SPECIAL REPORT 208

RADON POTENTIAL IN SAN LUIS OBISPO COUNTY, CALIFORNIA

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CALIFORNIA GEOLOGICAL SURVEY
Department of Conservation

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By

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PG #4265

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EXECUTIVE SUMMARY

Radon is a radioactive gas formed by the decay of small amounts of uranium and thorium naturally present in rock and soil. Sometimes radon gas can move from underlying soil and rock into houses and become concentrated in the indoor air, posing a significant lung cancer risk for the residents. Indoor radon exposure is estimated to be responsible for 21,000 lung cancer deaths annually in the United States (U.S. EPA, 2007).

Between October 28, 2004 and January 28, 2005, the Department of Public Health-Indoor Radon Program conducted an indoor-radon survey of 918 homes in San Luis Obispo County using short-term charcoal detectors. Based on survey results, an estimated 14,554 individuals out of 246,681* (5.9 percent) live in homes with radon levels at 4 picocuries per liter (pCi/L) or above in San Luis Obispo County. Four picocuries per liter is the U.S. EPA recommended action level above which remedial action should be considered. In zip code area 93465 (Templeton), 27.3 percent of homes measured had radon levels at or above the 4 pCi/L. In two other zip code areas, 93422 (Atascadero) and 93446 (Paso Robles), 18.8 and 8.9 percent of the homes measured at or above 4 pCi/L respectively. Zip code area 93451 (San Miguel) had 1 of 5 tests (20%) exceeding 4 pCi/L, but this rate should only be considered preliminary because of the small number of measurements.

Reporting indoor-radon survey results by county or by zip code areas is useful because the information can easily and quickly be made available to interested parties. However, there are several disadvantages to this approach. First, counties and zip code areas are often large and sometimes contain many different rock and soil types. Radon production and ease of movement in the subsurface can be quite different for different rock types and soils. Consequently, radon potential may vary greatly within county or zip code areas with many different rock and soil types. Second, homes are often not evenly distributed within county or zip code areas, so little or no indoor-radon data may be obtained for some geologic and soil units during indoor-radon surveys. For these reasons, some counties with hundreds or more indoor- radon tests, and some zip code areas with tens or hundreds of indoor-radon tests, may have few or no tests exceeding 4 pCi/L liter and still contain unidentified “pockets” or “hot spots” with relatively high percentages of homes exceeding 4 pCi/L. The chance of missing these “pockets” or “hot spots” can be greatly reduced by comparing indoor-radon test locations and results with geologic and soil units. Areas lacking radon test data that should be priorities for future indoor-radon testing can also be identified using this approach. Through a cooperative agreement with the Department of Public Health Indoor Radon Program, the California Geological Survey undertook a study using this approach and compared the 2004-2005 San Luis Obispo County indoor-radon survey data with available geology, soil and geochemical information for the county. Portions of San Luis Obispo County having high, moderate or low potential for homes with radon

*All radon zone population estimates are derived using 2000 census data levels at or above 4 pCi/L were identified during this activity. These radon potential areas, or “zones,” are shown on the1:100,000-scale (1 inch = 1.58 miles) maps of western and eastern San Luis Obispo County--included as Plate 1 and Plate 2 of this report. The report also includes the data utilized, and describes the approach taken to develop the radon potential zone map for San Luis Obispo County. Finally, the report identifies radon-data gaps for the county that could be addressed if resources become available.

This San Luis Obispo radon potential map is informational, not regulatory, and is intended as a guide to prioritize areas for public education on radon, and for targeting additional indoor-radon testing activities. The map cannot be used to determine the indoor-air radon level of a particular building. Each radon zone contains some homes testing above 4 pCi/L and some homes testing below 4 pCi/L. The only way to identify specific buildings with indoor-radon levels exceeding 4 pCi/L is through testing.

Radon statistics for the different San Luis Obispo County radon map categories are:

- High radon potential areas extend over 17.8 percent of the county (590 square miles) and relate to a group of Monterey Formation geologic units and portions of adjacent alluvial units that have a Monterey Formation component. The radon survey data suggest radon concentrations at or above 4 pCi/L for 24.6 percent of homes in this zone. An estimated 9,742 individuals live in the homes in high radon potential areas with radon levels at or above 4 pCi/L, and 713 may have radon concentrations in their homes exceeding 20 pCi/L.

- Moderate radon potential areas extend over approximately 30.9 percent of the county (1,025 square miles) and relate to occurrences of the Atascadero Formation, Paso Robles Formation, and Santa Margarita Sandstone. Radon survey results suggest 8.5 percent of moderate potential zone homes have radon levels at or above 4 pCi/L. The highest moderate potential zone radon test result was 12 pCi/L. An estimated 4,101 individuals live in homes with indoor-air radon concentrations at or above 4 pCi/L within moderate zone areas.

- Low radon potential areas extend over the remaining 51.4 percent of the county (1,689 square miles) and are comprised of a many of different geologic units. Survey results suggest 1.5 percent of homes in the low potential zone have radon levels at or above 4 pCi/L. The highest indoor-test result for the low potential zone was 10.8 pCi/L. An estimated 2,382 individuals live in homes with radon levels at or above 4 pCi/L within low zone areas.

