DEPARTMENT OF CONSERVATION
CALIFORNIA GEOLOGICAL SURVEY

SPECIAL REPORT 182

RADON POTENTIAL IN SOUTHERN LOS ANGELES COUNTY

2005

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Radon gas is a naturally occurring radioactive gas that is colorless and odorless. It forms from the radioactive decay of small amounts of uranium naturally present in rocks and soils. Breathing air with a concentrated level of radon gas can result in an increased risk of developing lung cancer. The California Geological Survey has developed a 1:100,000-scale radon potential zone map for southern Los Angeles County. The map is based on the relative radon potentials of different geologic units. Geologic unit radon potentials were evaluated using short-term indoor-radon measurement data, provided by the Department of Health Services-Radon Program, and airborne radiometric data from the National Uranium Resource Evaluation project (NURE—a U.S. Department of Energy program in the 1970s and early 1980s). The DHS indoor-radon data for southern Los Angeles County range from less than 0.3 picocuries per liter (pCi/L) to 159.6 pCi/L (the detection limit is 0.3 pCi/l). The radon level at which the U.S. EPA recommends considering remedial actions for radon reduction in residences is 4.0 pCi/l.

Four radon potential zones were developed for the map: High, High-Qa (areas of recent alluvium with increased radon potential), Moderate, and Low. Comparisons of radon data for each zone show that the zones are statistically different from each other. The estimated percentages of buildings in each zone with indoor radon levels of 4.0 (pCi/l) or higher are: 28.3 percent in the High zone; 20.6 percent in the High-Qa zone; 9.7 percent in the Moderate zone, and 2.4 percent in the Low zone.

The High, High-Qa, and Moderate Zones comprise about 15 percent of the southern Los Angeles County map area but contain more than 82 percent of the 4.0 pCi/l or higher sites in the DHS radon database. Within these three zones an estimated 165,000 individuals live in buildings likely to have radon levels of 4.0 pCi/l or higher based on short-term tests. If all four radon potential zones are considered, an estimated 353,000 individuals (about 4 percent of the total population in southern Los Angeles County) live in buildings that are likely to have radon levels of 4.0 pCi/l or higher based on short-term tests. These exposure estimates, and the presence of some high radon measurements in all radon potential zones, underscore the importance of indoor radon testing regardless of location. Although exposure to elevated indoor radon levels is possible in all zones, the southern Los Angeles County radon potential map is useful because it identifies those areas with the greatest chance for such radon exposures to occur.

The California Department of Health Services, Radon Program provided funding for this project through Interagency Agreement No. 02-26265.

INTRODUCTION

Purpose

This report documents the procedures used by the California Department of Conservation, California Geological Survey (CGS) to produce the radon potential map of southern Los Angeles County for the California Department of Health Services (DHS). This report also describes radon potentials for geologic formations in southern Los Angeles County. Only minimal background information on radon and radon health issues is included, and radon testing and remediation practices are not discussed. The following websites contain information about radon and health issues, testing and remediation: http://www.dhs.ca.gov/radon and http://www.epa.gov/iaq/radon/pubs.

Background Information on Radon and Health

Radon gas is a naturally occurring, radioactive gas that is odorless and colorless. It forms from the radioactive decay of small amounts of uranium and thorium naturally present in rocks and soils. Typical concentrations of uranium and thorium for many rocks and soils are on the order of a few parts-per-million (ppm). The average uranium content for the earth's continental crust is about 2.5-2.8 ppm. Certain rock types, such as black (organic-rich) shales, some granitic rocks, and rhyolites can have uranium and thorium present at levels of tens to hundreds of ppm. While all buildings have some potential for elevated indoor-radon levels, buildings on rocks and associated soils containing concentrations of uranium will have a greater likelihood of elevated indoor-radon levels.

Radon gas moves readily through rock and soil along micro-fractures and through pore-spaces between mineral grains. Movement away from its site of origin is typically a few meters to tens of meters, but may be up to several hundred meters. Many conditions affect how far radon can move in the subsurface but the ultimate limitation is the relatively short half-lives of radon's different isotopes. Because radon-222 (a daughter element of uranium-238) has the longest half-life, it is usually the predominant radon isotope in indoor air. Radon gas moves from the soil into buildings in various ways. It can move through cracks in slabs or basement walls, pores and cracks in concrete blocks, through-going floor-wall joints, and openings around pipes. Radon moves into buildings from the soil when air pressure inside the buildings is lower than the air pressure outside. When exhaust fans are used, or the inside air is heated, or wind is blowing across the building, the building's internal air pressure is lowered. Because radon enters buildings from the adjacent soil, radon levels are typically highest in basements and ground floor rooms. It can also enter those buildings that use private wells. The ground water drawn from wells contains dissolved radon gas, which can be released, for example, through the use of the bathroom shower. However, radon gas from this source typically accounts for only about 5 percent of the total radon in indoor air (WRRTC, 1997).

Breathing air with a concentrated level of radon gas results in an increased risk of developing lung cancer. Not everyone exposed to radon will develop lung cancer, however the estimated annual number of lung cancer deaths in the United States attributable to radon is 15,000 to 22,000 according to the U.S. Environmental Protection Agency (U.S. EPA) (U.S. EPA, 2002). The average radon concentration for indoor air in American homes is about 1.3 pCi/l, based on a 1991 national survey (U.S. EPA, 1992). The average radon concentration in outdoor air is about 0.4 pCi/l. The

U.S. EPA recommends that individuals avoid long-term exposures to radon concentrations above 4.0 pCi/l. Based on long-term radon test statistics, the U.S. EPA estimates that more than 6 million houses (about 1 out of 15) in the United States have radon levels above 4.0 pCi/l and more than 60,000 homes have radon levels above 20 pCi/l (U.S. EPA, 1992).

Although radon levels are used as a guide for acceptable levels of exposure and for action levels, it is primarily the inhalation of two radon daughter elements, polonium-218 and polonium-214, that leads to lung cancer. These elements have very short half-lives and when they enter the lungs they attach to lung tissue or trapped dust particles and quickly undergo radioactive decay. This is in contrast to the longer-lived radon-222 that is mostly exhaled before it undergoes radioactive decay. The alpha particles emitted as polonium-218 and polonium-214 decay are thought to cause cancer by damaging the DNA (deoxyribonucleic acid) in lung tissue cells, resulting in abnormal or tumorous cell growth (Brookins, 1990).

The most common radon testing methods utilize either charcoal or alpha-track type detectors. These detectors are exposed to the air in a building for a period of time, according to the manufacturer's instructions, and then sent to a laboratory for analysis. Charcoal detectors are usually exposed for a few days under closed building conditions, while alpha track detectors are typically exposed for periods of weeks or months under normal building conditions. These tests are simple and inexpensive and homeowners can do this testing. Test results are reported in units of picocuries per liter (pCi/l). The U.S. EPA recommends action to reduce indoor-radon levels if they exceed 4.0 pCi/l. Longer-duration measurements (alpha-track detector measurements) have an advantage because they "average out" short-term fluctuations in radon levels that relate to factors such as weather changes. Consequently, long-term measurements should be more representative of long-term average radon levels. However, fewer long-term measurements are done because of the time required.

Use and Limitations of Radon Potential Maps

Radon potential maps are maps that identify areas where geologic conditions are more likely to contribute to excessive indoor radon levels. They are intended to assist federal, state and local government agencies and private organizations in targeting their radon program activities and resources. These maps are not intended for determining which buildings have excessive indoor radon levels. In addition to geology, indoor radon levels can be influenced by local variability in factors such as soil permeability and climatic conditions, and by factors such as building design, construction, condition, and usage. Consequently, radon levels for a specific building can only be determined by indoor radon testing of that building, regardless of what radon zone it is located within.

DEVELOPMENT OF THE SOUTHERN LOS ANGELES COUNTY RADON POTENTIAL MAP

Project Overview

The part of Los Angeles County mapped for radon potential in this project is that portion south of latitude 34.3750 degrees (the approximate latitude of Santa Clarita), and excludes Santa Catalina Island. Referred to as “southern Los Angeles County” in this report, this area encompasses about 1989 square miles.

The southern Los Angeles County radon potential zones are based on short-term (charcoal detector) indoor radon test data, provided by the DHS Radon Program, airborne gamma-ray survey data from the 1970s NURE project, and available geologic maps from the Dibblee Foundation and California Geological Survey. The approach taken to develop the radon potential zones assumes that geologic units with higher percentages of test data at 4.0 pCi/l or greater and units with NURE eU (equivalent uranium)[1] data at 5.0 ppm or greater will have more buildings with radon levels exceeding 4.0 pCi/l. The steps in developing the radon potential zones were:

1. Use the GIS (Geographical Information System) to relate the indoor-radon test data and NURE data to specific geologic units.
2. Rank geologic units for relative radon potential on the basis of the percentage of measurements equal to or exceeding 4.0 pCi/l (see Appendix 1).
3. Subdivide the geologic units into three groups—high, moderate and low—using percentages determined in step 2.
4. Review NURE data (see Appendix 2) to adjust categories as needed. Several geologic units were added to the “moderate” category and several other units were deleted from this category based on NURE Data.[2]

Table 1 indicates the final groups of geologic units selected during this screening process and their assigned radon potential.

[1] NURE Project estimates of the soil and rock uranium content at each location, in parts per million, were calculated using the gamma-ray data that were collected. These estimates are designated by the abbreviation eU (equivalent uranium) to distinguish them from a conventional chemical analysis of uranium.

[2] Geologic units deleted from the moderate category were those at the lower end of the moderate range of 4.0 pCi/l or greater incidence rates that had few eU measurements of 5.0 ppm or greater.

The location of high and moderate radon potential zones in southern Los Angeles County is tied to the geologic units classified as having high or moderate radon potential in Table 1. The final high potential and moderate radon potential zone boundaries were established 0.2 miles out from the high and moderate potential geologic unit boundaries. This 0.2 mile wide buffer zone was used to account for uncertainties in geologic unit boundaries and for situations where high or moderate radon potential units may be close to the surface but covered by a low radon potential unit. The High-Qa potential radon zone boundary is an exception and is not based on the addition of a 0.2 mile buffer zone. The High-Qa zone boundary was located to separate areas with higher concentrations of ≥ 4.0 pCi/l test data from areas with lower concentrations of these data in map unit Qa (i.e., recent alluvium). The final radon potential zones identified for southern Los Angeles County are: "High," "High-Qa, " Moderate," "Low." In some cases, high or moderate potential geologic units are close enough so that their buffer zones overlap each other or overlap with the High-Qa zone. In such cases, High zone areas received priority over High-Qa and Moderate zone areas, and High-Qa areas received priority over Moderate zone areas in constructing the southern Los Angeles radon potential map. Table 2a and Table 2b contain information about the radon data characteristics for each radon zone. Table 3a and Table 3b provide information about the occurrence of different ranges of indoor-radon measurements for the four radon zones. In addition to the four radon potential zones shown on the southern Los Angeles County radon potential map, five areas are recommended for follow-up indoor radon testing based upon NURE data alone.

The statistical significance of the final four radon potential zones was checked using the nonparametric Mann-Whitney rank sum test. The test compared the indoor-radon data populations for each radon potential zone and found that each population set was statistically different from the others. These test results are evidence that the radon zones developed in this study do in fact represent areas with different radon potentials.

Use of Geologic Maps

This project utilized 1:250,000-scale maps prepared in the 1950s and 1960s by the California Division of Mines and Geology (the previous name for the California Geological Survey), and more recent 7.5-minute quadrangle geologic maps (1:24,000-scale) published by the Dibblee Foundation[3]. The Dibblee Foundation maps used in this project are listed in Appendix 2.

The southern Los Angeles County area is covered by portions of three 1:250,000-scale geologic map quadrangles: Los Angeles, San Bernardino and Santa Ana. The 1:250,000-scale maps were available at the time of the NURE project in the 1970s and airborne gamma-ray data were referenced to the geologic units depicted on those maps. The southern Los Angeles County area is contained within all or parts of 43 7.5-minute quadrangles (the quadrangles are listed in Appendix 2). The Dibblee Foundation has published geologic maps for all or parts of 38 of these quadrangles. The 1:250,000-scale geologic maps show that alluvial deposits dominate the area without published Dibblee Foundation maps, the central portion of the Los Angeles Basin.

[3] Dibblee Foundation geologic maps were used to maintain consistency in geologic unit definitions across the southern Los Angeles County area and with Ventura and Santa Barbara counties. The 1:250,000-scale Geologic Atlas maps were used because the NURE data, collected in the 1970s, are referenced to the geologic formations defined on these maps.

Dibblee Foundation maps were utilized for this project in order to maintain map unit consistency across the southern Los Angeles County area. Their use also allows the geologic unit-based radon potential zones for southern Los Angeles County to be compared and related to the radon potential zones previously developed for Ventura and Santa Barbara that are also based on geologic-units defined on Dibblee Foundation maps. Finally, the 7.5-minute Dibblee Foundation maps depict map units are at sufficient detail for development of the radon potential map at 1:100,000-scale. Enlarging the 1:250,000-scale geologic maps to 1:100,000-scale is not a viable approach as it magnifies the limitations of detail that can be shown at 1:250,000-scale, creating inaccuracies in features such as geologic boundaries.

