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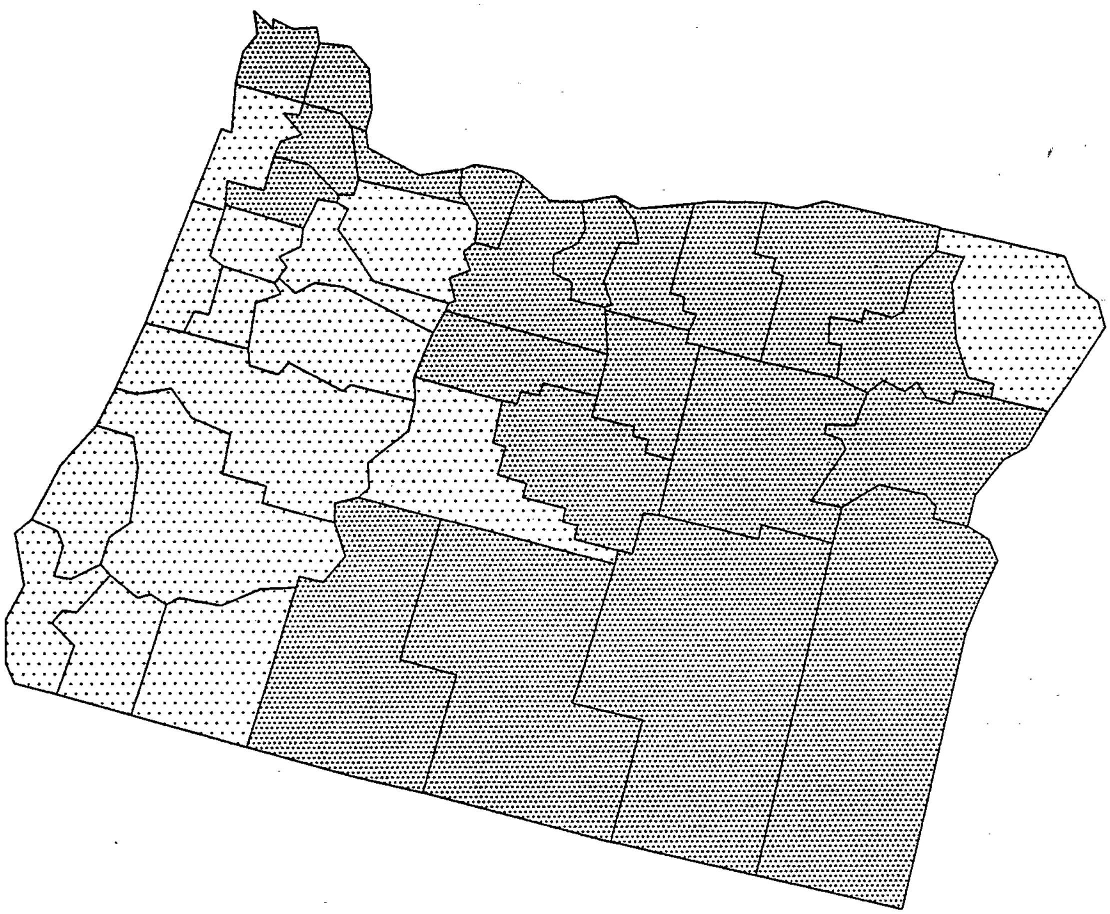
EPA's Map of Radon Zones

OREGON



EPA'S MAP OF RADON ZONES
OREGON

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.

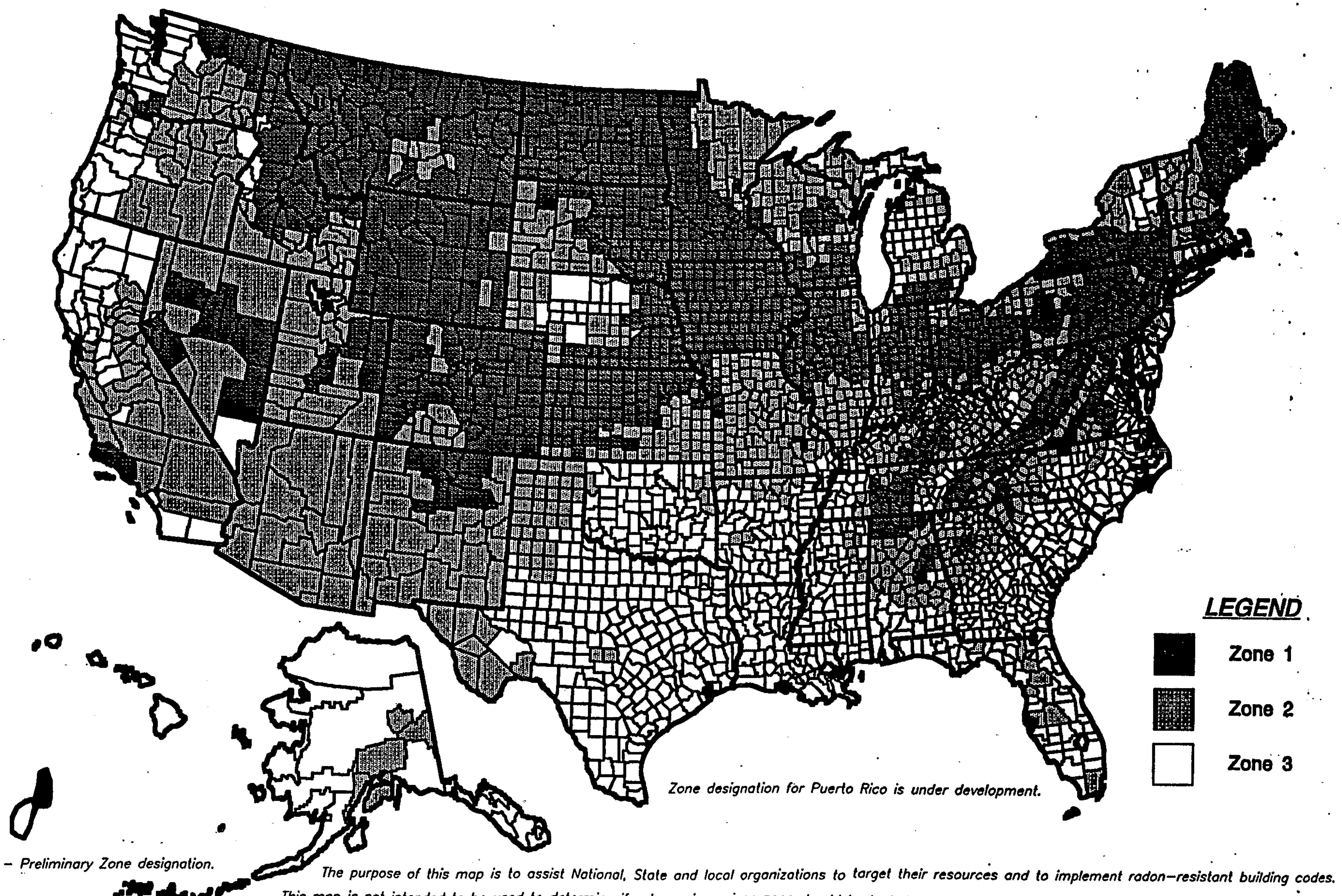
The Map of Radon Zones and its supporting documentation establish no regulatory requirements. Use of this map by State or local radon programs and building code officials is voluntary. The information presented on the Map of Radon Zones and in the supporting documentation is not applicable to radon in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

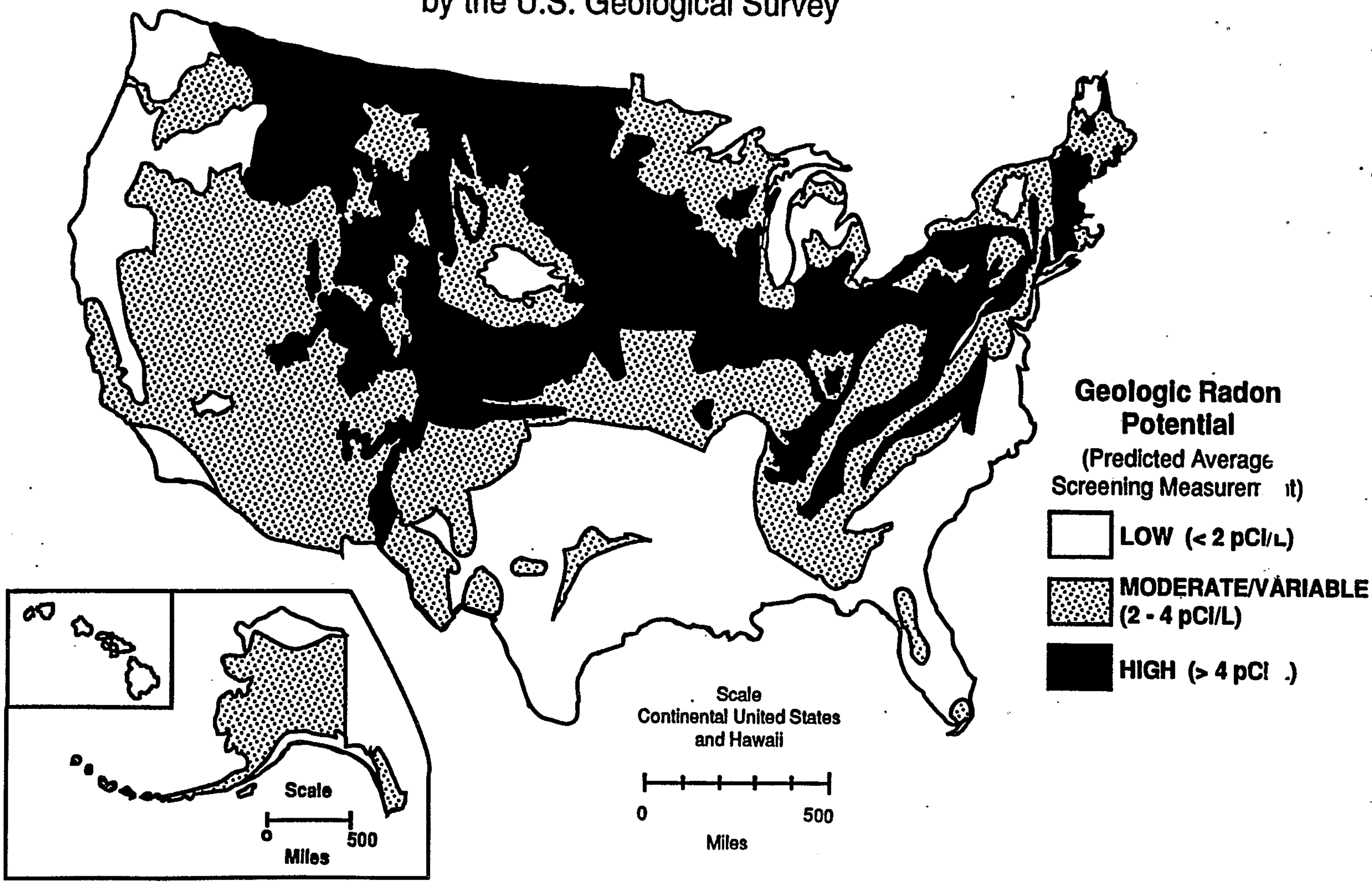
This map is not intended to be used to determine if a home in a given zone should be tested for radon. Homes with elevated levels of radon have been found in all three zones. *All homes should be tested, regardless of geographic location.*

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



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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 ≥ 2 pCi/L and ≤ 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

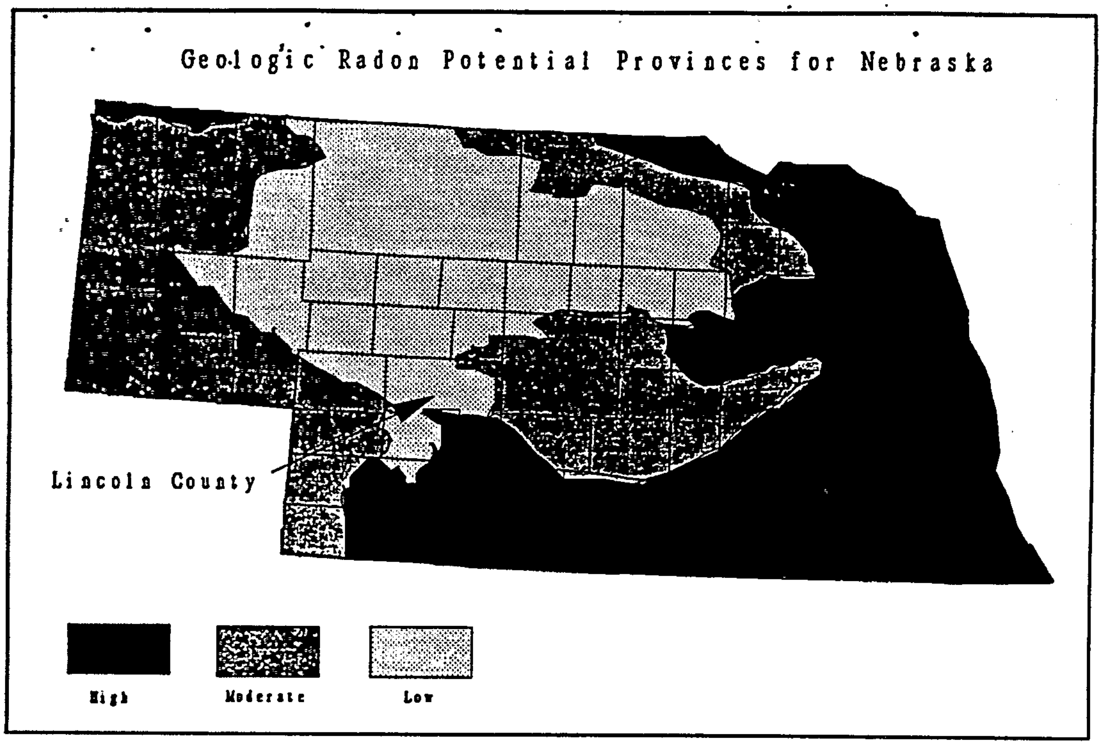
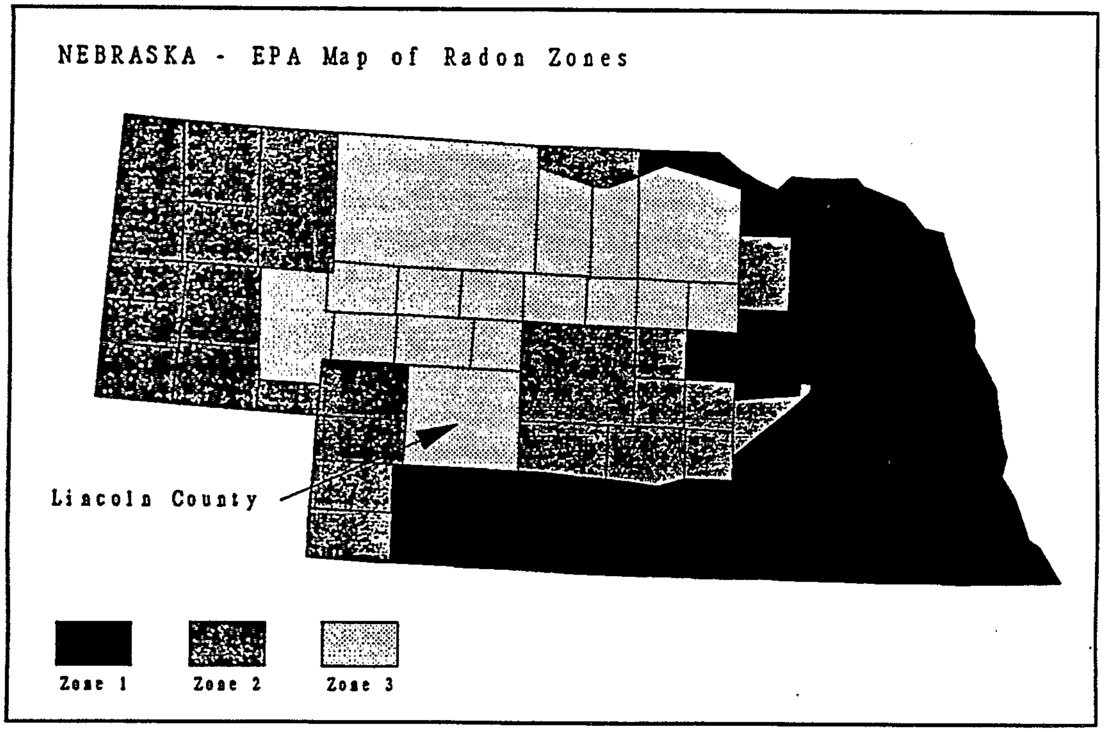


