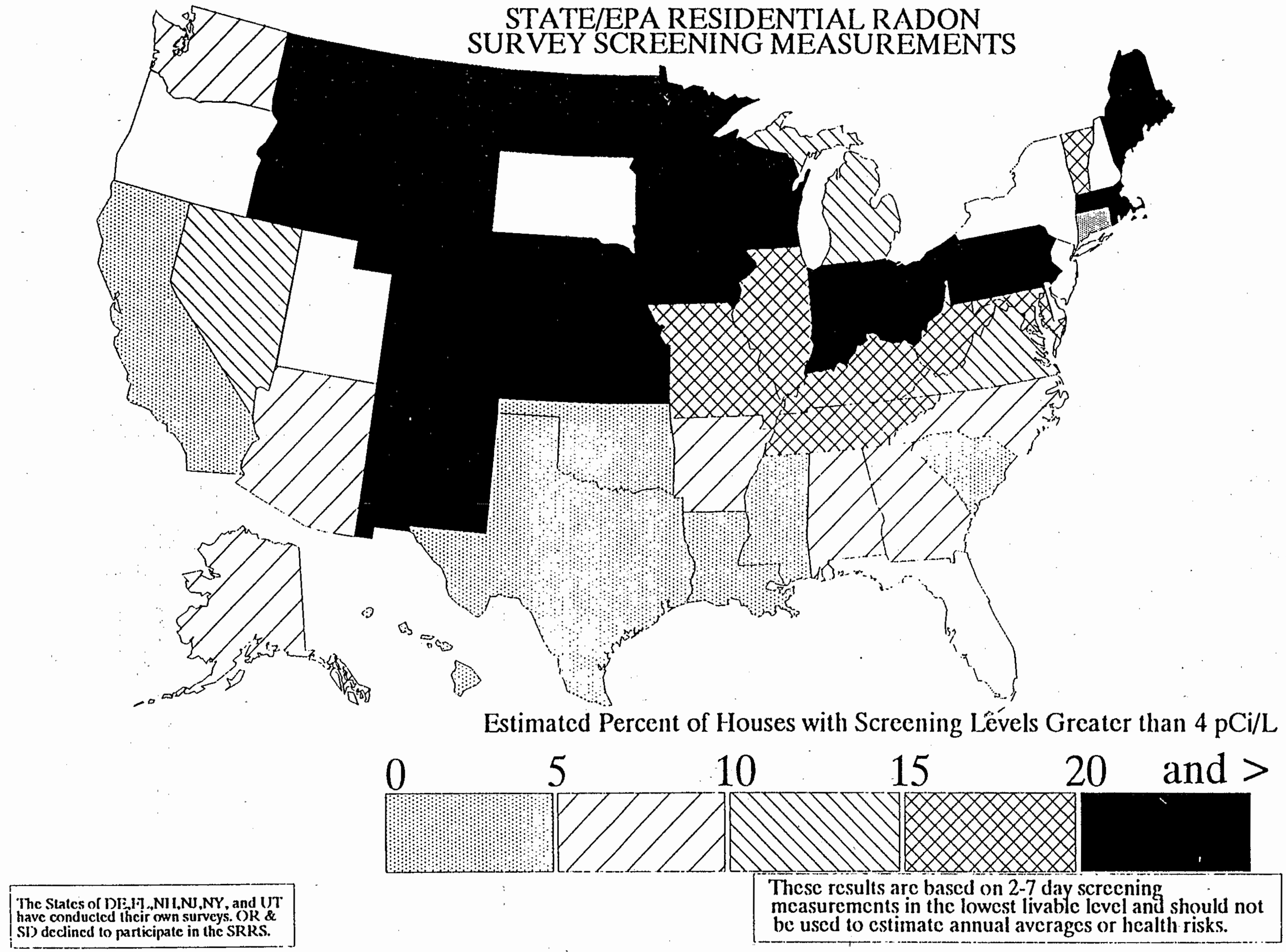


Figure 3. Percent of homes tested in the State/EPA Residential Radon Survey with screening indoor radon levels exceeding 4 pCi/L.

Data for only those counties with five or more measurements are shown in the indoor radon maps in the state chapters, although data for all counties with a nonzero number of measurements are listed in the indoor radon data tables in each state chapter. In total, indoor radon data from more than 100,000 homes nationwide were used in the compilation of these assessments. Radon data from State or regional indoor radon surveys, public health organizations, or other sources are discussed in addition to the primary data sources where they are available. Nearly all of the data used in these evaluations represent short-term (2-7 day) screening measurements from the lowest livable space of the homes. Specific details concerning the nature and use of indoor radon data sets other than the State/EPA Residential Radon Survey are discussed in the individual State chapters.

## RADON INDEX AND CONFIDENCE INDEX

Many of the geologic methods used to evaluate an area for radon potential require subjective opinions based on the professional judgment and experience of the individual geologist. The evaluations are nevertheless based on established scientific principles that are universally applicable to any geographic area or geologic setting. This section describes the methods and conceptual framework used by the U.S. Geological Survey to evaluate areas for radon potential based on the five factors discussed in the previous sections. The scheme is divided into two basic parts, a Radon Index (RI), used to rank the general radon potential of the area, and the Confidence Index (CI), used to express the level of confidence in the prediction based on the quantity and quality of the data used to make the determination. This scheme works best if the areas to be evaluated are delineated by geologically-based boundaries (geologic provinces) rather than political ones (state/county boundaries) in which the geology may vary across the area.

*Radon Index.* Table 1 presents the Radon Index (RI) matrix. The five factors—indoor radon data, geology, aerial radioactivity, soil parameters, and house foundation type—were quantitatively ranked (using a point value of 1, 2, or 3) for their respective contribution to radon potential in a given area. At least some data for the 5 factors are consistently available for every geologic province. Because each of these main factors encompass a wide variety of complex and variable components, the geologists performing the evaluation relied heavily on their professional judgment and experience in assigning point values to each category and in determining the overall radon potential ranking. Background information on these factors is discussed in more detail in the preceding sections of this introduction.

Indoor radon was evaluated using unweighted arithmetic means of the indoor radon data for each geologic area to be assessed. Other expressions of indoor radon levels in an area also could have been used, such as weighted averages or annual averages, but these types of data were not consistently available for the entire United States at the time of this writing, or the schemes were not considered sufficient to provide a means of consistent comparison across all areas. For this report, charcoal-canister screening measurement data from the State/EPA Residential Radon Surveys and other carefully selected sources were used, as described in the preceding section. To maintain consistency, other indoor radon data sets (vendor, state, or other data) were not considered in scoring the indoor radon factor of the Radon Index if they were not randomly sampled or could not be statistically combined with the primary indoor radon data sets. However, these additional radon data sets can provide a means to further refine correlations between geologic factors and radon potential, so they are

**TABLE 1. RADON INDEX MATRIX.** "ppm eU" indicates parts per million of equivalent uranium, as indicated by NURE aerial radiometric data. See text discussion for details.

INCREASING RADON POTENTIAL →

| FACTOR | POINT VALUE | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| INDOOR RADON (average) | < 2 pCi/L | 2 - 4 pCi/L | > 4 pCi/L |
| AERIAL RADIOACTIVITY | < 1.5 ppm eU | 1.5 - 2.5 ppm eU | > 2.5 ppm eU |
| GEOLOGY* | negative | variable | positive |
| SOIL PERMEABILITY | low | moderate | high |
| ARCHITECTURE TYPE | mostly slab | mixed | mostly basement |

*GEOLOGIC FIELD EVIDENCE (GFE) POINTS: GFE points are assigned in addition to points for the "Geology" factor for specific, relevant geologic field studies. See text for details.

| | | |
|---|---|---|
| Geologic evidence supporting: | HIGH radon | +2 points |
| | MODERATE | +1 point |
| | LOW | -2 points |
| No relevant geologic field studies | | 0 points |

**SCORING:**

| Radon potential category | Point range | Probable average screening indoor radon for area |
|---|---|---|
| LOW | 3-8 points | < 2 pCi/L |
| MODERATE/VARIABLE | 9-11 points | 2 - 4 pCi/L |
| HIGH | 12-17 points | > 4 pCi/L |

POSSIBLE RANGE OF POINTS = 3 to 17

**TABLE 2. CONFIDENCE INDEX MATRIX**

INCREASING CONFIDENCE →

| FACTOR | POINT VALUE | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| INDOOR RADON DATA | sparse/no data | fair coverage/quality | good coverage/quality |
| AERIAL RADIOACTIVITY | questionable/no data | glacial cover | no glacial cover |
| GEOLOGIC DATA | questionable | variable | proven geol. model |
| SOIL PERMEABILITY | questionable/no data | variable | reliable, abundant |

**SCORING:**

| | |
|---|---|
| LOW CONFIDENCE | 4 - 6 points |
| MODERATE CONFIDENCE | 7 - 9 points |
| HIGH CONFIDENCE | 10 - 12 points |

POSSIBLE RANGE OF POINTS = 4 to 12

included as supplementary information and are discussed in the individual State chapters. If the average screening indoor radon level for an area was less than 2 pCi/L, the indoor radon factor was assigned 1 point, if it was between 2 and 4 pCi/L, it was scored 2 points, and if the average screening indoor radon level for an area was greater than 4 pCi/L, the indoor radon factor was assigned 3 RI points.

Aerial radioactivity data used in this report are from the equivalent uranium map of the conterminous United States compiled from NURE aerial gamma-ray surveys (Duval and others, 1989). These data indicate the gamma radioactivity from approximately the upper 30 cm of rock and soil, expressed in units of ppm equivalent uranium. An approximate average value of eU was determined visually for each area and point values assigned based on whether the overall eU for the area falls below 1.5 ppm (1 point), between 1.5 and 2.5 ppm (2 points), or greater than 2.5 ppm (3 points).

The geology factor is complex and actually incorporates many geologic characteristics. In the matrix, "positive" and "negative" refer to the presence or absence and distribution of rock types known to have high uranium contents and to generate elevated radon in soils or indoors. Examples of "positive" rock types include granites, black shales, phosphatic rocks, and other rock types described in the preceding "geologic data" section. Examples of "negative" rock types include marine quartz sands and some clays. The term "variable" indicates that the geology within the region is variable or that the rock types in the area are known or suspected to generate elevated radon in some areas but not in others due to compositional differences, climatic effects, localizeddistribution of uranium, or other factors. Geologic information indicates not only how much uranium is present in the rocks and soils but also gives clues for predicting general radon emanation and mobility characteristics through additional factors such as structure (notably the presence of faults or shears) and geochemical characteristics (for example, a phosphate-rich sandstone will likely contain more uranium than a sandstone containing little or no phosphate because the phosphate forms chemical complexes with uranium). "Negative", "variable", and "positive" geology were assigned 1, 2, and 3 points, respectively.

In cases where additional reinforcing or contradictory geologic evidence is available, Geologic Field Evidence (GFE) points were added to or subtracted from an area's score (Table 1). Relevant geologic field studies are important to enhancing our understanding of how geologic processes affect radon distribution. In some cases, geologic models and supporting field data reinforced an already strong (high or low) score; in others, they provided important contradictory data. GFE points were applied for geologically-sound evidence that supports the prediction (but which may contradict one or more factors) on the basis of known geologic field studies in the area or in areas with geologic and climatic settings similar enough that they could be applied with full confidence. For example, areas of the Dakotas, Minnesota, and Iowa that are covered with Wisconsin-age glacial deposits exhibit a low aerial radiometric signature and score only one RI point in that category. However, data from geologic field studies in North Dakota and Minnesota (Schumann and others, 1991) suggest that eU is a poor predictor of geologic radon potential in this area because radionuclides have been leached from the upper soil layers but are present and possibly even concentrated in deeper soil horizons, generating significant soil-gas radon. This positive supporting field evidence adds two GFE points to the score, which helps to counteract the invalid conclusion suggested by the radiometric data. No GFE points are awarded if there are no documented field studies for the area.

"Soil permeability" refers to several soil characteristics that influence radon concentration and mobility, including soil type, grain size, structure, soil moisture, drainage, slope, and permeability. In the matrix, "low" refers to permeabilities less than about 0.6 in/hr; "high" corresponds to greater than about 6.0 in/hr, in U.S. Soil Conservation Service (SCS) standard soil percolation tests. The SCS data are for water permeability, which generally correlates well with the gas permeability of the soil except when the soil moisture content is very high. Areas with consistently high water tables were thus considered to have low gas permeability. "Low, "moderate", and "high" permeability were assigned 1, 2, and 3 points, respectively.

Architecture type refers to whether homes in the area have mostly basements (3 points), mostly slab-on-grade construction (1 point), or a mixture of the two. Split-level and crawl space homes fall into the "mixed" category (2 points). Architecture information is necessary to properly interpret the indoor radon data and produce geologic radon potential categories that are consistent with screening indoor radon data.

The overall RI for an area is calculated by adding the individual RI scores for the 5 factors, plus or minus GFE points, if any. The total RI for an area falls in one of three categories—low, moderate or variable, or high. The point ranges for the three categories were determined by examining the possible combinations of points for the 5 factors and setting rules such that a majority (3 of 5 factors) would determine the final score for the low and high categories, with allowances for possible deviation from an ideal score by the other two factors. The moderate/variable category lies between these two ranges. A total deviation of 3 points from the "ideal" score was considered reasonable to allow for natural variability of factors—if two of the five factors are allowed to vary from the "ideal" for a category, they can differ by a minimum of 2 (1 point different each) and a maximum of 4 points (2 points different each). With "ideal" scores of 5, 10, and 15 points describing low, moderate, and high geologic radon potential, respectively, an ideal low score of 5 points plus 3 points for possible variability allows a maximum of 8 points in the low category. Similarly, an ideal high score of 15 points minus 3 points gives a minimum of 12 points for the high category. Note, however, that if both other factors differ by two points from the "ideal", indicating considerable variability in the system, the total point score would lie in the adjacent (i.e., moderate/variable) category.

***Confidence Index***. Except for architecture type, the same factors were used to establish a Confidence Index (CI) for the radon potential prediction for each area (Table 2). Architecture type was not included in the confidence index because house construction data are readily and reliably available through surveys taken by agencies and industry groups including the National Association of Home Builders, U.S. Department of Housing and Urban Development, and the Federal Housing Administration; thus it was not considered necessary to question the quality or validity of these data. The other factors were scored on the basis of the quality and quantity of the data used to complete the RI matrix.

Indoor radon data were evaluated based on the distribution and number of data points and on whether the data were collected by random sampling (State/EPA Residential Radon Survey or other state survey data) or volunteered vendor data (likely to be nonrandom and biased toward population centers and/or high indoor radon levels). The categories listed in the CI matrix for indoor radon data ("sparse or no data", "fair coverage or quality", and "good coverage/quality") indicate the sampling density and statistical robustness of an indoor radon data set. Data from the State/EPA Residential Radon Survey and statistically valid state surveys were typically assigned 3 Confidence Index points unless the data were poorly distributed or absent in the area evaluated.

Aerial radioactivity data are available for all but a few areas of the continental United States and for part of Alaska. An evaluation of the quality of the radioactivity data was based on whether there appeared to be a good correlation between the radioactivity and the actual amount of uranium or radium available to generate mobile radon in the rocks and soils of the area evaluated. In general, the greatest problems with correlations among eU, geology, and soil-gas or indoor radon levels were associated with glacial deposits (see the discussion in a previous section) and typically were assigned a 2-point Confidence Index score. Correlations among eU, geology, and radon were generally sound in unglaciated areas and were usually assigned 3 CI points. Again, however, radioactivity data in some unglaciated areas may have been assigned fewer than 3 points, and in glaciated areas may be assigned only one point, if the data were considered questionable or if coverage was poor.

To assign Confidence Index scores for the geologic data factor, rock types and geologic settings for which a physical-chemical, process-based understanding of radon generation and mobility exists were regarded as having "proven geologic models" (3 points); a high confidence could be held for predictions in such areas. Rocks for which the processes are less well known or for which data are contradictory were regarded as "variable" (2 points), and those about which little is known or for which no apparent correlations have been found were deemed "questionable" (1 point).

The soil permeability factor was also scored based on quality and amount of data. The three categories for soil permeability in the Confidence Index are similar in concept, and scored similarly, to those for the geologic data factor. Soil permeability can be roughly estimated from grain size and drainage class if data from standard, accepted soil percolation tests are unavailable; however, the reliability of the data would be lower than if percolation test figures or other measured permeability data are available, because an estimate of this type does not encompass all the factors that affect soil permeability and thus may be inaccurate in some instances. Most published soil permeability data are for water; although this is generally closely related to the air permeability of the soil, there are some instances when it may provide an incorrect estimate. Examples of areas in which water permeability data may not accurately reflect air permeability include areas with consistently high levels of soil moisture, or clay-rich soils, which would have a low water permeability but may have a significantly higher air permeability when dry due to shrinkage cracks in the soil. These additional factors were applied to the soil permeability factor when assigning the RI score, but may have less certainty in some cases and thus would be assigned a lower CI score.

The Radon Index and Confidence Index give a general indication of the relative contributions of the interrelated geologic factors influencing radon generation and transport in rocks and soils, and thus, of the potential for elevated indoor radon levels to occur in a particular area. However, because these reports are somewhat generalized to cover relatively large areas of States, it is highly recommended that more detailed studies be performed in local areas of interest, using the methods and general information in these booklets as a guide.

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# APPENDIX A
# GEOLOGIC TIME SCALE

| Subdivisions (and their symbols) | | | | | | Age estimates of boundaries in mega-annum (Ma)[1] | |
|---|---|---|---|---|---|---|---|
| Eon or Eonothem | Era or Erathem | Period, System, Subperiod, Subsystem | | Epoch or Series | | | |
| Phanerozoic[2] | Cenozoic[2] (Cz) | Quaternary[2] (Q) | | Holocene | | 0.010 | |
| | | | | Pleistocene | | 1.6 | (1.6–1.9) |
| | | Tertiary (T) | Neogene[2] Subperiod or Subsystem (N) | Pliocene | | 5 | (4.9–5.3) |
| | | | | Miocene | | 24 | (23–26) |
| | | | Paleogene[2] Subperiod or Subsystem (Pe) | Oligocene | | 38 | (34–38) |
| | | | | Eocene | | 55 | (54–56) |
| | | | | Paleocene | | 66 | (63–66) |
| | Mesozoic[2] (Mz) | Cretaceous (K) | | Late | Upper | 96 | (95–97) |
| | | | | Early | Lower | 138 | (135–141) |
| | | Jurassic (J) | | Late | Upper | | |
| | | | | Middle | Middle | | |
| | | | | Early | Lower | 205 | (200–215) |
| | | Triassic (₮R) | | Late | Upper | | |
| | | | | Middle | Middle | | |
| | | | | Early | Lower | ~240 | |
| | Paleozoic[2] (Pz) | Permian (P) | | Late | Upper | | |
| | | | | Early | Lower | 290 | (290–305) |
| | | Carboniferous Systems (C) | Pennsylvanian (P) | Late | Upper | | |
| | | | | Middle | Middle | | |
| | | | | Early | Lower | ~330 | |
| | | | Mississippian (M) | Late | Upper | | |
| | | | | Early | Lower | 360 | (360–365) |
| | | Devonian (D) | | Late | Upper | | |
| | | | | Middle | Middle | | |
| | | | | Early | Lower | 410 | (405–415) |
| | | Silurian (S) | | Late | Upper | | |
| | | | | Middle | Middle | | |
| | | | | Early | Lower | 435 | (435–440) |
| | | Ordovician (O) | | Late | Upper | | |
| | | | | Middle | Middle | | |
| | | | | Early | Lower | 500 | (495–510) |
| | | Cambrian (Є) | | Late | Upper | | |
| | | | | Middle | Middle | | |
| | | | | Early | Lower | ~570[3] | |
| Proterozoic (P̶) | Late Proterozoic (Z) | None defined | | | | 900 | |
| | Middle Proterozoic (Y) | None defined | | | | 1600 | |
| | Early Proterozoic (X) | None defined | | | | 2500 | |
| Archean (A) | Late Archean (W) | None defined | | | | 3000 | |
| | Middle Archean (V) | None defined | | | | 3400 | |
| | Early Archean (U) | None defined | | | | 3800 ? | |
| pre-Archean (pA)[4] | | | | | | | |

[1] Ranges reflect uncertainties of isotopic and biostratigraphic age assignments. Age boundaries not closely bracketed by existing data shown by ~. Decay constants and isotopic ratios employed are cited in Steiger and Jäger (1977). Designation m.y. used for an interval of time.

[2] Modifiers (lower, middle, upper or early, middle, late) when used with these items are informal divisions of the larger unit; the first letter of the modifier is lowercase.

[3] Rocks older than 570 Ma also called Precambrian (p-Є), a time term without specific rank.

[4] Informal time term without specific rank.

## APPENDIX B
## GLOSSARY OF TERMS

Units of measure

**pCi/L** (picocuries per liter)- a unit of measure of radioactivity used to describe radon concentrations in a volume of air. One picocurie ($10^{-12}$ curies) is equal to about 2.2 disintegrations of radon atoms per minute. A liter is about 1.06 quarts. The average concentration of radon in U.S. homes measured to date is between 1 and 2 pCi/L.

**Bq/m$^3$** (Becquerels per cubic meter)- a metric unit of radioactivity used to describe radon concentrations in a volume of air. One becquerel is equal to one radioactive disintegration per second. One pCi/L is equal to 37 Bq/m$^3$.

**ppm** (parts per million)- a unit of measure of concentration by weight of an element in a substance, in this case, soil or rock. One ppm of uranium contained in a ton of rock corresponds to about 0.03 ounces of uranium. The average concentration of uranium in soils in the United States is between 1 and 2 ppm.

**in/hr** (inches per hour)- a unit of measure used by soil scientists and engineers to describe the permeability of a soil to water flowing through it. It is measured by digging a hole 1 foot (12 inches) square and one foot deep, filling it with water, and measuring the time it takes for the water to drain from the hole. The drop in height of the water level in the hole, measured in inches, is then divided by the time (in hours) to determine the permeability. Soils range in permeability from less than 0.06 in/hr to greater than 20 in/hr, but most soils in the United States have permeabilities between these two extremes.