Use of Indoor-Radon Measurement Data

The DHS Radon Program provided CGS with indoor-radon data from 1729 locations within southern Los Angeles County (Figure 1). These data are short-term radon measurements of homes using charcoal canister detectors between March 1990 and March 2004. The data range from below 0.3 pCi/l (the detection limit) to 159.6 pCi/l, and 145 sites had results that equaled or exceeded 4.0 pCi/l (Figure 2). The charcoal canisters were analyzed at a NEHA (National Environmental Health Association) certified lab (lab certification was under the U.S. EPA Radon Proficiency Program for the older data).

Multiple radon analyses were available for some of the sites. Usually these analyses were made at different times, varying from weeks to months but sometimes years apart. Typically, the earliest analysis detected the highest radon level at a site. For the southern Los Angeles County study, only the highest radon level for each site was utilized because of the possibility that later lower radon measurements were made after some remediation activity had occurred. No information is available regarding remediation activities at particular sites.

Comparison of Indoor Radon Data with Geologic Units

Using GIS, the DHS short-term indoor radon data were compared with the geologic map units indicated on Dibblee Foundation 7.5-minute geologic maps for southern Los Angeles County. The results of this comparison are tabulated in Appendix 1. Sixty-nine geologic units had at least one associated indoor radon measurement. 127 locations did not fall within quadrangles with a published Dibblee Foundation map, but the 1:250,000 scale Geologic Atlas for Los Angeles indicates that these locations are principally associated with alluvium in the central part of the Los Angeles basin.

Appendix 1 shows that only 13 geologic units have 19 or more radon measurements (enough for at least minimal confidence in their statistics). Table 4 lists these 13 units in decreasing order by percentage $\geq$ 4.0 pCi/l. Those units with the highest percentages of $\geq$ 4.0 pCi/l measurements are Miocene marine siliceous shales. The NURE data screening process, discussed in the following section, also recognized these marine shales as potentially significant for radon. The geologic units in Table 4 fall naturally into 3 groups, based on the percentage of $\geq$ 4.0 pCi/l data, > 29 percent, 10 to 12 percent, and 6 percent or less, with correspondingly “high,” “moderate” and “low” relative

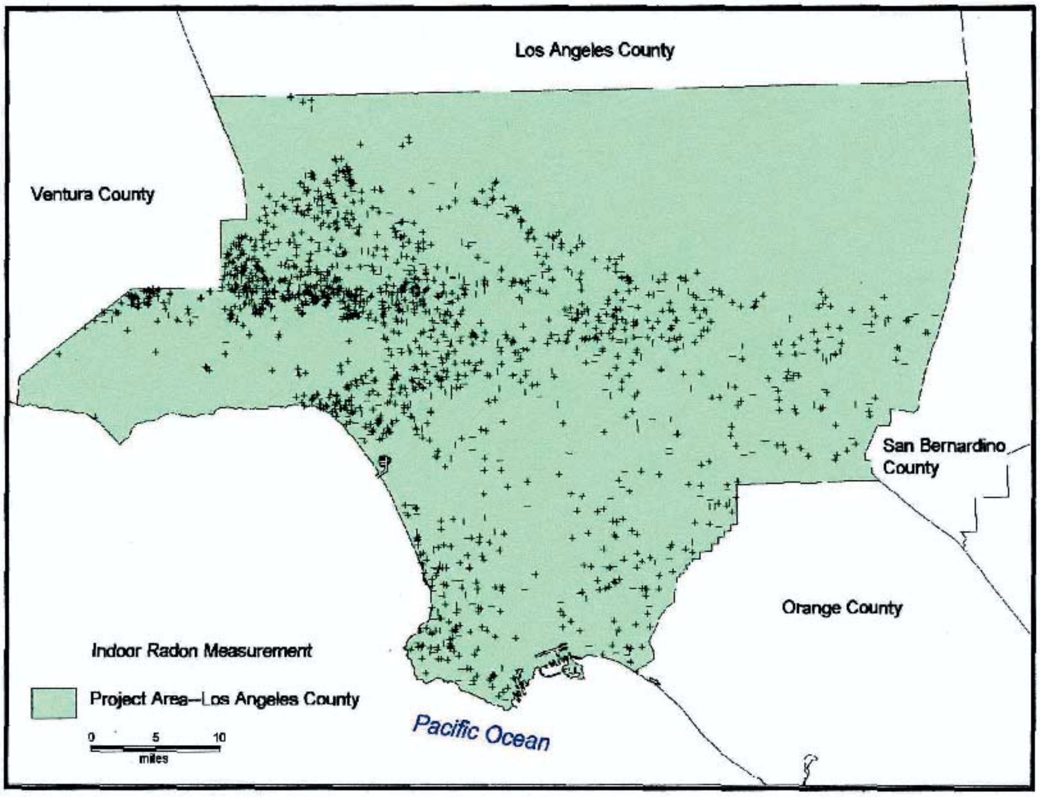

Figure 1. DHS Short-Term Radon Tests for Southern Los Angeles County

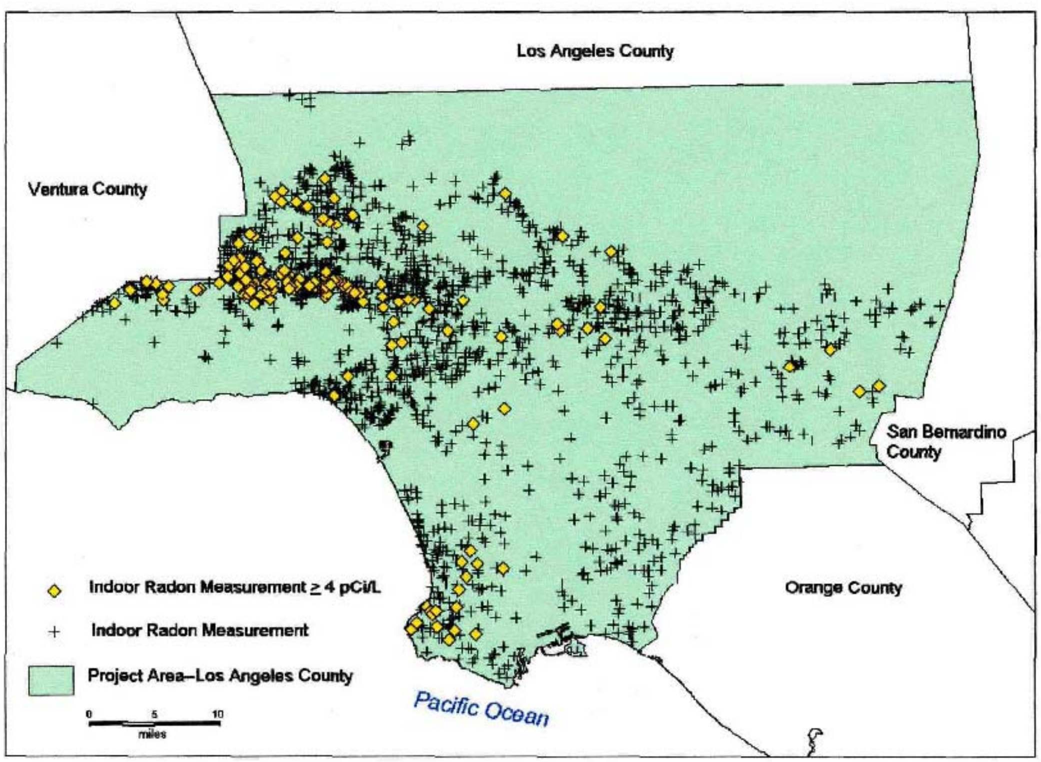

Figure 2. DHS Short-Term Radon Test Results ≥ 4.0 pCi/l for Southern Los Angeles County

radon potentials. Ultimately, boundaries between High and Moderate radon potential units and Moderate and Low radon potential units were chosen at 20 percent and 6 percent respectively. The "high," "moderate" and "low" radon potential zones are based on these geologic unit groupings and definitions, as are the radon zone designations listed in Table 1.

Alluvial geologic units (relatively young loose sediments derived by erosion of adjacent topographically-higher areas) are problematic for radon zone mapping. Alluvial units typically cover large areas and the alluvium may be derived from multiple source areas with different rock types. When multiple sources are involved, the radon potential of the alluvium may vary significantly from location to location. Such rock type and geochemical differences are not usually indicated on geologic maps in sufficient detail to allow reliable division of alluvial units into areas of higher or lower radon potential. Consequently, there is often little certainty that areas of an alluvial unit with few or no radon measurements will have similar incidence rates to areas of the unit with many measurements.

Rock type and chemical variability are usually less for non-alluvial geologic units so assumptions for unmeasured areas of non-alluvial units based upon available data elsewhere in the unit are often more reliable. In this study, plotting radon data locations within the alluvium map unit "Qa" showed that the incidence of $\geq$ 4.0 pCi/l data was much higher in a relatively small portion of the Qa area in the western part of southern Los Angeles County. The "High-Qa" area represents this portion of the Qa unit (Figure 5). The High-Qa boundary was located to separate areas of Qa with a higher incidence of $\geq$ 4.0 pCi/l measurements from lower incidence areas. See Table 5 to compare radon data for the High-Qa area and the remaining lower radon Qa areas (listed in the table as Qa-Low; note that Qa-Low areas are not shown separately on the radon potential map but are contained within the Low Radon Potential Zone).

Map Unit-Information[4] *(modified from descriptions on Dibblee Foundation Maps by R. Churchill)*	**7.5 minute Quadrangle Maps Where the Map Unit is Present**	**Radon Data**[5]	**Radon Zone Designation**	**Justification For Rn Zone Designation and Targeting for Additional Testing**
Tud-Unnamed Shale (upper Modelo Formation by others, equivalent to Sisquoc Formation of Dibblee in Ventura Basin)—	Canoga Park, Van Nuys	**Rate=31.6%** n = 19 ≥ 4.0 pCi/l = 6 Max = 31.4 pCi/l	**High**	Indoor-test data suggest more than 20 percent of the associated buildings will have indoor radon levels exceeding 4 pCi/l; *radon testing of buildings located on this geologic map unit should be a priority.*
Tush-Unnamed Shale (upper Modelo Formation, or Santa Margarita Formation by others; equivalent to Sisquoc Formation of Dibblee in Ventura basin	Calabasas, Canoga Park, Hollywood, Los Angeles San Fernando, Sunland	**Rate=29.8%** n = 57 ≥ 4.0 = 17 Max = 11.7 pCi/l	**High**	Indoor-test data suggest more than 20 percent of the associated buildings will have indoor radon levels exceeding 4 pCi/l; *radon testing of buildings located on this geologic map unit should be a priority.* Priority supported by NURE airborne radiometric data.
Qa-High-A selected area of Qa (Recent Alluvium) which has an increased incidence of indoor-radon measurements exceeding 4 pCi/l.	Calabasas, Canoga Park, Oat Mountain, San Fernando, Thousand Oaks, Van Nuys	**Rate=20.6%** n = 180 ≥ 4.0 pCi/l = 37 Max = 104.2 pCi/l	**High**	Indoor-test data suggest more than 20 percent of the associated buildings will have indoor radon levels exceeding 4.0 pCi/l; *radon testing of buildings located within this selected area of recent alluvium should be a priority.*

Table 1. Radon Priority Units and Justification For Radon Zone Designation

[4] Additional geologic information for some units is available in Appendix 1.
[5] Definitions of terms—Rate is the percent of indoor radon measurements exceeding or equal to 4.0 picocuries per liter; n is the number of indoor radon measurements available for this unit; ≥ 4.0 pCi/l is the number of indoor measurements for this unit exceeding or equal to 4.0 picocuries per liter; Max is the highest indoor measurement obtained for this unit.

Map Unit-Information *(modified from descriptions on Dibblee Foundation Maps by R. Churchill)*	**7.5 minute Quadrangle Maps Where the Map Unit is Present**	**Radon Data**	**Radon Zone Designation**	**Justification For Rn Zone Designation and Targeting for Additional Testing**
Tma-Monterey Formation, Altamira Shale-upper part (equivalent to Puente Formation north of Palos Verdes Fault)	Redondo Beach, San Pedro, Torrance (*Palos Verdes Peninsula*)	**Rate=8.6%** n = 35 ≥ 4.0 pCi/l = 3 Max = 36.6 pCi/l	**Moderate**	Indoor-test data suggest 6 to 20 percent of the associated buildings will have indoor radon levels exceeding 4.0 pCi/l; recent school testing results identified several schools with rooms exceeding 4.0 pCi/l; *testing of buildings on this unit is recommended to better evaluate the radon potential of this map unit.*
Tmat-Monterey Formation, Altamira Shale-lower part (equivalent to Puente Formation north of Palos Verdes Fault)	Redondo Beach, San Pedro, Torrence (*Palos Verdes Peninsula*)	**Rate uncertain** n = 9 ≥ 4.0 pCi/l = 2 Max = 9.6 pCi/l	**Moderate**	Limited indoor-test data suggest more than 6 percent of the associated buildings may contain indoor radon levels exceeding 4.0 pCi/l; *additional testing of buildings on this unit is recommended to better evaluate the radon potential of this map unit.*
Tmad-Monterey Formation, Diatomite In San Pedro Area (lithologically very similar to Valmonte Diatomite (Tmv), but probably equivalent in age to the Altamira Shale-upper part (Tma)-	San Pedro, Torrence (*Palos Verdes Peninsula*)	**Rate uncertain** n=0	**Moderate**	A Monterey Formation map unit without indoor-test data (other Monterey Formation map units are associated with an increased incidence of buildings with indoor air exceeding 4.0 picocuries per liter); *testing of buildings on this unit is recommended to better evaluate the radon potential of this map unit.*

Table 1 continued...