Figure 4



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

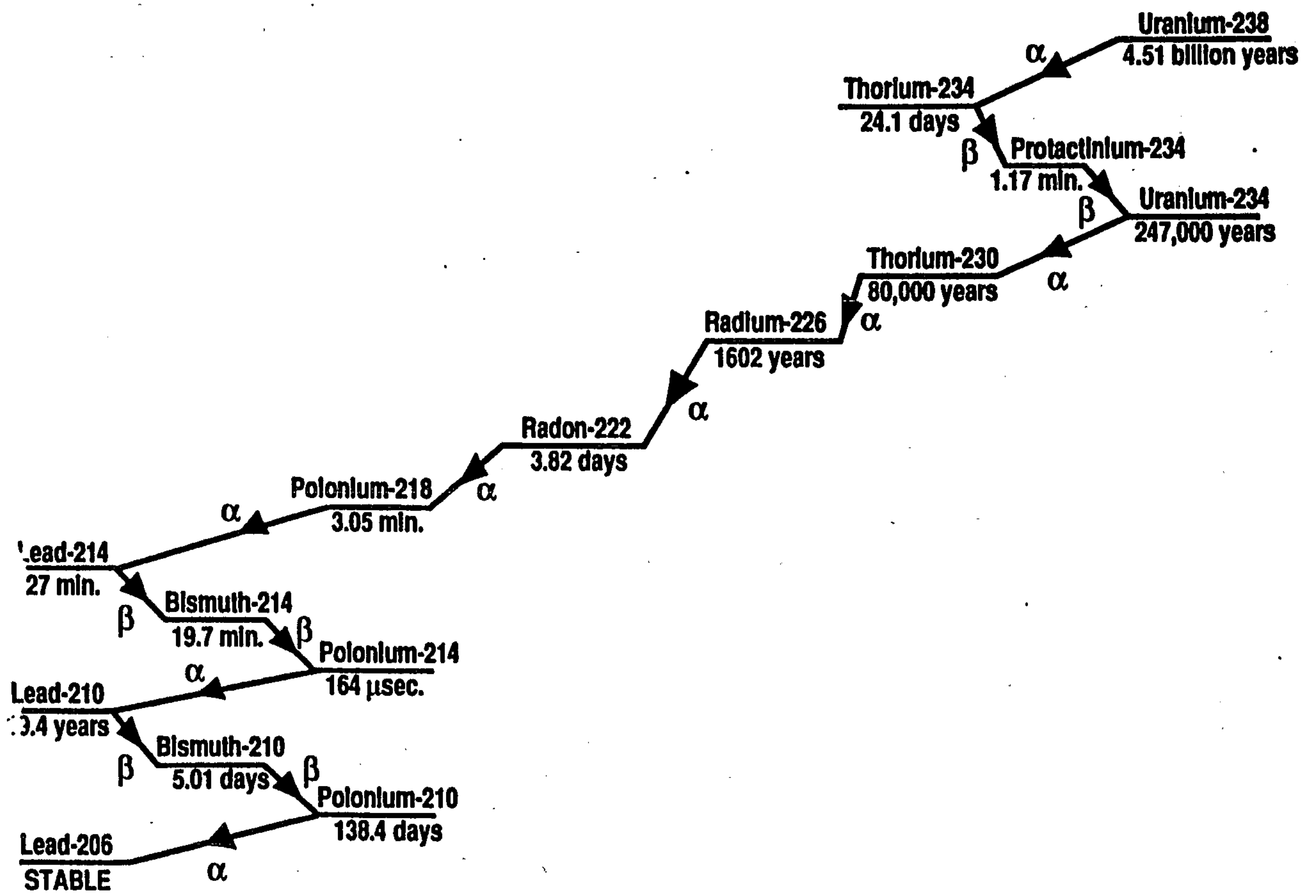

Figure 1. The uranium-238 decay series, showing the half-lives of elements and their modes of decay (after Wanty and Schoen, 1991). α denotes alpha decay, β denotes beta decay.

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 2×10^{-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).

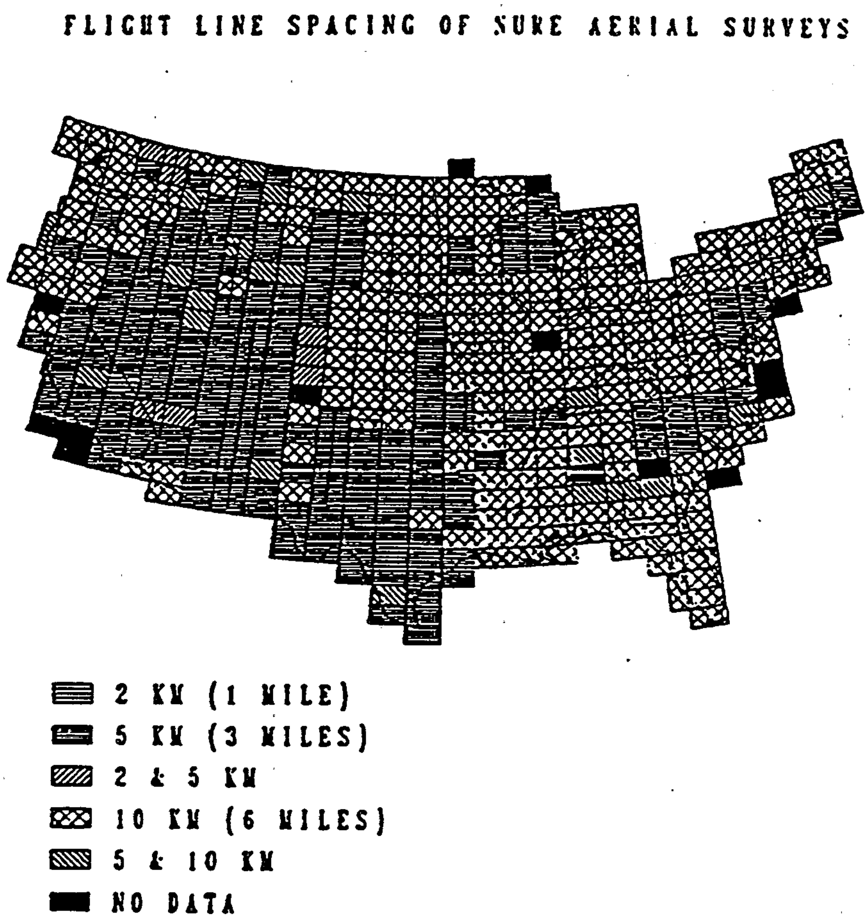

Figure 2. Nominal flightline spacings for NURE aerial gamma-ray surveys covering the contiguous United States (from Duval and others, 1990). Rectangles represent 1°x2° quadrangles.

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.

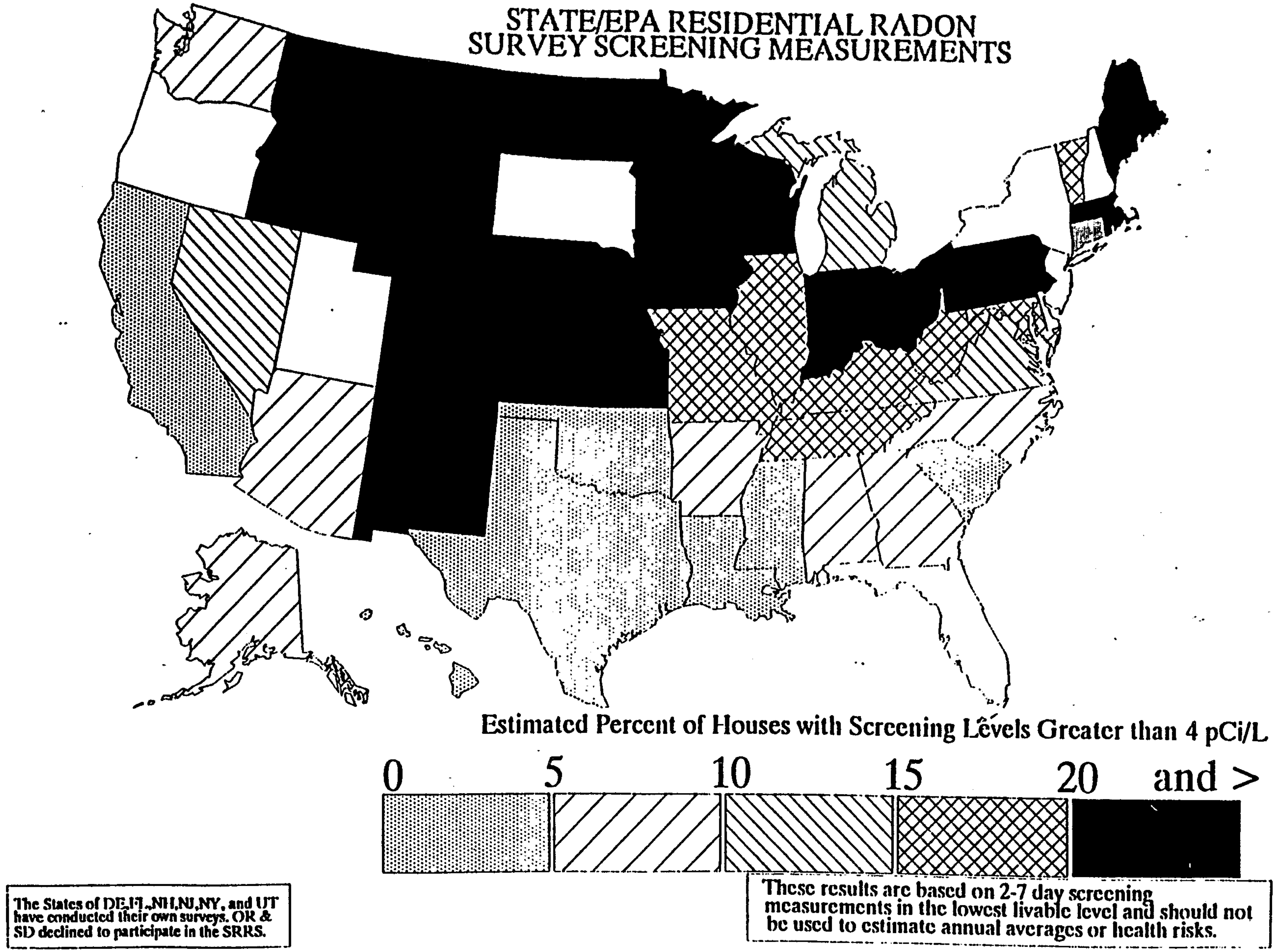

Figure 3. Percent of homes tested in the State/EPA Residential Radon Survey with screening indoor radon levels exceeding 4 pCi/L.

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.

REFERENCES CITED

Akerblom, G., Anderson, P., and Clavensjo, B., 1984, Soil gas radon--A source for indoor radon daughters: Radiation Protection Dosimetry, v. 7, p. 49-54.

Deffeyes, K.S., and MacGregor, I.D., 1980, World uranium resources: Scientific American, v. 242, p. 66-76.

Durrance, E.M., 1986, Radioactivity in geology: Principles and applications: New York, N.Y., Wiley and Sons, 441 p.

Duval, J.S., 1989, Radioactivity and some of its applications in geology: Proceedings of the symposium on the application of geophysics to engineering and environmental problems (SAGEEP), Golden, Colorado, March 13-16, 1989: Society of Engineering and Mineral Exploration Geophysicists, p. 1-61.

Duval, J.S., Cook, B.G., and Adams, J.A.S., 1971, Circle of investigation of an airborne gamma-ray spectrometer: Journal of Geophysical Research, v. 76, p. 8466-8470.

Duval, J.S., Jones, W.J., Riggle, F.R., and Pitkin, J.A., 1989, Equivalent uranium map of conterminous United States: U.S. Geological Survey Open-File Report 89-478, 10 p.

Duval, J.S., Reimer, G.M., Schumann, R.R., Owen, D.E., and Otton, J.K., 1990, Soil-gas radon compared to aerial and ground gamma-ray measurements at study sites near Greeley and Fort Collins, Colorado: U.S. Geological Survey Open-File Report 90-648, 42 p.

Dziuban, J.A., Clifford, M.A., White, S.B., Bergstein, J.W., and Alexander, B.V., 1990, Residential radon survey of twenty-three States, *in* Proceedings of the 1990 International Symposium on Radon and Radon Reduction Technology, Vol. III: Preprints: U.S. Environmental Protection Agency report EPA/600/9-90/005c, Paper IV-2, 17 p.

Gammage, R.B., Wilson, D.L., Saultz, R.J., and Bauer, B.C., 1993, Subtereanean transport of radon and elevated indoor radon in hilly karst terranes: Atmospheric Environment (in press).

Gundersen, L.C.S., Reimer, G.M., and Agard, S.S., 1988a, Correlation between geology, radon in soil gas, and indoor radon in the Reading Prong, *in* Marikos, M.A., and Hansman, R.H., eds., Geologic causes of natural radionuclide anomalies: Missouri Department of Natural Resources Special Publication 4, p. 91-102.

Gundersen, L.C.S, Reimer, G.M., Wiggs, C.R., and Rice, C.A., 1988b, Map showing radon potential of rocks and soils in Montgomery County, Maryland: U.S. Geological Survey Miscellaneous Field Studies Map MF-2043, scale 1:62,500.

Gundersen, Linda C.S., 1991, Radon in sheared metamorphic and igneous rocks, *in* Gundersen, Linda C.S., and Richard B. Wanty, eds., Field studies of radon in rocks, soils, and water: U.S. Geol. Survey Bulletin no. 1971, p. 39-50.

Henry, Mitchell E., Kaeding, Margret E., and Monteverde, Donald, 1991, Radon in soil gas and gamma-ray activity of rocks and soils at the Mulligan Quarry, Clinton, New Jersey, *in* Gundersen, Linda C.S., and Richard B. Wanty, eds., Field studies of radon in rocks, soils, and water: U.S. Geol. Survey Bulletin no. 1971, p. 65-75.

Klusman, R. W., and Jaacks, J. A., 1987, Environmental influences upon mercury, radon, and helium concentrations in soil gases at a site near Denver, Colorado: Journal of Geochemical Exploration, v. 27, p. 259-280.

Kovach, E.M., 1945, Meteorological influences upon the radon content of soil gas: Transactions, American Geophysical Union, v. 26, p. 241-248.

Kunz, C., Laymon, C.A., and Parker, C., 1989, Gravelly soils and indoor radon, *in* Osborne, M.C., and Harrison, J., eds., Proceedings of the 1988 EPA Symposium on Radon and Radon Reduction Technology, Volume 1: U.S. Environmental Protection Agency Report EPA/600/9-89/006A, p. 5-75--5-86.