Geologic terms and terms related to the study of radon

**aerial radiometric, aeroradiometric survey** A survey of radioactivity, usually gamma rays, taken by an aircraft carrying a gamma-ray spectrometer pointed at the ground surface.

**alluvial fan** A low, widespread mass of loose rock and soil material, shaped like an open fan and deposited by a stream at the point where it flows from a narrow mountain valley out onto a plain or broader valley. May also form at the junction with larger streams or when the gradient of the stream abruptly decreases.

**alluvium, alluvial** General terms referring to unconsolidated detrital material deposited by a stream or other body of running water.

**alpha-track detector** A passive radon measurement device consisting of a plastic film that is sensitive to alpha particles. The film is etched with acid in a laboratory after it is exposed. The etching reveals scratches, or "tracks", left by the alpha particles resulting from radon decay , which can then be counted to calculate the radon concentration. Useful for long-term (1-12 months) radon tests.

**amphibolite** A mafic metamorphic rock consisting mainly of pyroxenes and(or) amphibole and plagioclase.

**argillite, argillaceous** Terms referring to a rock derived from clay or shale, or any sedimentary rock containing an appreciable amount of clay-size material, i.e., argillaceous sandstone.

**arid** Term describing a climate characterized by dryness, or an evaporation rate that exceeds the amount of precipitation.

**basalt** A general term for a dark-colored mafic igneous rocks that may be of extrusive origin, such as volcanic basalt flows, or intrusive origin, such as basalt dikes.

**batholith** A mass of plutonic igneous rock that has more than 40 square miles of surface exposure and no known bottom.

**carbonate** A sedimentary rock consisting of the carbonate ($CO_3$) compounds of calcium, magnesium, or iron, e.g. limestone and dolomite.

**carbonaceous** Said of a rock or sediment that is rich in carbon, is coaly, or contains organic matter.

**charcoal canister** A passive radon measurement device consisting of a small container of granulated activated charcoal that is designed to adsorb radon. Useful for short duration (2-7 days) measurements only. May be referred to as a "screening" test.

**chert** A hard, extremely dense sedimentary rock consisting dominantly of interlocking crystals of quartz. Crystals are not visible to the naked eye, giving the rock a milky, dull luster. It may be white or gray but is commonly colored red, black, yellow, blue, pink, brown, or green.

**clastic** pertaining to a rock or sediment composed of fragments that are derived from preexisting rocks or minerals. The most common clastic sedimentary rocks are sandstone and shale.

**clay** A rock containing clay mineral fragments or material of any composition having a diameter less than 1/256 mm.

**clay mineral** One of a complex and loosely defined group of finely crystalline minerals made up of water, silicate and aluminum (and a wide variety of other elements). They are formed chiefly by alteration or weathering of primary silicate minerals. Certain clay minerals are noted for their small size and ability to absorb substantial amounts of water, causing them to swell. The change in size that occurs as these clays change between dry and wet is referred to as their **"shrink-swell"** potential.

**concretion** A hard, compact mass of mineral matter, normally subspherical but commonly irregular in shape; formed by precipitation from a water solution about a nucleus or center, such as a leaf, shell, bone, or fossil, within a sedimentary or fractured rock.

**conglomerate** A coarse-grained, clastic sedimentary rock composed of rock and mineral fragments larger than 2 mm, set in a finer-grained matrix of clastic material.

**cuesta** A hill or ridge with a gentle slope on one side and a steep slope on the other. The formation of a cuesta is controlled by the different weathering properties and the structural dip of the rocks forming the hill or ridge.

**daughter product** A nuclide formed by the disintegration of a radioactive precursor or "parent" atom.

**delta, deltaic** Referring to a low, flat, alluvial tract of land having a triangular or fan shape, located at or near the mouth of a river. It results from the accumulation of sediment deposited by a river at the point at which the river loses its ability to transport the sediment, commonly where a river meets a larger body of water such as a lake or ocean.

**dike** A tabular igneous intrusion of rock, younger than the surrounding rock, that commonly cuts across the bedding or foliation of the rock it intrudes.

**diorite** A plutonic igneous rock that is medium in color and contains visible dark minerals that make up less than 50% of the rock. It also contains abundant sodium plagioclase and minor quartz.

**dolomite** A carbonate sedimentary rock of which more than 50% consists of the mineral dolomite ($CaMg(CO_3)_2$), and is commonly white, gray, brown, yellow, or pinkish in color.

**drainage** The manner in which the waters of an area pass, flow off of, or flow into the soil. Also refers to the water features of an area, such as lakes and rivers, that drain it.

**eolian** Pertaining to sediments deposited by the wind.

**esker** A long, narrow, steep-sided ridge composed of irregular beds of sand and gravel deposited by streams beneath a glacier and left behind when the ice melted.

**evapotranspiration** Loss of water from a land area by evaporation from the soil and transpiration from plants.

**extrusive** Said of igneous rocks that have been erupted onto the surface of the Earth.

**fault** A fracture or zone of fractures in rock or sediment along which there has been movement.

**fluvial, fluvial deposit** Pertaining to sediment that has been deposited by a river or stream.

**foliation** A linear feature in a rock defined by both mineralogic and structural characteristics. It may be formed during deformation or metamorphism.

**formation** A mappable body of rock having similar characteristics.

**glacial deposit** Any sediment transported and deposited by a glacier or processes associated with glaciers, such as glaciofluvial sediments deposited by streams flowing from melting glaciers.

**gneiss** A rock formed by metamorphism in which bands and lenses of minerals of similar composition alternate with bands and lenses of different composition, giving the rock a striped or "foliated" appearance.

**granite** Broadly applied, any coarsely crystalline, quartz- and feldspar-bearing igneous plutonic rock. Technically, granites have between 10 and 50% quartz, and alkali feldspar comprises at least 65% of the total feldspar.

**gravel** An unconsolidated, natural accumulation of rock fragments consisting predominantly of particles greater than 2 mm in size.

**heavy minerals** Mineral grains in sediment or sedimentary rock having higher than average specific gravity. May form layers and lenses because of wind or water sorting by weight and size and may be referred to as a "placer deposit." Some heavy minerals are magnetite, garnet, zircon, monazite, and xenotime.

**igneous** Said of a rock or mineral that solidified from molten or partly molten rock material. It is one of the three main classes into which rocks are divided, the others being sedimentary and metamorphic.

**intermontane** A term that refers to an area between two mountains or mountain ranges.

**intrusion, intrusive** The processes of emplacement or injection of molten rock into pre-existing rock. Also refers to the rock formed by intrusive processes, such as an "intrusive igneous rock".

**kame** A low mound, knob, hummock, or short irregular ridge formed by a glacial stream at the margin of a melting glacier; composed of bedded sand and gravel.

**karst terrain** A type of topography that is formed on limestone, gypsum and other rocks by dissolution of the rock by water, forming sinkholes and caves.

**lignite** A brownish-black coal that is intermediate in coalification between peat and subbituminous coal.

**limestone** A carbonate sedimentary rock consisting of more than 50% calcium carbonate, primarily in the form of the mineral calcite ($CaCO_3$).

**lithology** The description of rocks in hand specimen and in outcrop on the basis of color, composition, and grain size.

**loam** A permeable soil composed of a mixture of relatively equal parts clay, silt, and sand, and usually containing some organic matter.

**loess** A fine-grained eolian deposit composed of silt-sized particles generally thought to have been deposited from windblown dust of Pleistocene age.

**mafic** Term describing an igneous rock containing more than 50% dark-colored minerals.

**marine** Term describing sediments deposited in the ocean, or precipitated from ocean waters.

**metamorphic** Any rock derived from pre-existing rocks by mineralogical, chemical, or structural changes in response to changes in temperature, pressure, stress, and the chemical environment. Phyllite, schist, amphibolite, and gneiss are metamorphic rocks.

**moraine** A mound, ridge, or other distinct accumulation of unsorted, unbedded glacial material, predominantly till, deposited by the action of glacial ice.

**outcrop** That part of a geologic formation or structure that appears at the surface of the Earth, as in "rock outcrop".

**percolation test** A term used in engineering for a test to determine the water permeability of a soil. A hole is dug and filled with water and the rate of water level decline is measured.

**permeability** The capacity of a rock, sediment, or soil to transmit liquid or gas.

**phosphate, phosphatic, phosphorite** Any rock or sediment containing a significant amount of phosphate minerals, i.e., minerals containing $PO_4$.

**physiographic province** A region in which all parts are similar in geologic structure and climate, which has had a uniform geomorphic history, and whose topography or landforms differ significantly from adjacent regions.

**placer deposit** See heavy minerals

**residual** Formed by weathering of a material in place.

**residuum** Deposit of residual material.

**rhyolite** An extrusive igneous rock of volcanic origin, compositionally equivalent to granite.

**sandstone** A clastic sedimentary rock composed of sand-sized rock and mineral material that is more or less firmly cemented. Sand particles range from 1/16 to 2 mm in size.

**schist** A strongly foliated crystalline rock, formed by metamorphism, that can be readily split into thin flakes or slabs. Contains mica; minerals are typically aligned.

**screening level** Result of an indoor radon test taken with a charcoal canister or similar device, for a short period of time, usually less than seven days. May indicate the potential for an indoor radon problem but does not indicate annual exposure to radon.

**sediment** Deposits of rock and mineral particles or fragments originating from material that is transported by air, water or ice, or that accumulate by natural chemical precipitation or secretion of organisms.

**semiarid** Refers to a climate that has slightly more precipitation than an arid climate.

**shale** A fine-grained sedimentary rock formed from solidification (lithification) of clay or mud.

**shear zone** Refers to a roughly linear zone of rock that has been faulted by ductile or non-ductile processes in which the rock is sheared and both sides are displaced relative to one another.

**shrink-swell clay** See clay mineral.

**siltstone** A fine-grained clastic sedimentary rock composed of silt-sized rock and mineral material and more or less firmly cemented. Silt particles range from 1/16 to 1/256 mm in size.

**sinkhole** A roughly circular depression in a karst area measuring meters to tens of meters in diameter. It is funnel shaped and is formed by collapse of the surface material into an underlying void created by the dissolution of carbonate rock.

**slope** An inclined part of the earth's surface.

**solution cavity** A hole, channel or cave-like cavity formed by dissolution of rock.

**stratigraphy** The study of rock strata; also refers to the succession of rocks of a particular area.

**surficial materials** Unconsolidated glacial, wind-, or waterborne deposits occurring on the earth's surface.

**tablelands** General term for a broad, elevated region with a nearly level surface of considerable extent.

**terrace gravel** Gravel-sized material that caps ridges and terraces, left behind by a stream as it cuts down to a lower level.

**terrain** A tract or region of the Earth's surface considered as a physical feature or an ecological environment.

**till** Unsorted, generally unconsolidated and unbedded rock and mineral material deposited directly adjacent to and underneath a glacier, without reworking by meltwater. Size of grains varies greatly from clay to boulders.

**uraniferous** Containing uranium, usually more than 2 ppm.

**vendor data** Used in this report to refer to indoor radon data collected and measured by commercial vendors of radon measurement devices and/or services.

**volcanic** Pertaining to the activities, structures, and extrusive rock types of a volcano.

**water table** The surface forming the boundary between the zone of saturation and the zone of aeration; the top surface of a body of unconfined groundwater in rock or soil.

**weathering** The destructive process by which earth and rock materials, on exposure to atmospheric elements, are changed in color, texture, composition, firmness, or form with little or no transport of the material.

# APPENDIX C
# EPA REGIONAL OFFICES

| EPA Regional Offices | State | EPA Region |
|---|---|---|
| EPA Region 1<br>JFK Federal Building<br>Boston, MA 02203<br>(617) 565-4502 | Alabama | 4 |
| | Alaska | 10 |
| | Arizona | 9 |
| | Arkansas | 6 |
| | California | 9 |
| EPA Region 2<br>(2AIR:RAD)<br>26 Federal Plaza<br>New York, NY 10278<br>(212) 264-4110 | Colorado | 8 |
| | Connecticut | 1 |
| | Delaware | 3 |
| | District of Columbia | 3 |
| | Florida | 4 |
| | Georgia | 4 |
| Region 3 (3AH14)<br>841 Chestnut Street<br>Philadelphia, PA 19107<br>(215) 597-8326 | Hawaii | 9 |
| | Idaho | 10 |
| | Illinois | 5 |
| | Indiana | 5 |
| | Iowa | 7 |
| EPA Region 4<br>345 Courtland Street, N.E.<br>Atlanta, GA 30365<br>(404) 347-3907 | Kansas | 7 |
| | Kentucky | 4 |
| | Louisiana | 6 |
| | Maine | 1 |
| | Maryland | 3 |
| EPA Region 5 (5AR26)<br>77 West Jackson Blvd.<br>Chicago, IL 60604-3507<br>(312) 886-6175 | Massachusetts | 1 |
| | Michigan | 5 |
| | Minnesota | 5 |
| | Mississippi | 4 |
| | Missouri | 7 |
| EPA Region 6 (6T-AS)<br>1445 Ross Avenue<br>Dallas, TX 75202-2733<br>(214) 655-7224 | Montana | 8 |
| | Nebraska | 7 |
| | Nevada | 9 |
| | New Hampshire | 1 |
| | New Jersey | 2 |
| EPA Region 7<br>726 Minnesota Avenue<br>Kansas City, KS 66101<br>(913) 551-7604 | New Mexico | 6 |
| | New York | 2 |
| | North Carolina | 4 |
| | North Dakota | 8 |
| | Ohio | 5 |
| EPA Region 8<br>(8HWM-RP)<br>999 18th Street<br>One Denver Place, Suite 1300<br>Denver, CO 80202-2413<br>(303) 293-1713 | Oklahoma | 6 |
| | Oregon | 10 |
| | Pennsylvania | 3 |
| | Rhode Island | 1 |
| | South Carolina | 4 |
| | South Dakota | 8 |
| | Tennessee | 4 |
| EPA Region 9 (A-3)<br>75 Hawthorne Street<br>San Francisco, CA 94105<br>(415) 744-1048 | Texas | 6 |
| | Utah | 8 |
| | Vermont | 1 |
| | Virginia | 3 |
| | Washington | 10 |
| EPA Region 10<br>1200 Sixth Avenue<br>Seattle, WA 98101<br>(202) 442-7660 | West Virginia | 3 |
| | Wisconsin | 5 |
| | Wyoming | 8 |

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| | | | |
|---|---|---|---|
| <u>Idaho</u> | Pat McGavarn<br>Office of Environmental Health<br>450 West State Street<br>Boise, ID 83720<br>(208) 334-6584<br>1-800-445-8647 in state | <u>Louisiana</u> | Matt Schlenker<br>Louisiana Department of<br>Environmental Quality<br>P.O. Box 82135<br>Baton Rouge, LA 70884-2135<br>(504) 925-7042<br>1-800-256-2494 in state |
| <u>Illinois</u> | Richard Allen<br>Illinois Department of Nuclear Safety<br>1301 Outer Park Drive<br>Springfield, IL 62704<br>(217) 524-5614<br>1-800-325-1245 in state | <u>Maine</u> | Bob Stilwell<br>Division of Health Engineering<br>Department of Human Services<br>State House, Station 10<br>Augusta, ME 04333<br>(207) 289-5676<br>1-800-232-0842 in state |
| <u>Indiana</u> | Lorand Magyar<br>Radiological Health Section<br>Indiana State Department of Health<br>1330 West Michigan Street<br>P.O. Box 1964<br>Indianapolis, IN 46206<br>(317) 633-8563<br>1-800-272-9723 In State | <u>Maryland</u> | Leon J. Rachuba<br>Radiological Health Program<br>Maryland Department of the<br>Environment<br>2500 Broening Highway<br>Baltimore, MD 21224<br>(410) 631-3301<br>1-800-872-3666 In State |
| <u>Iowa</u> | Donald A. Flater<br>Bureau of Radiological Health<br>Iowa Department of Public Health<br>Lucas State Office Building<br>Des Moines, IA 50319-0075<br>(515) 281-3478<br>1-800-383-5992 In State | <u>Massachusetts</u> | William J. Bell<br>Radiation Control Program<br>Department of Public Health<br>23 Service Center<br>Northampton, MA 01060<br>(413) 586-7525<br>1-800-445-1255 in state |
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## EPA REGION 10 GEOLOGIC RADON POTENTIAL SUMMARY

*by*

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EPA Region 10 includes the states of Alaska, Idaho, Oregon, and Washington. For each state, geologic radon potential areas were delineated and ranked on the basis of geologic, soils, housing construction, and other factors. Areas in which the *average screening indoor radon level of all homes within the area* is estimated to be greater than 4 pCi/L were ranked high. Areas in which the average screening indoor radon level of all homes within the area is estimated to be between 2 and 4 pCi/L were ranked moderate/variable, and areas in which the average screening indoor radon level of all homes within the area is estimated to be less than 2 pCi/L were ranked low. Information on the data used and on the radon potential ranking scheme is given in the introduction to this volume. More detailed information on the geology and radon potential of each state in Region 10 is given in the individual state chapters. The individual chapters describing the geology and radon potential of the states in EPA Region 10, though much more detailed than this summary, still are generalized assessments and there is no substitute for having a home tested. Within any radon potential area homes with indoor radon levels both above and below the predicted average likely will be found.

The geology and radon potential of the Pacific Northwest (fig. 1) and Alaska (fig. 2) is diverse; thus the two areas will be considered separately. The Pacific Northwest includes eight distinct major radon geologic provinces: the Coastal Range-Klamath Mountains, the Puget Lowland-Willamette River Valley, the Cascade Range, the Columbia Plateau-High Lava Plains-Blue Mountains, the northern Rocky Mountains, the Snake River plain, the middle Rocky Mountains, and the northern Basin and Range-Owyhee Plateau (fig. 1). Maps showing indoor radon averages for counties in the Pacific Northwest and boroughs in Alaska are shown in figures 3a and 3b. Averages range from less than 1.0 pCi/L to 14.9 pCi/L. Details of the indoor radon studies are described in the individual state chapters.

### PACIFIC NORTHWEST

#### Coastal Range-Klamath Mountains

The Coastal Range Province (1, fig. 1) extends from the Olympic Peninsula of Washington south to the coastal parts of the Klamath Mountains in southwestern Oregon. In Washington, the Coast Ranges are underlain principally by Cretaceous and Tertiary continental and marine sedimentary rocks and pre-Miocene volcanic rocks. In Oregon, the northern part of the Coastal Ranges is underlain principally by marine sedimentary rocks and mafic volcanic rocks of Tertiary age. The southern part of the Coast Range is underlain by Tertiary estuarine and marine sedimentary rocks, much of them feldspathic and micaceous. The Klamath Mountains (2, fig. 1) are dominated by Triassic to Jurassic metamorphic, volcanic, and sedimentary rocks, with some Cretaceous intrusive rocks. These metamorphic and volcanic rocks are largely of mafic composition. Large masses of ultramafic rocks occur throughout the Klamath area. Sand dunes and marine terraces are common along the coastal areas of this province.

The radon potential of the Coastal Range Province is low overall. Most of the area has high rainfall and, as a consequence, high soil moisture. Uranium in the soils is typically low, although soils of the Oregon part of the Coast Ranges tend to be higher in uranium than do soils of

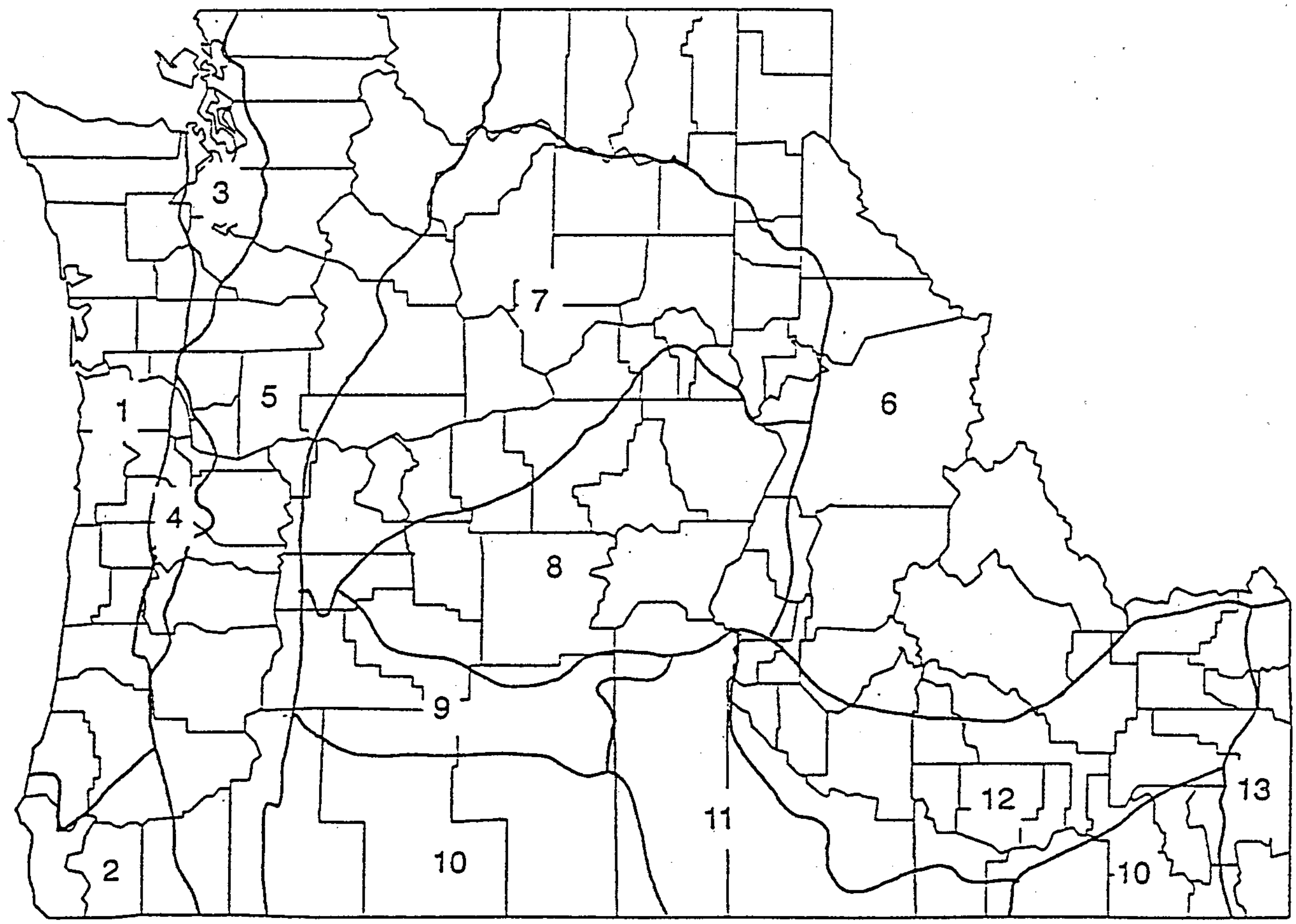


Figure 1- Radon geologic provinces of the Pacific Northwest (generalized from state chapters included in this report). 1- Coast Ranges; 2- Klamath Mountains; 3- Puget Lowland; 4- Willamette River Valley; 5- Cascade Range; 6- Northern Rocky Mountains; 7- Columbia Plateau; 8- Blue Mountains; 9- High Lava Plains; 10- Basin and Range; 11- Owyhee Plateau; 12- Snake River Plain; and 13- Middle Rocky Mountains.

the Washington part. A few communities along the river valleys near the coast of Oregon may have locally elevated indoor radon where highly permeable, excessively well-drained soils occur on river alluvium with a modestly elevated uranium content. The northeastern corner of the Olympic Peninsula has lower rainfall and lower soil moisture than does the rest of the Coastal Range Province. Here, highly permeable, excessively well-drained soils may cause locally elevated indoor radon levels.