Map Unit-Information *(modified from descriptions on Dibblee Foundation Maps by R. Churchill)*	**7.5 minute Quadrangle Maps Where the Map Unit is Present**	**Radon Data**	**Radon Zone Designation**	**Justification For Rn Zone Designation and Targeting for Additional Testing**
Tm-Monterey Formation (Topanga or Modelo Formation by others in some quadrangles)	Baldwin Park, Beverly Hills, Burbank, Calabasas, Canoga Park, Hollywood, La Habra, Malibu Beach, Oat Mountain, Point Dume, San Fernando, San Dimas, Santa Susana, Sunland, Thousand Oaks, Topanga, Van Nuys, Yorba Linda	**Rate=5%** n = 60 ≥ 4.0 pCi/l = 3 Max = 23.3 pCi/l	**Moderate**	Previous work in Santa Barbara and Ventura Counties and indoor test data for Tm areas in central and eastern Los Angeles mapping project area show some Monterey Formation map units may be associated with an increased incidence of buildings with indoor air exceeding 4.0 picocuries per liter; *testing of buildings on this unit is recommended to better evaluate the radon potential of this map unit.* Priority supported by NURE airborne radiometric data.
Tmsi-Monterey Formation (Modelo Formation by others)	Canoga Park	**Rate uncertain** n = 4 ≥ 4.0 pCi/l = 1 Max = 51.6 pCi/l	**Moderate**	Limited indoor-test data suggest that more than 6 percent of the associated buildings may contain indoor radon levels exceeding 4.0 pCi/l; *testing of buildings on this unit is recommended to better evaluate the radon potential of this map unit.*

Table 1 continued...

Map Unit-Information *(modified from descriptions on Dibblee Foundation Maps by R. Churchill)*	**7.5 minute Quadrangle Maps Where the Map Unit Is Present**	**Radon Data**	**Radon Zone Designation**	**Justification For Rn Zone Designation and Targeting for Additional Testing**
Tmv-Monterey Formation, Valmonte Diatomite (equivalent to lower Puente Formation north of Palos Verdes Fault)	Redondo Beach, San Pedro, Torrance (*Palos Verdes Peninsula*)	**Rate uncertain** n = 4 ≥ 4.0 pCi/l = 1 Max = 9.3 pCi/l	**Moderate**	Limited indoor-test data suggest that more than 6 percent of the associated buildings may contain indoor radon levels exceeding 4.0 pCi/l; *testing of buildings on this unit is recommended to better evaluate the radon potential of this map unit.*
Tmlv-Monterey (Puente) Formation, La Vida Shale Member	Baldwin Park, La Habra, San Dimas, Yorba Linda	**Rate uncertain** n = 3 ≥ 4.0 pCi/l = 1 Max = 4.0 pCi/l	**Moderate**	Limited indoor-test data suggest that more than 6 percent of the associated buildings may contain indoor radon levels exceeding 4.0 pCi/l; *testing of buildings on this unit is recommended to better evaluate the radon potential of this map unit.* Priority supported by NURE airborne radiometric data.
Tmy-Monterey (Puente) Formation, Yorba Shale Member	Baldwin Park, La Habra, San Dimas Whittier, Yorba Linda	**Rate uncertain** n = 5 ≥ 4.0 pCi/l =1 Max = 6.6 pCi/l	**Moderate**	Limited indoor-test data suggest that more than 6 percent of the associated buildings may contain indoor radon levels exceeding 4.0 pCi/l; *testing of buildings on this unit is recommended to better evaluate the radon potential of this map unit.* Priority supported by NURE airborne radiometric data.

Table 1 continued...

Map Unit-Information *(modified from descriptions on Dibblee Foundation Maps by R. Churchill)*	**7.5 minute Quadrangle Maps Where the Map Unit is Present**	**Radon Data**	**Radon Zone Designation**	**Justification For Rn Zone Designation and Targeting for Additional Testing**
Tmsh-Monterey Formation (La Vida and Soquel Members of the Puente Formation by others) -	Hollywood, Los Angeles	**Rate uncertain** n = 7 ≥ 4.0 pCi/l = 2 Max = 5.5 pCi/l	**Moderate**	Limited indoor-test data suggest that more than 6 percent of the associated buildings may contain indoor radon levels exceeding 4.0 pCi/l; *testing of buildings on this unit is recommended to better evaluate the radon potential of this map unit.*
Tmsl- Monterey Formation (La Vida and Soquel Members of the Puente Formation, or upper Topanga Formation by others)	Los Angeles	**Rate uncertain** n = 11 ≥4.0 pCi/ = 2 Max = 8.5 pCi/l	**Moderate**	Limited indoor-test data suggest that more than 6 percent of the associated buildings may contain indoor radon levels exceeding 4.0 pCi/l; *testing of buildings on this unit is recommended to better evaluate the radon potential of this map unit.*
Tmu-Monterey Formation—Mostly shale member similar to Tm but included interbedded friable sandstone	Beverly Hills	**Rate uncertain** n = 0	**Moderate**	A Monterey Formation map unit without indoor test data; *testing of buildings on this unit is recommended to evaluate the radon potential of this map unit.*
Tml-Monterey Shale, lower part—marine biogenic thin bedded fissile semi-siliceous shale to soft shaly claystone; middle Miocene age; included in Modelo Formation by some	Santa Susana, Oat Mountain	**Rate uncertain** n = 0	**Moderate**	Previously identified association with elevated indoor-radon data in Santa Barbara and Ventura Counties and no indoor-radon data for this map unit in Los Angeles County; *testing of buildings on this unit is recommended to evaluate the radon potential of this map unit.*

Table 1 continued...

Map Unit-Information *(modified from descriptions on Dibblee Foundation Maps by R. Churchill)*	**7.5 minute Quadrangle Maps Where the Map Unit Is Present**	**Radon Data**	**Radon Zone Designation**	**Justification For Rn Zone Designation and Targeting for Additional Testing**
Tsq-Sisquoc Shale—marine clastic clay shale, includes some thin interbedded semi-siliceous layers; late Miocene age; included in Modelo Formation by some	Oat Mountain, Santa Susana	**Rate uncertain** n = 0	**Moderate**	Follow-up on NURE Airborne radiometric data anomaly; lack of indoor radon data for this map unit in Los Angeles County; *testing of buildings on this unit is recommended to evaluate the radon potential of this map unit.*
Ttuc-Upper Topanga Formation	Point Dume	**Rate uncertain** n = 10 ≥ 4.0 pCi/l = 1 Max = 10 pCi/l	**Moderate**	Follow-up on NURE Airborne radiometric data anomaly and limited Indoor Radon Data for this Unit in Los Angeles County; *testing of buildings on this unit is recommended to evaluate the radon potential of this map unit.*
sms-Santa Monica Slate	Beverly Hills, Canoga Park, Topanga, Van Nuys	**Rate uncertain** n = 10 ≥ 4.0 pCi/l = 3 Max = 10.8 pCi/l	**Moderate**	Limited indoor-test data suggest that more than 6 percent of the associated buildings may contain indoor radon levels exceeding 4.0 pCi/l; *testing of buildings on this unit is recommended to better evaluate the radon potential of this map unit*

Table 1 continued...

Map Unit-Information *(modified from descriptions on Dibblee Foundation Maps by R. Churchill)*	**7.5 minute Quadrangle Maps Where the Map Unit is Present**	**Radon Data**	**Radon Zone Designation**	**Justification For Rn Zone Designation and Targeting for Additional Testing**
qd-gn-ps- NURE airborne radiometric data anomalies within quartz diorite (qd), gneiss (gn) and Pelona Schist (ps) map units	Mt. Baldy, Mount San Antonio, Mt. Wilson, San Fernando, Sunland	**Rate uncertain** n = 0	**Moderate**	Follow-up on NURE Airborne radiometric data anomalies in intrusive igneous and metamorphic rock map units; lack of indoor radon data within these areas in Los Angeles County; *testing of buildings in these areas is recommended to evaluate the radon potential*
Tgvb-NURE airborne radiometric anomaly within the Glendora Volcanic Rocks-basalt flows (Tgvb) map unit	San Dimas	**Rate uncertain** n = 0	**Moderate**	Follow-up on NURE Airborne radiometric data anomaly in basalt map unit; lack of indoor radon data within the anomalous area of this unit in Los Angeles County; *testing of buildings in these areas is recommended to evaluate the radon potential*

Table 1 continued...

Zone	n	Median pCi/l	pCi/l at 25%	pCi/l at 75%	Min pCi/l	Max pCi/l
High	198	2.4	1.3	4.3	0.3	85.8
High-Qa	180	1.95	1.0	3.55	0.3	104.2
Moderate	267	1.2	0.7	2.1	0.3	36.6
Low	1084	0.5	0.3	1.0	0.3	159.6
All	1729	0.8	0.3	1.8	0.3	159.6

Table 2a. Radon Zone Data Characteristics

Zone	n	n ≥ 4.0 pCi/l data	% data ≥ 4.0 pCi/l	n ≥ 10.0 pCi/l data	% data ≥ 10.0 pCi/l	n ≥ 20.0 pCi/l data	% data ≥ 20.0 pCi/l	Area (sq-mi)
High	198	56	28.3	13	6.6	5	2.5	29.0
High-Qa	180	37	20.6	7	3.9	2	1.1	40.9
Moderate	267	32	9.7	6	2.3	2	0.75	233.8
Low	1084	26	2.4	7	0.65	4	0.37	1685.3
All	1729	145	8.4	33	1.91	13	0.75	1989

Table 2b. ≥ 4.0 pCi/l Incidence per Radon Potential Zone

Zone	% of all ≥ 4.0 pCi/l measurements	% of all ≥ 10.0 pCi/l measurements	% of all ≥ 20.0 pCi/l measurements	% Area	Cumulative % of n ≥ 4.0 pCi/l measurements	Cumulative % or south LA Area
High	38.62	39.39	38.46	1.46	38.62	1.46
High-Qa	25.52	21.21	15.38	2.06	64.14	3.52
Moderate	17.93	18.18	15.38	11.75	82.07	15.27
Low	17.93	21.21	30.77	84.73	100.00	100.00
All	100.00	100.00	100.00	100.00		

Table 3a. ≥ 4.0 pCi/l Incidence Rates for the South-half of Los Angeles County by Radon Potential Zones

Zone	Average Rate: n ≥ 4.0 pCi/l measurements per sq mi	Average Rate: All measurements per sq mi
High	1.93	6.83
High-Qa	0.90	4.40
Moderate	0.11	1.14
Low	0.015	0.64

Table 3b. Radon Data Distribution by Radon Potential Zone

Unit Symbol	Lithologic Summary	n	n ≥ 4.0 pCi/l	Percent ≥ 4.0 pCi/l	High (pCi/l)	Low (pCi/l)
Tud	Miocene marine diatomaceous shale	19	6	31.6	31.4	0.5
Tush	Miocene marine siliceous claystone and siltstone	57	17	29.8	11.7	0.4
Tma	Miocene marine siliceous shale (Monterey Formation, Altimara Shale member)	35	4	11.4	36.6	0.3
Qa	Recent alluvium	747	76	10.2	136.9	0.3
Qof	older alluvial fan gravel and sand	67	4	6.0	6.6	0.3
Qoa	older alluvial gravel, sand and silt	119	7	5.9	19.7	0.3
Qos	older stabilized dune and drift sand	37	2	5.41	4.6	0.3
Tm	Miocene marine siliceous shale (Monterey Formation)	60	3	5.0	23.3	0.3
qd	biotite quartz diorite	21	1	4.8	13.9	0.3
Qae	alluvial gravel and sand-north side of Puente Hills	80	3	3.8	7.5	0.3
Tmss	arkosic sandstone (Monterey Formation)	29	1	3.5	6.3	0.3
Qg	stream channel deposits of gravel, sand and silt	52	0	0	2.3	0.3
Qom	shallow marine and non-marine sand, pebbly sand gravel, and silt	23	0	0	2.2	0.3

Table 4. Map Units with 19 or More Radon Measurements

Unit	Description of Data	n	n ≥ 4.0 pCi/l	% ≥ 4.0 pCi/l	High (pCi/l)	Low (pCi/l)
High-Qa	Data from the selected higher elevated radon incidence portion of the recent alluvium map unit area	180	37	20.6	104.2	0.3
Low-Qa	Data from all recent alluvium outside of the High-Qa selected area	437	10	2.3	136.9	0.3
High-Qa + Low-Qa combined*	Data from all Qa areas except those incorporated into the High and Moderate Zones	617	47	7.6	136.9	0.3

Table 5. Indoor-Radon Data Summary for the Qa (recent alluvium) Geologic Unit

*This is not the entire Qa radon data, but only those not contained within the 0.2-mile buffer zone areas for the High and Moderate radon potential zones (buffer zones are discussed on page 23). The Qa radon data within these buffer zones are not statistically different from the non-Qa High and Moderate zone data. These Qa areas are not shown separately on the radon potential map, as High-Qa zone areas, for this reason. For statistics on all Qa data see Appendix 1.