- 16,225 individuals out of 246,681 (6.6 percent) are estimated to live in homes with indoor radon levels at or above 4 pCi/L in San Luis Obispo County, based on summing the estimates for individual radon potential zones (*This estimate takes into consideration the differences in radon potential for geologic units and population distribution within the county).*

INTRODUCTION

Purpose

This report documents the procedures used by the California Department of Conservation, California Geological Survey (CGS), to produce the 2008 Radon Potential Zone Map of San Luis Obispo County for the California Department of Public Health (CDPH). This report also describes radon potentials for geologic formations in San Luis Obispo 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.cdph.ca.gov/healthinfo/environhealth/Pages/Radon.aspx 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. The average uranium content for the earth's continental crust is about 2.5-2.8 ppm. Typical concentrations of uranium and thorium for many rocks and soils are on the order of a few parts-per-million (ppm). Certain rock types, such as organic-rich shales, some granitic rocks, and rhyolites may 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 located on rocks and associated soils containing higher concentrations of uranium will have an increased likelihood of elevated indoor radon levels.

Radon gas readily moves through rock and soil along micro-fractures and through pore-spaces between mineral grains. Radon movement away from its site of origin is typically limited to a few meters to tens of meters because of the relatively short half-lives of radon isotopes (3.8 days for radon-222, 55.6 seconds for radon-220 and 3.96 seconds for radon-210), but movement may be hundreds of meters in some cases. Additional conditions, such as soil moisture content, also affect how far radon can move in the subsurface. Because radon-222 (a radioactive-decay product uranium-238) has the longest half-life of the several radon isotopes, 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-to-wall joints, and openings around pipes. Radon enters buildings from the soil when air pressure inside the buildings is lower than air pressure in the soil. When exhaust fans are used, inside air is heated, or wind is blowing across a 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. Radon can also enter a building in water from private wells. All ground water contains some dissolved radon gas. The travel time of water from an aquifer to a home in a private well is usually too short for much radon decay so radon is available to be released in the house during water usage, for example through use of a bathroom shower. However, normal water usage typically adds only about 1 pCi/l (picocurie per liter) of radon to indoor air for 10,000 pCi/l of radon in water (Grammer and Burkhart, 2004).

Breathing air with an elevated 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 21,000 according to the U.S. Environmental Protection Agency (U.S. EPA, 2007). 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, 2007). 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 ≥ 4.0 pCi/l. Based on long-term radon test statistics, the U.S. EPA estimates about 1 out of 15 homes in the United States have radon levels ≥ 4.0 pCi/l

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 radioactive decay products (also called *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 during decay of polonium-218 and polonium-214 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 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 (a short-term test), while alpha-track detectors are typically exposed for periods of weeks or months to as long as a year under normal building conditions (a long-term test). These tests are simple and inexpensive and homeowners can do this testing themselves. Test results are reported in units of picocuries per liter (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, short-term measurements are more commonly used because of the shorter 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 advisory, not regulatory, 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, local variability in soil permeability and climatic conditions, and factors such as building design, construction, condition, and usage, may influence indoor radon levels. 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 SAN LUIS OBISPO COUNTY RADON POTENTIAL MAP

Radon Mapping Overview

The CGS-CDPH Radon Program radon potential maps show areas, called radon potential zones, where residences have relatively high, moderate or low chance for indoor-air with ≥ 4.0 pCi/l radon levels. Since 2005, the California Geological Survey (Churchill, 2005; 2006; and 2007), has used the following radon zones for these maps, which have been broadly defined on the basis of short-term indoor radon tests as follows:

High Zone—20 percent or more ≥ 4.0 pCi/l indoor-measurements
Moderate Zone—5 to 19.9 percent ≥ 4.0 pCi/l indoor-measurements
Low Zone—less than 5 percent ≥ 4.0 pCi/l indoor-measurements

These definitions make it easier to compare the radon zones between counties. For example, the highest zones in Counties A, B and C might have 25 percent, 35 percent and 8 percent ≥ 4.0 pCi/l indoor-measurements respectively. Using the above definitions, the highest zones in Counties A and B would be classified as having high radon potential while the highest zone in County C would have moderate radon potential.

Development of radon zones involves the following steps and considerations:

1) Indoor-radon data are grouped by geologic unit, or geologic unit and soil unit (where appropriate digital soil maps are available).

2) The different geologic unit or geologic unit-soil unit areas are classified as having high, moderate or low indoor-radon potential based on their percentage of ≥ 4.0 pCi/l measurements. Units with 20% or more indoor

measurements ≥ 4.0 pCi/l are classified "high" potential, units with 5 to 19.9% ≥ 4.0 pCi/l measurements are classified "moderate" potential, and units with < 5% ≥ 4.0 pCi/l measurements or no measurements are classified low potential unless other information is available supporting a higher classification status (see item 3).

3) Indoor-radon measurements from about 25 to 30 different sites, distributed over the areal extent of a unit, are considered necessary for a reliable assessment of the unit's radon potential. A provisional "Moderate" or "High" radon potential may be assigned some units having less than 25 measurements (if many or all of the available indoor measurements exceed ≥ 4.0 pCi/l, if several measurements exceed 10 or 20 pCi/l, if the same unit elsewhere in California is known to have moderate or high radon potential, or if other data such as airborne or ground gamma-ray spectrometry or uranium data from soil or sediment samples suggest elevated indoor-radon potential for the unit).