Puget Lowland-Willamette River Valley

The Puget Lowland (3, fig. 1) is underlain almost entirely by glacial deposits and Holocene alluvium. Most of the glacial and alluvial material of the Puget Lowland is derived from the Cascades to the east, and from the mountains of the Olympic peninsula to the west. River alluvium and river terraces underlie most of the Willamette River valley (4, fig. 1). However, many of the hills that rise above the plains of the Lowland are underlain by Tertiary basalts and marine sediments.

The Puget Lowland overall has very low radon potential because of low uranium content of soils and because high rainfall produces high soil moisture, which slows radon movement. Houses in most townships in the Bonneville Power Administration study from Tacoma northward average less than 1 pCi/L radon. Structures built on locally very steep or well-drained soils, especially on the east side of the lowland area, may be among the few likely to have elevated indoor radon levels. The geologic radon potential is moderate only in the southern part of the Puget Lowland, south of Tacoma, where excessively drained soils and somewhat elevated uranium in soils occur.

The Willamette River Valley has moderate radon potential overall. Much of the area has somewhat elevated uranium in soils, and many areas have excessively drained soils and soils with high emanating power. Studies by the Oregon Department of Health and the Bonneville Power Administration indicate that houses in many counties and townships in the valley average between 2 and 4 pCi/L radon.

Cascade Range

The Cascade Range (5, fig. 1) can be divided into two geologic terranes: a northern terrane composed principally of Mesozoic metamorphic rocks intruded by Mesozoic and Tertiary granitic rocks, and a southern terrane composed of Tertiary and Holocene volcanic rocks. The Holocene volcanic centers are responsible for locally thick volcanic-ash deposits east of the Cascade Mountains. Within the southern terrane, the western Cascades are dominated by Tertiary andesite flows, basalt flows, and pyroclastic rocks, whereas the eastern Cascades have many recently active volcanoes and are underlain by late Tertiary to Quaternary basaltic and andesitic volcanic rocks.

Overall, the sparsely populated Cascade Range Province has low radon potential because of the low uranium and high moisture contents of the soils. Areas that are exceptions to this include the Columbia River Gorge, where highly permeable, excessively well drained soils underlie many of the communities, and thus the radon potential is moderate. Much of the alluvium in the Gorge is also derived from the upper Columbia River valley, where the uranium content of the geologic materials is higher than the rocks within the Cascade Mountain Province itself. Studies by the Oregon Department of Health and the Bonneville Power Administration show that indoor radon levels in homes in population centers along the Columbia River average 2 to 4 pCi/L.

## Columbia Plateau, High Lava Plains, and Blue Mountains

The Columbia Plateau (7, fig. 1) is underlain principally by Miocene basaltic and andesitic volcanic rocks, tuffaceous sedimentary rocks and tuff. An extensive veneer of Pleistocene glaciofluvial outwash, eolian, and lacustrine deposits covers these volcanic rocks. The High Lava Plains (9, fig. 1) are underlain by Miocene basaltic and volcanic rocks like those of the Columbia Plateau without the veneer of younger sedimentary rocks. The Blue Mountains (8, fig. 1) have similar basaltic and andesitic rocks and also include significant outcrop areas of Triassic and Jurassic sedimentary and volcanic rocks, weakly metamorphosed in many areas, and younger intrusive rocks.

The Columbia Plateau, with its areas of extensive Pleistocene glacio-fluvial outwash, eolian, and lacustrine deposits, contains locally highly permeable soils, soils with high emanating coefficients, and elevated soil uranium levels. This area has generally moderate radon potential. Although the Blue Mountains have relatively low uranium in soils, average indoor radon levels are in the 2-4 pCi/L range, probably because most population centers occur in alluviated valleys with highly permeable soils. This area has moderate radon potential. In contrast, the High Lava Plains, with much lower uranium in soils and only local areas of highly permeable soils, have low overall radon potential.

## Northern Rocky Mountains

The Northern Rocky Mountains (6, fig. 1) comprise the mountainous terrane of the northeast and north-central parts of Washington and northern and central Idaho. This area is underlain by Precambrian and Paleozoic sedimentary rocks, and by Mesozoic metamorphic rocks; all are intruded by Mesozoic and Tertiary granitic rocks. The largest intrusive mass, the Idaho Batholith, is a complex of granitic rock units that range from diorite to granite. Highly uraniferous, Late Cretaceous to early Tertiary granites crop out throughout the Northern Rocky Mountains. An extensive, though dissected, veneer of Tertiary volcanic rocks crops out over much of the central Idaho portion of the Northern Rocky Mountains.

The Northern Rocky Mountains Province has high radon potential. Excessively well drained glaciofluvial outwash or coarse gravels in alluvial fans underlie many of the valleys throughout the area. The granitic material in much of the outwash contains moderate to locally high concentrations of uranium. Areas where uranium occurrences are found, such as in the granitic and metamorphic terranes in the mountains north of Spokane, may have structures with extreme levels of indoor radon. Buildings in most of the alluvial valleys in Washington and Idaho north, northwest, and east of Spokane may be expected to have average indoor radon screening measurements above 4 pCi/L.

## Snake River Plain

The Snake River Plain (12, fig. 1) forms an arcuate depression in southern Idaho that is underlain principally by basaltic volcanic rocks of generally low eU (1 ppm or less). However, alluvium from neighboring mountains and silicic tuffaceous sedimentary rocks covers much of the upper Snake River Valley near Wyoming and the western end of the Snake River Plain near Boise and south of Mountain Home. These materials have eU values that range from 1.5-5.0 ppm. Those areas underlain by basalt have low to locally moderate radon potential. However, those areas where basalt is overlain by silicic tuffaceous sedimentary rocks and alluvium along the Snake River Valley have high overall radon potential. Most populous areas are in the latter category.

Middle Rocky Mountains

The Middle Rocky Mountains Province (13, fig. 1) forms a strip along the border between Wyoming and Idaho and comprises two areas. The northern area is the Yellowstone Plateau, a high-standing plateau area underlain mostly by rhyolites containing moderate amounts of uranium. To the south are complexly faulted and folded mountain ranges of Paleozoic and Mesozoic sedimentary rocks, including uranium-bearing phosphatic rocks.

The high average uranium content of the volcanic rocks of the Yellowstone area and the coarse alluvium in the valleys of the southern mountain areas suggest that this province has high geologic radon potential.

Basin and Range Province, Owyhee Plateau

The very sparsely populated northern part of the Basin and Range Province (10, fig. 1) lies along the southern and southeastern edge of Region 10. It is composed of tectonically extended areas where linear mountain ranges alternate with valleys and less extended plateau areas. It is underlain mainly by basaltic to andesitic volcanic rocks, silicic ash-flow tuffs, including some welded tuffs, and sediments derived from these units. Several playa basins occupy the centers of the valleys. The Owyhee Plateau of southwestern Idaho (11, fig. 1) consists of Tertiary and Quaternary basalt, andesite, and rhyolite, and sediments derived from these units. A few caldera complexes, some of them with associated uranium mineralization, occur within the Owyhee Plateau. Some mountain ranges in the eastern part of this province are underlain mainly by Paleozoic and Mesozoic sedimentary rocks. Based on the high aeroradiometric signature of most of the exposed rock units and the presence of many highly permeable soil units, the radon potential of this area is generally high .

ALASKA

Alaska can be divided from north to south into eight geologic radon provinces: the Arctic Coastal Plain, the Arctic Foothills, the Arctic Mountains, Central Alaska, the Northern Plateaus (a subprovince of Central Alaska), the Alaska-Aleutian Ranges, the Coastal Trough, and the Border Ranges Provinces (fig. 2).

Arctic Coastal Plain

The Arctic Coastal Plain Province (North Slope, 1, fig. 2) consists primarily of Quaternary sediment, most of of which is composed of alluvium, glacial debris, and eolian sand and silt. A belt of Tertiary sedimentary rocks along the eastern third of the area separates the coastal plains from the foothills to the south.

This area has low radon potential. No significant uranium occurrences are known in this area, and the number of gamma-ray anomalies is low when compared with other parts of Alaska. The coastal plain is unglaciated and contains tundra soils and permafrost. These soils probably have low gas transmissivity because of water or ice saturation.

Arctic Foothills

The Arctic Foothills Province (2, fig. 2) is largely composed of marine and nonmarine Cretaceous sandstone and shale. The Cretaceous beds are folded into west-trending anticlines and synclines. Part of the area was covered by glaciers.

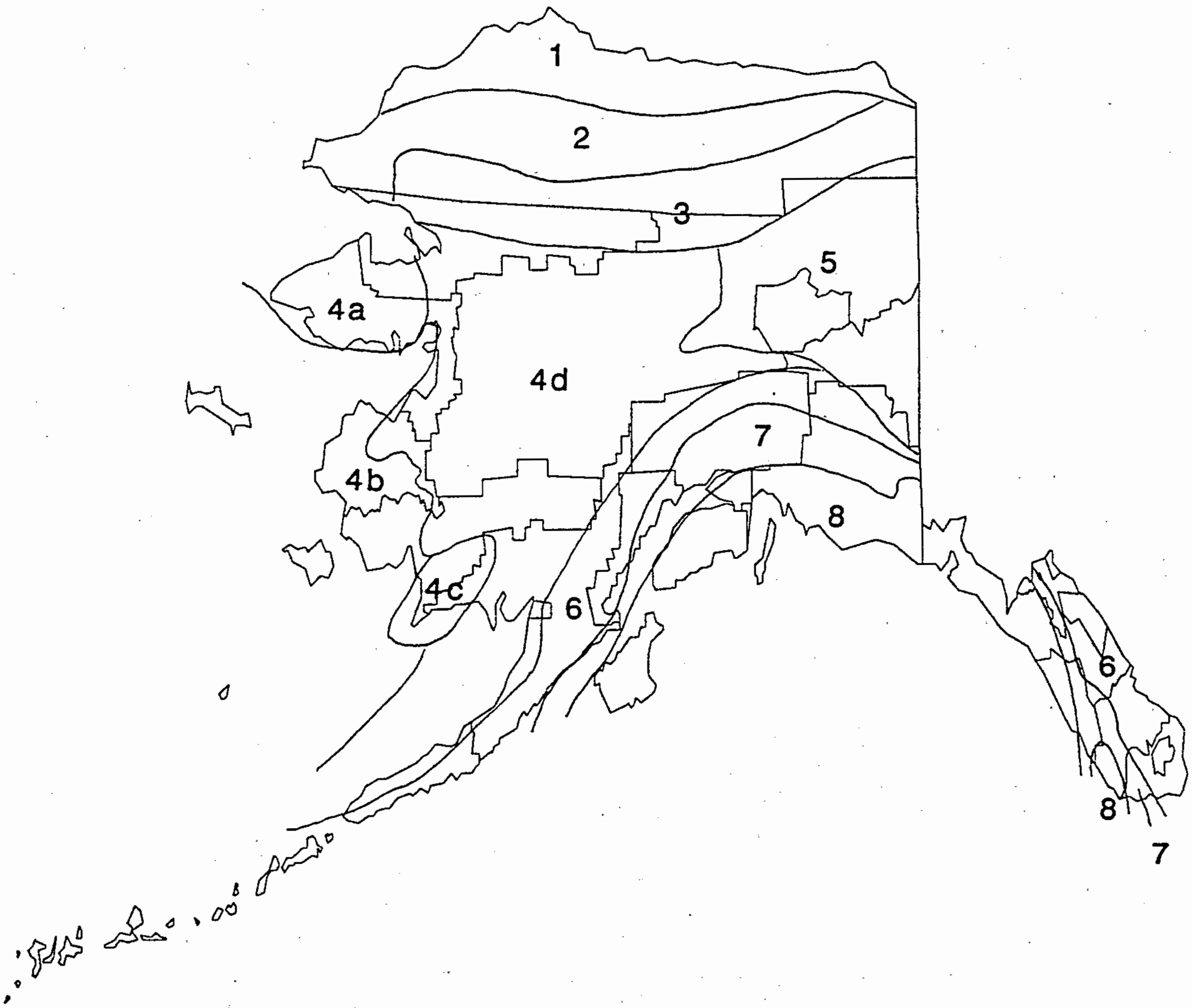


Figure 2- Physiographic provinces of Alaska (from the state chapter included in this report). 1- Arctic Coastal Plain; 2- Arctic Foothills; 3- Arctic Mountains; 4- Central Province, 4a- Seward Peninsula, 4b- Bering Shelf, 4c- Ahklun Mountains, 4d- Western Alaska, 4e- Northern Plateaus; 5- Alaska-Aleutian Province; 6- Coastal Trough; 7- Pacific Border Ranges; and 8- Coast Mountains.

This area has low radon potential overall. The Cretaceous sandstone and shale that makes up the foothills could produce relatively large amounts of radon but no evidence that they do is on hand. The area contains no known uranium occurrences or deposits, and the part of the area where airborne gamma-ray measurements were made shows a low number of anomalies. The tundra soils have permafrost and apparent low gas transmissivity.

Arctic Mountains

The Arctic Mountains Province (3, fig. 2) is composed largely of upper Precambrian and Paleozoic marine sedimentary rocks. They are cut by west-trending thrust faults with upthrown sides to the south.

This area has moderate radon potential. The Precambrian and Paleozoic marine sedimentary rocks that make up the Arctic Mountains probably are not producers of high levels of radon as there is little or no phosphate rock or black shale in these sequences. There are no known significant uranium occurrences in this area. However, stream sediments in this province contain moderately high levels of uraniferous resistate minerals. The area has been glaciated, but much of the terrane is bare rock without surficial glacial material. The soils are classified as rock land, which includes glacial ice.

Central Province (exclusive of the Northern Plateaus subprovince)

The Central Province, an area of plains, plateaus, and rounded mountains, is geologically complex. The Central Province is divided into five subprovinces: Western Alaska, Seward Peninsula, Aklun Mountains, the Bering Shelf (4a-d, fig. 2) and the Northern Plateaus (5, fig. 2). The Northern Plateaus are considered separately below.

Western Alaska is underlain mostly by Cretaceous marine sedimentary rocks and lower Paleozoic sedimentary and metamorphic rocks. A large area of Cretaceous and Tertiary volcanic rock is present in the western part of this subprovince. The Seward Peninsula consists mostly of Precambrian and Paleozoic metamorphic rocks, with lesser amounts of Precambrian and Paleozoic sedimentary rocks, Quaternary sediments, and Tertiary and Quaternary mafic volcanic rocks. The Aklun Mountains are composed mostly of marine sedimentary rocks and small intrusive masses of Jurassic and Tertiary age. The Bering Shelf is covered almost entirely by Quaternary surficial sediments, with minor areas of Tertiary volcanic rocks.

Overall the Central Province has moderate radon potential as many radon-producing rocks occur there. There are, for instance, several areas of uraniferous granites together with felsic intrusive and volcanic rocks. In addition, the area contains a few uranium deposits of potentially commercial size at Death Valley on the Seward Peninsula and in the Healy Creek coal basin. The area also contains a significant number of gamma-ray anomalies. Nearly all of the area falls within a belt of uraniferous stream sediments. The schist that produces high indoor radon near Fairbanks is in this area. Little of the province has been glaciated. The soils are mostly of the Tundra type with variable permafrost. Significant areas of rockland and subarctic brown forest soils occur. The latter soils may have high gas transmissivity.

Northern Plateaus

The Northern Plateaus subprovince (5, fig. 2) is covered by flat-lying Tertiary basin-fill (nonmarine clastic rocks), Quaternary surficial deposits, Precambrian through Cretaceous mostly marine sedimentary rocks, Paleozoic and Precambrian metamorphic rocks, and Mesozoic intrusive and volcanic rocks. The metamorphic rocks include metamorphosed granites and amphibolite.

The mesozoic intrusives are msotly gabbro and diabase. The Tintina and Denali fault zones cross this subprovince.

The Northern Plateaus subprovince has a moderate radon potential overall. A moderate number of aeroradiometric anomalies occurs in the s[illegible]vince. Although indoor radon data are sparse, indoor radon in parts of the Fairbanks and Fairbanks Northstar Boroughs is high. Felsic intrusives are scattered in two belts, one intruding Paleozoic and Precambrian metamorphic rocks in the southeast one-third of the subprovince and one intruding Lower Paleozoic and (or) Precambrian sedimentary rocks along the northwest margin of the subprovince. The area contains one known significant uranium and thorium deposit at Mount Prindle. Uranium is high in stream sediments in the south-central part and along the northwest border of the subprovince.

Alaska-Aleutian Ranges and Coastal Mountains

The Alaska-Aleutian Ranges and Coastal Mountains Province (6, fig. 2) includes the Aleutian Peninsula, a northeast-trending mountain belt in south-central Alaska that includes Mt. McKinley, a southeast-trending mountain belt that extends from the Mt. McKinley area southeastward to Canada, and the Coast Mountains in the southeast. On the Aleutian Peninsula from Unimak Pass westward, the bedrock consists mostly of Quaternary and Tertiary volcanic rocks and Tertiary sedimentary rocks. Tertiary and Quaternary volcanic rocks are also common northeast of the Pass, but other rocks, including Jurassic and Cretaceous sedimentary rocks and Jurassic intrusive rocks of intermediate and felsic composition, are also common in this area. In addition, large masses of Tertiary mafic volcanic rocks and Jurassic or Cretaceous intermediate intrusives are found in the area west of Cook Inlet and southwest of Mount McKinley. A varied assortment of Phanerozoic rocks are present in the Talkeetna Mountains and southeastward to the Canadian border. These include Paleozoic mafic volcanic rocks together with their sedimentary and metamorphic derivatives; Mesozoic mafic volcanic flows and tuffs, together with various units of shale, conglomerate, graywacke, and slate; and Tertiary and Quaternary intermediate volcanic rocks, Tertiary felsic intrusives, and Quaternary glacial deposits including eolian sand and silt. The Coastal Mountains are composed mostly of ultramafic, intermediate, and silicic volcanic intrusive rocks of varying ages, and Paleozoic through Mesozoic sedimentary rocks. These rocks are highly deformed and variably metamorphosed.

This area has moderate radon potential overall, although the uncertainty is high. The Aleutian-Alaska Range contains felsic intrusives and other rocks that are likely to be uranium-rich, although no significant uranium occurrences are known in this area. However, the area has a moderate to substantial number of anomalously uranium-rich stream sediment samples. Most of the area is or was covered by glaciers and glacial outwash may be highly permeable in many areas. Soils are mostly classified as rockland or tundra.

Coastal Trough

The Coastal Trough Province (7, fig. 2) includes a series of Cenozoic depositional basins containing thick sequences of Tertiary continental clastic and volcanic rocks that generally overlie Cretaceous or older sedimentary rocks penetrated by Tertiary intrusive rocks. Mesozoic sedimentary rocks and Pleistocene, mostly glacial, deposits, occur in some areas.

The radon potential of this area is moderate overall, but locally high indoor radon levels could occur near uranium occurrences. The Coastal Trough Province contains Tertiary continental clastic rocks similar to units that produce uranium in the western conterminous United States. The overall uranium content of these rocks is not high, but small uranium occurrences are found in the

Susitna Lowlands and in the Admiralty trough in southeastern Alaska. Soils are mostly brown and gray-brown podzolic forest soils, which could have high gas transmissivity. Heavy rainfall and saturated soils in southeast Alaska likely retards soil gas migration.

Pacific Border Ranges

The Border Ranges Province (8, fig. 2) is generally south and west of the Coastal Trough Province. Jurassic and Cretaceous sedimentary and metamorphic rocks with interbedded mafic volcanic rocks and some gabbro make up most of the Border Ranges rocks. A fairly large area of early Tertiary sedimentary, volcanogenic sedimentary rocks, and volcanic rocks is found in the Prince William Sound area.

The Border Ranges Province generally has low radon potential, although some uranium-bearing rocks and uranium occurrences are likely to be present. The uranium deposit at Bokan Mountain is associated with a uranium-rich peralkaline granite. The uranium content of stream sediments in the Border Ranges is intermediate for Alaska, although data are absent from many areas. Podzolic brown and gray-brown forest soils are common in the Border Ranges, and they could have high gas permeability. However, in this part of Alaska annual rainfall is about 14 feet, and water saturation likely retards gas flow in soils on all but the steepest slopes.