Use of NURE Airborne Radiometric Data

Background Information

During the 1970s, airborne gamma-ray spectral data were collected throughout the United States along a grid of east-west and north-south flight lines as part of the National Uranium Resource Evaluation project (NURE). East-west lines are typically 3 to 6 miles apart and north-south lines are typically 12 miles apart. The NURE project used helicopters with special analytical equipment to detect and record the intensity of gamma-ray energy from the decay of bismuth-214 from the uppermost 20 to 30 cm of the surface of soil and rocks at a number of locations along each flight line. The helicopters flew several hundred feet above the surface and measurements were collected, on average, a little more than 100 feet apart along the flight lines. Estimates of the soil and rock uranium content at each location, in parts per million, were calculated using the gamma-ray data that were collected. These estimates are designated by the abbreviation eU (equivalent uranium) to distinguish them from a conventional chemical analysis of uranium. The estimates are possible because bismuth-214 is one of the radioactive decay products for uranium-238 and, with some exceptions, the amount of bismuth-214 present will be proportional to the amount of uranium-238 present in the rock or soil.

The goal of the NURE airborne gamma-ray study was to identify new uranium ore deposits. Areas identified as having higher eU were exploration targets for follow-up examination on the ground by geologists. Because radon-222 is also a decay product of uranium-238 and is followed closely in the decay path by bismuth-214, NURE data is also useful in identifying areas more likely to have elevated radon levels in soil and rock. In preparing the radon potential map for southern Los Angeles County, the NURE data were used to identify specific areas along flight lines likely to have elevated radon in soil and rocks based on the presence of elevated eU. These areas were then compared with geologic maps to identify those map units more likely to have elevated radon levels.

NURE Airborne Gamma-ray Spectral Data for Southern Los Angeles County

The NURE flight-line data used in this project were obtained a from a U.S. Geological Survey compilation (Duval, 2000). Southern Los Angeles County contains a total of 482.5 miles of flight lines with data for 22,181 locations along the flight lines (see Figure 3). Flight-line spacing is generally about 2.9 miles between east-west oriented lines and 11.8 miles between north-south oriented lines. A limitation of the NURE Airborne Gamma-ray data for this project is that none were collected over large metropolitan areas so the radon potential of the central Los Angles metropolitan area cannot be evaluated with this approach.

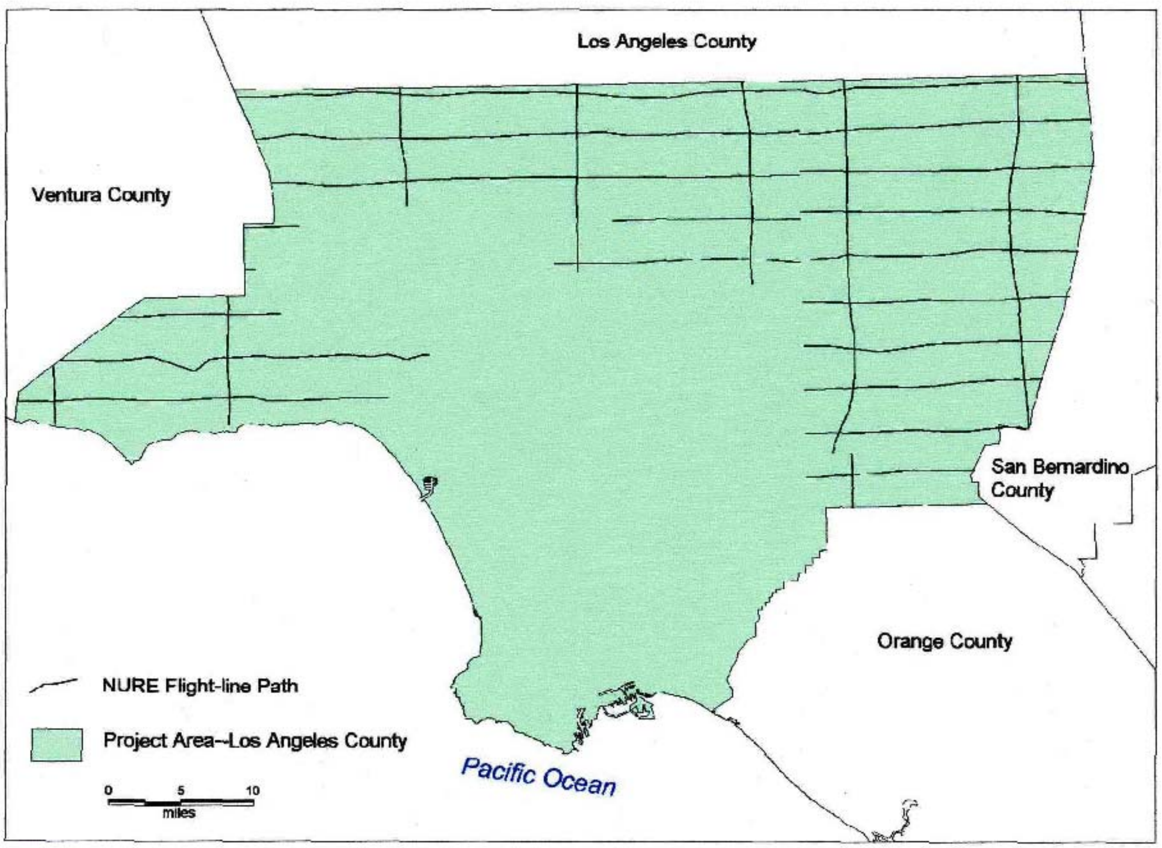

Figure 3. Map of NURE Flight-line Coverage for Southern Los Angeles County. Areas without NURE flight-line coverage were evaluated using indoor-radon data alone, as described in the previous section of this report

NURE Data Analysis

Geologic units were screened for elevated eU content using NURE flight-line data for the portions of southern Los Angeles County flown during the NURE survey.

Screening involved identifying locations along flight lines where eU abundances equaled or exceeded 5.0 parts-per-million (ppm). 5.0 ppm eU was chosen as a screening threshold because it is approximately twice the average uranium content of the earth's crust (about 2.5 to 2.6 ppm). This approach was used previously during development of the radon potential maps for Santa Barbara and Ventura Counties (Churchill, 1995). It is reasonable to expect more indoor-air radon problems for buildings on soils and rock with uranium contents above 5.0 ppm eU than on soil and rock with average or below average uranium contents. For the southern Los Angeles County NURE flight-line data, 2.47 percent of the data points (i.e., 548 of 22,181 locations along flight-lines) equal or exceed 5.0 ppm eU (Figure 4).

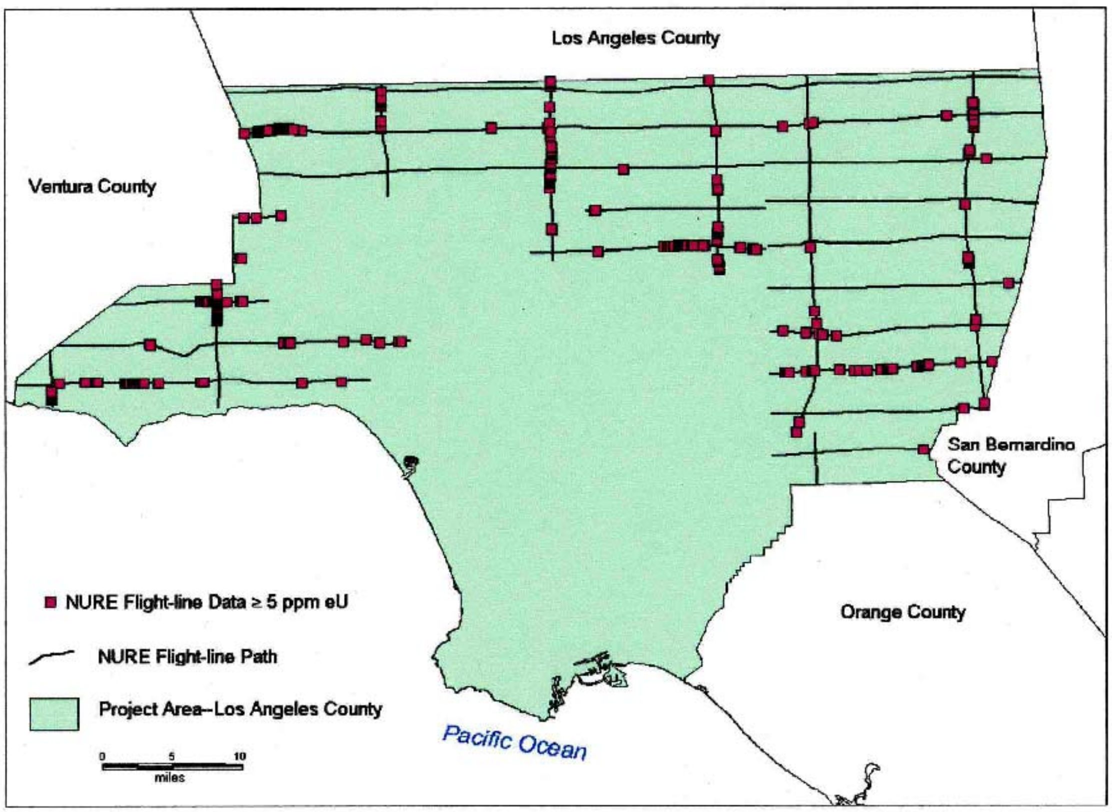

Figure 4. NURE Data Locations where eU Levels are ≥ 5.0 ppm

The results of this screening activity are summarized in Appendix 2, which shows that 42 geologic map units contain at least one data point at, or exceeding, 5.0 ppm eU. Three rock groups, consisting of 8 map units, stand out in that they account for 53.7 percent of the 5.0 ppm or greater NURE data points. These groups are, Miocene marine siliceous shale, quartz diorite and gneiss.

These groups relate to the map units defined on Dibblee Foundation geologic maps as follows[6]:

Miocene marine siliceous shale includes 5 map units: Monterey Formation (Tm), Sisquoc Shale (Tsq), Monterey Formation—La Vida Shale Member (Tmlv), Monterey Formation—Yorba Shale Member (Tmy), and an "Unnamed Shale" (Tush). These units contain 28.3 percent of the 5.0 ppm or higher NURE data points.

Miocene marine siliceous shale in southern Los Angeles County is primarily composed of Monterey Formation (also known as the Monterey Shale), and the Sisquoc Shale. Both are Miocene age fine-grained siliceous marine shales similar in composition and geologic history. These Dibblee map units are combined on maps for the Los Angeles area by other geologists within a unit named the Modelo Formation (see the Dibblee map unit descriptions in Table 1). Other geologists identify the Monterey Formation in the San Dimas and Yorba Linda 7.5-minute quadrangles (La Vida Shale and Yorba Shale members) as Puente Formation on maps.

The final Dibblee map unit in this group is the "Unnamed Shale" in the Calabasas quad. Other geologists have mapped this unit as the Modelo Formation. Altogether, these Miocene marine siliceous shale units account for 155 (28.3 percent) of the 548 flight-line data points with $\geq$ 5.0 ppm eU.

Quartz diorite includes 2 map units: quartz diorite (qd) and quartz diorite mixed with granite and granodiorite (qdg). These units contain 18.6 percent of the 5.0 or higher NURE data points.

Quartz diorite, Cretaceous in age, is medium grained and consists of plagioclase, biotite, K-feldspar, quartz and hornblende in order of decreasing abundance (see the Dibblee map unit descriptions in Table 1). It sometimes includes lenses of gneiss and in places is intruded by sills, dikes and pods of granite. Quartz diorite and a related granodiorite unit account for 102 (18.6 percent) of the 548 data points at or exceeding 5.0 ppm eU.

Gneiss includes 1 map unit: gn. This unit contains 6.8 percent of the 5.0 ppm eU or higher NURE data points.

Gneiss of uncertain age, possibly Precambrian, consists of banded white to gray laminae of quartz and feldspar alternating with dark gray to black laminae rich in biotite and hornblende (see the Dibblee map unit descriptions in Appendix 1). This unit locally contains calc-silicate rock and white marble. The gneiss is contorted, sheared, migmatized and locally contains younger quartz diorite. Gneiss is located in the Mt. Wilson, Mt. Baldy, San Fernando, and Chilao Flat quadrangles and accounts for 37 (6.8 percent) of the 548 data points at or exceeding 5.0 ppm eU.