Muessig, K., and Bell, C., 1988, Use of airborne radiometric data to direct testing for elevated indoor radon: Northeastern Environmental Science, v. 7, no. 1, p. 45-51.

Ronca-Battista, M., Moon, M., Bergsten, J., White, S.B., Holt, N., and Alexander, B., 1988, Radon-222 concentrations in the United States--Results of sample surveys in five states: Radiation Protection Dosimetry, v. 24, p. 307-312.

Rose, A.W., Washington, J.W., and Greeman, D.J., 1988, Variability of radon with depth and season in a central Pennsylvania soil developed on limestone: Northeastern Environmental Science, v. 7, p. 35-39.

Schery, S.D., Gaeddert, D.H., and Wilkening, M.H., 1984, Factors affecting exhalation of radon from a gravelly sandy loam: Journal of Geophysical Research, v. 89, p. 7299-7309.

Schumann, R.R., and Owen, D.E., 1988, Relationships between geology, equivalent uranium concentration, and radon in soil gas, Fairfax County, Virginia: U.S. Geological Survey Open-File Report 88-18, 28 p.

Schumann, R.R., and Gundersen, L.C.S., 1991, Regional differences in radon emanation coefficients in soils: Geological Society of America Abstracts With Programs, v. 23, no. 1, p. 125.

Schumann, R.R., Peake, R.T., Schmidt, K.M., and Owen, D.E., 1991, Correlations of soil-gas and indoor radon with geology in glacially derived soils of the northern Great Plains, *in* Proceedings of the 1990 International Symposium on Radon and Radon Reduction Technology, Volume 2, Symposium Oral Papers: U.S. Environmental Protection Agency report EPA/600/9-91/026b, p. 6-23--6-36.

Schumann, R.R., Owen, D.E., and Asher-Bolinder, S., 1992, Effects of weather and soil characteristics on temporal variations in soil-gas radon concentrations, *in* Gates, A.E., and Gundersen, L.C.S., eds., Geologic controls on radon: Geological Society of America Special Paper 271, p. 65-72.

Sextro, R.G., Moed, B.A., Nazaroff, W.W., Revzan, K.L., and Nero, A.V., 1987, Investigations of soil as a source of indoor radon, *in* Hopke, P.K., ed., Radon and its decay products: American Chemical Society Symposium Series 331, p. 10-29.

Sterling, R., Meixel, G., Shen, L., Labs, K., and Bligh, T., 1985, Assessment of the energy savings potential of building foundations research: Oak Ridge, Tenn., U.S. Department of Energy Report ORNL/SUB/84-0024/1.

Smith, R.C., II, Reilly, M.A., Rose, A.W., Barnes, J.H., and Berkheiser, S.W., Jr., 1987, Radon: a profound case: Pennsylvania Geology, v. 18, p. 1-7.

Tanner, A.B., 1964, Radon migration in the ground: a review, *in* Adams, J.A.S., and Lowder, W.M., eds., The natural radiation environment: Chicago, Ill., University of Chicago Press, p. 161-190.

Tanner, A.B., 1980, Radon migration in the ground: a supplementary review, *in* Gesell, T.F., and Lowder, W.M. (eds), Natural radiation environment III, Symposium proceedings, Houston, Texas, v. 1, p. 5-56.

U.S. Department of Agriculture, 1987, Principal kinds of soils: Orders, suborders, and great groups: U.S. Geological Survey, National Atlas of the United States of America, sheet 38077-BE-NA-07M-00, scale 1:7,500,000.

U.S. Department of Energy, 1976, National Uranium Resource Evaluation preliminary report, prepared by the U.S. Energy Research and Development Administration, Grand Junction, Colo.: GJO-11(76).

Wanty, Richard B., and Schoen, Robert, 1991, A review of the chemical processes affecting the mobility of radionuclides in natural waters, with applications, *in* Gundersen, Linda C.S., and Richard B. Wanty, eds., Field studies of radon in rocks, soils, and water: U.S. Geological Survey Bulletin no. 1971, p. 183-194.

Washington, J.W., and Rose, A.W., 1990, Regional and temporal relations of radon in soil gas to soil temperature and moisture: Geophysical Research Letters, v. 17, p. 829-832.

White, S.B., Bergsten, J.W., Alexander, B.V., and Ronca-Battista, M., 1989, Multi-State surveys of indoor ^{222}Rn: Health Physics, v. 57, p. 891-896.

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 (Ꞧ)		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 (P)	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 (pЄ), 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

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841 Chestnut Street
Philadelphia, PA 19107
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EPA Region 4
345 Courtland Street, N.E.
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EPA Region 5 (5AR26)
77 West Jackson Blvd.
Chicago, IL 60604-3507
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EPA Region 6 (6T-AS)
1445 Ross Avenue
Dallas, TX 75202-2733
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EPA Region 7
726 Minnesota Avenue
Kansas City, KS 66101
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San Francisco, CA 94105
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1200 Sixth Avenue
Seattle, WA 98101
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State	EPA Region
Alabama	4
Alaska	10
Arizona	9
Arkansas	6
California	9
Colorado	8
Connecticut	1
Delaware	3
District of Columbia	3
Florida	4
Georgia	4
Hawaii	9
Idaho	10
Illinois	5
Indiana	5
Iowa	7
Kansas	7
Kentucky	4
Louisiana	6
Maine	1
Maryland	3
Massachusetts	1
Michigan	5
Minnesota	5
Mississippi	4
Missouri	7
Montana	8
Nebraska	7
Nevada	9
New Hampshire	1
New Jersey	2
New Mexico	6
New York	2
North Carolina	4
North Dakota	8
Ohio	5
Oklahoma	6
Oregon	10
Pennsylvania	3
Rhode Island	1
South Carolina	4
South Dakota	8
Tennessee	4
Texas	6
Utah	8
Vermont	1
Virginia	3
Washington	10
West Virginia	3
Wisconsin	5
Wyoming	8

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STATE GEOLOGICAL SURVEYS

May, 1993

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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

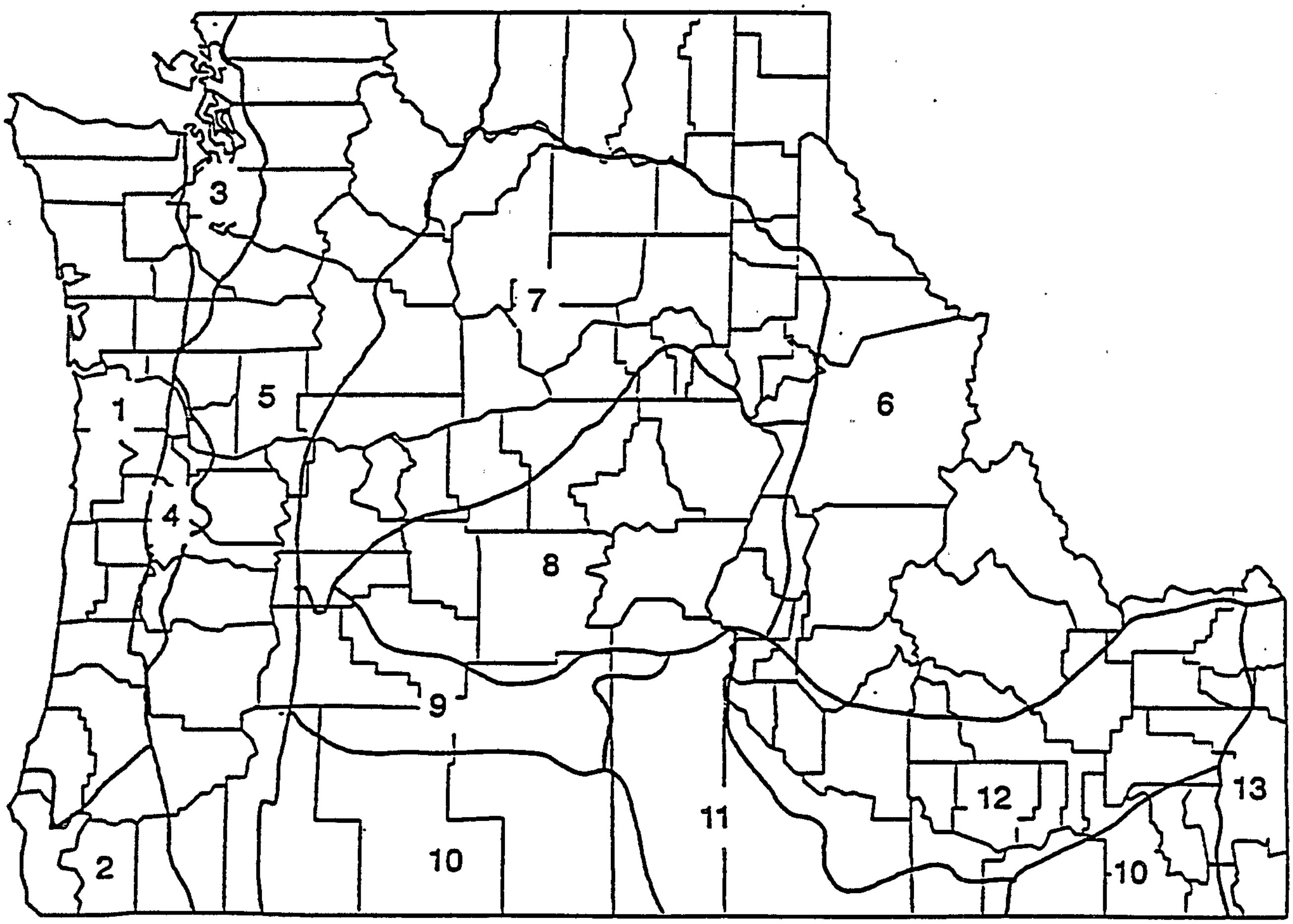


Figure 1- Radon geologic provinces of the Pacific Northwest (generalized from state chapters included in this report). 1- Coast Ranges; 2- Klamath Mountains; 3- Puget Lowland; 4- Willamette River Valley; 5- Cascade Range; 6- Northern Rocky Mountains; 7- Columbia Plateau; 8- Blue Mountains; 9- High Lava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

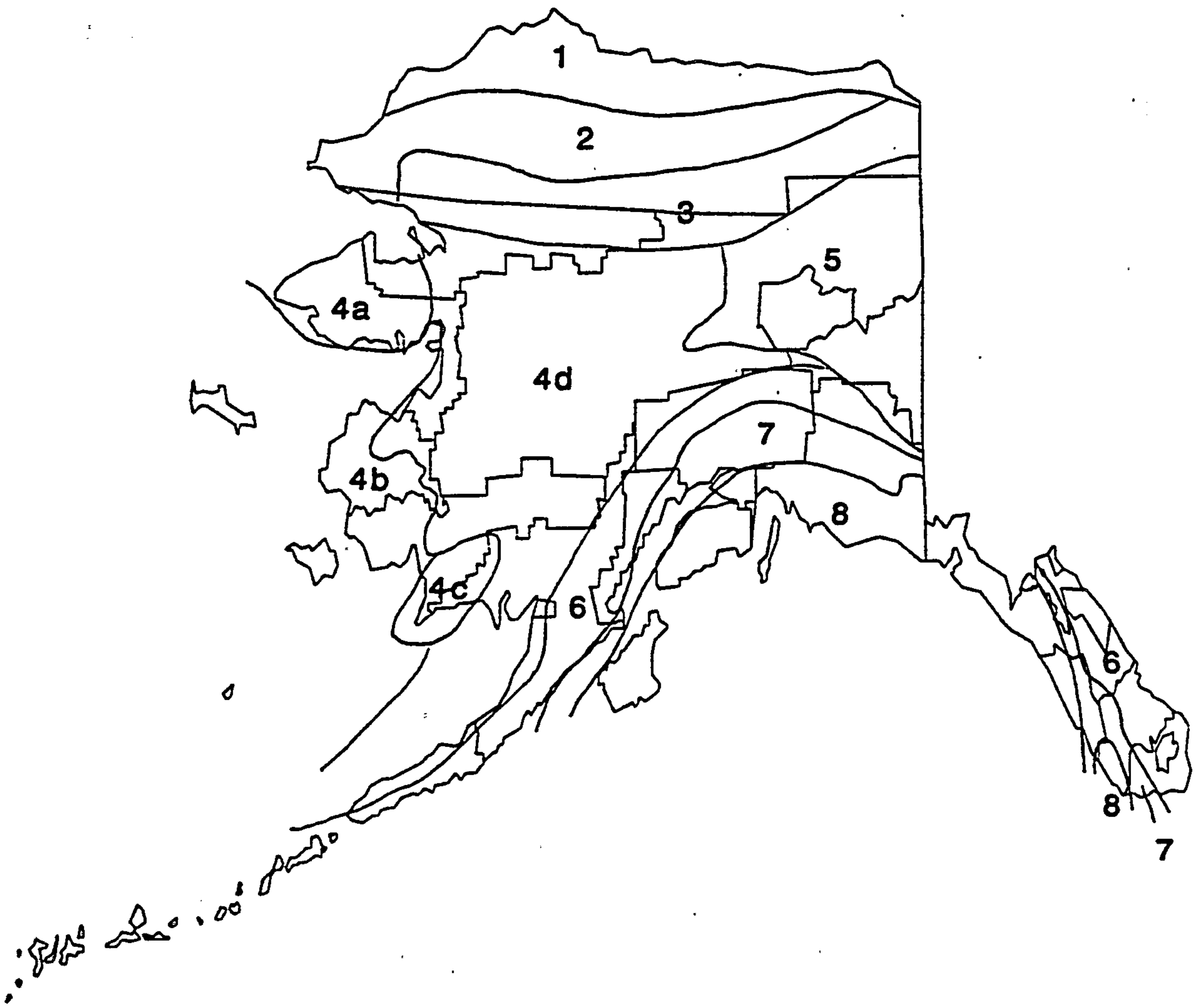


Figure 2- Physiographic provinces of Alaska (from the state chapter included in this report). 1- Arctic Coastal Plain; 2- Arctic Foothills; 3- Arctic Mountains; 4- Central Province, 4a- Seward Peninsula, 4b- Bering Shelf, 4c- Ahklun Mountains, 4d- Western Alaska, 4e- Northern Plateaus; 5- Alaska-Aleutian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

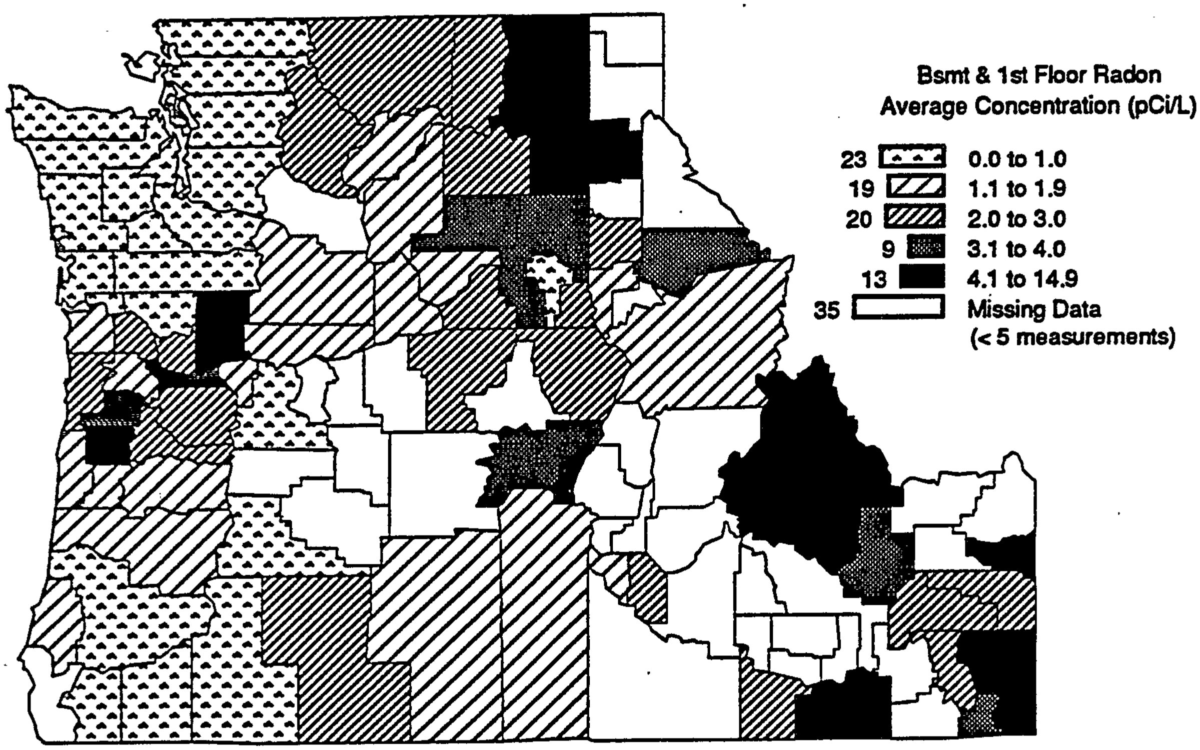


Figure 3A. Screening indoor radon data from the State/EPA Residential Radon Survey and the Oregon Radon Project, for counties with 5 or more measurements in the conterminous part of EPA Region 10. Histograms in map legends show the number of counties in each category. The number of samples in each county 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.