4) The final high-potential and moderate-potential radon zone areas are the aggregate of high potential unit occurrences and moderate potential unit occurrences respectively, each with an added 0.2 mile-wide (approximately 1,000 foot) buffer zone. If high and moderate potential buffer zones overlap, the high potential buffer zone takes precedence. Where sufficient indoor-radon data and soil unit data are present, these data may support modification of the final high and moderate zone boundaries by restricting high or moderate zone boundaries to certain soil unit boundaries or using geologic unit boundaries, without a 0.2 mile wide buffer zone, as the high or moderate zone boundaries. All areas not classified as high or moderate radon potential are considered low radon potential.

5) Finally, indoor-radon data populations for the high, moderate and low potential zones are statistically compared using a difference of mean t-test or a Mann-Whitney Rank Sum test, as appropriate, to confirm that the zones are statistically different in radon potential. If the zones differ statistically, the radon potential zone development process is complete and the final potential zone areas are plotted on a 1:100,000-scale base map. If zones do not differ statistically, classification boundary adjustments may be made, or a radon potential zone category may be added or dropped so that the radon potential zones indicated on the final map are statistically different.

Faults and shear zones are not indicated on 1:100,000-scale radon potential maps. Portions of radon zone areas underlain by faults and shear zones may have increased potential for elevated indoor-radon because such features provide pathways for radon flow. However, faults and shear zones are not identified separately on the 1:100,000-scale radon potential maps because the minimum fault or shear zone width that can be depicted by a map line at this scale is about 150-200 feet whereas fractures of an inch width or less can be significant pathways for radon movement to a buildings foundation. Soil and alluvium may obscure faults and shear zones from recognition or prevent their precise location on geologic maps except where detailed site-specific investigations have been conducted. Consequently, at 1:100,000-scale mapping, it is better to base priority for indoor testing on zone designation rather than attempt to target fault and shear zone locations. It must be kept in mind that the only way to determine the radon concentration it a particular building is to do an indoor radon test, irrespective of geologic or soil information. All radon zone categories will have some buildings with indoor radon levels $\geq$ 4 pCi/l. Where situations require a local detailed investigation of indoor radon and fault or shear zone relationships, accurate fault or shear zone maps of 1:24,000 or more detailed scale should be used or developed to guide testing.

SAN LUIS OBISPO COUNTY SHORT-TERM INDOOR-RADON SURVEY RESULTS

Overview

A survey of 918 San Luis Obispo County homes was conducted by the California Department of Public Health--Radon Program between October 28, 2004 and January 28, 2005. The CDPH Radon Program solicited participation in this survey via direct mailing to 25,000 homeowners in San Luis Obispo County with 3.7 percent (918 homeowners) agreeing to participate. The survey participants received a free charcoal detector, which they placed and exposed according to instructions, and subsequently mailed to the Radon Program contract lab for measurement.

Figure 1 shows the distribution of CDPH radon survey locations in San Luis Obispo County. Fifty-four locations had results that equaled or exceeded 4.0 pCi/l and these are shown in *Figure 2.* The radon survey data range from 0.3 pCi/l (the detection limit) to 57.6 pCi/l. *Table 1* summarizes radon survey results by Zip Code Zone.

Radon Survey Data Exposure Information and Quality

Residents exposed their detector kits for four days. Thirty-nine duplicate tests were made during the survey and the results are listed in Appendix A. For 21 sites below 1 pCi/l, the range of test pair differences ranged from 0.0 to 0.4 pCi/l. For 15 sites with measurements between 1 and 4 pCi/l, test pair differences ranged from 0.0 to 0.7 pCi/l. For the two test pairs above 4 pCi/l, the differences between detectors were 0.6 pCi/l and 0.8 pCi/l. Appendix B shows the results of 52 field blank radon detectors submitted for analysis during the San Luis Obispo radon survey. Multiple and follow-up tests for three locations are shown in Appendix C. At the first location, in San Luis Obispo city, 8 tests taken on three occasions during a two month period ranged from 0.3 to 0.6 pCi/l (all below 1 pCi/l). At the second location, in Paso Robles, two successive tests were 1.3 pCi/l and 2.9 pCi/l (both below 4 pCi/l). Two tests at a third location in Atascadero, two months apart, were 8.1 pCi/l and 20.2 pCi/l (both above 4 pCi/l).