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[6] Dibblee map unit descriptions are included in Appendix 2 for each 7.5 minute quadrangle map containing the unit where NURE flight-line data were 5.0 ppm eU or above.

Summary of NURE Airborne Gamma-ray Spectral Data Screening Results

The NURE data screening process identified those geologic units that contained measurements $\geq$ 5.0 ppm eU. Of the 42 geologic units identified, eight units account for 53.7 percent of the $\geq$ 5.0 ppm eU data. These units belong to three rock-type categories: Miocene marine siliceous shale; quartz diorite; and gneiss. Rock types in the first category have been previously identified as often containing background uranium levels above the average crustal background level of 2.5 ppm (Durham, 1987; Leventhal, 1989; Churchill, 1997, 1991; Otton, 1993; Carlisle, D. and Azzouz, H., 1993) and have been associated with elevated indoor radon levels in some homes and schools in Santa Barbara and Ventura counties (Churchill, 1997; Churchill and Youngs, 1993; Carlisle and Azzouz, 1993) and at some schools on the Palos Verdes Peninsula in Los Angeles County (Duval and others, 2004). Churchill (1991) and Otton (1993) previously suggested that some granitic rocks and gneiss in California might be associated with elevated indoor radon levels.

RADON POTENTIAL ZONE CRITERIA

Radon Zone and Follow-up Test Area Designations

In keeping with the approach previously used for the Santa Barbara and Ventura County radon maps, high, medium and low radon potential zones have been designated for the southern Los Angeles County Radon Potential Map. However, two additional zones not previously used for Santa Barbara and Ventura Counties have been designated for southern Los Angeles County: high-radon potential alluvium (High-Qa) and Follow-up Test Areas. The radon potential zones and test area designations are based on the radon potential assignment made and discussed in the previous section of this report and are defined as follows:

- **High Potential**—geologic map units that may have 20 percent or more of the associated residences with radon levels equal to or exceeding 4.0 pCi/l in short-term tests (map units Tud and Tush).
- **High-Qa** (High Potential Alluvium)—recent alluvium areas that may have 20 percent or more of the associated residences with radon levels equal to or exceeding 4.0 pCi/l in short-term tests.
- **Moderate Potential**—geologic map units that may have 6 to 20 percent of associated resi dences with radon levels that equal or exceed 4.0 pCi/l in short-term tests (Tmat, Tmad, Tmsi, Tmv, Tmy, Tmsh, Tmsl, Tmv, Tml, Tsq, Ttuc, and sms). Tma and Tmy inclusion is justified by the results of a recent study of radon at school sites on the Palos Verdes Peninsula by Duvall and others (2004). Tm is included in this classification even though it only has 5.0 percent of associated residences at or above 4.0 pCi/l. This exception was made because: (1) Tm in some Dibblee Foundation maps is undifferentiated—so it may include portions of the Miocene marine units just listed but not designated separately; (2) there are a relatively small number of indoor-measurements for Tm in relation to its areal extent; and (3) NURE data screening results support Tm inclusion.

- **Low Potential—**geologic map units that likely have fewer than 6 percent of associated residences with radon levels that equal or exceed 4.0 pCi/l.
- **Follow-up Test Areas—**areas where indoor-radon test data are unavailable but where NURE Airborne Radiometric Data suggest an increased potential for buildings to have indoor-air radon levels exceeding the U.S. EPA guideline of 4.0 pCi/l based on the presence of ≥5 ppm eU data.

Those units with High or Moderate Potential designations are listed in Table 1, along with the map units where Follow-up Test Areas have been identified.

Radon Zone Boundaries

Figure 5 shows the radon potential zones and follow-up test areas for southern Los Angeles County that are identified in detail on the 1:100,000-scale map. The relationships between these zones, ≥ 4.0 pCi/l radon data and ≥ 5.0 ppm eU data are shown in Figure 6. The radon potential zone boundaries for the High and Moderate potential zones are based on the boundaries for geologic map units with those radon potential designations. Utilizing GIS, the final boundaries for these zones were derived by adding a 0.2-mile wide buffer zone to those units designated as having high or moderate potential. This buffer zone is utilized to compensate for uncertainties in the locations of map unit boundaries (e.g., in areas with poor rock exposure). The 0.2-mile wide buffer also should include some, if not most, of the situations where high potential or moderate potential geologic units are covered by a thin layer of alluvium, but are still close enough to the surface to potentially influence indoor-radon levels in buildings. The most likely place for this situation to occur is just outside of the mapped boundaries for high and moderate potential units. Where the resulting high potential (buffered) areas and moderate potential (buffered) areas overlap, areas with high potential were given preference for the final map.

The High-Qa potential zone boundary was determined by visual inspection of the geographic distribution of indoor-radon data for home sites on recent alluvium. It was drawn to include the greatest number of ≥ 4.0 pCi/l locations within a small geographic area such that the resulting incidence of 4.0 pCi/l or higher measurements is above 20 percent. No buffer zone was added to this subjectively selected boundary.

Follow-up test areas were subjectively defined to encompass areas along NURE Project flight-lines where equivalent uranium data appear to be several times above the average earth crustal background of 2.6 ppm uranium. No indoor-radon data for these areas are currently available in the DHS indoor-radon database. Consequently, radon testing of buildings in these areas should be encouraged to follow-up on the equivalent uranium anomalies seen in the NURE data.

The Low Potential zone areas were simply defined as all areas that are not designated as High Potential, High Potential-Qa, Moderate Potential, or a Follow-up Test Area.

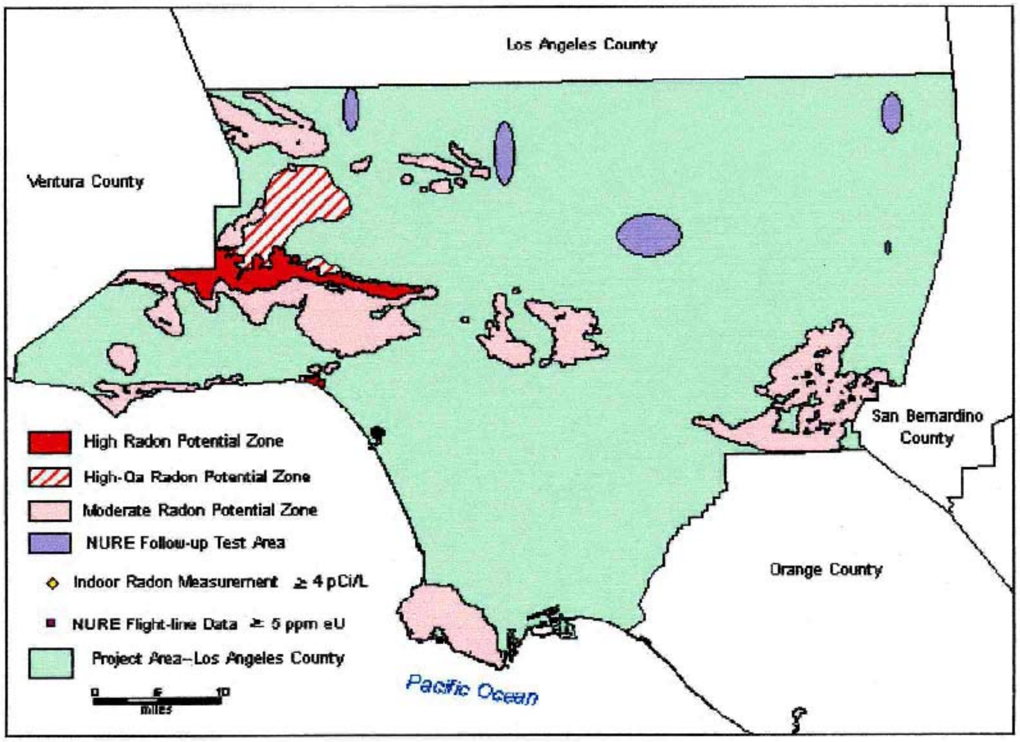

Figure 5. Radon Zones and Recommended Testing Areas for Southern Los Angeles County

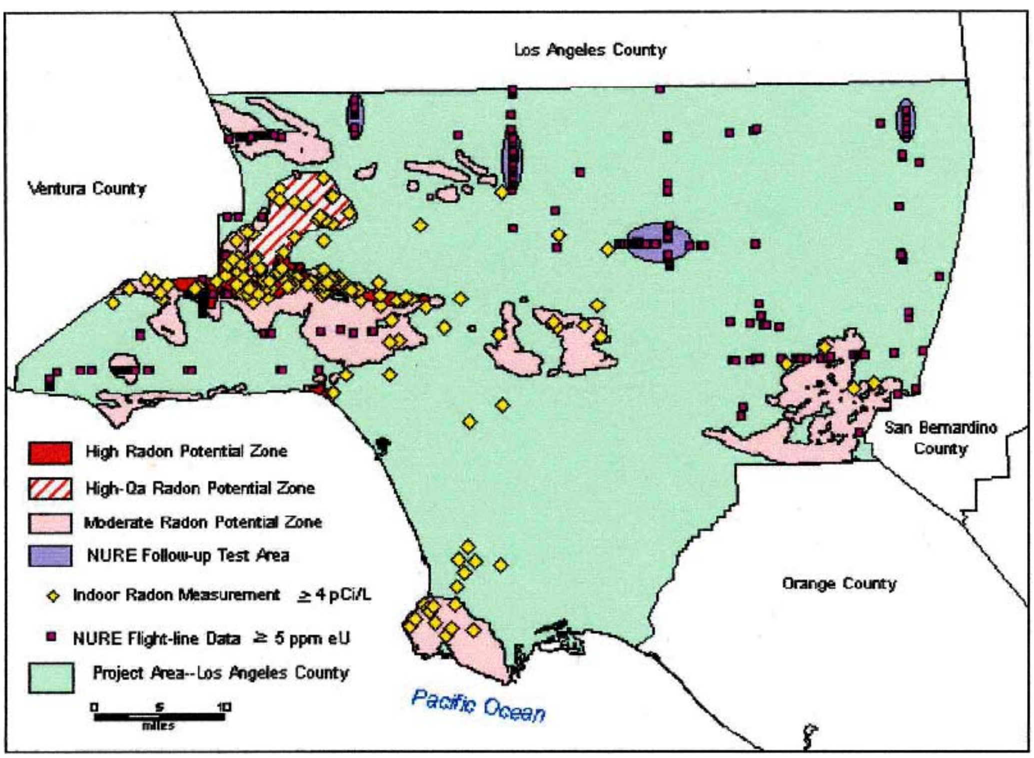

Figure 6. Comparison of $\geq$ 4.0 pCi/l Data Locations and $\geq$ 5.0 ppm eU NURE Data Locations with Radon Potential Zones and Recommended Test Areas for Southern Los Angeles County

RADON POTENTIAL ZONE STATISTICS

Indoor-Radon Measurement Data Characteristics

The statistical characteristics of the DHS indoor radon data for southern Los Angeles County radon potential zones are provided in Appendix 3 for both untransformed and log(10) transformed versions of the data.

Indoor-Radon Measurement Frequency Distributions

Frequency distributions of trace elements in rocks and soils, such as uranium and radon, are often best approximated using the lognormal distribution. However, because of the variety of geologic units and complex history of processes affecting them, geochemical data such as radon data cannot always be fitted to a specific frequency distribution (Rose and others, 1979, p. 33). The indoor-radon data for southern Los Angeles County are an example of this situation. Taken as a whole, the Indoor-Radon Test Data from DHS fail the Kolmogorov-Smirnov normality test in untransformed and log-transformed modes (Table 6). Consequently, all the data, considered together, are neither normally nor lognormally distributed. The non-lognormal frequency distribution may be because the data are a combination of samples from many different populations—each rock unit having its own unique radon frequency distribution. On an individual basis, the rock unit populations may be lognormal, but the aggregate population is not lognormal. This possibility is demonstrated by the log(10) transformed High Zone and Qa High Zone data passing the Kolmogorov-Smirnov Normality Test (Table 6). These zones consist of just a few closely related rock types.

Data non-normality has important implications for other statistical operations. For example, T-test comparisons should not be used for comparing non-normal (non-parametric) populations. For this reason, the Mann-Whitney Rank Sum Test is used for comparisons of sub-populations of the indoor-radon test data by radon zone in this mapping project and the results are discussed in a following section. A T-test comparison was made on the log-transformed data for the High and High-Qa radon potential zones because these transformed data were normally distributed, but the result was the same as for the Mann-Whitney Rank Sum Test. Non-normality may also have negative consequences for predictions of percentages of homes with indoor-radon levels exceeding 4.0 pCi/l if the predictions assumed a lognormal population distribution for the radon data.

The results of the statistical comparisons of radon potential zones for southern Los Angeles County are listed in Table 7. The results show that the indoor radon data populations for the four radon potential zones developed during this study are significantly different.