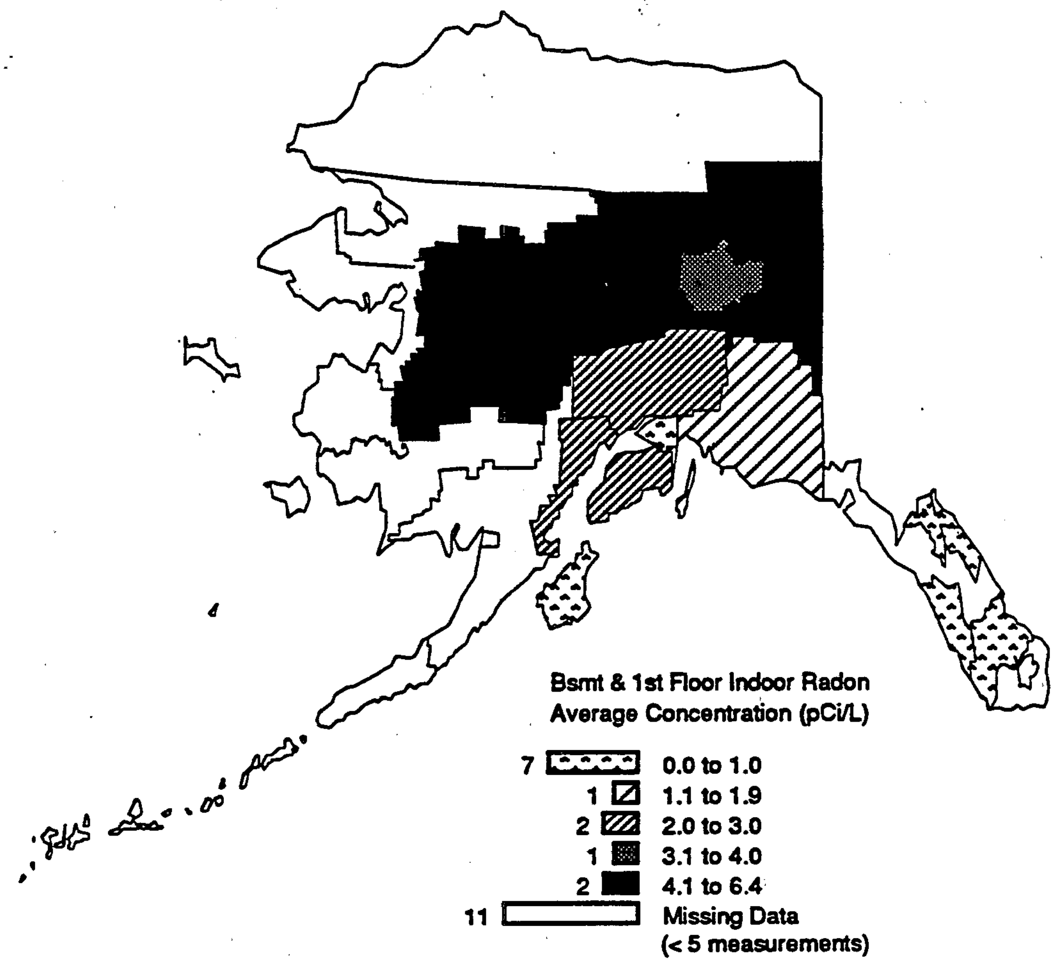


Figure 3B. Screening indoor radon data from the State/EPA Residential Radon Survey of Alaska, for counties with 5 or more measurements. Data are from 2-7 day charcoal canister tests. Histograms in map legends show the number of counties in each category. The number of samples in each county may not be 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 OREGON

by
James K. Otton
U.S. Geological Survey

INTRODUCTION

Oregon is a state of varied geologic and climatic settings and varied radon potential. This assessment of the radon potential of the state relied heavily on data provided by studies of indoor radon by the Oregon Division of Health and the Bonneville Power Administration (BPA), previous work by Duval, Otton, and Jones (1989) and Otton and Duval (1990), and geologic information derived from publications of the U.S. Geological Survey and the Oregon Department of Geology and Mineral Industries. Much information in the geographic setting section is derived from the National Atlas of the United States.

This is a generalized assessment of geologic radon potential of rocks, soils, and surficial deposits of Oregon. 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

Oregon is divisible into several physiographic provinces (fig. 1). The Coast Ranges lie along the Pacific coast and are dominated by low mountains with a relief of 1000-3000 feet. Southward the Coast Ranges give way to the Klamath Mountains where relief is generally greater than 3000 feet. Throughout these two areas less than 20 percent of the surface is gently sloping. The Willamette River Valley lies to the east of and parallels the Coast Ranges, but the valley dies out a little south of the central part of the state. The river valley is an area of plains and hills where 50-80 percent of the land's surface is gently sloping and the rest is hilly. The local relief ranges 300-500 feet. The Cascade Range lies east of the Willamette River Valley and the Klamath Mountains. The western Cascades are characterized by high mountains where greater than 80 percent of the land is steeply sloping and relief exceeds 3000 feet. The east side of the Cascades (the high Cascades) is marked by open high mountains where 20-50 percent of the land is gently sloping and the relief exceeds 3000 feet. The Deschutes-Umatilla Plateau (fig. 1) is characterized by tablelands of high relief (1000-3000 feet) where 50-80 percent of the land is gently sloping and greater than 75 percent of the gently sloped areas are in the uplands. The Blue Mountains and adjacent Joseph Upland are marked by open low (1000-3000 feet of relief) to open high (more than 3000 feet of relief) mountains where 20-50 percent of the area is gently sloping (fig. 1) and the rest is steeply sloping. The eastern boundary of the latter two areas is formed by the Snake River

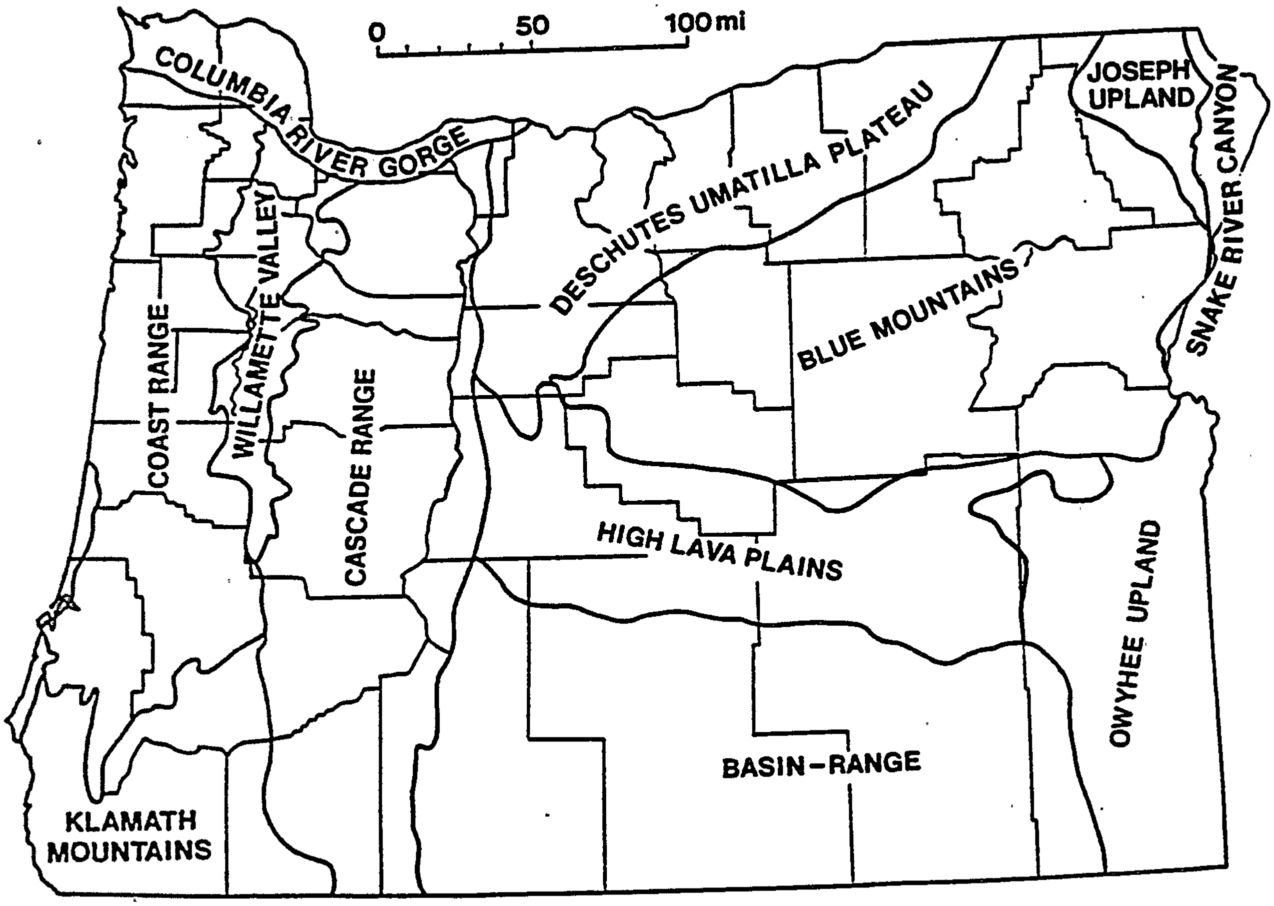


Figure 1- Physiographic divisions of Oregon. (Modified from U.S. Geological Survey, 1969).

Canyon along the Oregon-Idaho border. South of the Blue Mountains are the High Lava Plains, which are characterized by plains with high hills (500-1000 feet of relief) to low mountains (1000-3000 feet of relief) (fig. 1). The Basin and Range area of south-central Oregon is characterized by plains with high hills (500-1000 feet of relief), low mountains (1000-3000 feet of relief), and two high mountain ridges (greater than 3000 feet of relief) near the southern border of the state. The Owyhee Upland is underlain by tablelands of considerable relief (500-1000 feet). Fifty to eighty percent of these latter three areas are gently sloping and the rest is steeply sloping.

Precipitation ranges from 48 to 96 inches per year throughout most of the Coast Ranges and the Cascade Mountains. The Willamette River Valley receives 32 to 48 inches of rain per year. Most of the rest of Oregon is relatively dry with the interior areas east of the Cascades receiving only 8 to 16 inches of precipitation per year except for the Blue Mountains where 16 to 48 inches of precipitation fall.

Most people in Oregon live in cities and towns extending along the Willamette River valley from Portland to Eugene (fig. 2). The remainder of the population lives in coastal towns, in a series of communities in valleys south of Eugene, and in scattered communities in north-central and northeastern Oregon. Desert areas of southeastern Oregon are sparsely populated.

Most of the Coast Ranges and the Cascade Mountains are forest and woodland areas, but some cropland and pasture areas occur adjacent to the coast. The Willamette River valley is used mostly for cropland and, to a lesser extent, for pasture, woodland, and forest. The Deschutes-Umatilla Plateau includes cropland, and grasslands used for grazing. The Blue Mountains contain areas of grassland and semiarid shrublands used for grazing at lower altitudes and forest and woodlands used for grazing at higher altitudes. The Basin and Range and Owyhee Plateau of southeastern Oregon is dominated by desert shrubland used for grazing.

GEOLOGIC SETTING

The northern Coast Ranges are underlain principally by marine sedimentary rocks and mafic volcanic rocks of Tertiary age (fig. 3). The southern part of the Coast Range is underlain by Tertiary estuarine and marine sedimentary rocks that are commonly feldspathic and micaceous. The Klamath Mountains are dominated by Triassic to Jurassic metamorphic, volcanic, and sedimentary rocks but also contain some Cretaceous intrusive rocks. The metamorphic and volcanic rocks are largely of mafic composition. Large masses of ultramafic rocks occur throughout the Klamath area.

River alluvium and river terraces occur along most of the Willamette River valley, but many of the hills that rise above the plains are underlain by Tertiary basalts and marine sedimentary rocks. The western Cascades are dominated by Tertiary andesite and basalt flows and pyroclastic rocks. The eastern Cascades are underlain by late Tertiary to Quaternary basaltic and andesitic volcanic rocks and several recently active volcanoes. Extensive areas underlain by pumice and ash occur near Crater Lake.

The Deschutes-Umatilla Plateau is underlain principally by Tertiary basalt, basaltic breccia, tuffaceous sedimentary rocks and tuff. Thin surficial deposits composed of lacustrine sediments, glaciofluvial outwash, loess, and pediment gravels form much of the northeastern part of this plateau. The Blue Mountains and Joseph Upland are comprised mainly of Tertiary basalt and andesite, tuffaceous sedimentary rocks, and tuff; however, Triassic and Jurassic sedimentary and volcanic rocks and later intrusive rocks core uplifts in this area. The sedimentary and volcanic rocks are weakly metamorphosed in many areas.