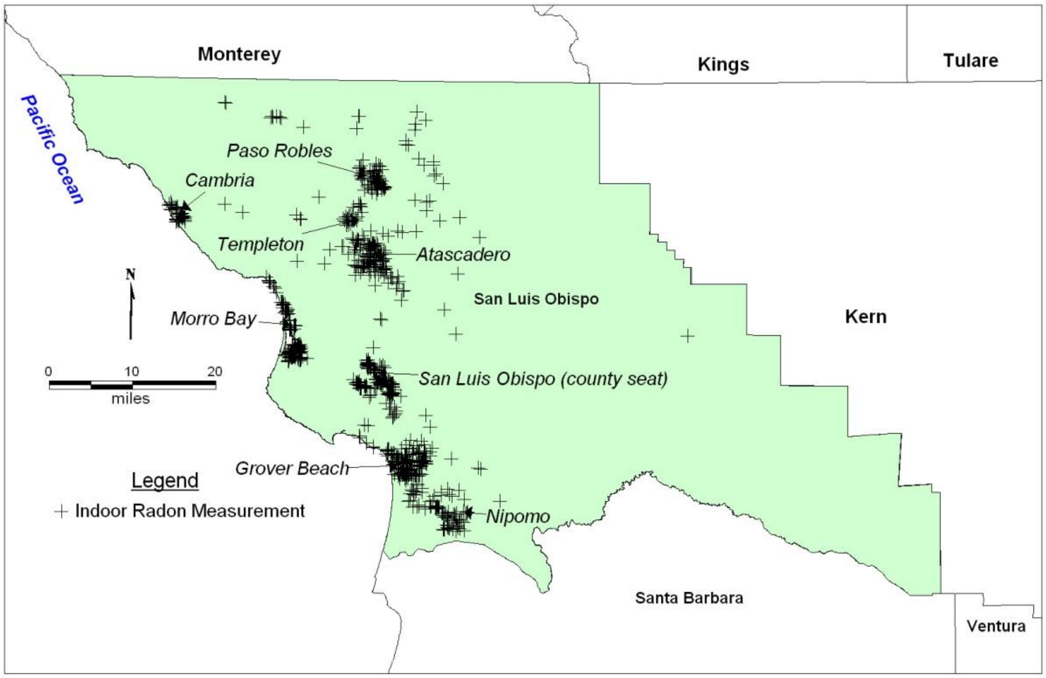

Figure 1. All CDPH Short-Term Radon Tests for San Luis Obispo County

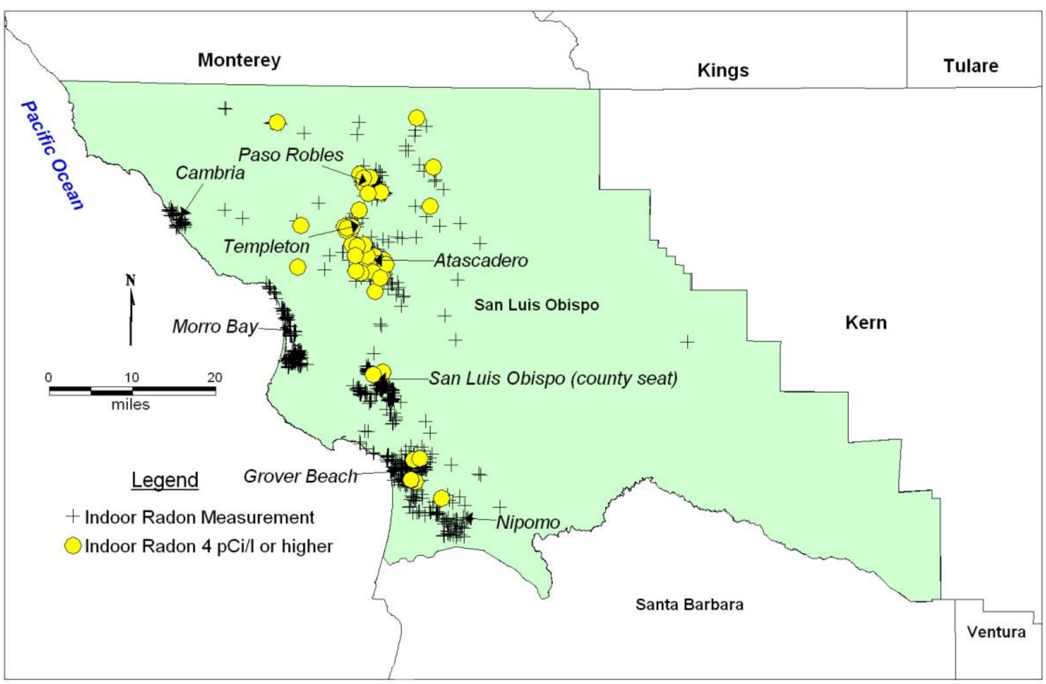

Figure 2. All CDPH Short-Term Radon Test Results for San Luis Obispo County—with 4.0 pCi/l or Greater Sites Shown as Yellow Circles

Zip Code	City/Region	Number of Measurements	Measurements ≥ 4.0 pCi/l	Percent ≥ 4 pCi/l
93401	San Luis Obispo	113	1	0.9
93402	Los Osos	97	0	0.0
93405	San Luis Obispo	53	1	1.9
93420	Arroyo Grande	132	6	4.6
93422	Atascadero	133	25	18.8
93423	Atascadero *(PO Box only)*	1	0	0.0
93424*	Avila Beach *(PO Box only)*	0*		
93426**	Bradley	2	0	0.0
93428	Cambria	42	0	0.0
93430	Cayucos	11	1	9.1
93432	Creston	2	0	0.0
93433	Grover Beach	28	0	0.0
93435*	Harmony *(PO Box only)*	0*		
93442	Morro Bay	44	0	0.0
93444	Nipomo	61	0	0.0
93445	Oceano	13	0	0.0
93446	Paso Robles	113	10	8.9
93449	Pismo Beach Shell Beach	27 2	0 0	0.0 0.0
93451**	San Miguel	5	1	20.0
93452*	San Simeon	0* (*See San Simeon discussion, page 32*)		
93453	Santa Margarita	5	0	0.0
93454***	Santa Maria	1	0	0.0
93461*	Shandon	0*		
93465	Templeton	33	9	27.3
	total	*918*	*54*	*5.9*

*No respondents to CDPH Indoor-Radon testing solicitation.
**Portion of Zip Code area in Monterey County
***Portion of Zip Code area in Santa Barbara County

Table 1. CDPH Indoor-Radon Short-Term Test Results for San Luis Obispo County by Zip Code Zone.