Data	N	K-S Dist.	P	Result
All data—Un-transformed	1729	0.405	<0.001	Failed
All Data—Log(10) transformed	1729	0.138	<0.001	Failed
High Zone—Un-transformed	198	0.317	<0.001	Failed
High Zone—Log(10) transformed	198	0.041	>0.200	Passed
High-Qa Zone—Un-transformed	180	0.356	<0.001	Failed
High-Qa Zone—Log(10) transformed	180	0.050	>0.200	Passed
Moderate Zone—Un-transformed	267	0.299	<0.001	Failed
Moderate Zone—Log(10) transformed	267	0.066	0.007	Failed
Low Zone—Un-transformed	1084	0.443	<0.001	Failed
Low Zone—Log(10) transformed	1084	0.186	<0.001	Failed

Table 6. Results of the Kolmogorov-Smirnov Normality Test for Untransformed and Log(10) Transformed Indoor-Radon Data, by Radon Potential Zone

Mann-Whitney Rank Sum Test					
Group	**N**	**Missing**	**Median**	**25%**	**75%**
High Zone	198	0	2.400	1.300	4.300
High-Qa Zone	180	0	1.950	1.000	3.550
Result	T = 31803.000 n(small) = 180 n(big) = 198 (P = 0.030) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = 0.030)				
High Zone	198	0	2.400	1.300	4.300
Moderate Zone	267	0	1.200	0.700	2.100
Result	T = 56426.000 n(small) = 198 n(big) = 267 (P =<0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P=<0.001)				
High Zone	198	0	2.400	1.300	4.300
Low Zone	1084	0	0.500	0.300	1.000
Result	T = 202064.000 n(small)=198 n(big)= 1084 (P=<0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P=<0.001)				
High-Qa Zone	180	0	1.950	1.000	3.550
Moderate Zone	267	0	1.200	0.700	2.100
Result	T = 47007.000 n(small) = 180 n(big) = 267 (P =<0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P=<0.001)				

Table 7. Mann-Whitney Rank Sum Test and T-Test Comparisons of Indoor-Radon Data by Radon Potential Zone

Group	N	Missing	Median	25%	75%
High-Qa Zone	180	0	1.950	1.000	3.550
Low Zone	1084	0	0.500	0.300	1.000
Result	T = 175421.000 n(small) = 180 n(big) = 1084 (P=<0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P=<0.001)				
Moderate Zone	267	0	1.200	0.700	2.100
Low Zone	1084	0	0.500	0.300	1.000
Result	T =242369.500 n(small) = 267 n(big) = 1084 (P=<0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P=<0.001)				
T-Test					
Group	N	Missing	Mean	Std Dev	SEM
Log(10) High Zone	198	0	0.374	0.442	0.0314
Log(10) High-Qa Zone	180	0	0.276	0.413	0.0308
Result	Difference 0.0980 t = 2.220 with 376 degrees of freedom (P = 0.027) 95 percent confidence interval for difference of means: 0.0112 to 0.185 The difference in the mean values of the two groups is greater than would be expected by chance; there is a statistically significant difference between the input groups (P = 0.027) Power of performed test with alpha = 0.050: 0.496 The power of the performed test (0.496) is below the desired power of 0.800. The negative findings should be interpreted cautiously.				

Table 7 continued...

Estimated Population Exposed to 4.0 pCi/l Radon or Greater Indoor-air in Southern Los Angeles County

Population estimates for each radon potential zone were obtained using GIS by overlaying the southern Los Angeles County radon potential zones with 2000 Census Tract data. For Census Tracts not completely within a radon potential zone, a portion Census Tract population proportional to the percent area of the Census Tract falling within the radon potential zone was used as the population contribution of that Census Tract to the total population of the radon potential zone. The estimated populations for the different radon potential zones are listed in Table 8.

Radon Potential Zone	Estimated Total Population within Zone—2000 Census Statistics	Estimated Total Households within Zone (avg. 2.98 persons)
High	99,879	33,516
High alluvium	280,630	94,171
Moderate	810,249	271,896
Low	7,832,197	2,628,254
All southern Los Angeles County	9,022,955	3,027,837
Follow-up Test Area—gn-gr	4,725	1,586
Follow-up Test Area—Tvgb	829	278

Table 8. Population Estimates for Southern Los Angeles County Radon Zone Areas (based on 2000 U.S. Census Data).

Table 9 shows the estimated populations of residents for each radon potential zone and the estimated number of residences exposed to different radon levels. These estimates are based on the estimated population for each zone multiplied by the $\geq$ 4.0 pCi/l percentage for each zone from Table 2.

Rn Zone	Estimated Total Population*	Est. Population* at ≥ 4.0 pCi/l Conditions	Est. Population* at ≥ 10.0 pCi/l Conditions	Est. Population* at ≥ 20.0 pCi/l Conditions	Percent Area/ sq.mi.
High	99,879 1.1%	28,266 8.0%	6,592 7.6%	2,497 6.1%	1.46% 29.0 mi^2
High-alluvium	280,630 3.1%	57,810 16.4%	10,945 12.6%	3,087 7.6%	2.06% 40.9 mi^2
Moderate	810,249 9.0%	78,594 22.3%	18,636 21.4%	6,077 15.0%	11.75% 233.8 mi^2
Low	7,832,197 86.8%	187,972 53.3%	50,909 58.5%	28,979 71.3%	84.73% 1685.3 mi^2
Population Estimates Weighted by Radon Zone					
Totals (weighted by Zone)	9,022,955 100.0%	352,642 100.0%	87,082 100.1%	40,640 100.0%	100.00%/ 1989 mi^2
Percent population exposed to excessive radon		3.91%	0.97%	0.45%	
Population Estimates by Radon Level Without Regard to Data Location or Zone					
*All southern Los Angeles County (not weighted by zone)***	*9,022,955*	*757,928*	*172,338*	*67,672*	*100*
Percent Population exposed to excessive radon		*8.4%*	*1.91%*	*0.751%*	
Estimated Population in Follow-up Test Areas					
Follow-up Test Area—gn-gr	4,717	?	?	?	
Follow-up Test Area—Tvgb	829	?	?	?	

Table 9. Estimates of southern Los Angeles County Population Exposed to 4.0 pCi/l or Greater Indoor Radon Levels in Residences (based on 2000 U.S. Census Data).

*Information in the population column cells: 1) Population, 2) Percent of the population

**Based directly on radon test results, not weighted for location. The test results are biased because the sampling is not evenly distributed between the different radon potential zones. More samples are located in the higher radon potential zones so the overall rate for southern Los Angeles County is skewed to a higher incidence rate. The sum of the individual zone rates normalized or weighted by zone population should produce an overall incidence rate estimate more representative of the actual incidence rate for southern Los Angeles County.

Potential Radon Impacts on the Population of Southern Los Angeles County

The High, High-Qa and Moderate radon potential zones contain 15.27 percent of the southern Los Angeles County area. This area contains:

- 47.65% of the southern Los Angeles County population estimated to live in residences with indoor-air levels ≥ 4.0 pCi/l
- 38.48% of the southern Los Angeles County population estimated to live in residences with indoor-air levels ≥ 10.0 pCi/l
- 23.6% of the southern Los Angeles County population estimated to live in residences with indoor-air radon levels ≥ 20.0 pCi/l

These results indicate that geology based radon potential zones can successfully target areas within southern Los Angeles County where excessive indoor radon levels are more likely to be found (i.e., where the highest percentages of buildings with excessive indoor-radon levels are expected to occur). Such information is helpful for government agencies and non-profit organizations involved in public health by indicating where the greatest benefit may be obtained from radon testing programs and public awareness efforts. However, the results also show that buildings with excessive indoor radon levels occur in all zones. Factors other than geology, such as soil permeability, building condition, design and usage also have important impacts on indoor radon levels. Therefore, anyone concerned about possible exposure to radon in their residence should test, regardless of location. The U.S. EPA recommends testing of all residences regardless of location.

Comparison of the Results of this Study to Previous Work

In a 1989-1990 DHS study, Lui and others (1991) surveyed 862 residences in Ventura County and northwestern Los Angeles County for indoor-radon levels using long-term alpha-track detectors. The detectors were exposed for one year in these residences. Lui and others (1991) found approximately three percent of the tested residences had average annual radon levels ≥ 4.0 pCi/l. This rate exceeded the 0.8 percent ≥ 4.0 pCi/l residences estimated for the state from previous DHS work. The Lui and others approach utilized random sampling by Zip code zone and they estimated percentages of residences exceeding 4.0 pCi/l at 14 percent, 8 percent and 1 percent for their “high,” “medium” and “low” regions respectively. Their report recommended that more detailed radon studies based on geology, soil permeability, and building type, rather than random Zip code based sampling, be conducted to more accurately define high-risk areas in the region.

The Lui and others study had 280 indoor measurements within the northwestern portion of Los Angeles County (west from about Beverly Hills and San Fernando), which ranged from 0.1 to 15.9 pCi/l. The locations of these measurements were compared to the radon potential zones developed from short-term measurements for southern Los Angeles County. The results of this comparison are shown in Table 10.

Radon Zone (this study)	Number of Measurements	Median pCi/l	Low pCi/l	High pCi/l	Percent ≥ 4.0 pCi/l
High	34	2.05	0.5	11.8	8.8
High-Qa	40	1.60	0.5	4.0	2.5
Moderate	35	1.1	0.4	7.1	14.3
Low	171	0.9	0.3	8.6	2.3

Table 10. Comparison of DHS Long-term Alpha-track Measurements by Southern Los Angeles County Radon Potential Zone

Comparison of the radon potential zones developed in this study with the long-term data of Lui and others (1991), by the same statistical method used for the short-term data (Mann-Whitney rank sum test), found statistically significant differences between all zones except the High and High-Qa zones. Thus, the long-term measurement data from Lui and others generally support the radon potential zone designations developed from short-term measurements in this study. Differences in percent ≥ 4.0 pCi/l measurements per zone (i.e., the High and Moderate Zone percentages) and the lack of statistical difference between the High and High-Qa zones may result from the smaller number of long-term measurements and possible within zone spatial distribution differences between long-term and short-term measurements. Using the percent ≥ 4.0 pCi/l measurements per zone for long-term radon measurements in Table 10 and the 2000 Census population data per radon potential zone, estimates for the number of individuals residing in residences with radon levels ≥ 4.0 pCi/l were made and are provided in Table 11.

Radon Zone	Estimated Population in Residences with Radon Levels ≥ 4.0 pCi/l
High	8,789 (2.8%)
High Qa	7,016 ((2.3%)
Moderate	115,866 (37.7%)
Low	180,141 (57.8%)
Total	311,812 (100%)

Table 11. Radon Exposure Estimates Based on Long-Term Radon Measurements

The exposure estimates in Table 11, based on long-term measurements, are lower for the High and High-Qa zones, and higher for the Moderate zone, and similar for the Low zone than the Table 9 estimates, based on short-term data. The overall estimates, weighted by radon zone, for the number of individuals in residences with radon levels ≥ 4.0 pCi/l in southern Los Angeles County is roughly similar for the two approaches—311,812 (3.5 percent) based on long-term measurements) and 352,642 (3.9 percent) based on short-term measurements.

SUMMARY OF PROCEDURES AND RESULTS

Short-term indoor radon test data from DHS, and NURE project airborne radiometric data, were used to identify geologic units with relatively higher or lower radon potential in southern Los Angeles County. Geologic units were classified as having high, moderate or low radon potential based the percentage of 4.0 pCi/l or higher indoor-radon data and the percentage of 5 ppm or higher eU airborne radiometric data.

High Radon Potential Zone areas on the southern Los Angeles County radon potential map correspond to the locations of high radon potential geologic units. A separate category, the High-Qa Radon Potential Zone, was developed for areas of recent alluvium with a relatively high percentage of $\geq$ 4.0 pCi/l indoor-measurement data. Moderate Radon Potential Zone areas correspond to the locations of moderate radon potential geologic units.

Buffer zones, 0.2 miles wide, were added to the boundaries of high potential and moderate potential geologic units to form the final High Radon Potential and Moderate Radon Potential Zone boundaries. The buffer zones were added as a margin of safety to compensate for uncertainties in the locations of the boundaries of these geologic units and for possible situations where these units are in the subsurface but still near enough to the surface to potentially impact indoor-radon levels in buildings. A buffer zone was not added to the High-Qa boundary because it was manually located to separate alluvial areas with higher percentages of $\geq$ 4.0 pCi/l data from lower percentage areas. High Radon Potential Zone buffer areas receive preference where they overlap High-Qa or Moderate Radon Potential Zone areas on the final southern Los Angeles radon potential map. High-Qa Radon Potential Zone areas receive preference over Moderate Radon Potential Zone buffer areas on the final map. Low Radon Potential Zone areas on the southern Los Angeles radon potential map consist of all areas not included within the High, High-Qa, or Moderate Radon Potential Zones.

The final radon potential zones have the following characteristics:

High Radon Potential Zone: this zone comprises 1.46 percent (29 square miles) of the southern Los Angeles County area and contains 38.6 percent of $\geq$ 4.0 pCi/l short-term radon data in the DHS database.