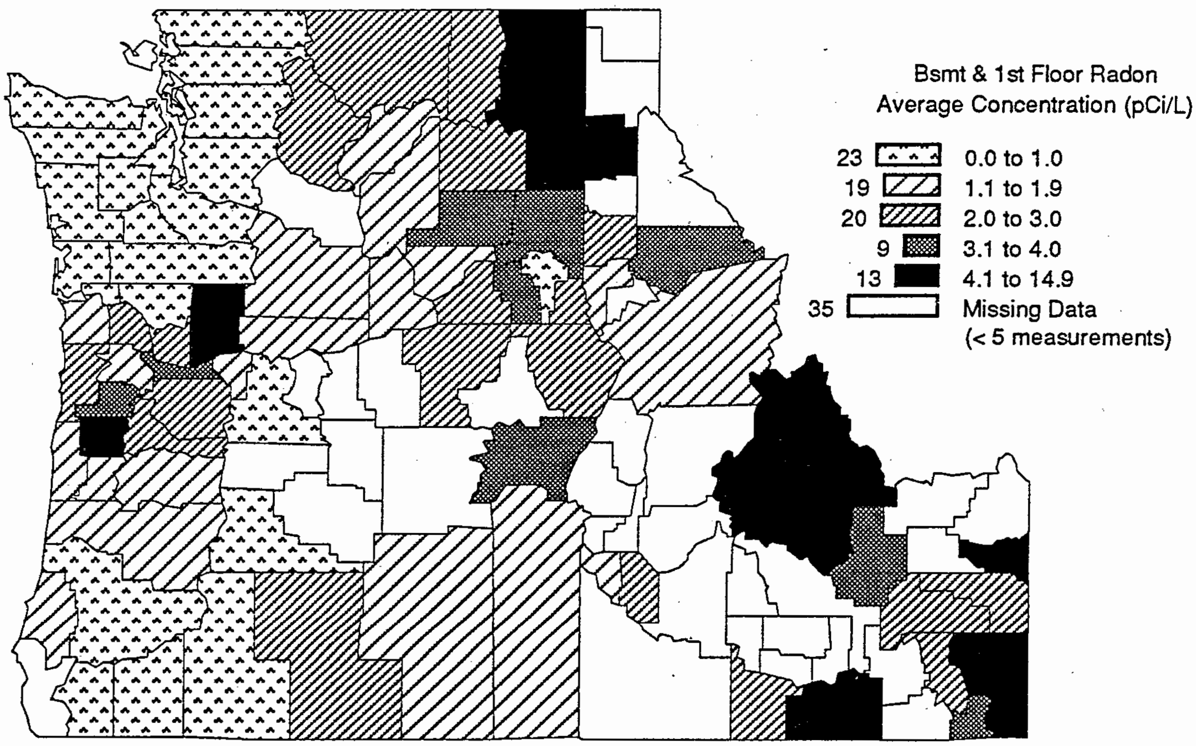


Figure 3A. Screening indoor radon data from the State/EPA Residential Radon Survey and the Oregon Radon Project, for counties with 5 or more measurements in the conterminous part of EPA Region 10. Histograms in map legends show the number of counties in each category. The number of samples in each county may not be sufficient to statistically characterize the radon levels of the counties, but they do suggest general trends. Unequal category intervals were chosen to provide reference to decision and action levels.

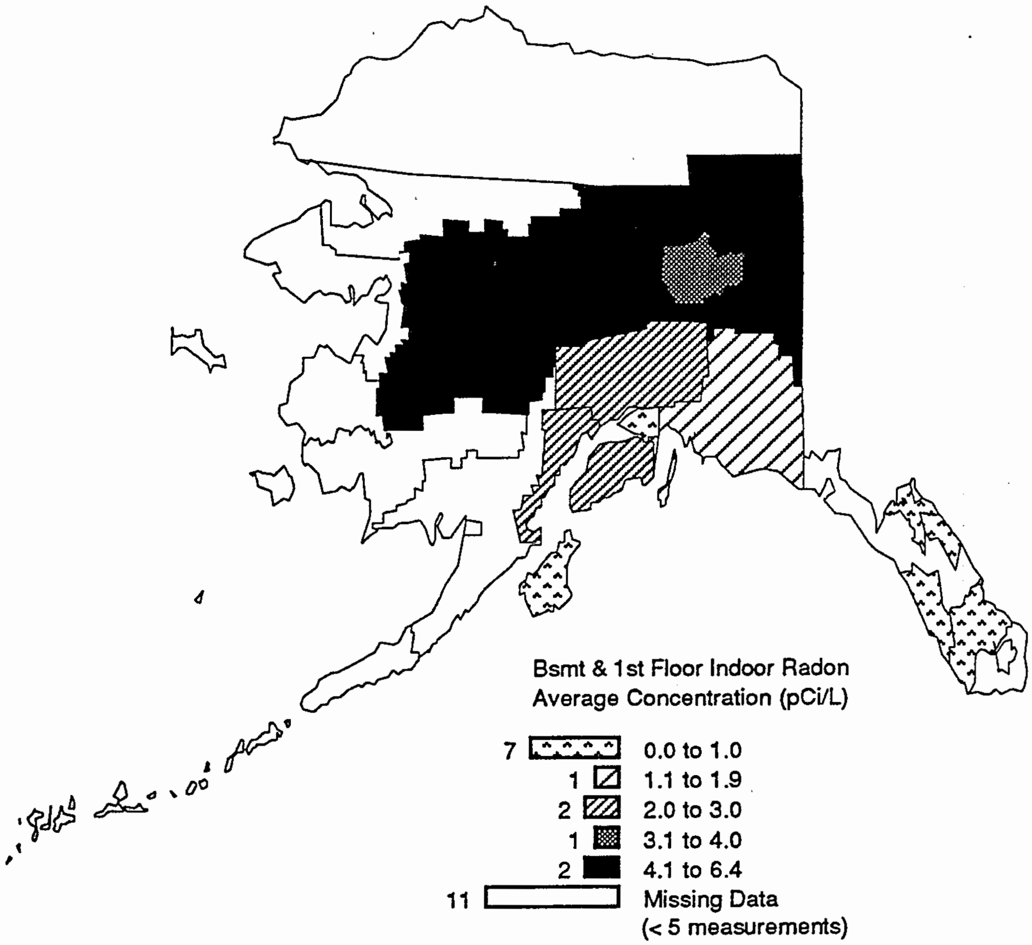


Figure 3B. Screening indoor radon data from the State/EPA Residential Radon Survey of Alaska, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county may not be sufficient to statistically characterize the radon levels of the counties, but they do suggest general trends. Unequal category intervals were chosen to provide reference to decision and action levels.

# PRELIMINARY GEOLOGIC RADON POTENTIAL ASSESSMENT OF ALASKA

*by*
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## INTRODUCTION

The state of Alaska is characterized by complex geology and soils developed on rugged terrain in cool, moist climates. It is a large, sparsely populated area. Indoor radon data are only available for the populated areas. For many areas conclusions are very general because of the lack of field studies and the general lack of data. It is, however, hoped that the study will suffice as a general guide to future studies and planning in terms of radon potential.

This is a generalized assessment of geologic radon potential of rocks, soils, and surficial deposits of Alaska. The scale of this assessment is such that it is inappropriate for use in identifying the radon potential of small areas such as neighborhoods, individual building sites, or housing tracts. Any localized assessment of radon potential must be supplemented with additional data and information from the locality. Within any area of a given radon potential ranking, there are likely to be areas with higher or lower radon levels than characterized for the area as a whole. Indoor radon levels, both high and low, can be quite localized, and there is no substitute for testing individual homes. Elevated levels of indoor radon have been found in every State, and EPA recommends that all homes be tested. For more information on radon, the reader is urged to consult the local or State radon program or EPA regional office. More detailed information on state or local geology may be obtained from the State geological survey. Addresses and phone numbers for these agencies are listed in chapter 1 of this booklet.

## GEOGRAPHIC SETTING

Alaska occupies the great northwestern peninsula of North America; it is an extension of the North American Cordillera. Alaska can be divided from north to south into the following physiographic provinces (Wahrhaftig, 1965): The Arctic Coastal Plain, Arctic Foothills, Arctic Mountains, Central province (including Northern Plateaus, Western Alaska, Seward Peninsula, Bering Shelf, and Aklun Mountains subprovinces), Alaska-Aleutian Ranges (including the Coast Mountains of southeastern Alaska), Coastal Trough, and Pacific Border Ranges (fig. 1).

The southeastern corner of southeastern Alaska lies about 500 miles from the State of Washington, the nearest part of the conterminous 48 states. The southeast corner of southeast Alaska lies about 1800 miles from the northwest end of the north slope and about 2300 miles from Attu Island, Alaska's and the USA's most eastern point (west of 180 degrees E. longitude). Alaska is the largest state in the USA and is the least populated of all the states. It occupies 591,000 square miles.

According to the 1990 census there were 550,043 people in Alaska, about one third of whom live in Anchorage and about one half of whom live in Anchorage and Fairbanks combined. Alaska averages about 1.1 people per square mile (fig. 2).

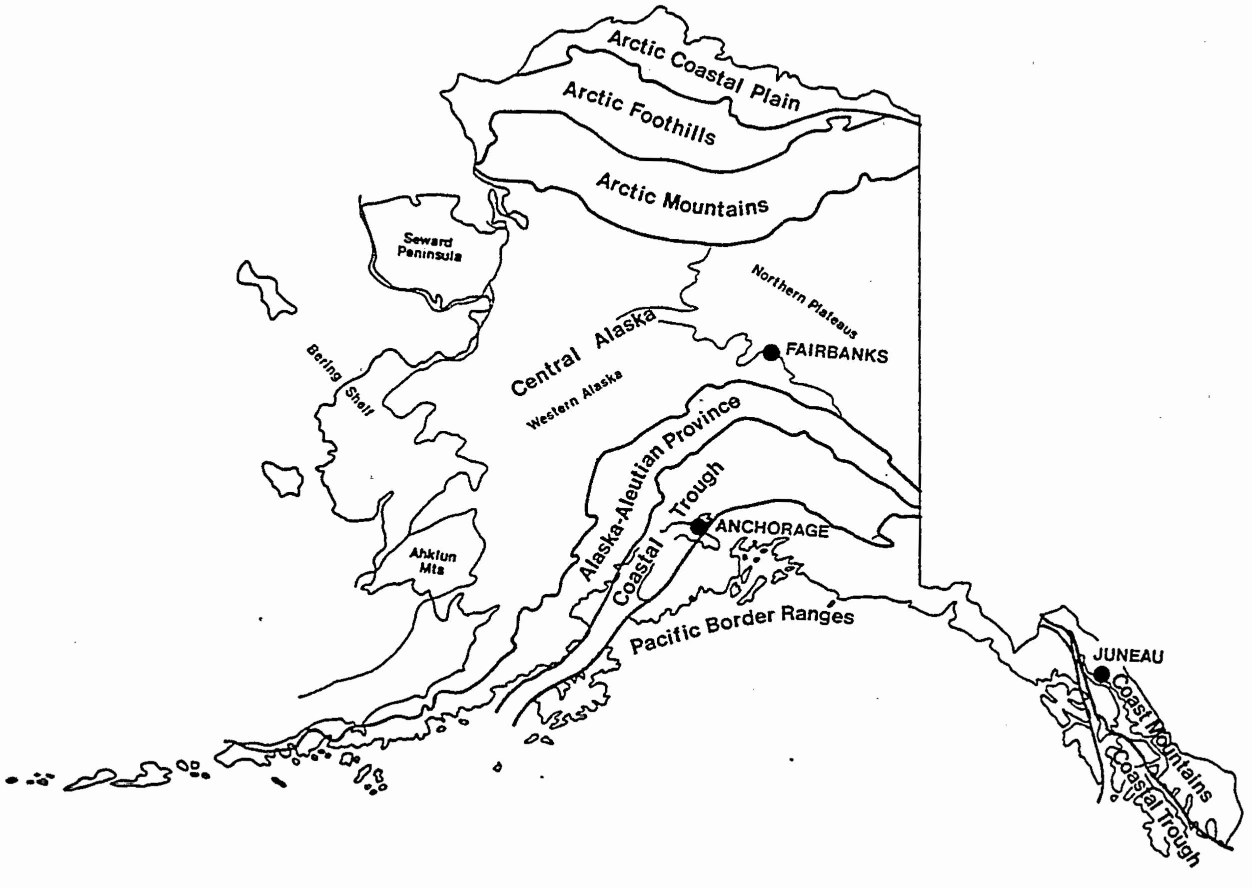



Figure 1. Physiographic provinces of Alaska (Wahrhaftig, 1965).

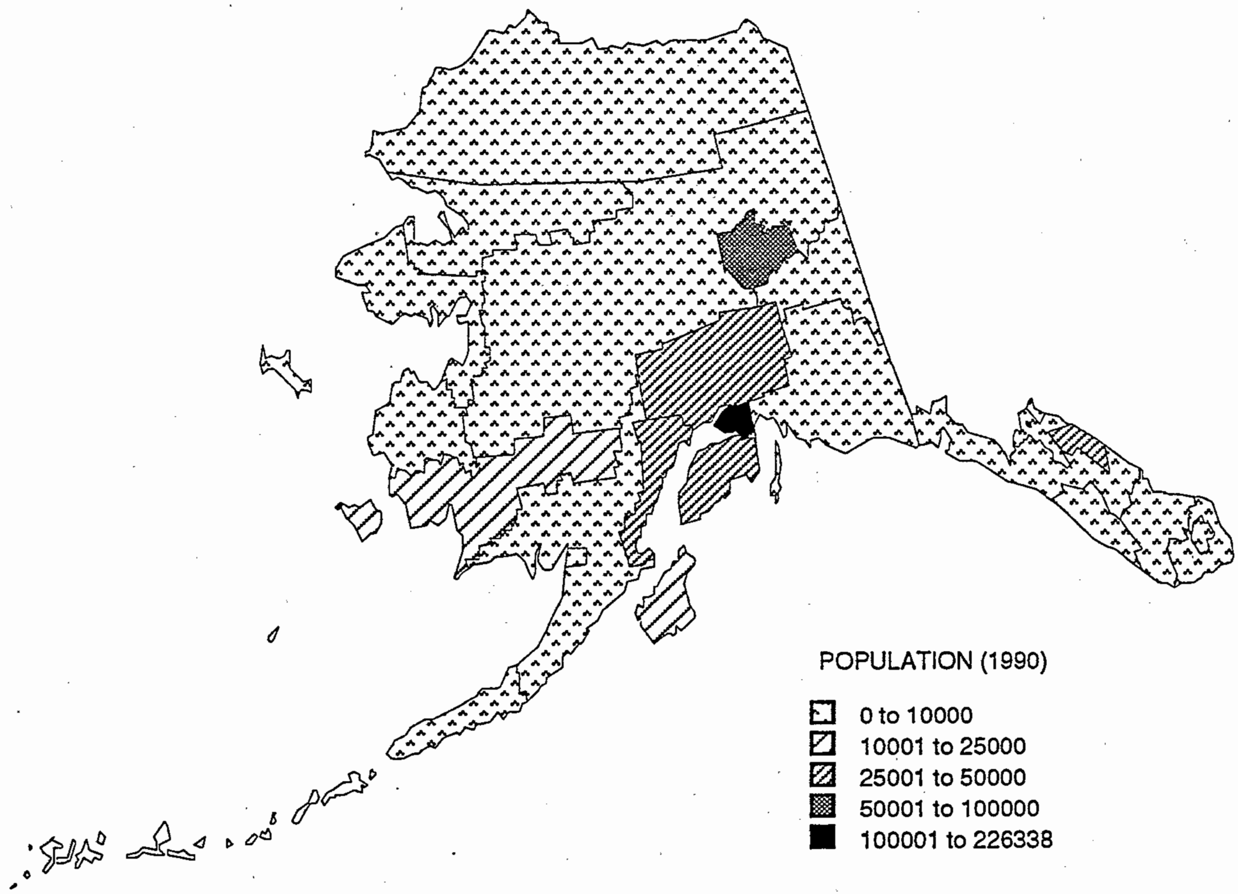



Figure 2. Population of boroughs in Alaska (1990 U.S. Census data).

## GEOLOGIC SETTING

The geology of Alaska varies widely (fig. 3). As many as 60 tectonostratigraphic terranes have been recognized in Alaska (Jones and others, 1987; Monger and Berg, 1987). Terranes were defined by Howell (1985) as "fault-bounded geologic entities of regional extent each characterized by a geologic history distinct from neighboring terranes". These terranes were accreted to the western North American craton during the last 200 million years and now form Alaska. Diverse assemblages of igneous, metamorphic, and sedimentary rocks ranging from Precambrian to Holocene make up these terranes. Numerous Tertiary basins that contain largely continental deposits of coal-bearing clastic rock formed after the terranes were in place. Stone and Wallace (1987) grouped the terranes into framework provinces each containing several terranes of similar tectonic or geologic style. The tectonostratigraphic terrane boundaries are coincident with fault zones in many areas.

The geology of Alaska is summarized below on the basis of the physiographic provinces and subprovinces of Wahrhaftig (1955). Terrane summaries included for each physiographic division were abstracted from Jones and others (1987) and Monger and Berg (1987). Rocks characteristic of each terrane form the bedrock in much of Alaska, but they are not part of the surface geology in some areas and do not play a direct role in radon generation in those areas.

Surficial deposits in the Arctic Coastal Plain consist mostly of alluvium, eolian sand, and silt of Quaternary age. A belt of marine and nonmarine conglomerate, sandstone, shale, and mudstone of Tertiary age that separates the coastal plain from the Arctic Foothills to the south is found along the eastern 1/3 of the area. The Arctic Coastal Plain province is underlain by the North Slope subterrane (Precambrian to Lower Paleozoic basement rocks overlain by Mississippian through Triassic and younger Mesozoic sedimentary rocks).

Surface rocks in the Arctic Foothills province are largely composed of marine and nonmarine Cretaceous sandstone and shale, but some Paleozoic and Mesozoic rocks are also present. The Cretaceous beds are folded into west-trending anticlines and synclines. The North Slope (see above), Endicott Mountains (Sequences of Devonian clastic rocks, Mississippian shale and carbonate rocks, and Upper Paleozoic and Mesozoic chert, argillite and calcareous rocks), and DeLong Mountains (thick Devonian and Mississippian carbonates and younger sequences of chert and argillite) subterranes of the Arctic terrane underlie the Arctic Foothills province.

The Arctic Mountains province (Brooks Range) is composed largely of upper Precambrian and Paleozoic marine sedimentary rocks. These rocks are cut by west-trending thrust faults with their upthrown sides to the south. The Endicott Mountains (see above) and Hammond subterranes (polymetamorphosed assemblage of Middle Paleozoic and older carbonate rocks, calc-schist, quartz-mica schist, quartzite, and metarhyolite intruded by Devonian gneissic granitic rocks) underlie most of the province. Several other terranes underlie small parts of the province. Among these are the Angayucham terrane, (complex assemblage of oceanic rocks, including: gabbro, diabase, pillow basalt, tuff, chert, graywacke, argillite, and minor limestone; Mississippian to Jurassic sedimentary rocks; Late Carboniferous and Late Jurassic volcanic basalts; and thrust sheets of ultramafic rocks which are found throughout the section).

The Central province, a large area of plains, plateaus and rounded mountains, is geologically complex. The Central province was divided into five physiographic subprovinces by Wahrhaftig (1965). These are the Northern Plateaus, Western Alaska, Seward Peninsula, Aklun Mountains, and Bering Shelf subprovinces. More than 20 different terranes underlie the Central province (Jones and others, 1987).

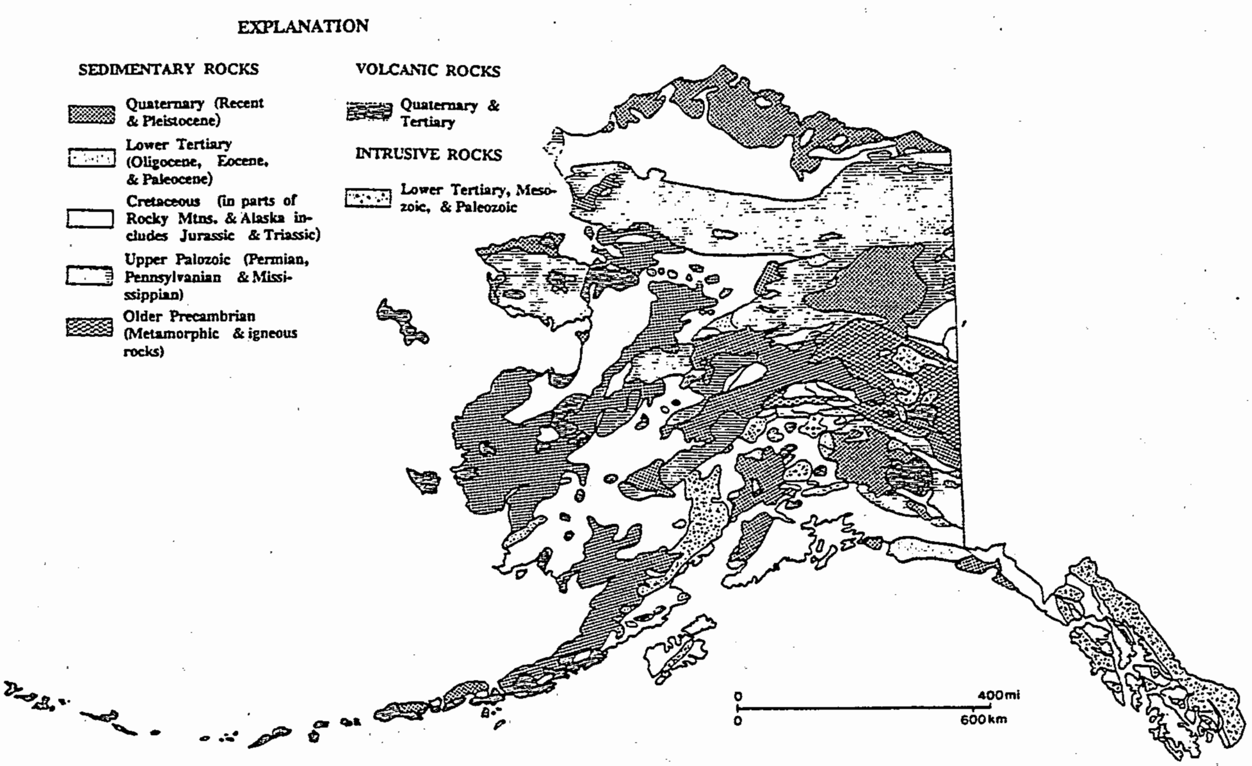



Figure 3. Generalized geologic map of Alaska (Kinney, 1965).