San Luis Obispo County Geologic Unit Radon Potentials

Indoor-radon data from the CDPH Radon Program 2004-2005 survey of San Luis Obispo County residences are tabulated by geologic unit in Appendix D, and by geologic unit and soil unit in Appendix E. The 1:100,000-scale digital geologic map compilation for San Luis Obispo County Rosenberg (2007) was used to determine the geologic unit present at radon measurement locations. The NRCS digital soil maps for San Luis Obispo County (NRCS, 2005a, b, c, and d), available for downloading at: http://soildatamart.nrcs.usda.gov/Survey.aspx?County=CA079, were used to determine soil type at each measurement location for compilation of Appendix E.

Table 2 lists 13 geologic units likely to have high or moderate radon potential based in indoor-radon measurement results. The status of 9 of these units is provisional (indicated by “High?” or “Moderate?”)—less certain because they have few associated indoor-radon measurements or are Monterey Formation subunits without indoor data. Other data (airborne radiometric data, uranium data from soil samples and sediment samples, and soil data) were reviewed to see if they supported either high or moderate designations for the provisional units in Table 2, and to identify additional geologic units that may have elevated radon potential but lack indoor-radon measurements. Following sections of this report discuss these data and their ramifications. Table 3 lists geologic units having 25 or more indoor radon measurements and few or no 4.0 pCi/l or greater measurements (i.e., units with sufficient radon measurement data to statistically support their low radon potential classification).

Geologic Unit (From Rosenberg, 2007)	**Incidence Rate (R) of CDPH ≥ 4 pCi/l, Indoor Measurements in percent**	**Rn Potential Designation**
All Monterey Formation Units (siliceous mudstone, Miocene) with indoor radon data	**R = 27.8%,** N* = 54 N ≥ 4.0 pCi/l = 15 Maximum = 20.2 pCi/l	**High** R ≥ 20%
Tml-Monterey Formation (lower or semi-siliceous mudstone)	**R = 30.8%** N = 39 N ≥ 4.0 pCi/l = 12 Maximum = 20.2 pCi/l	**High** R ≥ 20%
Tmu-Monterey Formation (siliceous shale)	**R uncertain (*too few data*),** N = 10 N ≥ 4.0 pCi/l = 2 Maximum = 7.4 pCi/l	**High?** Apparent R = 20%
Tm-Monterey Formation (undifferentiated)	**R uncertain (*too few data*)** N = 3 N ≥ 4.0 pCi/l = 1 Maximum = 13.6 pCi/l	**High ?**
Tmmb-Monterey Formation (silty shale)	**R uncertain (*too few data*)** N = 1 N ≥ 4.0 pCi/l = 0 Maximum = 3.5 pCi/l	**High?**
Tmmd-Monterey Formation (diatomite)	**R uncertain (*too few data*)** N = 1 N ≥ 4.0 pCi/l = 0 Maximum = 3.2 pCi/l	**High?**
Tmb-Monterey Formation (basal member-siltstone, dolomitic claystone, and siliceous sandstone)	**R uncertain (*no data*)** N = 0	**High?**
Tmc-Monterey Formation (siliceous shale)	**R uncertain (*no data*)** N = 0	**High?**
Tmg-Monterey Formation (Gould Shale Member)	**R uncertain (*no data*)** N = 0	**High?**
Tmw-Monterey Formation (Whiterock Bluff Shale Member)	**R uncertain (*no data*)** N = 0	**High?**
Qoa (only Qoa near Monterey Fm)	**R =** R uncertain (*too few data*), N = 14 N ≥ 4.0 pCi/l = 5 Maximum = 10.8 pCi/l	**High?** Apparent R ≥ 20%
Ka-Atascadero Formation, undivided	**R=15.2%** N=33 N ≥ 4.0 pCi/l = 5 Maximum = 57.6 pCi/l	**Moderate** 5% < R < 20%
Qpr, QTp and TQp—Paso Robles Formation	**R = 6.9%** N = 101 N ≥ 4.0 pCi/l = 7 Maximum = 5.6 pCi/l	**Moderate** 5% < R < 20%
Tsm-Santa Margarita Sandstone	**R = 7.4%** N = 27 N ≥ 4.0 pCi/l = 2 Maximum = 4.3 pCi/l	**Moderate** 5% < R < 20%

*N=the number of CDPH indoor-radon data available from houses located on the geologic unit indicated in the first column of the table.

Table 2. High and Moderate Radon Potential Geologic Units in San Luis Obispo Co. Based on 2004-2005 CDPH Short-Term Indoor Radon Data

Geologic Unit (Rosenberg, 2007)	**Incidence Rate (R) of CDPH Indoor-Radon Measurements ≥ 4 pCi/l, in percent**	**Radon Potential Designation**
KJf-Franciscan Assemblage, undivided	**R=0** N=53 Maximum = 2.5 pCi/l	**Low** R < 5 %
Qal-Latest Pleistocene to Holocene alluvium, undifferentiated	**R=1.7%** N=119 N≥4.0 = 2 Maximum = 7.3 pCi/l	**Low** R < 5 %
Qos-Latest Pleistocene to Holocene dune sand	**R=2.9%** N=68 N≥4.0 = 2 Maximum = 7.3 pCi/l	**Low** R < 5 %
Qs-Latest Holocene beach sand	**R=0%** N=115 Maximum = 3.4	**Low** R < 5 %
Qso-Latest Pleistocene to Holocene dune sand	**R=0.0%** N=74 Maximum= 2.1 pCi/l	**Low** R < 5 %
Qt-Early to late Pleistocene stream terrace deposits	**R=0.0** N=30 Maximum = 2.8 pCi/l	**Low** R < 5 %