High-Qa Radon Potential Zone: this zone comprises 2.06 percent (40.9 square miles) of the southern Los Angeles County area and contains 25.5 percent of all $\geq$ 4.0 pCi/l short-term radon data in the DHS database.

Moderate Radon Potential Zone: this zone comprises 11.75 percent (233.8 square miles) of the southern Los Angeles County area and contains 17.9 percent of $\geq$ 4.0 pCi/l short-term radon data in the DHS database.

Low Radon Potential Zone: this zone comprises 84.73 percent (1,685.3 square miles) of the southern Los Angeles County area and contains 17.9 percent of $\geq$ 4.0 pCi/l short-term radon data in the DHS database.

All four radon potential zones contain short-term indoor-radon measurements above 30 pCi/l. The maximum measurement for each zone is: High, 85.8 pCi/l; High-Qa, 104.2 pCi/l; Moderate, 36.6 pCi/l; and Low, 159.6 pCi/l.

Statistical comparison of the indoor-radon data for the four radon potential zones, using the Mann-Whitney Rank Sum Test, shows that each radon potential zone is statistically different from the other zones. The fact that the radon potential zones are statistically different supports the validity of the approach used in this study to identify areas of higher and lower radon potential in southern Los Angeles County.

An estimated 165,000 individuals live in residences likely to measure $\geq$ 4.0 pCi/l in short-term radon tests within the combined High, High-Qa and Moderate Radon Potential Zone areas (i.e., concentrated within 15.27 percent of the southern Los Angeles County radon map area). An additional 188,000 individuals are estimated to live in residences likely to measure $\geq$ 4.0 pCi/l in short-term tests within the Low Radon Potential Zone area (i.e., scattered throughout 84.73 percent of the southern Los Angeles County radon map area).

Just under 41,000 individuals are estimated to be exposed to indoor-radon levels measuring 20 pCi/l or higher on short-term tests in southern Los Angeles County. Of these individuals, 2,500 are within the High Zone, 3,100 are within the High-Qa Zone, 6,100 are within the Moderate Zone, and 29,000 are within the Low Zone. These exposure estimates, and the identification of high radon levels in residences in all radon potential zones, underscore the importance of radon testing to determine the radon levels in buildings regardless of the location.

Long-term alpha track measurements (280 measurements) from a 1989-1990 DHS study of a portion of Los Angeles County generally support the radon potential zones developed from the short-term test data, except for the High-Qa zone. Population estimates for exposures to $\geq$ 4.0 pCi/l radon levels in residences based on the long-term measurements are lower for the High and High-Qa zones and higher for the Moderate zone than estimates based on short-term measurements. However, the overall estimates for the population exposed to $\geq$ 4.0 pCi/l radon levels in residences in southern Los Angeles County is roughly similar for both approaches, 311,812 based on long-term measurements and 352,642 based on short-term measurements.

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APPENDIX 1

Unit Symbol	Unit Name and Lithology Summary	n	n ≥ 4pCi/l	% ≥ 4pCi/l*	High (pCi/l)	Low (pCi/l)
blank	alluvial areas outside of currently published mapping by the Dibblee Foundation	125	0	0	3.6	0.3
af	artificial fill	12	2	16.6	4.9	0.3
bi	basaltic to diabase dikes; Oligocene	1	0		3.3	
db	diabase; includes sills within Tmlv (La Vida Shale Member—Monterey Formation); Miocene	1	0		3.9	
gn	gneiss; Precambrian	1	0		0.5	
gqd	Granitic Rocks—gneissoid quartz diorite; late Mesozoic (Cretaceous)	8	0		2.5	0.3
gr	Granitic Rocks—quartz monzonite-granodiorite late Mesozoic (Cretaceous)	2	0		1.6	0.8
Kcg	Unnamed Strata—marine conglomerate of cobbles and pebbles of metavolcanic and granitic rocks and quartzite in sandy matrix; upper Cretaceous	4	0		1.7	1.1
Qa	alluvium; unconsolidated floodplain deposits of silt, sand and gravel; Holocene	747	76	10.2	136.9	0.3
Qae	Older Surficial Sediments—slightly elevated, locally dissected alluvial gravel and sand on north side of Puente Hills; Pleistocene	80	3	3.8	7.5	0.3
qd	Biotite Quartz diorite; Cretaceous	21	1	4.8	13.9	0.3
Qds	Surficial Sediments—loose dune and drift sand; Holocene	3	0		1.2	0.3

Unit Symbol	Unit Name and Lithology Summary	n	n ≥ 4pCi/l	% ≥ 4pCi/l*	High (pCi/l)	Low (pCi/l)
Qf	Surficial Sediments—alluvial fan gravel derived from Verdugo Mountains	13	0		1.3	0.3
Qg	stream channel deposits of gravel, sand and silt; Holocene	52	0	0	2.3	0.3
Qlhc	La Habra Formation—sandstone and pebble conglomerate; abundant siliceous shale pebbles south of Puente Hills; interbedded siltstone in middle part of unit; Pleistocene	1	0		0.5	
Qls	landslide debris; Holocene	6	0		2	0.5
Qoa	remnants of older alluvial deposits of gravel, sand and silt; Pleistocene	120	7	5.8	19.7	0.3
Qof	alluvial fan gravel and sand	67	4	6.0	6.6	0.3
Qog	elevated remnants of older alluvial gravel and fanglomerate	1	0			0.3
Qom	Shallow Marine Sediments—marine sand, pebbly sand gravel and silt; probably in part non-marine alluvium; Pleistocene	23	0		2.2	0.3
Qos	Older Surficial Sediments—older stabilized dune and drift sand; Pleistocene	37	2	5.4	4.6	0.3
Qsp	San Pedro Formation—marine sandstone, locally pebbly; Pleistocene	2	0		0.9	0.5

Unit Symbol	Unit Name and Lithology Summary	n	n ≥ 4pCi/l	% ≥ 4pCi/l*	High (pCi/l)	Low (pCi/l)
QTs	Saugus Formation—terrestrial sandstone and pebble-cobble conglomerate of mostly granitic detritus and lesser amounts of gneiss, gabbro and anorthosite detritus, and thin interbeds of clay-siltstone; deposited by streams; Pliocene and Pleistocene	9	0		2.4	0.3
sms	Santa Monica Slate—slate phyllite hornfels, composed of mica, quartz and feldspar, in places contains quartz veinlets; metamorphosed from marine shale, possibly in part from greywacke;; late Jurassic	10	3		10.8	0.3
Tb	fine-grained basalt to mafic andesite submarine flows, pillowed flows and breccias; in places intruded into marine sediments as peperite breccias; Miocene	1	0		1.8	
Tcva	Conejo Volcanics—andesitic breccia—autoclastic flow breccia and some mud-flow (laharic) breccas; Miocene	8	0		2.3	0.5
Tcvad	Conejo Volcanics—submarine and subaerial andesite-dacite breccia; Miocene	3	0		0.3	0.3

Unit Symbol	Unit Name and Lithology Summary	n	n ≥ 4pCi/l	% ≥ 4pCi/l*	High (pCi/l)	Low (pCi/l)
Tcvb	Conejo Volcanics—submarine and subaerial basaltic flows and flow-breccias, composed of basaltic to basaltic-andesitic rocks, includes some reworked breccias of basaltic detritus; Miocene	3	0		1.7	0.5
Tcvbp	Conejo Volcanics—submarine and subaerial basaltic breccia, similar to Tcvb but somewhat more andesitic; Miocene	4	0		1.5	0.3
Tf	Fernando Formation—sandy micaceous siltstone to claystone, locally includes thin layers of sandstone; Pliocene	1	0		0.7	
Tfp	Fernando Formation "Pico" claystone—moderately deep marine micaceous silty claystone or siltstone; late (?) Pliocene	1	0		0.3	
Tfr	Fernando Formation—marine claystone; Pliocene to early Pleistocene	4	0		1.1	0.3
Tfs	Fernando Formation—marine sandstone; includes pebble conglomerate and locally minor siltstone; Pliocene to early Pleistocene	1	0		0.3	
Tfsc	Fernando Formation—nonmarine sandstone and arkosic conglomerate if granitic pebbles and cobbles in a sandstone matrix, Pliocene Pliocene to early Pleistocene	3	0		1	0.3

Unit Symbol	Unit Name and Lithology Summary	n	n ≥ 4pCi/l	% ≥ 4pCi/l*	High (pCi/l)	Low (pCi/l)
Tls	Detrital Sediments of Lindero Canyon—marine sandstone, locally conglomeratic; Miocene	1	0		1.1	
Tlsc	Detrital Sediments of Lindero Canyon—marine calcareous sandstone; includes conglomerate composed of cobbles of metavolcanic, granitic and quartzitic rocks and of sandstone derived from Chatsworth Formation; Miocene	4	0		1.7	0.4
Tm	Monterey Formation—marine biogenic thin bedded platy siliceous shale; locally brittle, porcelaneous, or cherty; in places a fissile diatomaceous semi-siliceous shale; middle and late Miocene age; Topanga or Modelo Formation by others in some quads	60	3	5.0	23.3	0.3
Tma	Monterey Formation—Altamira Shale, upper part—deep marine, biogenic, clastic, thin-bedded siliceous and phosphatic shale with interbeds of limestone and siltstone, locally organic and diatomaceous; with cherty and porcelaneous shale at base; equivalent to Puente Formation north of Palos Verdes Fault	35	4	11.4	36.6	0.3

Unit Symbol	Unit Name and Lithology Summary	n	n ≥ 4pCi/l	% ≥ 4pCi/l*	High (pCi/l)	Low (pCi/l)
Tmat	Monterey Formation—Altamira Shale—lower part—deep marine biogenic shale and mudstone with tuffaceous and dolomitic strata throughout, at or near top contains fine-grained, semi-indurated tuff bed (Miraleste Tuff), near middle contains bentonitic Portuguese Tuff, and contains flows and intrusions of basaltic rocks; equivalent to Puente Formation north of Palos Verdes Fault	9	2		9.6	0.3
Tmc	Monterey (Puente) Shale—marine clay shale; siltstone and minor semi-siliceous shale; Miocene	1	0		0.6	
Tmcg	Monterey Formation—marine conglomerate of granitic detritus; Miocene	2	0		1.8	1.5
Tmlv	Monterey Formation—La Vida Shale Member—thin bedded, platy siliceous shale, clay shale, and siltstone, some strata of tan dolomite and sandstone; late Miocene age; equivalent to Puente Formation	3	1		4.0	0.3
Tms	Monterey Formation—unassigned sandstone, arkosic, locally pebbly	7	1		159.6	0.3
Tmsh	Monterey Formation—siliceous shale, locally porcelaneous and silty; Miocene	7	2		5.5	0.6

Unit Symbol	Unit Name and Lithology Summary	n	n ≥ 4pCi/l	% ≥ 4pCi/l*	High (pCi/l)	Low (pCi/l)
Tmsi	Monterey Formation—marine biogenic and clastic, similar to Tm but includes nearly equal amounts of interbedded clay shale, siltstone and sandstone; middle(?) and late Miocene age; Modelo Formation by others	4	1		51.6	0.3
Tmsl	Monterey Formation—micaceous silty shale and siltstone; includes some semi-siliceous to siliceous shale and thin sandstone beds; Miocene	11	2		8.5	0.3
Tmss	Monterey Formation—arkosic sandstone; includes some interbedded silty shale; Miocene	29	1	3.5	6.3	0.3
Tmu	Monterey Formation—marine shale with interbedded friable sandstone; Miocene	2	0		1.3	0.9
Tmv	Monterey Formation—Valmonte Diatomite—deem marine biogenic, clastic; punky laminated diatomaceous shale and mudstone; late Miocene; equivalent to lower Puente Formation north of Palos Verdes Fault	4	1		9.3	0.3
Tmy	Monterey Formation—Yorba Linda Shale Member—marine, thin bedded, platy siliceous to semi-siliceous to silty shale; locally thin sandstone and dolomite; late Miocene; equivalent to Puente Formation	5	1		6.6	0.6

Unit Symbol	Unit Name and Lithology Summary	n	n ≥ 4pCi/l	% ≥ 4pCi/l*	High (pCi/l)	Low (pCi/l)
Tsc	Sycamore Canyon Formation—marine micaceous silty clay shale, in places includes thin layers of sandstone	1	0		1.7	
Tscg	Sycamore Canyon Formation—marine conglomerate composed of cobbles and pebbles of granitic rocks and quartz diorite, gneiss and a few of andesitic porphyry and quartzite, in arkosic sandstone matrix	1	0		1.1	
Tscs	Sycamore Canyon Formation—marine arkosic sandstone with minor conglomerate	2	0		1	0.9
Tsp	Sespe Formation—nonmarine; Oligocene	6	0		1.8	0.3
Tsr	Saugus Formation, Sunshine Ranch Member—terrestrial claystone, siltstone, and fine grained sandstone; or interbedded conglomerate and fine grained sediments with local peat; mostly Pliocene	10	0		2.4	0.3
Tsu	Santa Susana Formation—sandstone and micaceous silty claystone; Paleocene	2	0		0.7	0.3
Ttcg	Middle Topanga Formation—conglomerate of cobbles and pebbles of granitic, metaporphyritic and quartzitic rocks in soft sandy matrix	1	0		0.3	
Ttls	Lower Topanga Formation—marine arkosic sandstone; Miocene	1	0		0.7	