The Seward Peninsula, on the western end of the Central province, consists mostly of Precambrian and Paleozoic metamorphic rocks. There is, however, an area of Precambrian and Paleozoic sedimentary rocks in the northwest part of the peninsula, a belt of Quaternary sediments along its northern edge, and an area of Tertiary and Quaternary mafic volcanic rocks generally in the center of the northeast part of the Peninsula. The Seward Peninsula is primarily underlain by the Seward terrane (Mica schist, micaceous calc-schist, metavolcanics, marble, and high grade gneissic rocks; rocks of probable Precambrian and known Devonian age are present but some ages are uncertain), but parts are underlain by the Crazy Mountains (Cambrian quartzitic sandstone and other younger Paleozoic sedimentary rocks) and Koyukuk terranes (andesitic volcanic rocks together with conglomerate, graywacke, and mudstone). Small parts of the Peninsula are underlain by other terranes (Jones and others, 1987).

The Bering Shelf, on the western end of the Central province and south of the Seward Peninsula, is covered almost entirely by Quaternary surficial sediments and scattered areas of Tertiary volcanic rocks. The Bering Shelf is underlain almost entirely by the Crazy Mountain terrane (see above).

The Aklun Mountains subprovince lies south of the Bering Shelf. It is covered mostly by Precambrian through Cretaceous marine sedimentary rocks, consisting of sandstone, shale, and limestone. The Aklun Mountain subprovince also contains small felsic intrusive bodies of Jurassic and Tertiary age. Southwest-trending faults and folds and at least one major southeast-trending fault are present in the Aklun Mountains. The subprovince is mostly underlain by the Togiak (Jurassic and Lower Cretaceous volcanic and volcaniclastic rocks including pillowed flows, tuffs, breccias, conglomerates, graywackes, chert and a minor amount of Cretaceous limestone) and GoodNews (chert, pillow basalt, tuff, limestone, and blocks of ultramafic rock; dated limestones vary from Ordovician to Permian; lawsonite-bearing metamorphic rocks in some areas) terranes.

The eastern third of the Central province is covered by the Northern Plateaus subprovince. About the western half of this subprovince underlies flat-lying Tertiary basin fill (nonmarine clastic rocks) and Quaternary surficial deposits. The northeastern part of the northern plateaus subprovince, along the Canadian border, is a complex area of Precambrian through Cretaceous mostly marine sedimentary rocks and Paleozoic metamorphic rocks that contain fairly large areas of Mesozoic intrusive and volcanic rocks. Much of the southern and southeastern parts of the subprovince is composed of a large variety of Paleozoic and Precambrian metamorphic rocks that were penetrated by felsic intrusions. The Tintina fault, which is generally followed by the Yukon River, trends southeast through the central part of the area. The Denali fault, which forms the southeast boundary of the subprovince, more or less parallels the Tintina. A complex grouping of terranes underlies most of the northern plateaus. The southeastern part is underlain by Yukon-Tanana (metamorphic rock including Paleozoic granitoid protoliths and Devonian marble) terrane. The northern part is underlain by Crazy Mountain (see above); Tozitna (Paleozoic (?) and Mesozoic gabbro, basalt, diabase, argillite, tuff, chert, and conglomerate; also includes Permian Limestone and Mississippian radiolarian cherts); and Porcupine terrane (phyllite, slate, quartzite and carbonate rocks overlain by sedimentary complex ranging from Cambrian (?) to Devonian in age) terranes. The western part of the Northern Plateaus province includes the Ruby (phyllite, schist, marble, quartzite, marble, amphibolite, granite, and metachert) and other terranes. The easternmost part of this province, near the Canadian Border, is underlain by phyllite, slate, and siltstone that is part of the North American craton (not an accreted terrane).

The largest subprovince of the Central province is Western Alaska (fig. 1). Large areas of Cretaceous and lower Paleozoic sedimentary and metamorphic rocks are present in the western half of this subprovince. The Cretaceous rocks are mostly marine conglomerate, graywacke, sandstone, and siltstone. The lower Paleozoic rocks are both sedimentary and metamorphic and consist of limestone, dolomite, siltstone, argillite, chert, schist, quartzite, and greenstone. A large area of Cretaceous and Tertiary volcanic rock is present in the western part of this subprovince just east of the Seward Peninsula. Prominent faults cross the western Alaska subprovince from east to west. The Mulchatna, Kaltag, Farewell, and Iditarod-Nixon faults trend southwest through the western half of this subprovince. The Western Alaska subprovince is underlain by a large number of terranes. The largest of these are Koyukuk (andesitic flow tuffs, breccias, agglomerates, conglomerates, graywacke, and mudstone; locally interbedded limestone contains Early Cretaceous fossils); Kahiltna (Late Jurassic to Early Cretaceous deep marine graywacke, tuffs, pelitic rocks and minor amounts of chert, limestone, and conglomerate); Nixon Fork (reefal and platform carbonate rocks of Ordovician to Upper Devonian age overlain by Permian, Triassic, and Cretaceous sedimentary rocks); Dilinger (Paleozoic graptolitic shale, basinal carbonate rocks, and turbiditic sandstone and shale together with overlying Jurassic sandstone and siltstone); Innoko (Late Paleozoic and early Mesozoic chert, argillite, graywacke, and volcanic sandstone, conglomerate, and tuff); and Minchumina (Ordovician chert, argillite, and quartzite together with chert as young as Devonian).

The Alaska-Aleutian province includes the Aleutian Peninsula, a northeast-trending belt in south-central Alaska that includes Mt. McKinley, a southeast-trending belt that extends from the Mt. McKinley area south eastward to Canada, and the Coast Mountains in southeastern Alaska. On the Aleutian Peninsula from Unimak Pass westward, the bedrock consists mostly of Quaternary and Tertiary volcanic rocks and Tertiary sedimentary rocks. Quaternary and Tertiary volcanic rocks are also important east of the Unimak Pass but other rocks including Jurassic and Cretaceous sedimentary rocks and Jurassic intrusive rocks of intermediate and felsic composition are also important in this area. In addition, in the area west of Cook Inlet and southwest of Mount McKinley, large bodies of Tertiary mafic volcanics and Cretaceous or Jurassic intermediate intrusives are found. A varied assortment of Phanerozoic rocks is present in the area from Mt. McKinley southeastward to the Canadian border. This assortment includes Paleozoic mafic volcanic rocks and their sedimentary and metamorphic derivatives; Mesozoic mafic volcanic flows and tuffs, together with various units of shale, conglomerate, graywacke, and slate; and Tertiary and Quaternary intermediate volcanic rocks, Tertiary felsic intrusives, and Quaternary glacial deposits including eolian sand and silt. The Alaska-Aleutian province is mostly underlain in the west by the Peninsular (Paleozoic and Mesozoic igneous and sedimentary rocks including limestone, argillite, basalt, tuff, andesitic flows, breccias, volcanic sandstone and siltstone, and batholithic granitic rocks; also included is the andesitic arc assemblage), Kahiltna (see above), and Crazy Mountain terranes (see above), and in the north by the Yukon-Tanana terrane (see above). The Coastal Mountains in southeastern Alaska consist mostly of ultramafic, intermediate, and felsic intrusives, Mesozoic mafic volcanic rock, and Mesozoic through Paleozoic sedimentary rocks. The Tracy Arm (metamorphosed pelitic and quartzofeldspathic schist and paragneiss, marble, amphibolite, and minor serpentinite) and Taku (variably metamorphosed upper Paleozoic and Triassic basalt and local felsic volcanic rock, carbonate rock, and pelite; includes some undated metamorphosed clastic and volcanic rocks) terranes underlie most of the Coast Mountains.

The Coastal Trough province includes a row of basins that were active centers of deposition during the Cenozoic. The province includes the Cook Inlet and Copper River Basins in southern Alaska and the Admiralty Trough in southeastern Alaska. These depositional basins contain thick sequences of Tertiary continental clastic rocks that generally overlie Cretaceous or older sedimentary rocks and have been penetrated and covered by Tertiary volcanic rocks. Mesozoic sedimentary rocks are abundant in the area north of Cook Inlet basin and large areas of Pleistocene, mostly glacial deposits, are found at the north end of Cook Inlet basin and in the Copper River basin. Large areas of Tertiary volcanic rocks are present in the vicinity of Shelikof Strait and the Wrangell Mountains in southern Alaska and on Admiralty, Kupreanof, and Wrangell Islands in southeastern Alaska. The coastal trough province is bounded by regional faults such as the Bruin Bay and Border Ranges faults that trend southwest in the Cook Inlet area and the Clarence Strait and Chatham Strait faults that trend southeast in southeastern Alaska. In southern Alaska the Coastal Trough province is underlain by <u>Crazy Mountains</u> (see above), <u>Wrangellia</u> (in ascending order, Upper Paleozoic arc-related volcanic breccias, flows, and clastic rocks; Permian limestone, pelitic rocks, and chert; Triassic black cherty argillite; a thick sequence of pillow basalt; basinal spiculitic argillaceous and calcareous rocks; and predominantly clastic rocks of Jurassic and Cretaceous age); <u>Peninsular</u> (see above); and <u>Kahiltna</u> (see above) terranes. In southeast Alaska much of the Coastal Trough province is underlain by the <u>Stikinia</u> terrane (Mississippian, Permian, Triassic and Jurassic marine and nonmarine volcanic and sedimentary rocks together with coeval granodioritic batholithic rocks).

The Border Ranges province is generally south and west of the coastal trough province. This province includes the Chilcat and Baranof Mountains and Prince of Wales Island in southeastern Alaska. Cretaceous and Jurassic sedimentary and metamorphic rocks with interbedded mafic volcanic rocks and some gabbro comprise most of the Border Ranges rocks. A fairly large area of lower Tertiary sedimentary, volcanogenic, and volcanic rocks is found in the Prince William Sound area. In southeastern Alaska, the Border ranges consist mostly of Paleozoic metamorphic and Paleozoic to Mesozoic sedimentary rock together with some intermediate intrusives of Cretaceous and Tertiary age. The metamorphic rocks are mainly Devonian Schist, phyllite, marble, and amphibolite. The sedimentary rocks are mainly Paleozoic shale, siltstone, graywacke, conglomerate, and limestone and a Cretaceous melange containing blocks of flysch, greenstone, limestone, chert, granodiorite, schist, layered gabbro, and serpentinite in a pelitic matrix. In southern Alaska the Border Ranges province is underlain primarily by the <u>Chugach</u> (mostly weakly metamorphosed Cretaceous graywacke and slate interbedded locally with radiolarian chert, gabbro, pillow basalt, and ultramafic rocks); <u>Yakutat</u> (Upper Mesozoic graywacke and shale intercalated with lenses of chert, argillite, and volcanic rocks); <u>Ghost Rocks</u> (strongly deformed assemblage of pillow lava, pillow breccia, and tuff with andesitic to basaltic composition interbedded with Late Cretaceous to Oligocene sandstone and mudstone and intruded by sparse plutons) terranes. In southeastern Alaska most of the Border Ranges province is underlain by the <u>Alexander</u> terrane which includes the <u>Admiralty</u> (Devonian and Mississippian basalt, carbonate rocks, and chert in contact with Ordovician flysch); <u>Annette</u> (variably metamorphosed Ordovician to Triassic intrusive, extrusive, clastic and carbonate rocks); and <u>Craig</u> (Pre-Ordovician metamorphic complex and Ordovician to Triassic mafic and felsic volcanic rocks and terriginous clastic and carbonate rocks) subterranes.

*Uranium deposits and radioactive anomalies:* Table 1 lists the major uranium deposits and other significant uranium occurrences in Alaska. Both igneous and sedimentary types are present, but none are found in populated areas (fig. 4; table 1). Only the Bokan Mountain deposit has actually produced uranium (MacKevett, 1963). As presently known, only the Death Valley and Bokan Mountain deposits are potential U producers. In addition to the deposits listed in table 1, many small radioactive mineral occurrences (several as U and Th bearing placer deposits) and radioactive anomalies were reported by Eakins (1969, 1975). National Uranium Resource

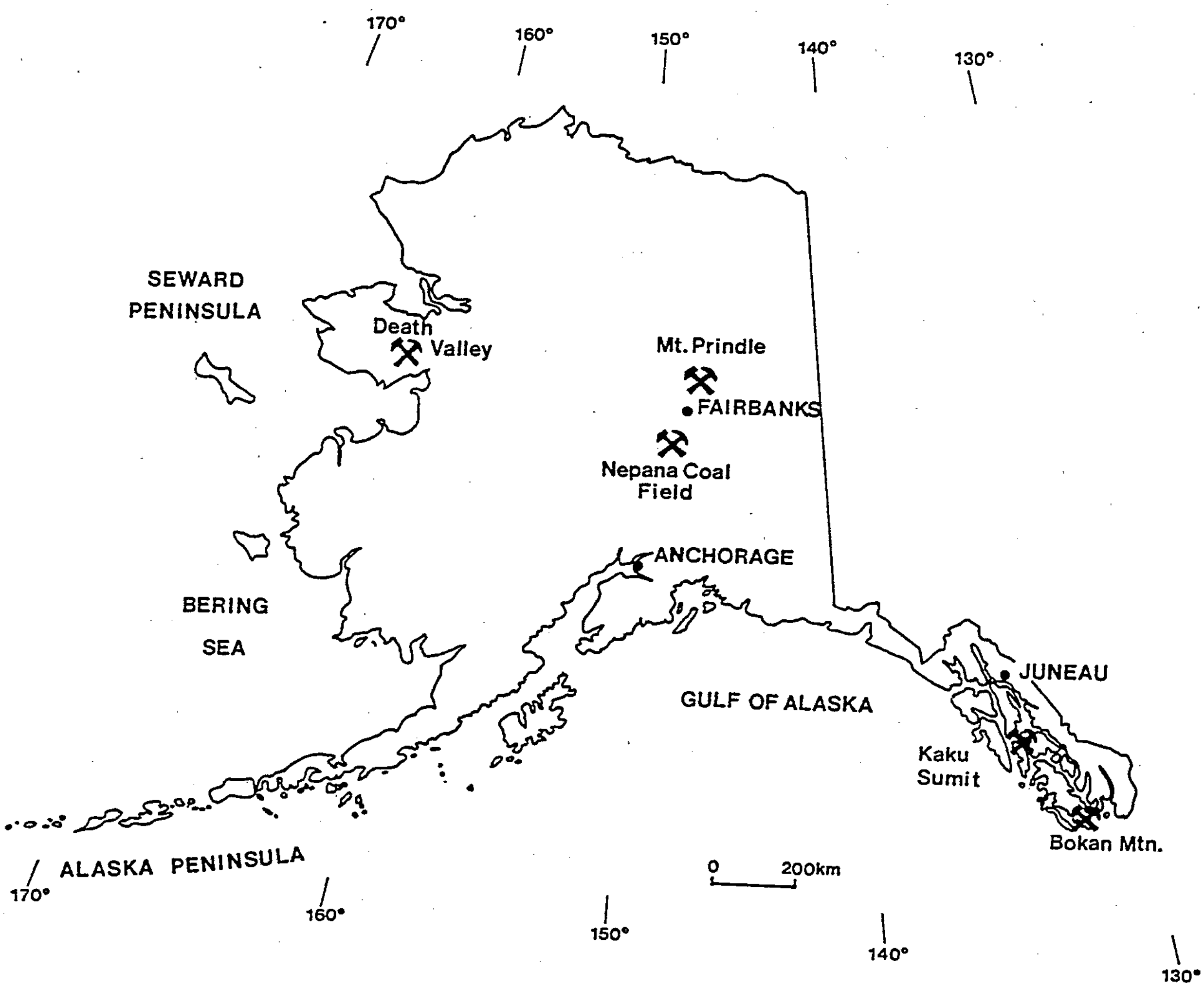



Figure 4. Uranium deposits of Alaska.

Evaluation (NURE) surveys enumerated 1520 radioactive anomalies in an area that covers about 2/3 of the State (Dickinson and others, 1983). It should be noted, however, that uranium enrichment in the rock is not necessary to produce elevated radon to be in homes, and in the case of very young uranium deposits, even high concentrations of uranium may not cause elevated radon in homes because the uranium would be in gross disequilibrium with its daughter products.

TABLE 1. Uranium deposits in Alaska.

| Area | Type of deposit | Reserves | Reference |
|---|---|---|---|
| Death Valley | Epigenetic, sandstone | 1 M lbs. $U_3O_8$ | Dickinson (1988) |
| Bokan Mountain | Peralkaline granite | 800 K lbs. $U_3O_8$ | MacKevett (1963) |
| Nenana Coal Field | Epigenetic and other | unknown | Dickson (1981) |
| Mount Prindle | Igneous | unknown | Armbrustmacher (1989) |
| Keku Strait | Epigenetic sandstone and phosphate | unknown | Dickinson and Vuletich (1990) |

## SOILS AND SURFICIAL DEPOSITS

The soils of Alaska are controlled largely by the cool moist climate and the rugged terrane. The soil terminology used below generally follows the nomenclature of the National Cooperative Soil Survey Classification of 1967. The distribution of soils is summarized from the National Atlas of the United States (U.S. Department of Agriculture, 1987; fig. 5).

About 2/3 of Alaska is covered by tundra. The tundra soils are largely aquepts and cryaquepts of the Inceptisol order. These soils are characterized by undecomposed plant material, generally high moisture content, and the presence of permafrost in the area generally north of the arctic circle (fig 6). Radon transmissivity in these soils is presumed to be poor because of the water and ice content. No large population centers are found in these areas.

Soils classified as rockland, which includes glacial ice, cover about 1/4 of Alaska (fig. 5). These surfaces are generally found in the rugged mountain ranges such as the Brooks, Alaska, Aleutian, Chugach, Kenai, Wrangell, St. Elias, and Coast Ranges. No significant populated areas in Alaska are found on rockland.

Another group of Inceptisols, cryochrepts (subarctic brown forest soils) and cryandepts (brown podzolic or gray-brown podzolic soils) cover about 5 percent of the Alaskan area. The cryochrepts are mostly distributed along the valleys of the Yukon and Tanana Rivers in central Alaska and the cryandepts are on the Alaskan Peninsula. These soils rank high in radon transmissivity, but are not common in populated areas.

Spodosols make up about 3-1/2 percent of the surface area of Alaska. These soils are characterized by a low base content and a high content of amorphous material, aluminum, and probably iron. They are formed under acid conditions, generally on porous parent material, and they probably have relatively high gas transmissivity. Anchorage and Juneau are located in areas with spodosols.

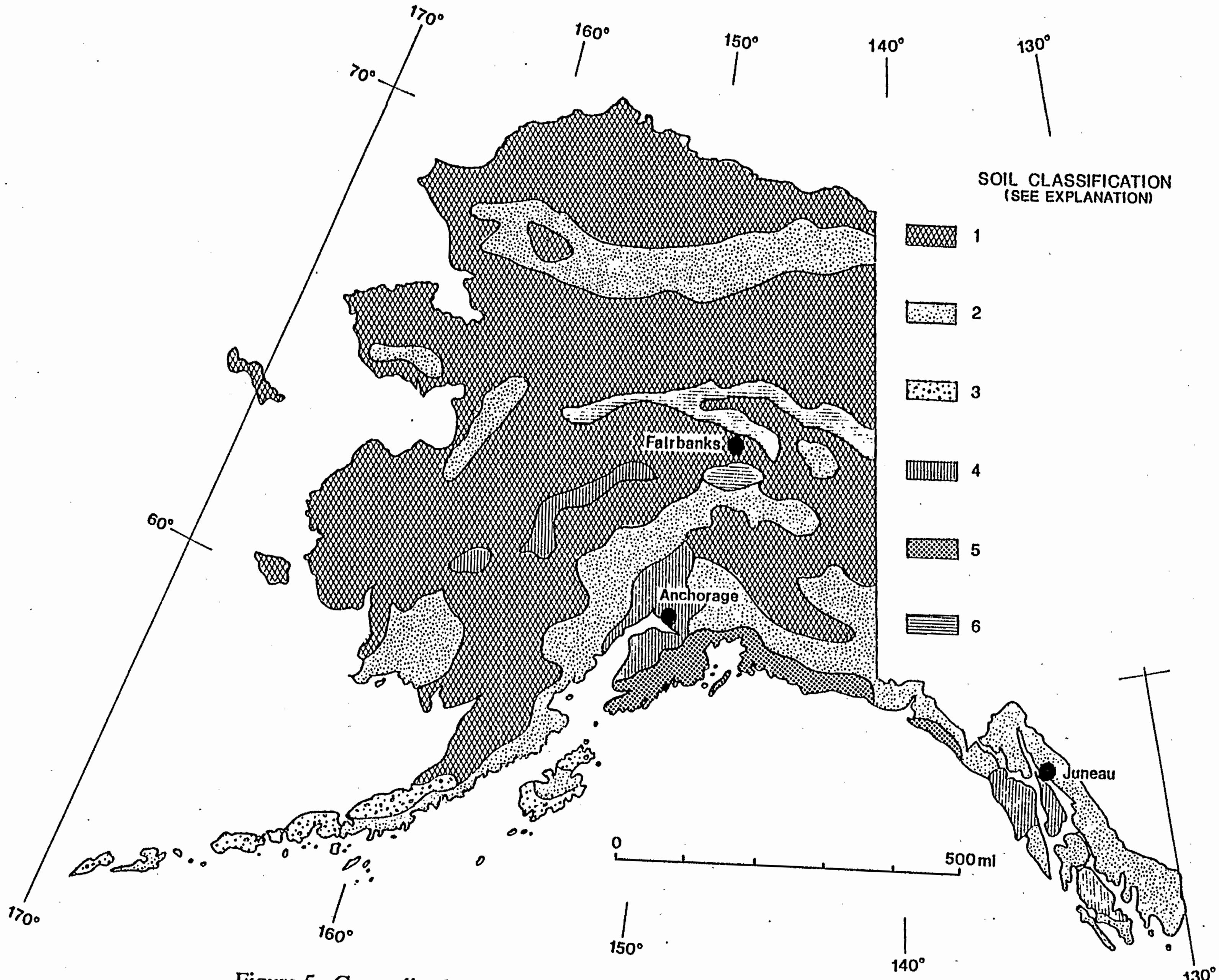



Figure 5. Generalized soils map of Alaska (after U.S. Department of Agriculture, 1987)

FIGURE 5 (continued). GENERALIZED SOILS MAP OF ALASKA
EXPLANATION

1. Cryaquepts (formertly Tundra). These are the Aquepts of cold climates. Aquepts are seasonly wet Inceptisols that have an organic surface horizon. Inceptisols are soils that have weakly differentiated horizons; materials in the soil have been altered or removed but have not accumulated. These soils are usually moist, but during the warm season of the year some are dry part of the time (66.5 percent).