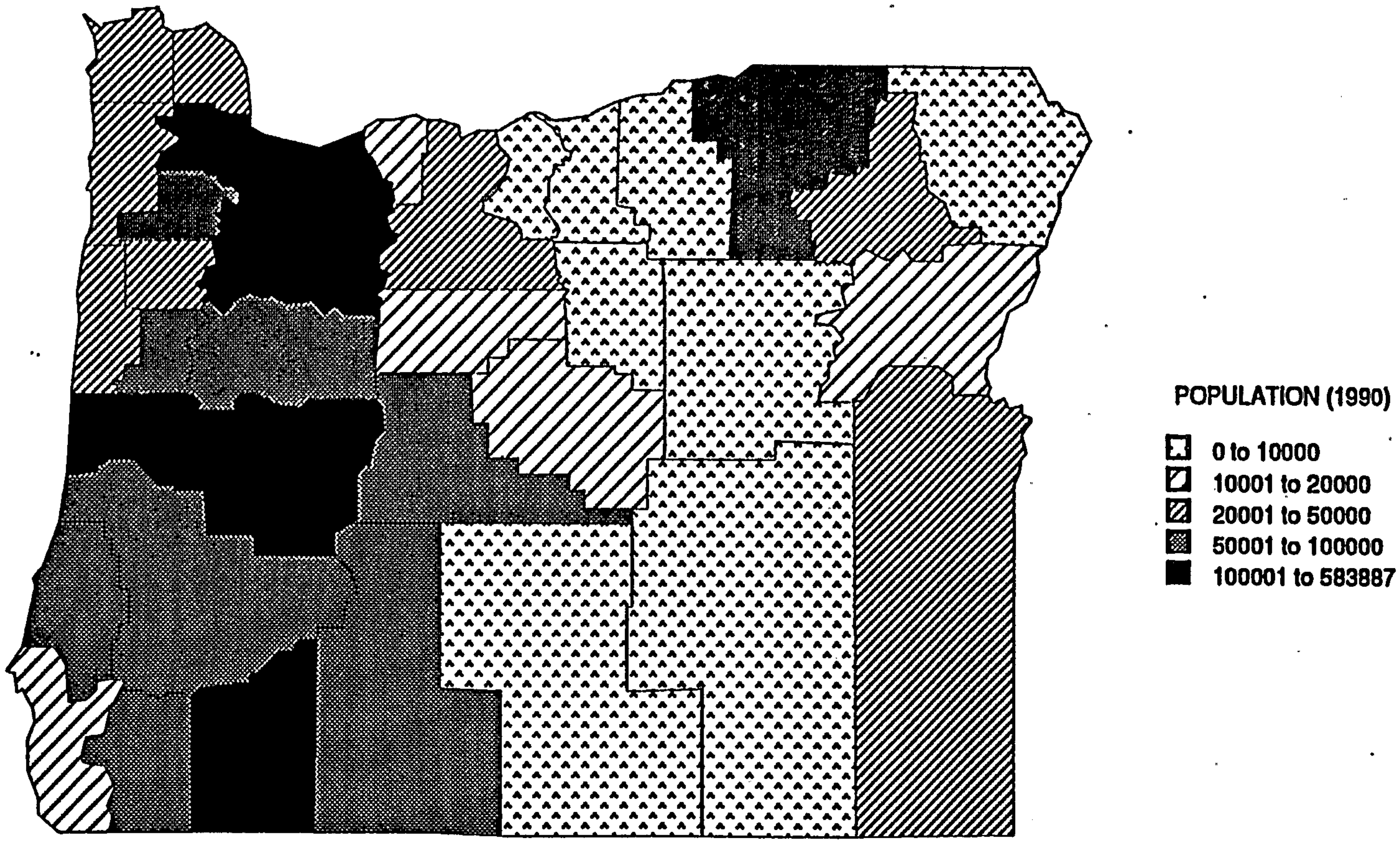


Figure 2. Population of counties in Oregon (1990 U.S. Census data).

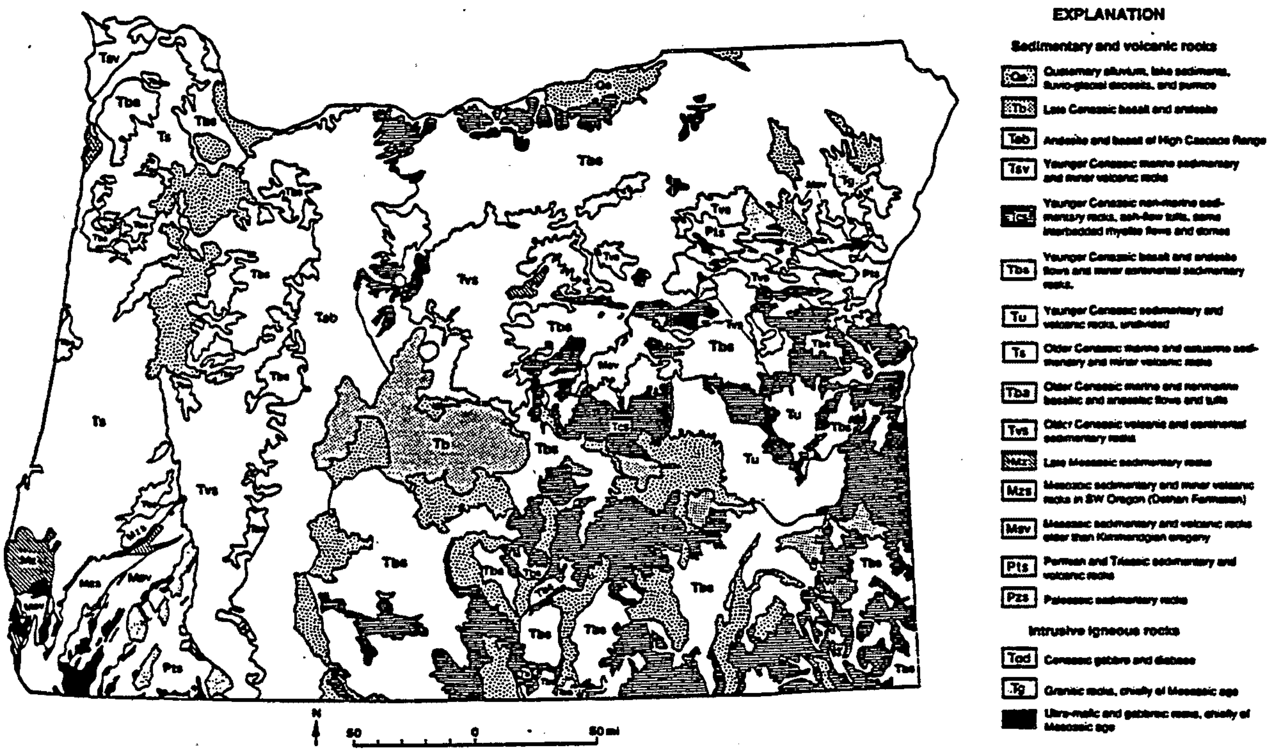


Figure 3- Generalized geologic map for the State of Oregon. (From U.S. Geological Survey, 1969).

The High Lava Plains are underlain by basalt flows of late Tertiary and Quaternary age and Tertiary silicic ash-flow tuff. The Basin and Range Province of Oregon is an area of basaltic to andesitic volcanic rocks, silicic ash-flow tuffs, some of them welded tuffs, and sediments derived from these units. Playa basins dot the landscape. The Owyhee Plateau is underlain by 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.

Aeroradiometric data for the state of Oregon (fig. 4) show that surface materials from the Cascade Range westward contain generally less than 1.5 ppm equivalent uranium (eU), with the exception of the Willamette River Valley, where eU values as much as 2.5 ppm are recorded locally. The northern and southern Coast Ranges show significantly different signatures, with the northern parts, underlain mostly by mafic volcanic rocks, being less than 0.5 ppm eU whereas the southern part, underlain by micaceous and feldspathic sedimentary rocks, ranging from 0.5-1.5 ppm eU. The Klamath Mountains are mixed in their eU signature with some metamorphosed sedimentary rocks and granites showing as much as 2.5 ppm, whereas the ultramafic rocks and other metamorphosed mafic volcanic rocks and sedimentary rocks show less than 1 ppm eU. East of the Cascades, much of the western part of the Basin and Range, and the Blue Mountains are very low in eU, ranging from 0.0 to 1.5 ppm. A broad area of elevated eU values (as much as 3.5 ppm in Umatilla County) occurs northwest of the Blue Mountains in the Deschutes-Umatilla Plateau in Sherman, Gilliam, Morrow and Umatilla Counties (fig. 5). Underlying bedrock in this area consists of basalts of the Columbia basin. Basalts are generally low in uranium content (<1 ppm), however, it appears that the elevated eU signatures in this area are due to surficial deposits of loess and eolian sand derived from the nearby Columbia River Valley. Sediment in the Columbia River Valley is derived in large part from more uraniferous rocks in the northeast corner of Washington and northern Idaho, transported to this part of the area by major late Pleistocene floods.

In the eastern Basin and Range and the Owyhee Plateau, a patchwork of elevated (1.5-4.5 ppm) and low eU (0.5-1.5) values occurs. Elevated eU values appear to be associated with Tertiary silicic volcanic centers and sediments derived from those rocks whereas lower eU values are associated with basaltic and andesitic rocks. Two areas of uranium deposits near the Lakeview area (southern Harney County) and the northern McDermitt caldera area (southern Malheur County) are marked by fairly intense eU signatures (as much as 5.0 ppm).

Most uranium occurrences in Oregon are found in the Basin and Range Province where they are associated with rhyolitic volcanic centers; however, they are also scattered elsewhere in the Blue Mountains, the Klamath Mountains, and the southern part of the Coast Ranges, where they are associated with various sedimentary, volcanic, and intrusive rocks.

SOILS

As part of an earlier study for the Bonneville Power Administration, Duval and others (1989) evaluated permeability data in the county soil surveys for 24 of the 36 counties in the state (fig. 6). They compiled a map of the highly permeable soil associations (those soil associations dominated by soils with percolation tests greater than 6 in/hr) in those 24 counties (fig. 7). Highly permeable soils occur mainly in the upper Willamette River valley, along parts of the Columbia River valley, in the Milton-Freewater area, and in some coastal areas.

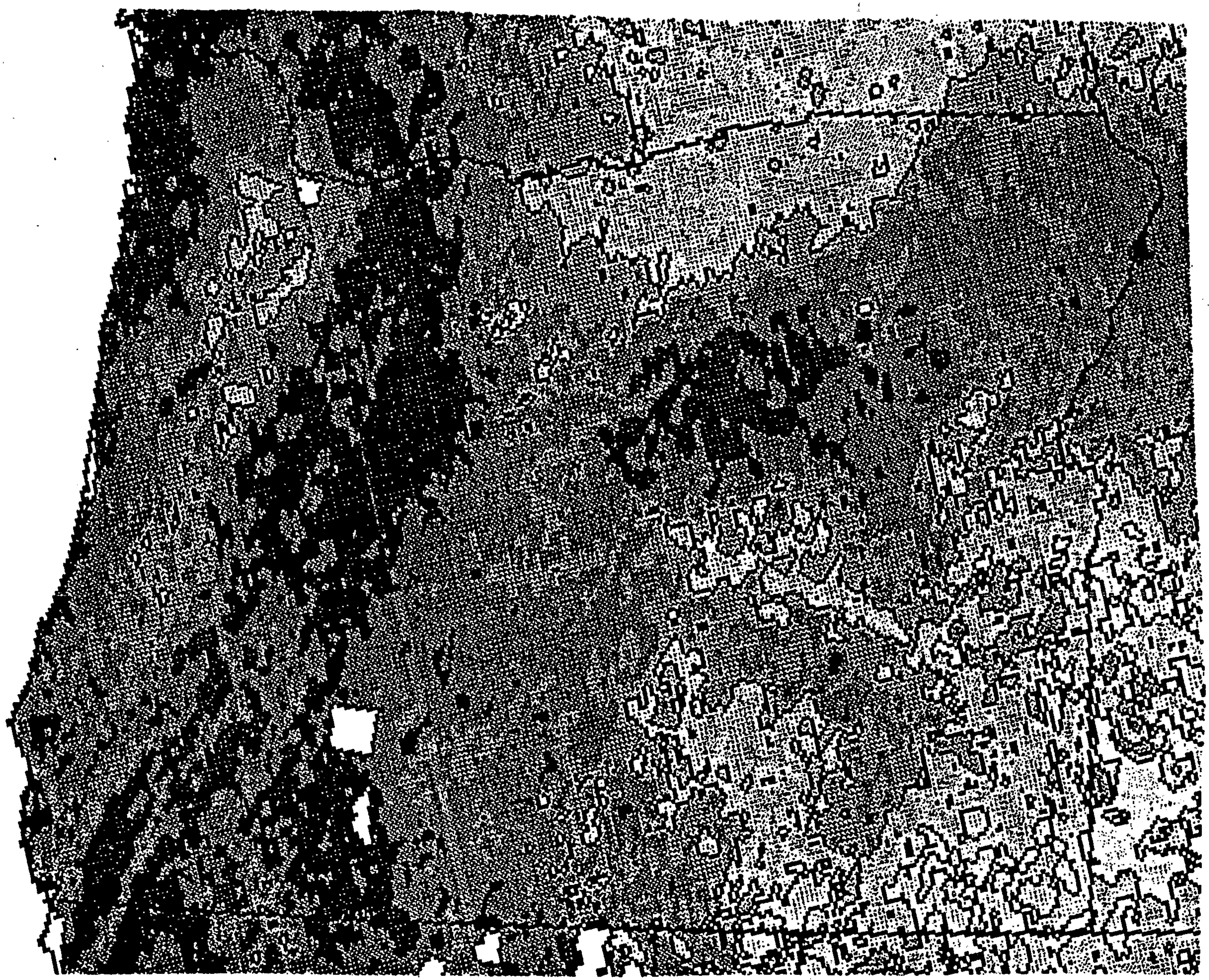


Figure 4- Aerial radiometric map of Oregon (after Duval and others, 1989). Contour lines at 1.5 and 2.5 ppm equivalent uranium (eU). Pixels shaded from 0 to 6.0 ppm eU at 0.5 ppm eU increments; darker pixels have lower eU values; white indicates no data.