Unit Symbol	Unit Name and Lithology Summary	n	n ≥ 4pCi/l	% ≥ 4pCi/l*	High (pCi/l)	Low (pCi/l)
Ttlsc	Topanga Formation—sandstone and interbedded sandy to silty shale, semi-siliceous shale, and pebble-cobble conglomerate of quartz diorite detritus; Miocene;	2	0		0.7	0.7
Ttqdb	Topanga (?) Formation—breccia with a few cobbles and boulders, all of biotite quartz diorite; Miocene	1	0		0.6	
Ttqdc	Topanga (?) Formation—conglomerate and breccia, all composed of biotite hornblende quartz diorite in sandstone matrix; Miocene	8	0		1.8	0.3
Ttsc	Topanga (?) Formation—marine and nonmarine sandstone, and interbedded sandy to silty shale, semisiliceous shale, and pebble-cobble conglomerate of quartz diorite detritus; Miocene	1	0		0.7	
Ttsi	Middle Topanga Formation—marine sandstone and some intercalated micaceous clay shale and siltstone	5	0		2.1	0.3
Ttuc	Upper Topanga Formation—marine claystone, bedded; middle Miocene age	12	1		10	0.3
Ttucg	Upper Topanga Formation—marine conglomerate of cobbles of granitic rocks, sandstone and volcanic rocks in sandstone matrix	1	0		1.5	

Unit Symbol	Unit Name and Lithology Summary	n	n ≥ 4pCi/l	% ≥ 4pCi/l*	High (pCi/l)	Low (pCi/l)
Ttus	Upper Topanga Formation—hard bedded marine sandstone; locally pebbly; Miocene	11	1		36.7	0.3
Ttusl	Upper Topanga Formation—marine micaceous clay shale or claystone, and thin interbeds of semi-friable sandstone; Miocene	6	1		7.5	1.4
Tud	Unnamed Shale—marine diatomaceous shale to diatomite; grades westward into Tush; late Miocene; upper Modelo Formation by others, equivalent to Sisquoc Formation of Dibblee in Ventura Basin	19	6	31.6	31.4	0.5
Tush	Unnamed marine silty clay shale, local calcareous nodules; in places contains interbeds of fine-grained sandstone; lower part locally contains thin lenses of semi-siliceous or diatomaceous shale; late Miocene age; upper Modelo Formation, or Santa Margarita Formation by others; equivalent to Sisquoc Formation of Dibblee in Ventura Basin	59	17	28.8	11.7	0.4
Tuss	Unnamed sandstone with thin interbeds of silty shale	15	2		6.7	0.3
Tva	andesitic volcanic rocks—associated with the marine Middle Topanga Formation; Miocene	2	0		2.6	2.2

Unit Symbol	Unit Name and Lithology Summary	n	n ≥ 4pCi/l	% ≥ 4pCi/l*	High (pCi/l)	Low (pCi/l)
Tvb	basaltic volcanic rocks—associated with the marine Middle Topanga Formation; Miocene	6	0		3.8	0.5
totals		1729	145	8.4	159.6	0.3

* Incidence percentages for radon data at or above 4 pCi/l are only listed for those map units where the total number of analyses is large enough to provide some confidence in the incidence percentage. Typically, about 25 to 30 data points are the minimum required to uniquely define a population statistically. For this study, units have been considered reasonably defined with 19 or more available radon measurement data in order to include unit Tud in the radon zone development process.

APPENDIX 2

7.5-minute Quadrangle Name	Miles of NURE Project Flight-line	Number of Data Locations Along Flight-Line
Azusa	30.085	1409
Baldwin Park	30.133	1171
Beverly Hills	3.069	128
Burbank	7.064	420
Calabasas	12.531	557
Canoga Park	1.321	51
Chilao Flat	30.062	1351
Condor Peak	21.488	958
Crystal Lake	21.429	1274
El Monte	0	0
Glendora	21.477	1002
Hollywood	0	0
Inglewood	0	0
La Habra	10.97	440
Long Beach	0	0
Los Alamitos	0	0
Los Angeles	0	0
Malibu Beach	20.846	976
Mount Baldy	22.421	1082
Mount San Antonio	25.868	1190
Mt. Wilson	19.707	1042
Oat Mountain	21.515	866
Ontario	8.162	489
Pasadena	12.873	567
Point Dume	14.449	593
Redondo Beach	0	0
San Dimas	20.899	811
San Fernando	29.730	1187
San Pedro	0	0
Santa Susana	4.855	258
Seal Beach	0	0
South Gate	0	0
Sunland	30.071	1509
Thousand Oaks	4.007	155
Topanga	14.344	588
Torrance	0	0
Triunfo Pass	8.679	342
Van Nuys	0	0
Venice	0	0
Waterman Mountain	30.069	1584
Whittier	0	0
Yorba Linda	4.37	181
total	*480.494*	*22,181*

Table 1. NURE Flight-line Miles and Data Points by 7.5-minute Quadrangle for Southern Los Angeles County

Dibblee Map Unit		Number of Flight-line data points at 5 ppm Eu or greater	Percent of all Flight-line data points at 5 ppm Eu or greater	7.5-minute quadrangles containing 5 ppm Eu or greater locations
af	artificial fill	1	0.2	Mt. Wilson
an	Anorthosite-Gabbro Complex—anorthosite	1	0.2	Sunland
gn	Gneissic Rocks—gneiss	37	6.8	Chilao Flat, Mt. Baldy, Mt. Wilson, San Fernando,
gng	Gneissic Rocks—gneissoid granitic rocks	1	0.2	Mt. Wilson
gr	Granitic Rocks	17	3.1	Burbank, Chilao Flat, Mt. Wilson, Mt Baldy, Sunland, Waterman Mtn.
grd	Granodiorite	11	2.0	Mt. Wilson, Sunland
grdb	Granitic Rocks	1	0.2	Condor Peak
jgb	jotunite-norite-gabbro-diorite mafic complex	8	1.5	Sunland
Kcg	Unnamed Strata (Cretaceous)—conglomerate	1	0.2	Topanga
Kcs	Chatsworth Formation	1	0.2	Calabasas
Kss	Unnamed Strata (Cretaceous)—sandstone	1	0.2	Topanga
lgdp	Lowe Granodiorite—porphorytic	4	0.7	Chilao Flat
my	mylonite	3	0.6	Crystal Lake, Mount San Antonio
ps	Pelona Schist	13	2.4	Mount San Antonio
Qa	Surficial Sediments	29	5.3	Azusa, Baldwin Peak, Calabasas, Ontario, San Dimas
Qae	Older Dissected Surficial Sediments	3	0.6	Baldwin Peak
qd	Quartz Diorite	98	17.9	Mt. Wilson, Pasadena, San Fernando, Sunland
qdg	Quartz Diorite—mixed with granite and granodiorite	4	0.7	Mt. Wilson

Table 2. NURE Airborne Radiometric Equivalent Uranium Data Equal or Greater Than 5 ppm by Dibblee Map Geologic Unit

Dibblee Map Unit		Number of Flight-line data points at 5 ppm Eu or greater	Percent of all Flight-line data points at 5 ppm Eu or greater	7.5-minute quadrangles containing 5 ppm Eu or greater locations
Qg	Surficial Sediments—gravel and sand	13	2.4	Baldwin Peak, Mt. Wilson, Sunland, Topanga
Qls	Landslide Debris	23	4.2	Calabasas, Mt. Wilson, Oat Mtn, San Fernando, Topanga,
Qoa	Older Alluvium	25	4.6	Oat Mtn, Mt. Wilson, Sunland
Qof	Older Dissected Surficial Sediments—alluvial fan gravel and sand	2	0.4	Pasadena, Mt. Wilson
Qog	Older Dissected Surficial Sediments—gravel	1	0.2	Mt. Wilson
QTs	Saugus Formation	20	3.7	Santa Susana
sms	Santa Monica Slate	4	0.7	Beverly Hills Topanga
Tcvab	Submarine and Subaerial Volcanic Rocks—andesitic breccia	3	0.6	Point Dume
Tcvap	Submarine and Subaerial Volcanic Rocks—basaltic-andesitic breccia	3	0.6	Point Dume
Tgvb	Glendora Volcanic Rocks—basalt flows	4	0.7	San Dimas
Tgvc	Glendora Volcanic Rocks—volcanic conglomerate	1	0.2	San Dimas
Tll	Llajas Formation	9	1.6	Santa Susana
Tm	Monterey Shale (or Formation)	71	13.0	Calabasas, Oat Mtn
Tmlv	Monterey (Puente) Formation—La Vida Shale Member	6	1.1	San Dimas
Tmy	Monterey (Puente) Formation—Yorba Shale Member	1	0.2	San Dimas
Tsp	Sespe Formation	3	0.6	Point Dume
Tsq	Sisquoc Shale	50	9.1	Oat Mtn, Santa Susana

Table 2 continued...

Dibblee Map Unit		Number of Flight-line data points at 5 ppm Eu or greater	Percent of all Flight-line data points at 5 ppm Eu or greater	7.5-minute quadrangles containing 5 ppm Eu or greater locations
Ttlc	Lower Topanga Formation—clay shale	1	0.2	Triunfo Pass
Ttlcv	Lower Topanga Formation—clay shale	3	0.6	Point Dume
Ttlsv	Lower Topanga Formation—sandstone	11	2.0	Triunfo Pass
Ttog	Towsley Formation-conglomerate	1	0.2	San Fernando
Ttos	Towsley Formation—sandstone	1	0.2	San Fernando
Ttuc	Upper Topanga Formation—clay shale or claystone	26	4.7	Calabasas, Point Dume
Ttus	Upper Topanga Formation—sandstone	5	0.9	Calabasas, Topanga
Tush	Unnamed Shale (upper part of Modelo Fm, equivalent to Sisquoc Shale of Dibblee 1989, Ventura Basin)	27	4.9	Calabasas
total		548	100.6 %	

Table 2 continued...

APPENDIX 3

	All Indoor Rn Data	High Zone Rn Data	High-Qa Zone Rn Data	Moderate Zone Rn Data	Low Zone Rn Data
Size	1729	198	182	267	1084
Mean	1.965	4.379	3.332	2.039	1.279
Std Dev	6.959	8.584	8.223	3.302	6.939
Std Error	0.167	0.610	0.613	0.202	0.211
C.I. of Mean	0.328	1.203	1.209	0.398	0.414
Range	159.3	85.5	103.9	36.3	159.3
Max	159.6	85.8	104.2	36.6	159.6
Min	0.300	0.300	0.300	0.300	0.300
Median	0.800	2.400	1.950	1.200	0.500
25%	0.300	1.300	1.000	0.700	0.300
75%	1.800	4.300	3.550	2.100	1.000
Skewness	15.333	6.427	10.709	6.316	19.267
Kurtosis	283.785	49.550	113.011	53.783	398.273
K-S Dist.	0.405	0.317	0.356	0.299	0.444
K-S. Prob.	<0.001	<0.001	<0.001	<0.001	<0.001
Sum	3398.000	867.100	599.800	544.400	1386.700
Sum of Squares	90350.666	18312.070	14102.480	4010.860	53925.250

Table 1. Descriptive Statistics and Statistical Comparison of Indoor Measurement Data (non-transformed) for Southern Los Angeles County Radon Zones

	All Indoor Rn Data	High Zone Rn Data	High-Qa Zone Rn Data	Moderate Zone Rn Data	Low Zone Rn Data
Size	1729	198	180	267	1084
Mean	-0.0405	0.374	0.276	0.0873	-0.200
Std Dev	0.442	0.442	0.413	0.404	0.361
Std Error	0.0106	0.0314	0.0308	0.0247	0.0110
C.I. of Mean	0.0209	0.0620	0.0607	0.0487	0.0215
Range	2.726	2.456	2.541	2.086	2.726
Max	2.203	1.933	2.018	1.563	2.203
Min	-0.523	-0.523	-0.523	-0.523	-0.523
Median	-0.0969	0.380	0.290	0.0792	-0.301
25%	-0.523	0.114	0.000	-0.155	-0.523
75%	0.255	0.633	0.550	0.322	0.000
Skewness	0.933	0.335	0.322	0.512	1.549
Kurtosis	1.131	0.799	1.242	0.401	4.507
K-S Dist.	0.138	0.0406	0.0498	0.0656	0.186
K-S. Prob.	<0.001	0.556	0.327	0.007	<0.001
Sum	-70.018	74.079	49.703	23.322	-217.122
Sum of Squares	340.875	66.280	44.251	45.482	184.862

Table 2. Descriptive Statistics and Statistical Comparison of Indoor Measurement Data (log10-transformed) for Southern Los Angeles County Radon Zones