2. Rock Land is a miscellaneous land type that includes Cryandepts (see below), Cryumbrepts (Umbrepts of cold regions), Cryaquepts (see above), Cryorthods (see below), ice fields, and glaciers. These are generally shallow soils formed on moderately sloping or steep slopes. Umbrepts are Inceptisols with crystalline clay minerals, thick dark-colored surface horizons, and altered subsurface horizons that have lost mineral materials and that are low in bases (24 percent).

3. Cryandepts (formerly brown podzolic or gray brown podzolic soils) are Andepts of cold regions. Andepts are Inceptisols (see above) that have formed in ashy materials, have low bulk density and large amounts of amorphous materials or both.

4. Cryorthods (formerly podzols)-- Orthods of cold regions. Orthods are Spodosols that have a horizon in which organic matter plus compounds of iron and aluminum have accumulated. Spodosols with low base supply that have in subsurface horizons an accumulation of amorphous materials consisting of organic matter plus compounds of aluminum and usually iron; formed in acidic, mainly coarse-textured materials in humid and mostly cool or temperate climates (3.5 percent).

5. Cryopsamments and Quartzipsamments (formerly regosols)-- Cryopsamments are Psamments of cold regions, Quartzipsamments are Psamments that consist almost entirely of minerals that are highly resistant to weathering, mainly quartz. Psamments are Entisols that have textures of loamy fine or coarser sand. Entisols are soils with no pedogenic horizons (1 percent)

6. Cryochrepts (former subarctic brown forest soils) are the Ochrepts of cold regions. Ochrepts are Inceptisols that have formed in materials with crystalline clay minerals, have light-colored surface horizons, and have altered subsurface horizons that have lost mineral materials (5 percent).

Entisols, soils with no pedogenic horizons, make up <1 percent of the Alaskan soils. They are the cryopsamments and quartzipsamments that are found only along the south central and southeast coastal plains. They probably have high gas transmissivity, but are not found in populated areas except for the village of Cordova (fig. 5).

*Glacial deposits*: Nearly half (48 percent) of Alaska was previously covered by glaciers and as a result nearly half of the State is covered by glacial deposits. About 7 percent of the land area is presently covered by glacial ice (fig. 6). Glacial outwash areas have more permeable sediment than do areas of till, but for most glaciated areas the distribution of various sediments has not been mapped.

*Stream and River deposits*: Stream and river sediments cover much of Alaska especially in delta and basinal areas. Examples are the Yukon flats area and the Yukon delta. There also large areas of Quaternary sediments along the drainages of most of the major rivers. These deposits are complex mixtures of fine- and coarse-grained sediment. In general the fine-grained sediment is impervious (has low gas transmissivity) and the coarse-grained sediments are pervious (have high gas transmissivity). No data is available to allow generalization on the distribution of fine versus coarse-grained sediment on an area by area basis.

## INDOOR RADON DATA

Indoor radon data from Alaska are principally from the State/EPA Residential Radon Survey. This survey was conducted during the fall and winter of 1988 and 1989 by the Division of Geology and Geophysics (DGGS) of Alaska and the Environmental Protection Agency (EPA). The EPA analyzed the detectors and provided survey design and consultation through its contractor, Research Triangle Institute (RTI). DGGS provided information on demography, geology, and geography, selected participating households, and distributed the canisters (Nye and Kline, 1990).

The data for the Alaska indoor radon survey are organized by borough or by other area designations (fig. 7). Figure 8 shows the indoor radon concentration data for those areas where sufficient data was obtained and table 2 lists the indoor radon data for all areas in which data were collected in the State/EPA Residential Radon Survey. The southeast Fairbanks census area had the highest percent of radon values over 4 pCi/L. Forty-eight percent of the measurements in the southeastern Fairbanks area exceeded 4 pCi/L (fig. 8; table 2). Boroughs or other areas with average screening indoor radon levels exceeding 4 pCi/L in the State/EPA survey include Southeast Fairbanks, Yukon-Koyukuk, and Skagway-Yakutat-Angoon, although the latter is based on only three measurements (fig. 8; table 2) and should not be considered representative of all indoor radon levels in the area.

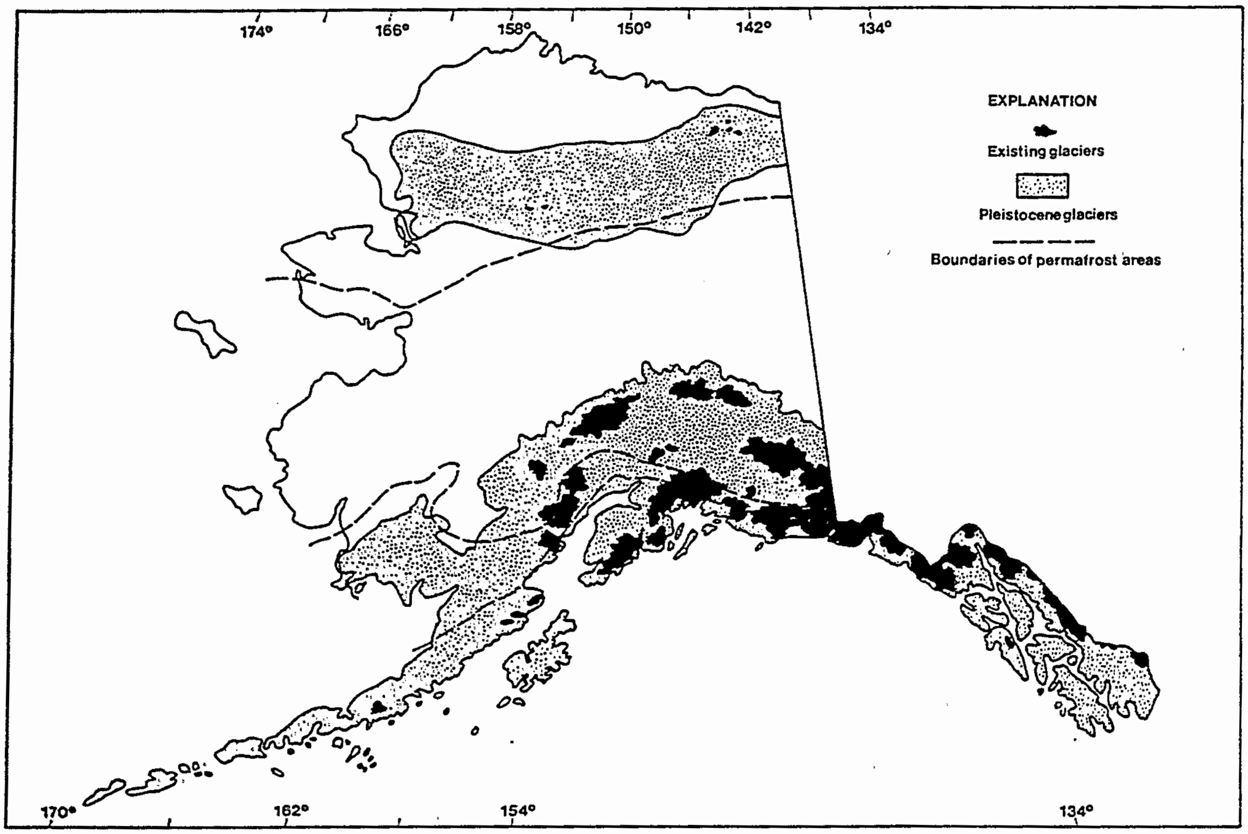



Figure 6. Permafrost and glaciers map of Alaska (Wahrhaftig, 1965).

TABLE 2. Screening indoor radon data from the EPA/State Residential Radon Survey of Alaska conducted during 1988-89. Data represent 2-7 day charcoal canister measurements from the lowest level of each home tested.

| BOROUGH | NO. OF MEAS. | MEAN | GEOM. MEAN | MEDIAN | STD. DEV. | MAX | %>4 pCi/L | %>20 pCi/L |
|---|---|---|---|---|---|---|---|---|
| ANCHORAGE | 282 | 1.0 | 0.6 | 0.6 | 1.6 | 16.4 | 3 | 0 |
| FAIRBANKS NORTHSTAR | 281 | 3.5 | 1.7 | 1.6 | 12.3 | 191.9 | 13 | 2 |
| HAINES | 12 | 1.0 | 0.5 | 0.6 | 1.2 | 4.1 | 8 | 0 |
| JUNEAU | 137 | 0.4 | 0.3 | 0.3 | 0.6 | 4.1 | 1 | 0 |
| KENAI PENINSULA | 135 | 2.6 | 1.1 | 1.3 | 3.9 | 26.3 | 18 | 1 |
| KETCHIKAN GATEWAY | 56 | 0.2 | 0.2 | 0.2 | 0.3 | 2.0 | 0 | 0 |
| KODIAK ISLAND | 27 | 0.4 | 0.2 | 0.2 | 0.6 | 2.4 | 0 | 0 |
| MATANUSKA-SUSITNA | 60 | 2.8 | 1.6 | 1.5 | 3.2 | 15.3 | 22 | 0 |
| SITKA | 24 | 0.3 | 0.2 | 0.1 | 0.4 | 1.8 | 0 | 0 |
| SKAGWAY-YAKUTAT-ANGOON | 3 | 4.2 | 2.6 | 5.3 | 3.3 | 6.9 | 67 | 0 |
| SOUTHEAST FAIRBANKS | 31 | 6.4 | 4.1 | 4.0 | 6.4 | 28.5 | 48 | 6 |
| VALDEZ-CORDOVA | 31 | 1.6 | 0.6 | 0.7 | 2.1 | 9.0 | 6 | 0 |
| WRANGELL-PETERSBURG | 35 | 0.3 | 0.2 | 0.2 | 0.5 | 2.6 | 0 | 0 |
| YUKON-KOYUKUK | 13 | 5.5 | 2.5 | 2.0 | 7.8 | 27.9 | 31 | 8 |

## GEOLOGIC RADON POTENTIAL

The occurrence of radon in Alaska is related to bedrock type, surface sediment type, soil type, and fault locations. Black shale and phosphatic rocks commonly have relatively high uranium contents. Phosphate deposits were found in Paleozoic and Mesozoic rocks in the Arctic Foothills province and in southeastern Alaska (Patton and Matzko, 1959; Dickinson, 1979a, 1979b). In addition, black shale beds were found in the Arctic Foothills province. Black shales are generally high in U, but no data is available for these rocks. Felsic igneous rocks, scattered around Alaska (Forbes, 1975; Jones and Forbes, 1977), generally contain 5-7 ppm U, which is higher than the average of 3.5 ppm for crustal igneous rocks (Wedepohl, 1971). One example is the Darby pluton on the Seward Peninsula which contains about 7 ppm U and is believed to be the source or U for the Death Valley deposit (Dickinson and others, 1987). Similar rocks are found in other parts of Alaska (Jones and Forbes, 1977). The Darby pluton is, like the rock in the Arctic Foothills province, located in an area with very low population density.

There are examples of high radon potential along fault zones in the conterminous 48 states (Gundersen, 1991). Special attention should be paid to faults as radon hazards in Alaska because of their abundance. Many if not most of the nearly 60 tectonostratigraphic terranes are separated from one another by fault zones. Most of the faults are not in populated areas, however. One exception is the Knik Fault which runs along the east side of suburban Anchorage. The Knik Fault passes near a radiometric anomaly along Turnagain Arm near Anchorage. The anomaly is over Quaternary sediment, but the exact location of the fault in this area is not known. A relation between the fault and the anomaly could exist.

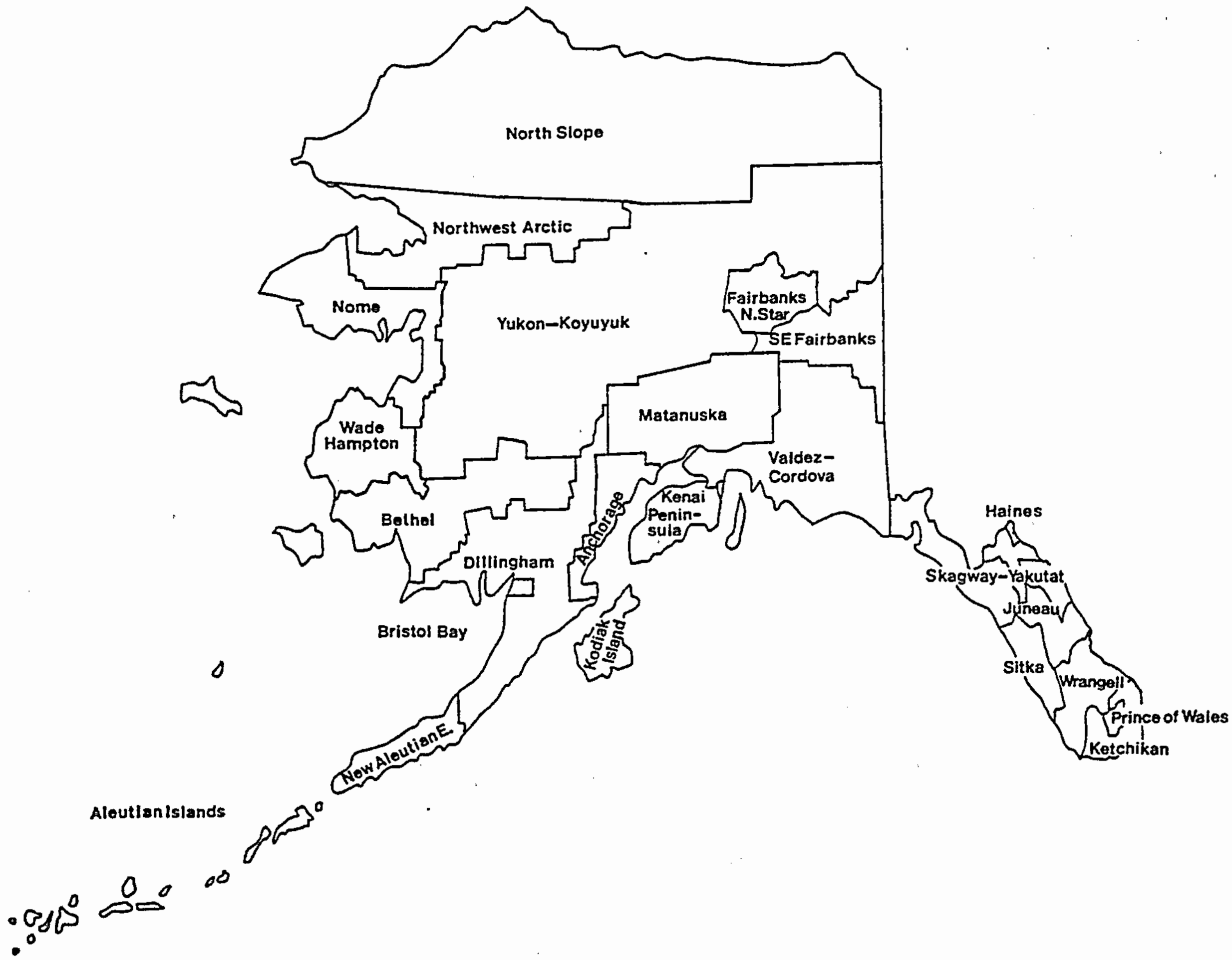
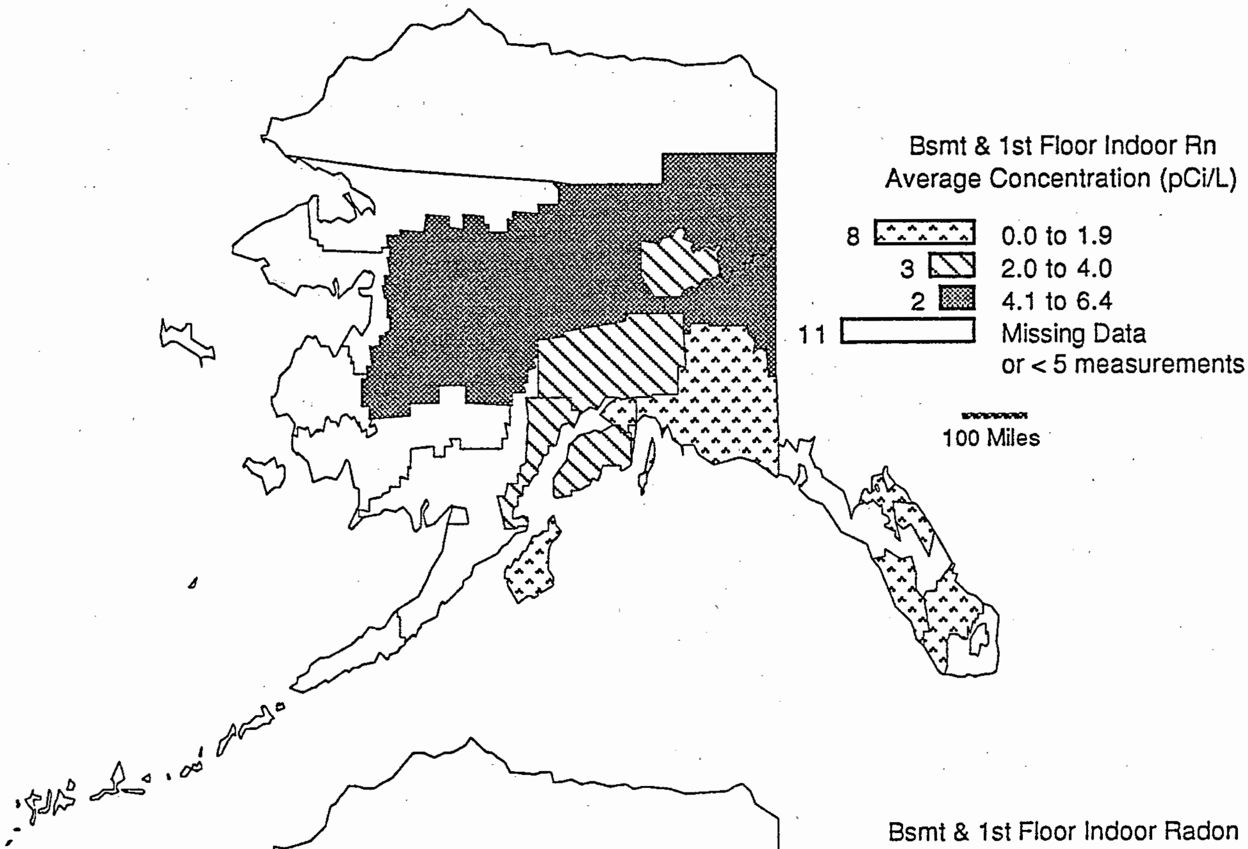



Figure 7. Boroughs and other subdivisions for plotting indoor radon data of Alaska.



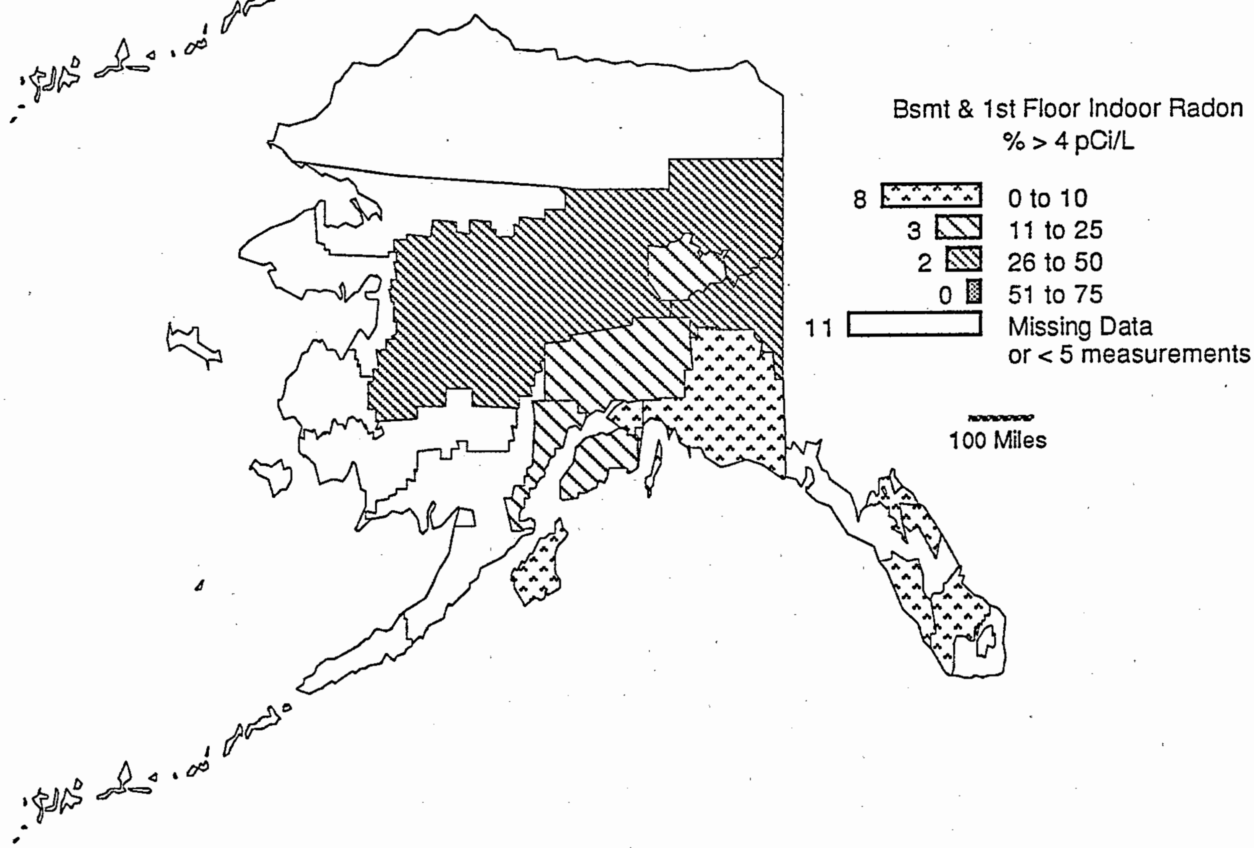




Figure 8. Screening indoor radon data from the EPA/State Residential Radon Survey of Alaska, 1988-89, for boroughs with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of boroughs or other areas in each category. The number of samples in each borough (See Table 2) may not be sufficient to statistically characterize the radon levels of the areas, but they do suggest general trends. Unequal category intervals were chosen to provide reference to decision and action levels.