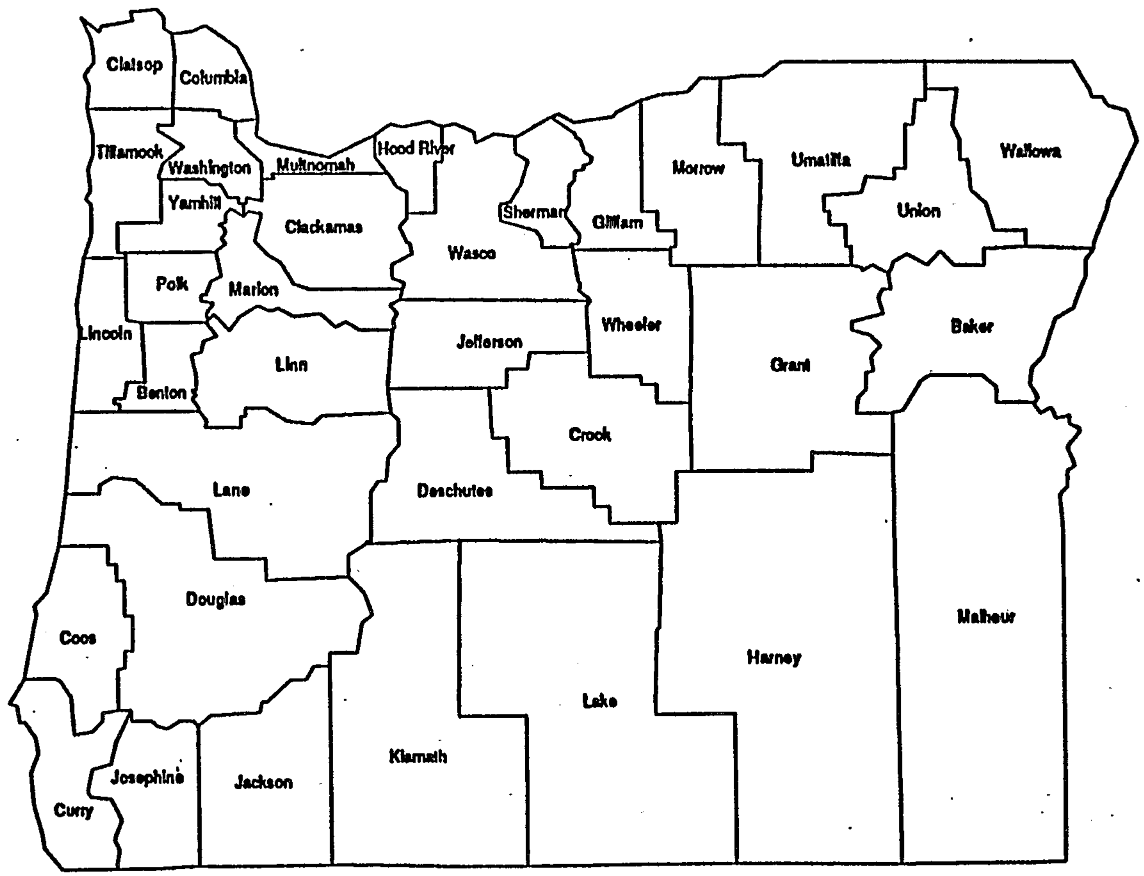
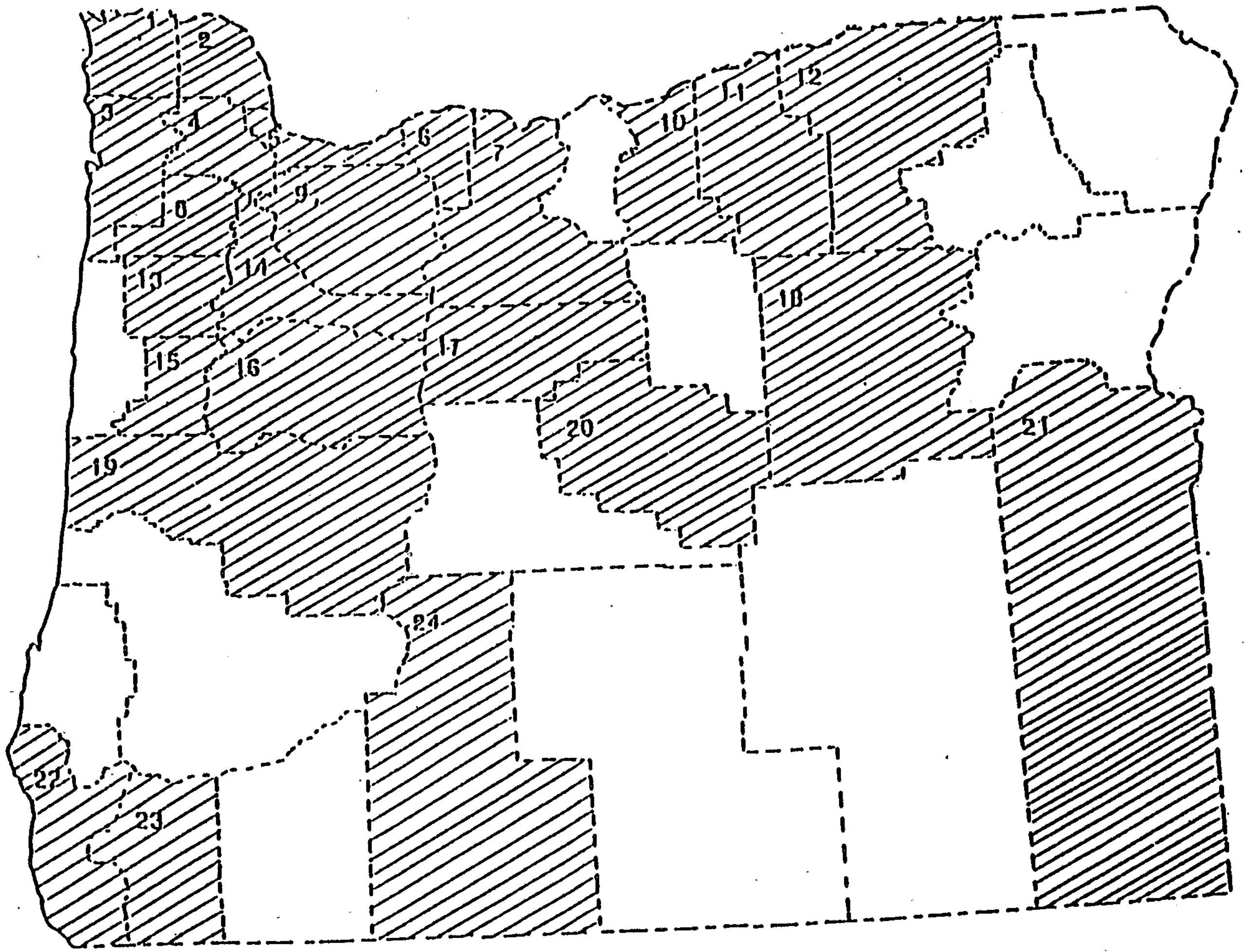


Figure 5- Map showing counties in the state of Oregon



Oregon: 1-Clatsop; 2-Columbia; 3-Tillamook; 4-Washington; 5-Multnomah; 6-Hood River; 7-Wasco; 8-Yamhill; 9-Clackamas; 10-Gilliam; 11-Morrow; 12-Umatilla; 13-Polk; 14-Marion; 15-Benton; 16-Linn; 17-Jefferson; 18-Grant; 19-Lane; 20-Crook; 21-Malheur; 22-Curry; 23-Josephine; 24-Klamath

Figure 6- Map showing counties studied by Duval and others (1989) to assess areas underlain by soil associations dominated by highly permeable soils (>6 in/hr in percolation tests).

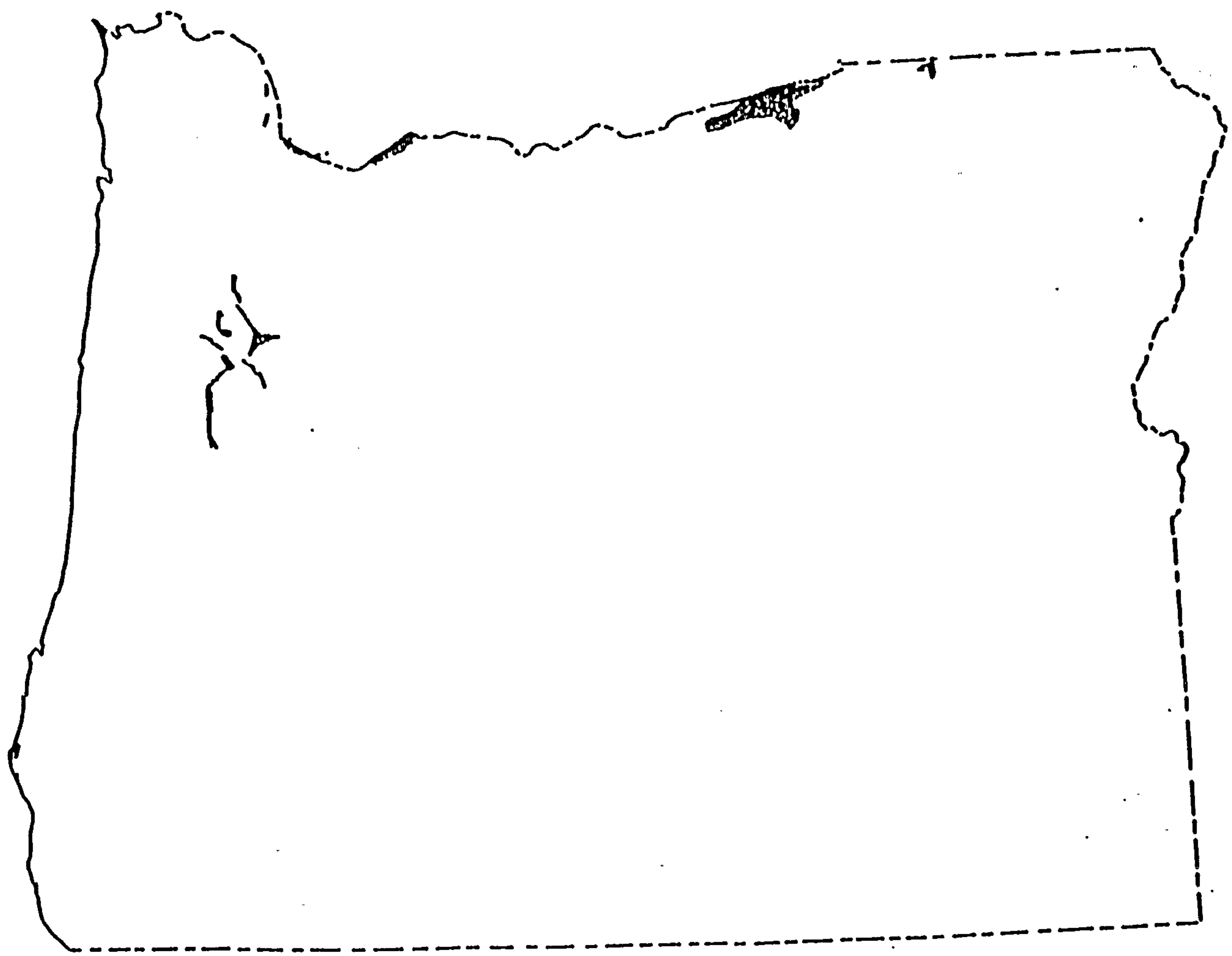


Figure 7- Map showing areas underlain by soil associations dominated by highly permeable soils (>6 in/hr in a percolation test) within the State of Oregon as assessed by Duval and others (1989).

Soils of the west flank of the Coast Range and all of the Cascades are typically very moist in the wintertime (pore space saturation ranges from 56-96 percent for a sandy loam and 74-99 percent for a silty clay loam) and moderately moist in the summertime (pore space saturation ranges 44-56 percent for a sandy loam and 58-74 percent for a silty clay loam) (Rose and others, 1990). Within the Willamette River Valley, on the east flank of the Coast Ranges, and on the Deschutes-Umatilla Plateau, soils are typically very moist in the winter (pore space saturation ranges 56-96 percent for a sandy loam and 74-99 percent for a silty clay loam) and slightly moist in the summer (pore space saturation ranges 24-44 percent for a sandy loam and 39-58 for a silty clay loam). In the Blue Mountains and the westernmost Basin and Range the soils are very moist in the winter (pore space saturation ranges from 56-96 percent for a sandy loam and 74-99 percent for a silty clay loam) and moderately moist in the summer (pore space saturation ranges 44-56 percent for a sandy loam and 58-74 percent for a silty clay loam). In the southeastern quadrant of the state soils are typically slightly moist in the winter (pore space saturation ranges 24-44 percent for a sandy loam and 39-58 for a silty clay loam) and slightly dry in the summer (pore space saturation ranges 4-24 percent in a sandy loam and 6-39 percent for a silty clay loam).

INDOOR RADON DATA

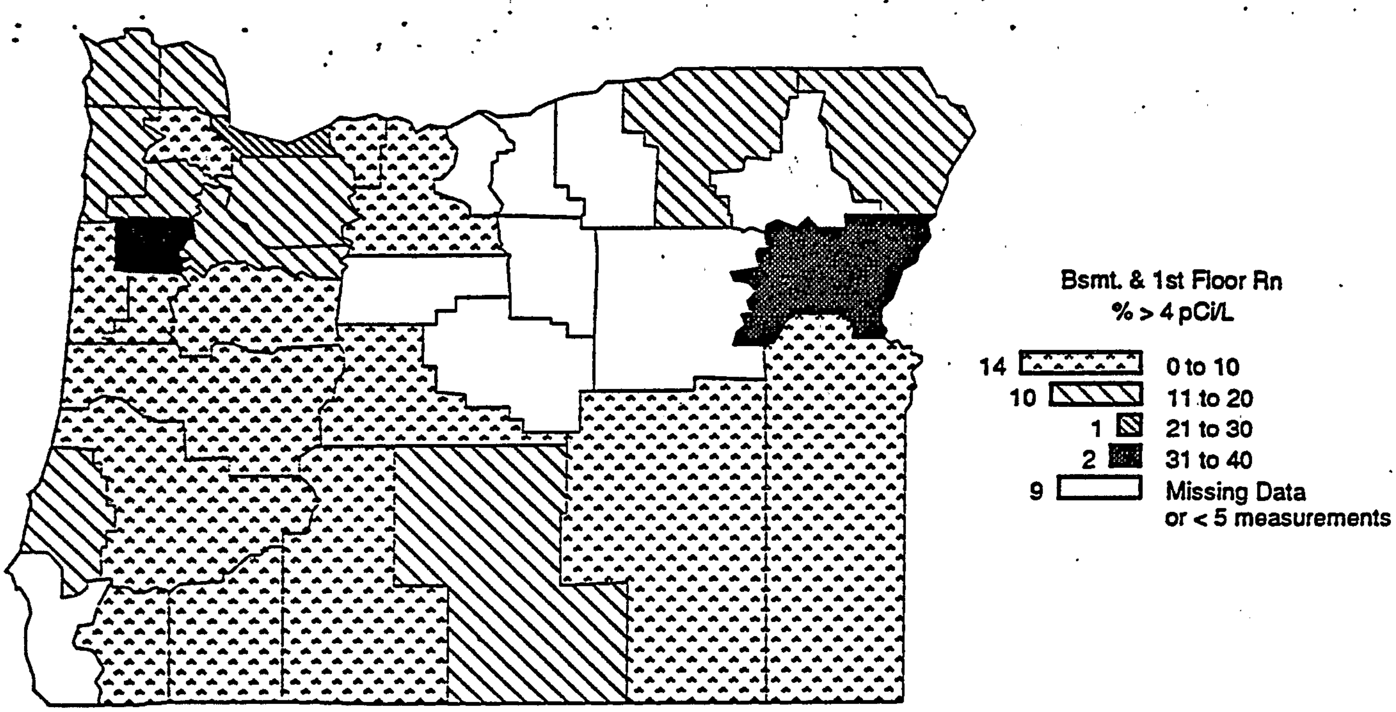
Indoor radon data for Oregon were gathered during the Oregon Radon Project conducted by the Oregon Division of Health during 1988-1990 (Table 1, fig. 8). Data are composed of 1,954 randomly-sampled 12-month alpha-track detector measurements. These data show that counties whose major population centers lie along the Columbia River Gorge and the Willamette River Valley generally have average indoor radon levels in the 2-4 pCi/L range. Polk County averages 7.2 pCi/L. Highest county maximum readings for the State also occur in this area. Three Pacific coastal counties also range 2-4 pCi/L. Averages for three northeastern counties range 2-4 pCi/L and Union County in the northeast has a single value of 3.3 pCi/L. Lake County in the south-central part of the State averages 2.8 pCi/L.

Another source for indoor radon data in the State of Oregon is an extended study conducted by the Bonneville Power Administration (BPA). Indoor radon tests were offered as part of BPA's weatherization program, extended to homeowners across its service area (parts of the states of Washington, Oregon, Idaho, Montana, and Wyoming). Three month, wintertime alpha-track measurements were made in participants' homes starting in the fall of 1985. The resultant data were gathered on a township location system and are portrayed in figure 9. In this figure all those townships with less than 5 measurements are shown but no data are given. For those townships with at least 5 measured houses, the percentage of those homes greater than 5 pCi/L is represented in 4 categories: 0 percent, 0-5 percent, 5-10 percent, and greater than 10 percent (5 pCi/L was used as an index by BPA under the assumption that a 5 pCi/L wintertime measurement would approximately equal a 4 pCi/L year-long measurement). Most of the indoor radon data for the State of Oregon in the BPA data set come from the populous areas of western Oregon.

Examination of data tables for the townships in Oregon from this study (Bonneville Power Administration, 1990) show the following:

1. Of 151 townships in Oregon with at least 5 measurements, 17 townships averaged greater than 2 pCi/L and 2 averaged greater than 4 pCi/L.