Table 3. Low Radon Potential Geologic Units in San Luis Obispo County Based on 2004-2005 CDPH Short-Term Indoor Radon Data (*only units with more than 25 measurements*)

NURE DATA REVIEW

Background

During the 1970s and early 1980s, the federal government funded the National Uranium Resource Evaluation (NURE) project. The goal of NURE was to identify new domestic sources (ore deposits) of uranium for energy and national defense. NURE uranium exploration activities included airborne gamma-ray spectral surveys that estimated the uranium content of soils and rocks along a grid of flight-lines, and (in some parts of California) the collection and analysis of soil and stream sediment samples for uranium. Locations with unusually high uranium levels were targets for additional work to see if economically recoverable uranium deposits were present.

Because radon is a radioactive decay product of uranium, areas with higher natural background amounts of uranium are generally more likely to have higher quantities of radon in the subsurface. Buildings in these areas have a greater potential for indoor-radon problems. Consequently, NURE uranium data for rock units, soils and sediments are valuable for radon mapping projects, particularly where indoor-radon measurements are sparse or lacking.

Airborne Radiometric Data

Airborne radiometric data used in this study are from a compilation by Duval (2000). Figure 3 shows the location of approximately 1,347 miles of flight lines within San Luis Obispo County flown during the 1980 NURE airborne radiometric survey and uranium anomaly locations along the flight lines. About 1,080 miles of flight lines were part of the San Luis Obispo 1x2 degree quadrangle survey, about 221 miles were part of the Bakersfield 1x2 degree quadrangle survey, 31 miles were part of the Los Angeles 1x2 degree quadrangle survey, and 15 miles were part of the Santa Maria 1x2 degree quadrangle survey. The flight-line grid pattern consists of east-west flight-lines, 2-4 miles apart, and north-south flight-lines, generally about 12 miles apart. Along the flight lines a specially equipped helicopter recorded approximately 54,800 gamma-ray spectral measurements. Data collection within the San Luis Obispo 1x2 degree quadrangle occurred at an average flight speed of 89 miles per hour and an average altitude of 347 feet. Data collection average speeds and altitudes were similar in the Bakersfield, Los Angeles and Santa Maria quadrangles. Under such conditions, measurements approximately represent uranium content within the upper 18 inches of surficial material over an area of approximately 48,000 square feet (or 1.1 acres; see High-Life Helicopters, 1980a and 1980b). Gamma-ray spectral data were collected for bismuth-214, a radioactive daughter product of uranium-238 (and the immediate daughter of radon-222); the bismuth-214 data were was used to estimate of the soil-rock uranium content in parts-per-million (ppm) at each of the 54,800 measurement locations. Because the uranium values are calculated from bismuth-214 data they are referred to as equivalent uranium (eU) data to distinguish them from uranium data determined by direct chemical methods (i.e., typical laboratory determinations for rock and soil samples by delayed neutron activation or fluorescence). Equivalent Uranium (eU) data can be impacted by soil moisture (Grasty, 1997), atmospheric inversion and other conditions, so eU data are treated in this study as a qualitative to semi-quantitative indicator of areas with increased uranium in rock or soil.

Two airborne eU anomaly definitions are considered in this study:

1) For eU data from San Luis Obispo 1X2 degree quadrangle the definition from the 1981 NURE report *(High Life Helicopters, Inc., 1981*) is: "Two consecutive averaged eU samples each being two or more standard deviations above the mean or three consecutive averaged eU samples, one of which is two or more standard deviations above the mean and two of which are one or more standard deviations above the mean."

2) Using eU data equal to or exceeding 7.5 ppm (3 times the average uranium content of the earth's crust) as a threshold for anomalies, the San Luis Obispo and Bakersfield 1x2 degree quadrangle data (from the NURE flight-line digital database)—257 eU data meet this criteria.

The eU anomaly locations for definition 1 and definition 2 can be compared in Figure 3. While there are some similarities in these anomaly distributions, definition 2 anomalies are more common and are more widely distributed than definition 1 anomalies.

Information summarizing flight-line uranium data for geologic units from the 1981 NURE report (High-Life Helicopters, 1981) is provided in Appendix F. A list of San Luis Obispo County flight line eU anomalies from the 1981 report is provided in appendix G. Airborne eU data ≥ 7.5 ppm eU are compared to 1:100,000 scale geologic map units in Appendix H.

The frequency of airborne uranium (eU) anomaly associations for particular geologic units, shown in Appendix G and Appendix H, suggests the most likely geologic units to have areas with elevated radon potentials are:

- Monterey Formation units, especially Tml, Tm, Tmu, and Tmw;
- Eocene and Paleocene marine sandstone, clay shale and minor conglomerate—Tss
- Santa Margarita Sandstone—Tsm
- Latest Pleistocene to Holocene alluvium, undifferentiated, Qa (Qa near Monterey Formation units?)
- Upper Cretaceous marine sandstone, conglomerate and minor mudstone—Ku
- Granitic rocks, undifferentiated--Kgr
- Paso Robles Formation—QTp