An eU radiometric map is not available for Alaska. However, the number of radioactive anomalies for each of the 1:250,000 quadrangle map areas in about-two thirds of the State are available (Dickinson and others, 1983; fig. 9). These results are based on the National Uranium Resource Evaluation (NURE) studies (LKB Resources, 1978a, 1978b, 1979). Most of the anomalies represent contrasts between rock types and in some cases between bedrock and ice or water. None of these anomalies has been identified as an important uranium deposit; however, their distribution is significant for radon evaluation. In each of 13 quadrangles from a total of 91, more than 40 anomalies were discovered (fig. 9). These anomalies can be grouped into two belts and two isolated areas. The largest anomaly belt begins in the Kateel River quadrangle and extends eastward through Melozitna, Tanana, Bettles, Beaver, Fort Yukon, Black River and Coleen. This area generally follows the drainage basin of the Yukon River and its tributaries, the Tanana, Porcupine, and Koyukuk. The other anomaly belt follows the Anchorage, Valdez and McCarthy quadrangles that are occupied by the Chugach and Wrangell Mountains and a southern extension of the Copper River Basin. The Medfra quadrangle, west of the Mt. McKinley quadrangle, by itself exhibited 58 anomalies, and the Tanacross quadrangle southeast of Fairbanks exhibited 42. The North Slope, Northern Foothills, Brooks Range, and the Alaska Peninsula were not covered by this study.

Figure 10 shows the uranium content of stream sediments based on analyses from the Geochemical Atlas (Weaver, 1983). This data is summarized as follows: A 200-mile-wide area of high values extends westward across the State from Norton Sound and the Seward Peninsula eastward through central Alaska, including most of the Brooks Range, to the Yukon Flats area and the Canadian Border. A smaller belt covers the Alaska Range with Mount McKinley approximately at its center. Small areas of intermediate values are found in the Chugach, Kenai, and Wrangell Mountains. Scattered areas of relatively high values are present in southeastern Alaska. Three belts of generally low values can be seen. These are approximately the North Slope, the Kuskokwin River drainage basin in the central part of the State, and the Cook Inlet-Matanuska Valley-Copper River basin area.

The following section is reproduced directly from Nye and Kline (1990):

"Interior Alaska has the highest proportion of homes with elevated radon concentrations as well as the individual homes with highest concentrations. In the interior, 3 percent of homes with the sample population had screening levels higher than 20 pCi/L and 17.6 percent of homes had radon screening levels that were higher than 4 pCi/L. Figure 3 [fig. 11, this report] summarizes the responses to a request for home site geographic information which was included with the report of test results that was sent to part participants in the survey. This figure shows that 30 to 35 percent of homes built in the hills around Fairbanks have elevated radon concentrations.

In the Fairbanks area, homes built in the hills adjacent to the valley floor with concrete slab or basement structures which are in contact with bedrock yielded the highest measured radon levels. These areas also included the highest proportion of homes with high radon. We do not yet know the proportion of homes with basements in contact with bedrock that do not have elevated radon concentrations. The data shown in Figure 3 [fig. 12, this report] homes located on hillside sites, includes homes which are built on thick accumulations of windblown glacial silt (loess). Thick accumulations of loess appear to be an effective barrier to radon migration. Homes built on alluvium from the Tanana and Chena Rivers are also at lower risk. High radon concentrations in homes which are sited in bedrock are likely to result from high fracture

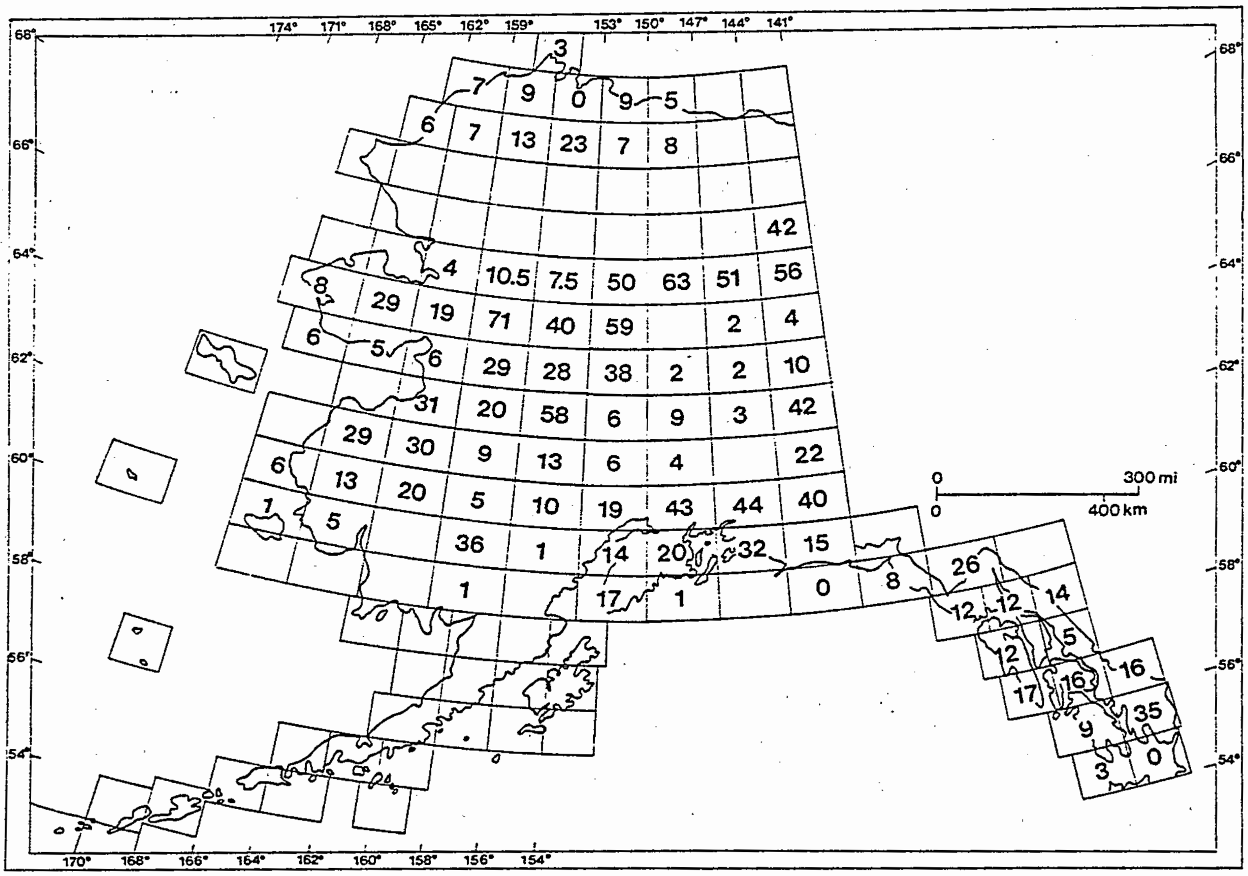



Figure 9. eU anomalies map of Alaska. From LKB Resources Inc. (1978a, 1978b, 1979).

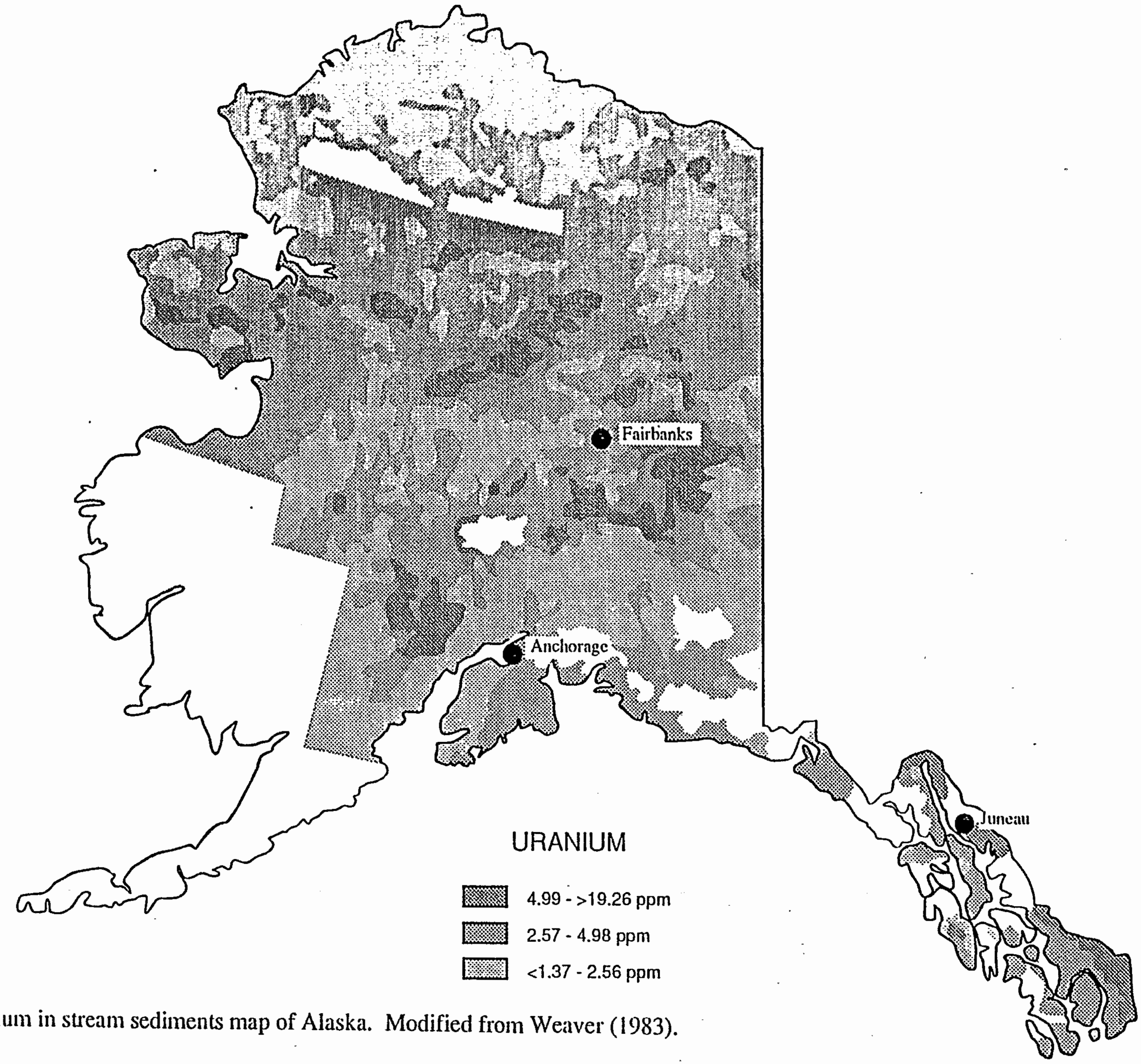



Figure 10. Uranium in stream sediments map of Alaska. Modified from Weaver (1983).

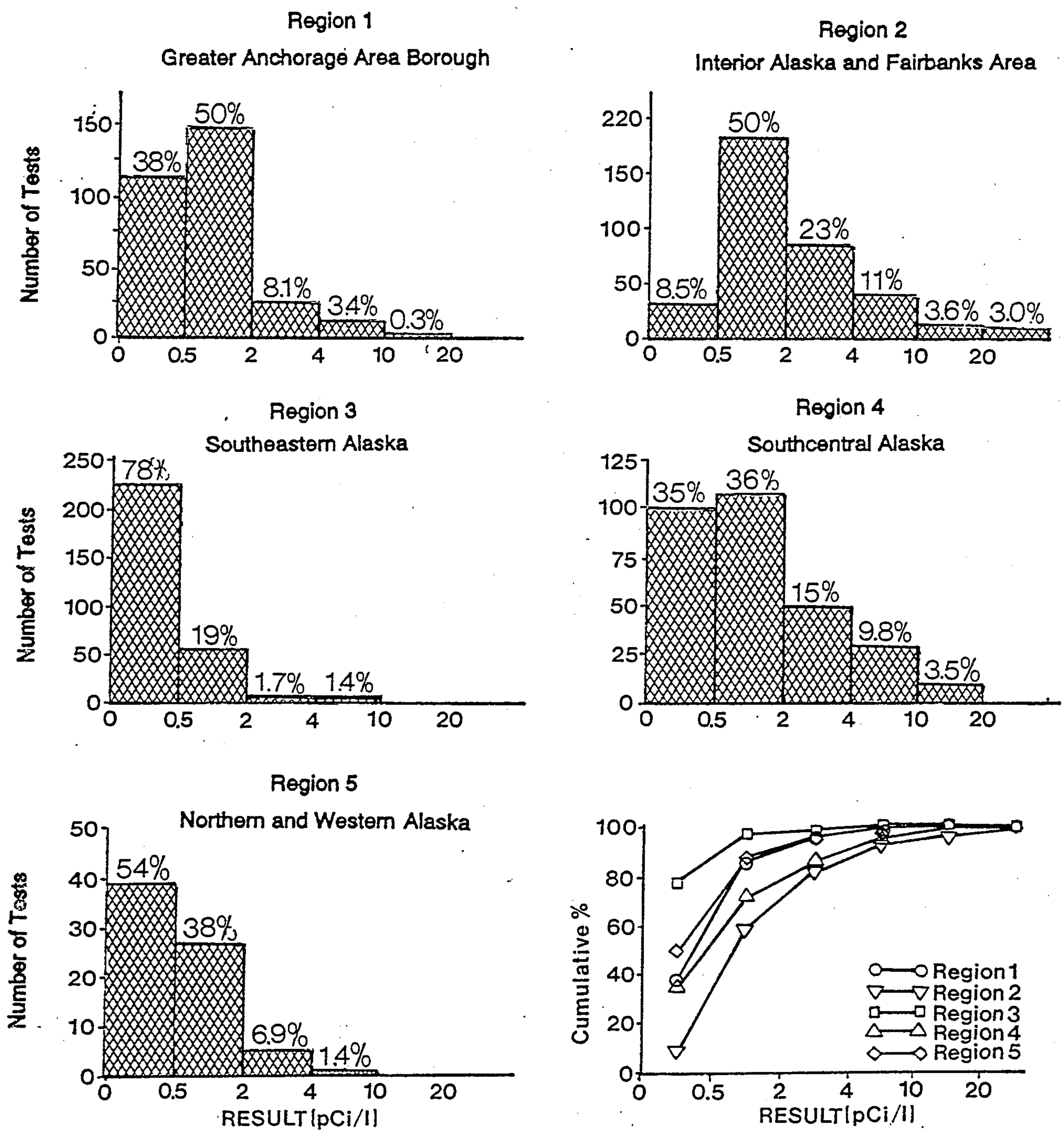



Figure 11. Histograms summarizing results of radon screening measurements (Nye and Kline, 1990).

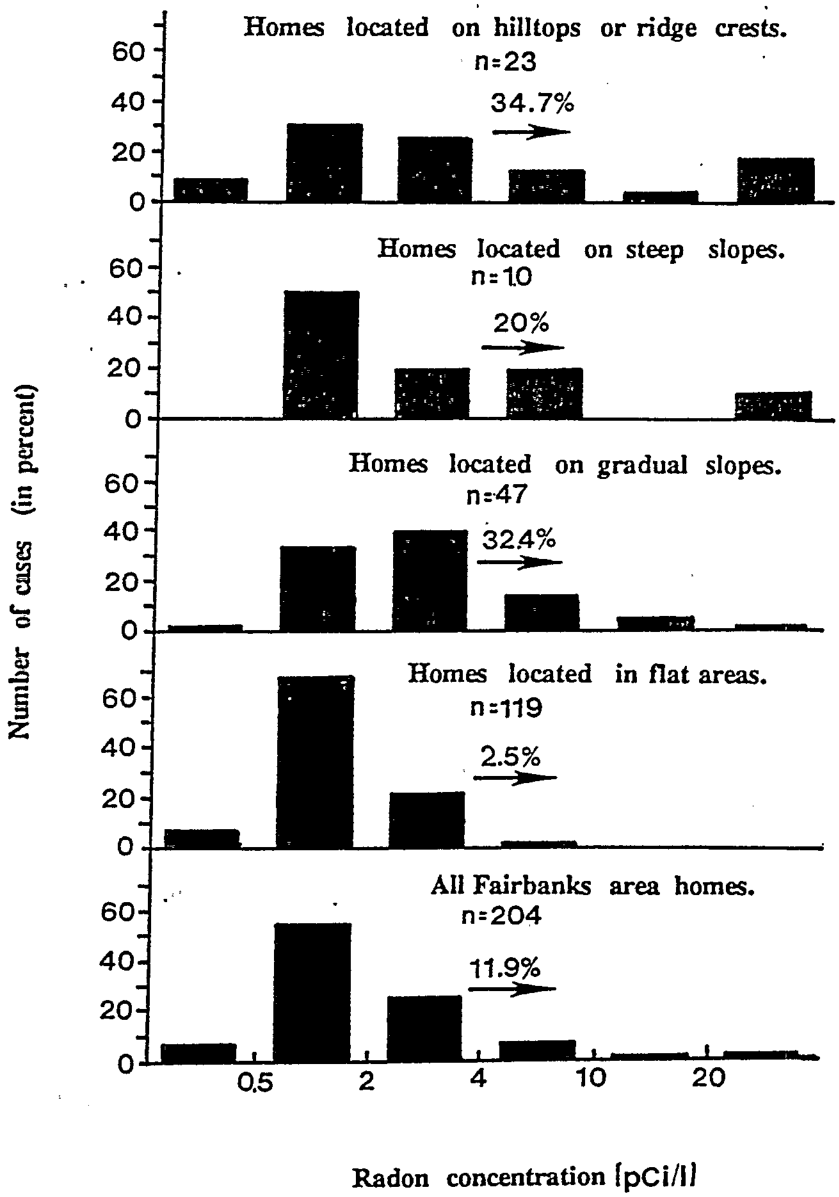



Figure 12. Histograms summarizing radon screening measurements and local geography of Fairbanks area homes (modified from Nye and Kline, 1990).

permeability of the bedrock as well as relatively high uranium concentration in the schist which comprises local bedrock. Low radon concentration in homes built on loess and alluvium may reflect low soil gas permeability, low uranium concentrations of soils, or both.

Throughout interior Alaska homes constructed on bedrock seem to be at higher risk for elevated radon concentrations. However, homes built on coarse glacial outwash deposits which are well drained can also have high radon concentrations. Outwash gravels may have sufficient porosity and permeability to allow significant amounts of soil gas to migrate into overlying structures. Outwash gravel may also contain abundant pebbles and boulders of rock types with higher uranium concentrations, including granitic rocks.

Based on survey data, south-central Alaska includes communities with a significant proportion of homes with elevated radon concentrations. The maximum radon concentrations detected in south-central Alaskan homes, however, are not as high as those measured in the Fairbanks area. The geologic setting of south-central Alaskan homes with elevated radon concentrations appears to be diverse. In some cases high radon screening levels can probably be attributed to the presence of coarse, well-sorted, granite-rich outwash. In other cases such concentrations appear to reflect proximity to bedrock.

Survey data indicate that Anchorage, southeastern Alaska, and northern and western Alaska have very few homes with elevated radon concentrations. In Anchorage this may reflect the abundance of fine-grained glacio-fluvial and glacio-marine sediments which underlie most of the borough. Fine-grained sediments such as these are characterized by low permeability, slow soil gas transport, and much reduced reservoir volume of soil gas; thus reducing the amount of radon which can be drawn into the home. Some of the homes included in the survey were located in the hills surrounding Anchorage. The fact that these homes also have low radon concentrations suggests that the local bedrock has low concentrations of uranium. The lack of homes with high radon in Anchorage probably reflects low gas permeability and pore volume of local soils, and low rates of radon production.

The low concentrations of radon in homes throughout southeastern Alaska are not well understood, geologically. Many of the underlying bedrock types should have sufficient uranium to produce a significant amount of radon, and many homes are built on extremely porous soils and fractured bedrock. The sample base includes homes in Juneau built on coarse talus fans and homes in the Mendenhall Valley built on coarse outwash with a high proportion of granitic cobbles. Similar materials in other regions have relatively high source concentrations of radon in soil gas. A high proportion of southeastern homes are built on pilings. Since these homes were structurally ineligible for the survey they do not influence the data presented here.