2. Overall, 513 of 12,079 measurements (4.2 percent) for the State equalled or exceeded 4 pCi/L.



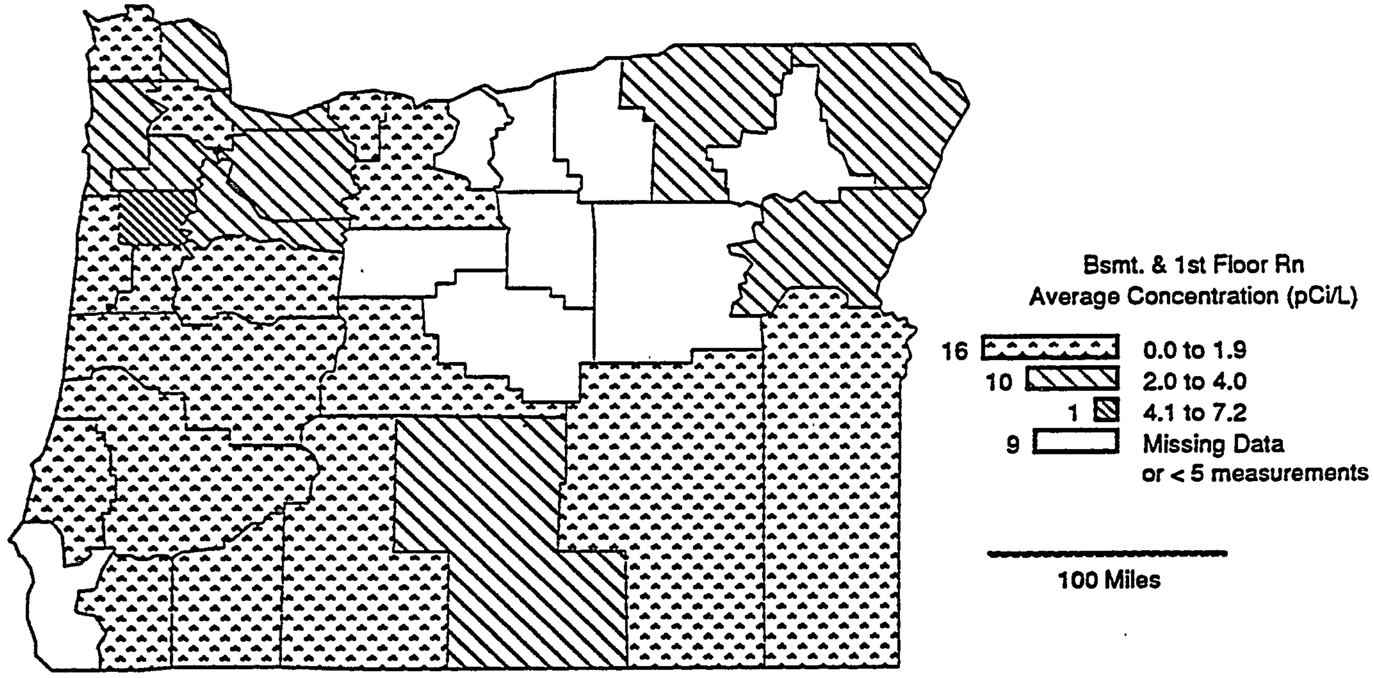


Figure 8. Indoor radon data from the Oregon Radon Project conducted by the Orgeon Division of Health, 1988-90, for counties with 5 or more measurements. Data are from 12-month alpha-track tests. Histograms in map legends show the number of counties in each category. The number of samples in each county (See Table 1) 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.

TABLE 1. Indoor radon data from the Oregon Radon Project conducted by the Oregon Division of Health. Data represent randomly-sampled12-month Alpha-track detector measurements collected during 1988-1990.

COUNTY	NO. OF MEAS.	MEAN	GEOM. MEAN	MEDIAN	STD. DEV.	MAXIMUM	%>4 pCi/L	%>20 pCi/L
BAKER	19	3.2	1.9	1.5	3.2	10.0	32	0
BENTON	108	1.2	0.9	0.9	1.1	6.0	4	0
CLACKAMAS	156	2.2	1.6	1.6	2.7	25.5	15	1
CLATSOP	29	1.4	0.8	0.5	2.4	8.7	14	0
COLUMBIA	9	2.6	2.3	2.2	1.6	6.0	11	0
COOS	38	1.9	1.2	1.1	2.6	15.6	11	0
CROOK	1	0.1	0.1	0.1	***	0.1	0	0
CURRY	1	0.8	0.8	0.8	***	0.8	0	0
DESCHUTES	42	0.8	0.5	0.5	1.2	7.2	2	0
DOUGLAS	21	0.7	0.6	0.4	0.9	3.4	0	0
GRANT	1	1.0	1.0	1.0	***	1.0	0	0
HARNEY	8	1.4	1.0	1.0	1.2	3.6	0	0
HOOD RIVER	21	1.5	1.1	0.8	1.1	3.3	0	0
JACKSON	135	1.0	0.7	0.7	1.2	6.0	4	0
JEFFERSON	2	0.7	0.6	0.7	0.4	0.9	0	0
JOSEPHINE	63	0.7	0.5	0.4	0.9	5.3	2	0
KLAMATH	31	0.6	0.5	0.4	0.7	3.1	0	0
LAKE	13	2.8	1.7	1.8	3.1	11.5	15	0
LANE	79	1.6	1.0	0.9	2.3	15.4	8	0
LINCOLN	11	1.6	1.2	0.9	2.2	7.8	9	0
LINN	57	1.3	0.9	0.9	1.4	5.9	7	0
MALHEUR	10	1.3	1.4	1.4	0.7	2.7	0	0
MARION	136	2.0	1.3	1.2	2.8	25.2	13	1
MORROW	2	1.4	1.3	1.4	0.5	1.7	0	0
MULTNOMAH	611	3.3	2.1	2.1	3.9	35.5	25	1
POLK	29	7.2	3.1	2.4	12.2	48.8	31	14
TILLAMOOK	9	2.3	1.7	2.4	1.7	5.7	11	0
UMATILLA	40	2.6	1.6	1.7	3.0	14.0	20	0
UNION	1	3.3	3.3	3.3	***	3.3	0	0
WALLOWA	8	2.2	0.8	0.3	3.4	9.9	13	0
WASCO	8	0.9	0.6	0.5	1.1	3.4	0	0
WASHINGTON	225	1.7	1.2	1.2	1.8	13.9	6	0
WHEELER	2	0.6	1.1	0.6	0.8	1.1	0	0
YAMHILL	28	3.4	2.1	1.9	4.5	20.9	18	4

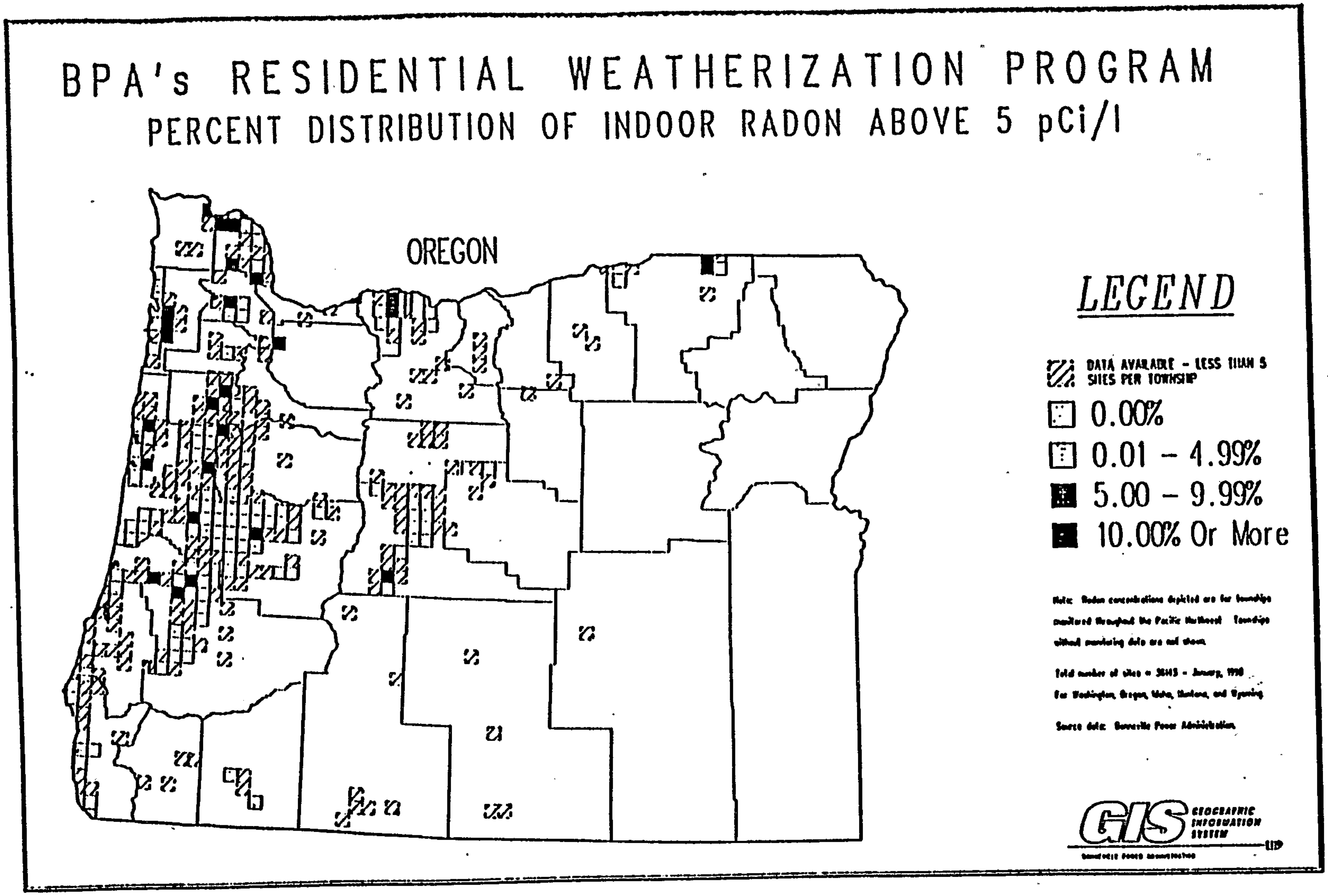


Figure 9- BPA's residential weatherization program, percent distribution of indoor radon above 5 pCi/L for the State of Oregon. Source- Bonneville Power Administration, 1990.

3. Townships averaging greater than 2 pCi/L are located along the Columbia River Valley; in scattered areas in the upper Willamette River Valley; in some river valleys in the central and southern Coast Range; and in the Milton-Freewater area (northeast Umatilla County).

GEOLOGIC RADON POTENTIAL

The available data suggest that selected parts of several counties across the State are likely to have average indoor radon levels above 2 pCi/L and a few areas are likely to have average levels above 4 pCi/L. In some counties these local areas may be sufficiently widespread to cause the countywide average to exceed 2 or even 4 pCi/L.

In the central and southern Coast Range, eU values are sufficiently elevated that, in spite of high soil moisture due to high precipitation, elevated indoor radon levels are likely where soils are highly permeable or steeply sloping. This can occur in many soils developed on coarse alluvial deposits along the several river valleys that cut through the Coast Range. Soils formed on sand dunes in coastal areas, although locally highly permeable, are less likely to produce high indoor radon levels because of probable low soil-gas radon concentrations and high soil moisture.

Similarly, precipitation is also relatively high in the Willamette River Valley and the eU signature of many soils is elevated compared to other areas west of the Cascades in Oregon and Washington. Scattered areas in the upper Willamette River Valley where soils are well-drained, steep, or soil textures permit high emanation of radon are likely to produce elevated indoor radon levels. Such soils are most common in river terrace areas near the Willamette River but they also occur in some broad valley areas without significant river deposits.

Areas along the Columbia River Gorge in various counties in northwest Oregon seem susceptible to elevated indoor radon where the soils formed on river terrace deposits. Such soils are often highly permeable, well-drained, and locally steep.

Houses sited on the highly permeable Yakima gravelly loam in the town of Milton-Freewater in northeastern Umatilla County are likely to have elevated indoor radon levels. The Yakima gravelly loam and the Pilot Rock silt loam (thin silt loam over gravel) underlie much of the city of Pendleton in north-central Umatilla County and elevated indoor radon levels are likely in this city.

Areas of elevated eU associated with silicic volcanic rocks in Harney and Malheur Counties in southeast Oregon probably cause average indoor radon levels above 4 pCi/L. This area is very sparsely populated. Most people in this area live on ranches and in small communities in river and stream valleys. Few homes are located directly on soils developed on the uraniferous volcanic rocks themselves. Where alluvium is derived from silicic volcanic rocks, elevated indoor radon levels are likely.

SUMMARY

There are nine distinct geologic provinces in Oregon for which radon potential may be evaluated: the Coast Range, the Klamath Mountains, the Willamette River Valley, the Cascade Range, the Deschutes Umatilla Plateau, the Blue Mountains and Joseph Upland, the High Lava Plains, the Basin and Range Province, and the Owyhee Plateau. A relative index of radon potential (RI) and an index of the level of confidence in the available data (CI) have been established (see discussion in chapter 1 of this volume). The nine geologic provinces in Oregon are evaluated in

Table 2. The Columbia River Gorge, although not a distinctive geologic province, is considered separately (see discussion below).

The radon potential of the Coast Range is low overall due to high rainfall and high soil moisture, and low to moderate levels of uranium in the soils and rocks of the area. Locally, however, structures on steep or excessively well-drained soils especially along many of the river valleys may have elevated indoor radon levels (>4 pCi/L). For example, houses in Clatsop, Tillamook, and Coos Counties show elevated indoor radon levels. The radon potential of the Klamath Mountains is similar to that of the Coast Ranges.

The overall radon potential of the Willamette River Valley is moderate. The uranium content of the soils is moderate, the soils locally include some with high emanating power, and some of the soils are excessively well-drained (fig. 7).

Radon potential in the Cascade Range is low due to low uranium and high soil moisture. However, houses sited on steep, excessively well-drained slopes are likely to have higher indoor radon levels including many areas along the Columbia River gorge.

The Deschutes Umatilla Plateau has moderate radon potential. This area has elevated uranium in soils, includes many dry alluvial soils with high permeability, and includes many soils that are likely to have high emanating power.

The Blue Mountains and Joseph Upland have moderate radon potential. The uranium content of soils and rocks is generally low (fig. 4), but most populated areas are located on valley-floor alluvium where highly permeable soils are producing locally elevated indoor radon levels.

The High Lava Plains have low radon potential overall, but the confidence in this assessment is low due to sparse data. The western part of the High Lava Plains has generally low uranium in soils. The eastern part of the Lava Plains includes some uraniferous silicic volcanic rocks and they or alluvium associated with them may be responsible for elevated indoor radon levels locally.

The Basin and Range has moderate radon potential, but the data are sparse and the confidence level is low. Although the soil uranium content is generally low in the western part of the province, soils are fairly dry, river alluvium may be locally highly permeable, and some are likely to have high radon emanating power. In the eastern part of the province many areas are uraniferous and some volcanic rocks host uranium deposits. These volcanic rocks and sediment derived from them are likely to produce elevated indoor radon levels. Structures inadvertently sited on uranium occurrences found locally in this area may have very high indoor radon levels.

The Owyhee Plateau has high radon potential, although the confidence level is low. Much of the area is underlain by uraniferous soils and rocks and alluvium derived from them which are likely to produce elevated indoor radon levels. Uranium prospects occur in many areas and structures sited on them are likely to have very high indoor radon levels.