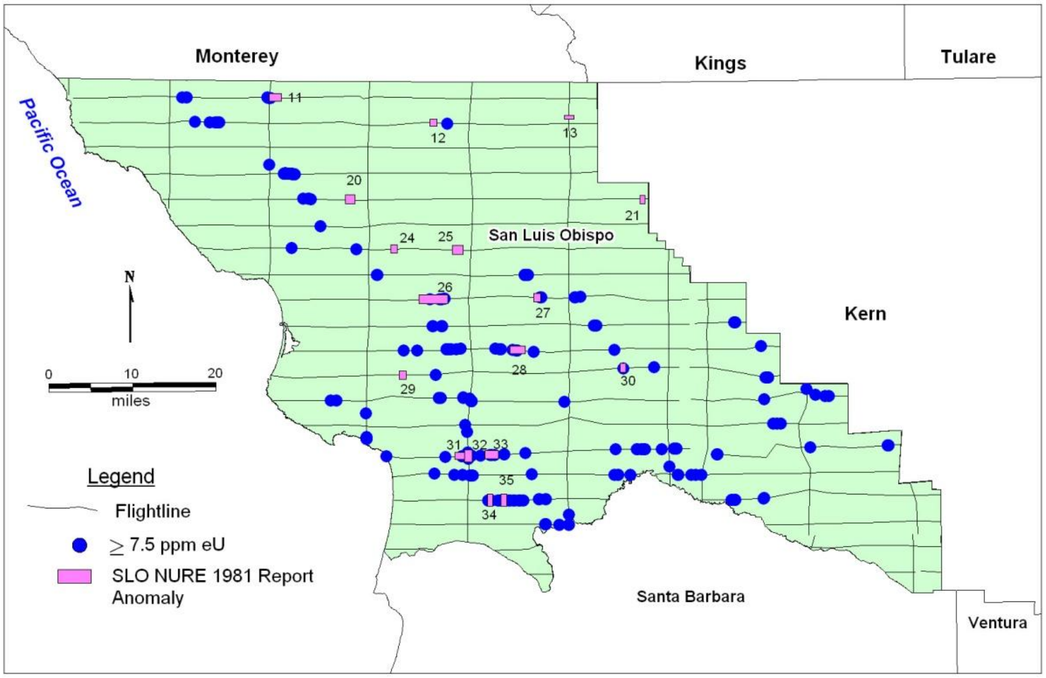

Figure 3. NURE Project Flight lines and Equivalent Uranium Anomalies

Flight line paths and ≥ 7.5 ppm eU data are from NURE airborne radiometric studies completed in the early 1980s for the San Luis Obispo, Bakersfield, Santa Maria, and Los Angeles 1X2 degree quadrangles. Anomalies identified in the 1981 NURE report for the San Luis Obispo quadrangle are shown in magenta; associated numbers refer to geologic information listed in Appendix G. No eU anomalies identified in the Bakersfield, Santa Maria and Los Angeles 1X2 degree quadrangle NURE studies are located within San Luis Obispo County.

Uranium in Soil, Stream Sediment and Talus Samples

NURE activities in San Luis Obispo County also resulted in the collection and analysis of 120 soil, 405 stream sediment, and 8 talus samples for total uranium. The distribution of the soil, stream sediment and talus samples in San Luis Obispo County is shown in Figure 4 (these data are available in Smith, 1997). Figure 5 shows the 10.7 percent of sample locations (shown in red), with samples that equal or exceed 5.0 ppm total uranium content (i.e., approximately twice the average uranium content of the earth's crust). Uranium data for these samples, grouped by the geologic unit present at the sample collection site, are listed in Appendix I.

Sixty-eight geologic units (1:100,000 scale map) have NURE uranium data available. Three geologic map units have 25 or more associated NURE samples, Qa (Latest Pleistocene to Holocene alluvium, undifferentiated; n=120); Qoa (Early to late Pleistocene alluvial deposits, undifferentiated; n=38) and QTp (Paso Robles Formation; n=73). The median uranium values for these units (combined sediment, soil and talus data) are as follows: Qa (2.925 ppm), Qoa