The small number of homes with elevated radon concentrations in northern and western Alaska may be due to several factors, including local soil conditions such as shallow permafrost and high water tables. Also, most of the communities included in this survey are sited on fine grained alluvial deposits such as overbank silt, rather than in upland areas where bedrock is exposed at or near the surface. Additionally, air exchange is probably more efficient in small homes during routine entry and exit" (Nye and Kline, 1990).

The data on which this study is based "do not reflect the fact that most homes in rural Alaska were structurally ineligible for this survey because they are built on pilings. Also there are many Alaskan communities which do not include homes which were eligible for this study under EPA guidelines" (Nye and Kline, 1990).

A compelling geological reason for the high indoor radon values obtained from the Fairbanks area is difficult to determine. The bedrock in the hills around Fairbanks is Precambrian to Paleozoic metamorphic rock (formerly termed the Birch Creek Schist). No data is at hand to suggest that the Birch Creek Schist is an abnormally high radon producer in the vicinity of Fairbanks. The Fairbanks 1:250,000 quadrangle produced only two gamma-ray anomalies in studies carried out during the NURE program. The Anchorage quadrangle produced 43 anomalies and the Juneau quadrangle produced 12. It should be noted that these airborne gamma-ray anomalies are based on measurement of Bismuth-214 decay and are more closely related to radon than to uranium. If abnormal amounts of radon are being generated by a particular rock unit such as the Birch Creek Schist, these values should show up in airborne Bi-214 measurements.

One of the two airborne radioactivity anomalies in the Fairbanks quadrangle was obtained over Quaternary sediments about 35 miles northwest of Fairbanks, the other was obtained over the Mississippian Totatlinika Schist about 55 miles south of Fairbanks. In addition, Eakins (1969) reported four uranium occurrences in stream sediment concentrates in the Fairbanks quadrangle. One is in the Easter Dome area where minor granitic bodies intruded the Birch Creek Schist about 10 miles northwest of Fairbanks. Stream concentrates contained as much as 70 ppm U in this area. Another is in the Pedro Dome-Gilmore Dome area about 15 miles northeast of Fairbanks, where high Au, Bi, and W contents are found in lodes and high Au contents are found in placers that are associated with the Birch Creek Schist. Panned concentrates from this area contained up to 660 ppm U and outcrop samples contained as much as 10 ppm U (Eakins, 1969). Placer deposits are difficult to assess for radon potential because the amount of radon that escapes uraniferous resistate minerals through the uranium decay series is not well known. In addition, houses are not often built on placer deposits and houses built on the alluvium in the Fairbanks area were low in radon. Two other U occurrences are the Liberty Bell Mine, 64 miles southwest of Fairbanks, and at Grubstake Creek 57 miles southwest of Fairbanks. They are too remote to suggest high uranium values in the Fairbanks area. None of these occurrences suggest abnormally high radon potential from the Birch Creek Schist in the hills around Fairbanks.

In the Anchorage quadrangle, most of the 43 airborne radiometric anomalies identified during the NURE studies are in the Chugach Mountains, away from populated areas. One strong anomaly, however, was located along Turnagain Arm near residential areas of Anchorage. This anomaly, as noted above, is near the Knik fault. It is also located on alluvium that is related to Cretaceous and/or Upper Jurassic deep water clastic rocks consisting of siltstone, graywacke, arkose, conglomeratic sandstone, pillow basalt, and other rocks. This sequence and a melange of other Cretaceous and Jurassic (?) rocks including flysch, greenstone, limestone, chert, granodiorite, schist, layered gabbro, and serpentinite form the hills above Anchorage to the west. Houses in these hills generally have low indoor radon readings.

The Juneau quadrangle contains two NURE airborne radiometric anomalies. Only one of these was near Juneau. It is located over the waters of Taku Inlet about 10 miles east of Juneau. The anomaly is next to Mesozoic and Paleozoic onshore rocks and may have resulted from the migration of subaerial radon gas from these rocks. The rocks consist of greenstone, graphitic schist, slate, chert, graywacke, quartzite, phyllite interlayered with marble, and a small amount of amphibolite.

## SUMMARY

The major physiographic provinces of Alaska are the land units used for radon potential estimates, except for the Central province, which is divided into the Northern Plateaus subprovince and an area made up of the remaining subprovinces (fig. 1). Each of these areas has a variety of geology and probably contains rock units that produce significantly high levels of radon. A brief summary of the estimated potential for radon in each province or group of subprovinces together with a radon potential index is given below (table 3).

The scores, particularly those for the confidence index, are low, in part because of dearth of data considering the large size of the areas. The indoor radon data is limited to populated areas and does not represent the entire land area of the province evaluated. Nevertheless, in the absence of adequate data these data are given some credibility. The aerial radioactivity is presented only in number of significant anomalies compiled by the NURE program for each 1:250,000 quadrangle area (LKB resources, Inc., 1978a, 1978b, 1979). The geology for these anomalies has been incompletely compiled, but is known in some cases. The aerial radiometric data is applicable within the constraints of the method of compilation. The geology for each province or subprovince is well known, but in some of the areas it is complex and indoor and(or) soil-gas radon information is lacking. Broad assumptions on radon potential based on geology have been used for the score compilation. Broad assumptions on water and ice saturation of the soils and its effect on soil-gas transmissivity were also used in the evaluations. No points were assigned for geologic field evidence because no documented field studies of radon in the geologic environment in Alaska were available.

The relatively flat-lying Cretaceous and Tertiary sedimentary rocks that make up the Arctic Coastal Plain could contain high radon producers, although there is no data to suggest they do. A radon potential score (RI) of 6 and confidence index (CI) of 6 is given for this province. These low values stem mostly from lack of data and the assumption that soil saturation with water and ice reduces radon transmissivity (figs. 5, 6). No significant uranium occurrences are known in this area and the number of gamma-ray anomalies is low for this area when compared with other parts of Alaska (figs. 4, 9). The area also is a low in radioactive resistate minerals in stream sediments (fig. 10). The coastal plain is unglaciated and contains tundra soils and permafrost.

The folded Cretaceous sandstone and shale that makes up most of the Arctic Foothills province could produce relatively large amounts of radon but, again, no evidence that they do is at hand. The province was assigned an RI of 7 and a CI of 6. The area contains no known U deposits (fig. 4), and the part of the area where airborne gamma-ray measurements were made shows a relatively low number of anomalies (fig. 9). The stream sediments show varied amounts of uraniferous placer sediments with some high values in the eastern part of the area (fig. 10). Part of the area was covered by glaciers (fig. 6). The soils are tundra soils with permafrost and apparent low gas transmissivity (fig. 5).

The Precambrian and Paleozoic marine sedimentary rocks that make up most of the Arctic Mountains province probably are not producers of large amounts of radon inasmuch as there is little phosphate rock or black shale in these sequences. An RI of 9 and a CI of 6 was estimated for this area. There are no known significant uranium occurrences in this area. The stream sediments are, however, moderately high in uraniferous resistate minerals (fig. 10). The area has been glaciated (fig. 6), but much of the terrane is bare rock without surficial glacial material. The soils are classified as rockland, which includes glacial ice.

The Central province excluding the Northern Plateaus subprovince is a vast area of varied geology and undoubtedly contains many rocks that are significant radon producers and many that are not. The area was assigned an RI of 11 and a CI of 6. Indoor radon was given a rank of 3, but with a very low confidence level because of the small number of measurements for such a vast area. The number of gamma-ray anomalies ranged from one in the Lake Clark quadrangle to 71 in the Kateel River quadrangle (fig. 9), and the area was given 2 RI points in this category. For geology, the area was given 3 points. It contains uranium deposits of potentially commercial size at Death Valley on the Seward Peninsula and in the Healy Creek Coal basin (fig. 4). There are several areas of uraniferous granites, felsic intrusives, and volcanic rocks in parts of this province together with various uranium occurrences in the Darby Mountains (Foley and Barker, 1986). Nearly all of the area lies within the belt of uraniferous stream sediment minerals (fig. 10). Little of the Central Province has been glaciated. The soils are mostly of the tundra type with variable permafrost. There are significant areas of rockland and Cryochrepts (subarctic brown forest soils), which may have high gas transmissivity. Water and ice saturation probably limits soil-gas transmissivity in some parts of the area. Soil permeability was ranked 2.

The Northern Plateaus subprovince, a large, geologically complex area, was assigned an RI of 11 and a CI of 7. Three points were given for indoor radon because of the high levels in parts of the Fairbanks and Fairbanks-Northstar boroughs. The Northern Plateaus subprovince was separated from the rest of the Central province in order to emphasize the high indoor radon levels in the Fairbanks area, even though that area represents only a small part of the subprovince, and to point out that high indoor radon levels are likely to occur locally in other parts of the Northern Plateaus as well as the remainder of the Central Province, though both areas are ranked moderate in geologic radon potential overall. Radioactivity, as measured by the number of anomalies, was rated 2. The number of anomalies for 1:250,000 quadrangles covering the Northern Foothills ranged from lows of two each in Fairbanks and Big Delta to highs of 59 in Tanana and 63 in Beaver. The schist that apparently produces high indoor radon near Fairbanks is in the Northern Plateaus subprovince, but no airborne gamma-ray anomalies were found over the schist in the Fairbanks area. There are, however, 10 anomalies over the schist in the Tanacross quadrangle 130 to 200 miles to the southeast of Fairbanks. Felsic intrusives are scattered in two belts, one intruding Paleozoic and Precambrian metamorphic rocks in the southeast one third of the subprovince and one intruding Lower Paleozoic and (or) Precambrian sedimentary rocks along the northwest margin of the subprovince. For geology the subprovince was rated 3. The area contains one known significant uranium and thorium deposit at Mount Prindle (fig. 4; Armbrustmacher, 1989). Uranium is high in stream sediments in the south-central part and along the northwest border of the subprovince (fig. 10). Soil permeability was ranked 2. In order of decreasing abundance the soils consist of Cryaquepts (tundra), Cryochrepts (former subarctic brown forest soils), and rockland. Soil permeability is variable, depending on water and ice saturation. The Cryochrepts and rockland may have fairly high gas transmissivity.

The Alaska-Aleutian Range was assigned an RI of 9 and a CI of 6 overall (table 3), though the area contains some felsic intrusives and other rocks that could be locally significant radon producers. Indoor radon was given a RI score of one and confidence index of one. No significant uranium occurrences are known in this province. The number of radiometric anomalies is relatively low. The McKinley quadrangle, for instance, only has six (fig. 9). The province, however, is an intermediate to high producer of uraniferous stream sediments (fig. 10). Most of the area is or was covered by glaciers. Soils are mostly classified as rockland or tundra (figs. 5, 6).

The Coastal Trough contains thick sequences of carbonized wood-bearing Tertiary continental clastic rocks similar to units that produce uranium in the western conterminous United States. Uranium content of these rocks is not high, however, especially in the Cook Inlet and Copper River basins. There is a slight northward increase in uranium content of the Tertiary sedimentary rocks in the Cook Inlet basin and small uranium occurrences are found in the Susitna Lowlands (Dickinson and Campbell, 1978). There are also small uranium deposits in the Admiralty trough in southeastern Alaska (Dickinson and Campbell, 1984; Dickinson and Vuletich, 1990). Stream sediments are low in radioactive minerals in the Cook Inlet and Copper River basin areas, and data from Admiralty Trough, where there are very few surface exposures, is sparse. Soils are mostly brown and gray-brown podzolic forest soils which could have high gas transmissivity. Heavy rainfall in southeast Alaska may retard soil gas migration. The Coastal Trough area was given an RI of 9 and a CI of 6 (table 3).

The rocks of the Border Ranges, which consist mostly of Cretaceous and Jurassic sedimentary and metamorphic rocks, together with some mafic volcanic and intrusive rocks, generally have low radon potential. The RI for this area is 7 and the CI is 6 (table 3). The uranium deposit at Bokan Mountain is associated with a peralkaline granite and it illustrates that because of the great geologic diversity some high radon producers are undoubtedly present. Uraniferous mineral content of stream sediments is intermediate for the Border Ranges, although data are absent for many parts of the area (fig. 10). The radioactive anomaly density is also low for the Border Ranges, although the Port Alexander quadrangle contains 17 and over half of the area is ocean water. Podzolic brown and gray-brown forest soils are common in the Border Ranges and they could have high gas transmissivity. In southern Southeastern Alaska, where annual precipitation is about 14 feet, water saturation probably retards gas flow in soils. Nearly all of the Border Ranges province was glaciated or is presently occupied by glaciers.

This is a generalized assessment of the State's geologic radon potential and there is no substitute for having a home tested. The conclusions about radon potential presented in this report cannot be applied to individual homes or building sites. Indoor radon levels, both high and low, can be quite localized, and within any radon potential area there will likely be areas with higher or lower radon potential that assigned to the area as a whole. Any local decisions about radon should <u>not</u> be made without consulting all available local data. For additional information on radon and how to test, contact your State radon program or EPA regional office. More detailed information on state or local geology may be obtained from the State geological survey. Addresses and phone numbers for these agencies are listed in chapter 1 of this booklet.

TABLE 3. RI and CI scores for geologic radon potential areas of Alaska.

| PROVINCE | Arctic Coastal Plain | | Arctic Foothills | | Arctic Mountains | | Central* | |
|---|---|---|---|---|---|---|---|---|
| FACTOR | RI | CI | RI | CI | RI | CI | RI | CI |
| INDOOR RADON | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 2 |
| RADIOACTIVITY | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 |
| GEOLOGY | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 |
| SOIL PERM. | 1 | 2 | 1 | 2 | 2 | 2 | 2 | 1 |
| ARCHITECTURE | 1 | - | 1 | - | 1 | - | 1 | - |
| GFE POINTS | 0 | - | 0 | - | 0 | - | 0 | - |
| TOTAL | 6 | 6 | 7 | 6 | 9 | 6 | 11 | 6 |
| RANKING | LOW | LOW | LOW | LOW | MOD | LOW | MOD | LOW |

| PROVINCE | Northern Plateaus | | Alaska-Aleutian Ranges** | | Coastal Trough | | Border Ranges | |
|---|---|---|---|---|---|---|---|---|
| FACTOR | RI | CI | RI | CI | RI | CI | RI | CI |
| INDOOR RADON | 3 | 2 | 2 | 2 | 2 | 2 | 1 | 2 |
| RADIOACTIVITY | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 |
| GEOLOGY | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| SOIL PERM. | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 1 |
| ARCHITECTURE | 1 | - | 1 | - | 1 | - | 1 | - |
| GFE POINTS | 0 | - | 0 | - | 0 | - | 0 | - |
| TOTAL | 11 | 7 | 9 | 6 | 9 | 6 | 7 | 6 |
| RANKING | MOD | MOD | MOD | LOW | MOD | LOW | LOW | LOW |

*Excluding Northern Plateaus
**including the Coast Mountains

RADON INDEX SCORING:

| Radon potential category | Point range | Probable screening indoor radon average for area |
|---|---|---|
| LOW | 3-8 points | < 2 pCi/L |
| MODERATE/VARIABLE | 9-11 points | 2 - 4 pCi/L |
| HIGH | > 11 points | > 4 pCi/L |

Possible range of points = 3 to 17

CONFIDENCE INDEX SCORING:

| | |
|---|---|
| LOW CONFIDENCE | 4 - 6 points |
| MODERATE CONFIDENCE | 7 - 9 points |
| HIGH CONFIDENCE | 10 - 12 points |

Possible range of points = 4 to 12

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# EPA's Map of Radon Zones

The USGS' Geologic Radon Province Map is the technical foundation for EPA's Map of Radon Zones. The Geologic Radon Province Map defines the radon potential for approximately 360 geologic provinces. EPA has adapted this information to fit a county boundary map in order to produce the Map of Radon Zones.

The Map of Radon Zones is based on the same range of predicted screening levels of indoor radon as USGS' Geologic Radon Province Map. EPA defines the three zones as follows: Zone One areas have an average predicted indoor radon screening potential greater than 4 pCi/L. Zone Two areas are predicted to have an average indoor radon screening potential between 2 pCi/L and 4 pCi/L. Zone Three areas are predicted to have an average indoor radon screening potential less than 2 pCi/L.

Since the geologic province boundaries cross state and county boundaries, a strict translation of counties from the Geologic Radon Province Map to the Map of Radon Zones was not possible. For counties that have variable radon potential (i.e., are located in two or more provinces of different rankings), the counties were assigned to a zone based on the predicted radon potential of the province in which most of its area lies. (See Part I for more details.)

ALASKA MAP OF RADON ZONES

The Alaska Map of Radon Zones and its supporting documentation (Part IV of this report) have received extensive review by Alaska geologists and radon program experts. The map for Alaska generally reflects current State knowledge about radon for its counties. Some States have been able to conduct radon investigations in areas smaller than geologic provinces and counties, so it is important to consult locally available data.

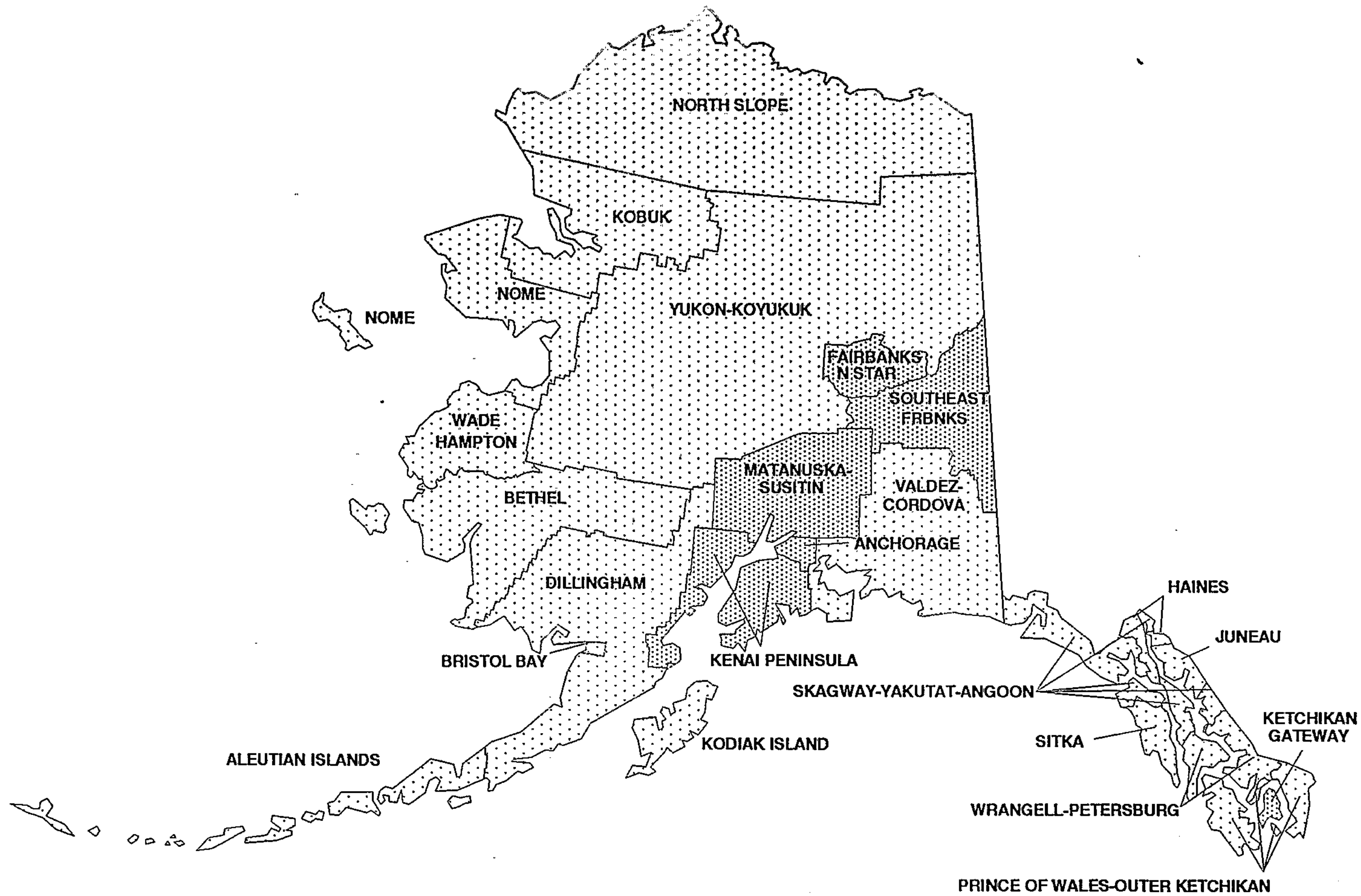
Two borough designations in Alaska do not strictly follow the methodology for adapting the geologic provinces to "county boundaries." The majority of land area in Juneau and Haines is in the moderate radon potential area of the Coast Mountain province. However, the available indoor radon data from these areas indicate low indoor radon measurements among the population centers. Therefore, the Alaska Department of Health and Social Services, the Alaska Cooperative Extension Service and the EPA have assigned Haines and Juneau to Zone 3.

Although the information provided in Part IV of this report -- the State chapter entitled "Preliminary Geologic Radon Potential Assessment of Alaska" -- may appear to be quite specific, it cannot be applied to determine the radon levels of a neighborhood, housing tract, individual house, etc. **THE ONLY WAY TO DETERMINE IF A HOUSE HAS ELEVATED INDOOR RADON IS TO TEST.** Contact the Region 10 EPA office or the Alaska radon program for information on testing and fixing homes. Telephone numbers and addresses can be found in Part II of this report.

# ALASKA - EPA Map of Radon Zones

The purpose of this map is to assist National, State and local organizations to target their resources and to implement radon-resistant building codes.

This map is not intended to determine if a home in a given zone should be tested for radon. Homes with elevated levels of radon have been found in all three zones. ***All homes should be tested, regardless of zone designation.***




Zone 1 Zone 2 Zone 3

IMPORTANT: Consult the publication entitled "Preliminary Geologic Radon Potential Assessment of Alaska" before using this map. This document contains information on radon potential variations within counties. EPA also recommends that this map be supplemented with any available local data in order to further understand and predict the radon potential of a specific area.