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 2. Radon Index (RI) and Confidence Index (CI) for geologic radon potential areas of Oregon. See figure 1 for locations of areas. See the introductory chapter for discussion of RI and CI.

FACTOR	Coast Range RI	Coast Range CI	Klamath Mountains RI	Klamath Mountains CI	Willamette Valley RI	Willamette Valley CI
INDOOR RADON	1	2	1	2	2	2
RADIOACTIVITY	1	3	1	3	2	3
GEOLOGY	2	2	2	2	2	2
SOIL PERMEABILITY	2	2	2	2	2	2
ARCHITECTURE	1	-	1	-	1	-
GFE POINTS	0	-	0	-	0	-
TOTAL	7	9	7	9	9	9
RANKING	LOW	MOD	LOW	MOD	MOD	MOD

FACTOR	Cascade Range RI	Cascade Range CI	Deschutes Umatilla RI	Deschutes Umatilla CI	Blue Mountains RI	Blue Mountains CI
INDOOR RADON	1	2	2	2	2	1
RADIOACTIVITY	1	3	2	3	1	3
GEOLOGY	2	2	2	2	2	1
SOIL PERMEABILITY	2	2	2	3	3?	1
ARCHITECTURE	1	-	1	-	1	-
GFE POINTS	0	-	0	-	0	-
TOTAL	7	9	9	10	9	6
RANKING	LOW	MOD	MOD	HIGH	MOD	MOD

\- Not used in CI.

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

TABLE 2 (continued)--Radon Index (RI) and Confidence Index (CI) for geologic radon potential areas of Oregon. See figure 1 for locations of areas. See the introductory chapter for discussion of RI and CI.

FACTOR	High Lava Plains RI	High Lava Plains CI	Basin & Range RI	Basin & Range CI	Owyhee Upland RI	Owyhee Upland CI	Columbia River Gorge RI	Columbia River Gorge CI
INDOOR RADON	1?	1	2?	1	1?	1	3	2
RADIOACTIVITY	1	3	1	3	3	3	1	3
GEOLOGY	2	1	3	1	2	1	2	2
SOIL PERMEABILITY	2	1	2	1	2	1	3	1
ARCHITECTURE	1	-	1	-	1	-	1	-
GFE POINTS	0	-	0	-	0	-	0	-
TOTAL	7	6	9	6	9	6	10	8
RANKING	LOW	LOW	MOD	LOW	MOD	LOW	MOD	MOD

- Not used in CI.

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

REFERENCES CITED IN THIS REPORT AND GENERAL REFERENCES RELAVENT TO RADON IN OREGON

Berry, M. R., 1981, Geology of the Lakeview uranium district, Oregon *in* Goodell, P. C. and Waters, A. C., eds., Uranium in volcanic and volcaniclastic rocks: AAPG Studies in Geology 13, p. 55-62.

Bonneville Power Administration, 1990, Radon monitoring results from BPA's residential conservation programs: Report No. 12: Portland, Oregon, Bonneville Power Administration, unpaginated.

Bradley, R., 1982, Mining districts and mineral deposits of the Basin and Range Province of Oregon: United States Geological Survey Open-File Report 82-0058, 15 p.

Cathrall, J. B. and Tuchek, E. T., Charles Sheldon Antelope Range and Sheldon National Antelope Refuge, Nevada and Oregon: *in* Marsh, S. P., Kropscot, S. J. and Dickinson, R. G., eds., Wilderness mineral potential; assessment of mineral-resource potential in U.S. Forest Service lands studied 1964-1984: U.S. Geological Survey Professional Paper 1300, p. 765-767.

Dayvault, R. D., Castor, S. B. and Berry, M. R., 1985, Uranium associated with volcanic rocks of the McDermitt Caldera, Nevada and Oregon, *in* Anonymous, Uranium deposits in volcanic rocks; proceedings of a technical committee meeting, El Paso, TX, Apr. 2-5, 1984: Panel Proceedings Series-International Atomic Energy Agency STI/PUB/690, p. 379-409.

Duval, J. S., Otton, J. K., and Jones, W. J., 1989, Estimation of radon potential in the Pacific Northwest using geological data: Portland, Oregon, Bonneville Power Administration, 146 p.

Duval, J. S., Jones, W. J., Riggle, F. R., and Pitkin, J. A., 1989, Equivalent uranium map of the conterminous United States: U.S. Geological Survey Open-File Report 89-478, 10 p.

Erdman, J. A. and Harrach, G. H., 1981, Uranium in big sagebrush from Western U.S. and evidence of possible mineralisation in the Owyhee Mountains of Idaho: Journal of Geochemical Exploration, v. 14, n. 1, p. 83-94.

Erikson, E. H., 1977, Preliminary study of the uranium favorability of Malheur County, Oregon: U. S. Department of Energy Report No.: GJBX-91(77), 16 p.

Moed, B.A., Nazaroff, A.V., Nero, M.B., Schwehr, M.B., and Van Heuvelen, A., 1984, Identifying areas with potential for high indoor radon levels: analysis of the National Airborne Radiometric Reconnaissance data for California and the Pacific Northwest: Berkeley, California, Lawrence Berkeley Laboratory Report No. LBL-16955, 70 p.

Nero, A.V., Schwehr, M.B., Nazaroff, W.W., and Revzan, K.L., 1986, Distribution of airborne radon-222 concentrations in U.S. homes: Science, v. 234, p.992-997.

Otton, J. K., 1987, Indoor radon; geologic controls in Pacific Northwest: Geological Society of America Abstracts with Programs, v. 19, n. 2, p. 122.

Otton, J. K. and Duval, J. S., 1990, Geologic controls on indoor radon in the Pacific Northwest, *in* U.S. Environmental Protection Agency, The 1990 international symposium on radon and radon reduction technology: Volume III. Preprints, unpaginated.

Peck. D. L., 1961, Geologic map of Oregon west of the 121st meridian: U.S. Geological Survey Miscellaneous Investigations Map I-325. Scale 1:500,000.

Peterman, Z. E., Coleman, R. G. and Bunker, C. M., 1981, Provenance of Eocene graywackes of the Flournoy Formation near Agness, Oregon; a geochemical approach: Geology, v. 9, n. 2, p. 81-86.

Reimer, G. M., 1981, Helium soil-gas survey of a portion of the McDermitt Caldera complex, Malheur County, Oregon: United States Geological Survey Open-File Report 81-0565, 10 p.

Ronkos, C. J., 1981, Geology, alteration, and mineralization in the pyroclastic and sedimentary deposits of the Bretz-Aurora Basin, McDermitt Caldera, Nevada-Oregon: Master' thesis, Univ. of Nevada, Reno, unknown p.

Roper, M. W. and Wallace, A. B., 1981, Geology of the Aurora uranium prospect, Malheur County, Oregon *in* Goodell, P. C. and Waters, A. C., eds., Uranium in volcanic and volcaniclastic rocks: AAPG Studies in Geology 13, p.81-88

Rose, A. W., Ciolkosz, E. J., and Washington, J. W., 1990, Effects of regional and seasonal variations in soil moisture and temperature on soil gas radon, *in* U.S. Environmental Protection Agency, The 1990 international symposium on radon and radon reduction technology: Volume III. Preprints, unpaginated.

Rytuba, J. J., 1977, Uranium content of tuffaceous sediments and opalite mercury deposits within the McDermitt Caldera, Oregon-Nevada: Geological Society of America Abstracts with Programs, v. 9, n. 4, p. 492.

Rytuba, J. J., 1979, Alteration aureole in McDermitt caldera in Nevada and Oregon: U. S. Geological Survey Professional Paper 1150, 79 p.

Rytuba, J. J. and Conrad, W. K., 1981, Petrochemical characteristics of volcanic rocks associated with uranium deposits in the McDermitt caldera complex *in* Goodell, P. C. and Waters, A. C., eds., Uranium in volcanic and volcaniclastic rocks: AAPG Studies in Geology, v. 13, p. 63-72

Rytuba, J. J. and Glanzman, R. K., 1979, Relation of mercury, uranium, and lithium deposits to the McDermitt Caldera complex, Nevada-Oregon *in* Ridge, J. D., ed., Papers on mineral deposits of western North America; proceedings of the Fifth quadrennial symposium of the International Association on the Genesis of Ore Deposits; Volume 2: Nevada Bureau of Mines Report 33, p. 109-117.

Rytuba, J. J., Glanzman, R. K. and Conrad, W. K., 1979, Uranium, thorium, and mercury distribution through the evolution of the McDermitt Caldera complex *in* Newman, G. W. and Goode, H. D., eds., Basin and Range symposium and Great Basin field conference, Oct. 7-11, 1979: Rocky Mountain Assoc. Geol., p. 405-412.

Rytuba, J. J., Minor, S. A. and McKee, E. H., 1981, Geology of the Whitehorse Caldera and caldera-fill deposits, Malheur County, Oregon: United States Geological Survey Open-File Report 81-1092, 22 p.

U.S. Geological Survey, 1969, Mineral and Water Resources of Oregon: Report of the Committee on Interior and Insular Affairs, Washington, U.S. Government Printing Office, 462 p.

U. S. Geological Survey and U. S. Bureau of Mines, 1984, Mineral resources of the Charles Sheldon Wilderness Study Area, Humboldt and Washoe counties, Nevada, and Lake and Harney counties, Oregon: U.S. Geological Survey Bulletin 1538, 139 p.

Walker, G. W., 1977, Geologic map of Oregon east of the 121st meridian: U.S. Geological Survey Miscellaneous Investigations Map I-902, Scale 1:500,000.

Walker, G. W., 1980, Preliminary report on the Lakeview uranium area, Lake County, Oregon: U. S. Geological Survey Open-File Report 80-532, 59 p.

Walker, G. W., 1980, Uranium in the Lakeview area, Oregon: U.S. Geological Survey Professional Paper 1175, 43 p.

Walker, G. W., 1985, Geology of the Lakeview uranium area, Lake County, Oregon, *in* Anonymous, Uranium deposits in volcanic rocks; proceedings of a technical committee meeting, El Paso, TX, Apr. 2-5, 1984: Panel Proceedings Series-International Atomic Energy Agency STI/PUB/690, p.411-447 p.

Wallace, A. B. and Roper, M. W., 1981, Geology and uranium deposits along the northeastern margin, McDermitt caldera complex, Oregon *in* Goodell, P. C. and Waters, A. C., eds., Uranium in volcanic and volcaniclastic rocks: AAPG Studies in Geology 13, p. 73-79.

Weissenberger, K. W., 1984, Lakeview uranium area, Lake County, Oregon; constraints on genetic modelling from a district-scale perspective: Ph.D. thesis, Stanford Univ., Stanford, CA, 367 p.

Wilkening, R. M. and Cummings, M. L., 1987, Mercury and uranium mineralization in the Clarno and John Day formations, Bear Creek Butte area, Crook County, Oregon: Oregon Geology, v. 49, n. 9, p. 103-110.

Wilson, R. D., Purdom, William, and Welton, Richard, 1989, Radon study of the Rogue Valley region of southern Oregon: Ashland, Oregon, Southern Oregon State College, unknown p.

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.)

OREGON MAP OF RADON ZONES

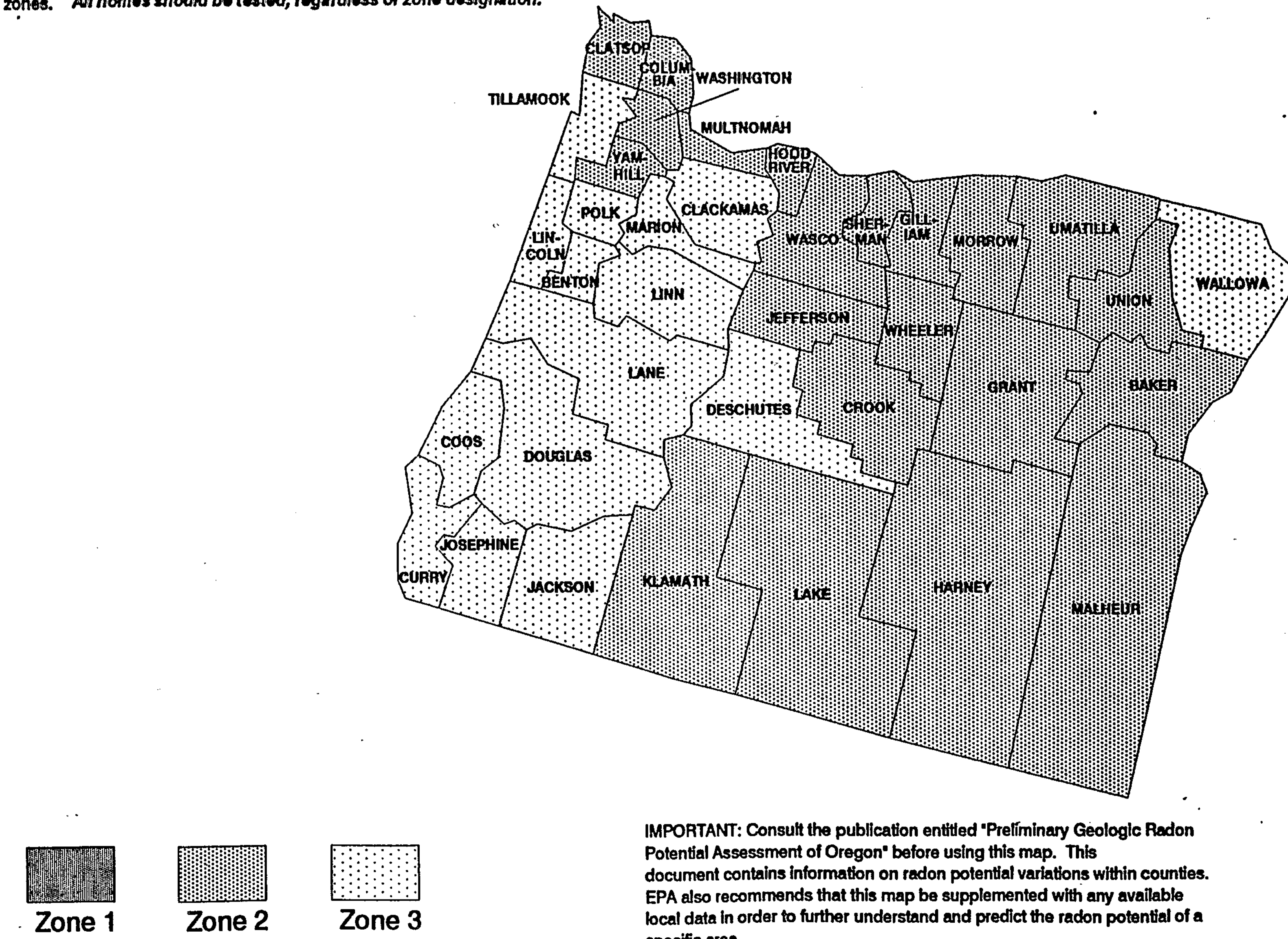
The Oregon Map of Radon Zones and its supporting documentation (Part IV of this report) have received extensive review by Oregon geologists and radon program experts. The map for Oregon generally reflects current State knowledge about radon for its counties. Some States have been able to conduct radon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

Although the information provided in Part IV of this report -- the State chapter entitled "Preliminary Geologic Radon Potential Assessment of Oregon" -- 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 Oregon radon program for information on testing and fixing homes. Telephone numbers and addresses can be found in Part II of this report.

OREGON - 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.***



IMPORTANT: Consult the publication entitled "Preliminary Geologic Radon Potential Assessment of Oregon" 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.