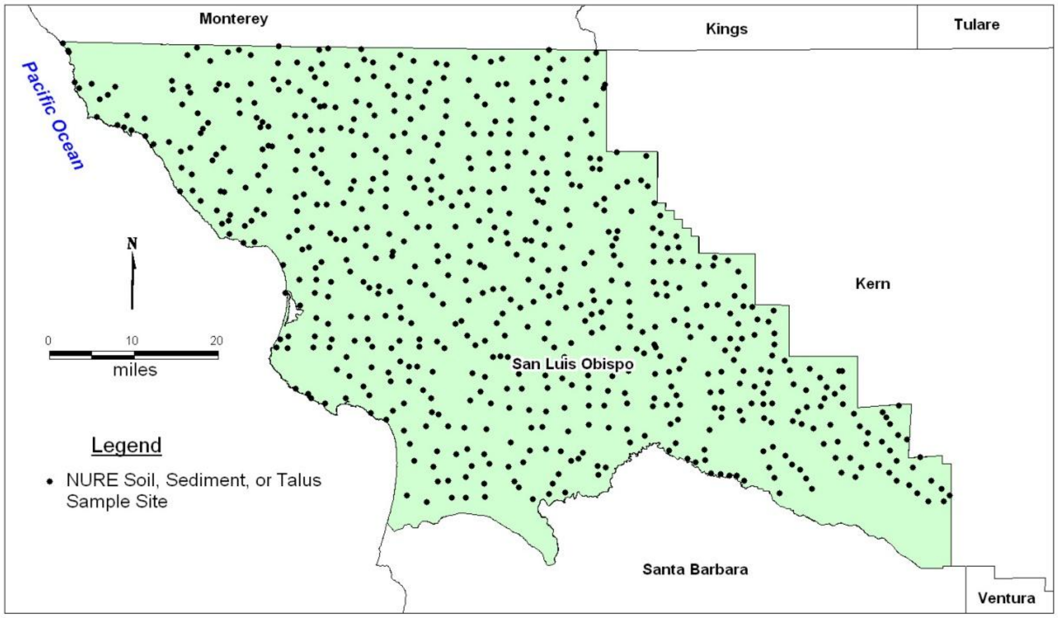

Figure 4. All NURE Soil, Stream Sediment and Talus Sample Locations

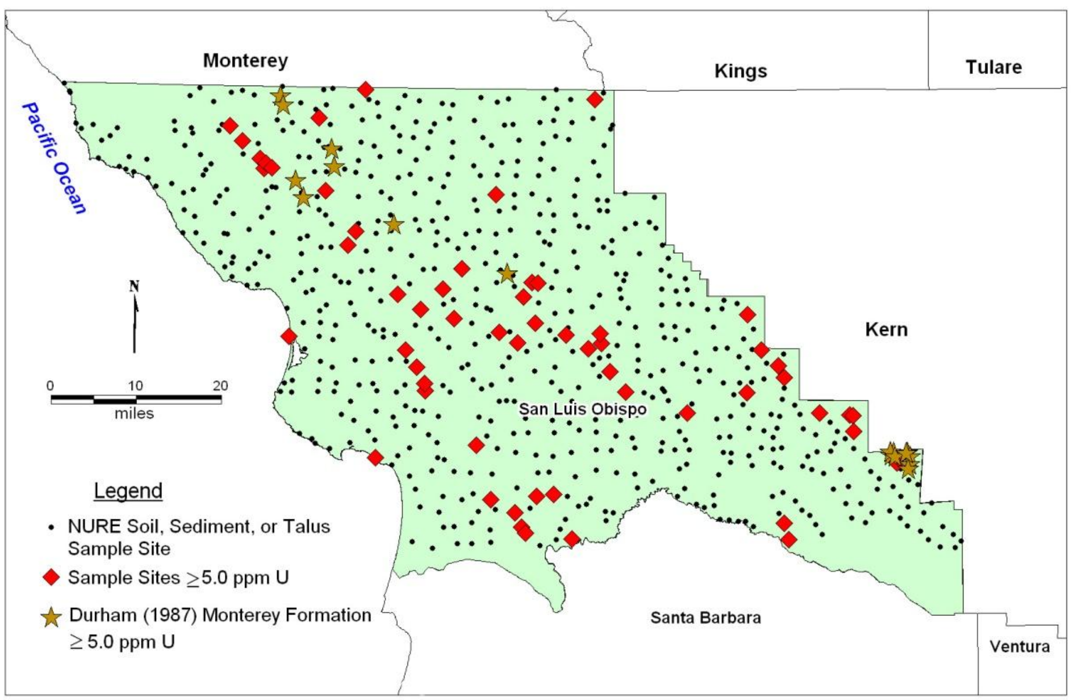

Figure 5. All NURE Soil, Stream Sediment and Talus Locations with ≥ 5.0 ppm Uranium Sites Highlighted in Red and ≥ 5 ppm Monterey Formation Uranium Locations from Durham (1987) in brown.

(2.435 ppm) and QTp (2.60 ppm). No individual Monterey Formation map unit has 25 or more uranium analyses. For Monterey Formation unit data taken together (n=60), the median uranium value is 4.20 ppm, significantly above the Qa, Qoa and QTp medians. The remaining units have too few uranium data to reliably determine their uranium population characteristics. Table 4 lists seven geologic map units with at least one associated NURE uranium analysis exceeding 10 ppm. This suggests at least small areas within these units may have higher radon (*Note Table 4 includes Monterey Formation units, Qoa and Qa previously discussed*).

Geologic Unit and NURE sample type	Highest NURE Uranium Analysis (ppm)
Tm-soil	56.99
Tmw-soil	14.97
Qoa-stream sediment	14.23
Qls-soil	13.85
Qya-stream sediment	12.83
Tm-stream sediment	10.50
Qa-stream sediment	10.03

Table 4. Geologic Units with One or More NURE Uranium Analyses Exceeding 10 ppm (See Appendix D for unit names).

Using 5 ppm uranium (approximately twice the average crustal uranium content) as a screening boundary to classify geologic units in Appendix 1 as having higher and lower radon potential, the most likely geologic units with elevated radon potentials in San Luis County are:

- Monterey Formation units—(at least Tm, Tml, Tmu and Tmw)
- gr and Kgr units--granitic rocks

Note that both the NURE airborne radiometric data and the soil-stream sediment-talus data support increased radon potential status for Monterey Formation units Tm, Tml, Tmu and Tmw, and Kgr.

In addition to the uranium NURE data, a study by Durham (1987) also documents elevated natural uranium concentrations in the Monterey Formation. Durham's study examined the uranium content of representative Monterey Formation samples from Monterey, San Luis Obispo, Kern and Santa Barbara counties. Samples from 24 locations within San Luis Obispo County had uranium contents ranging from 2.31 to 767 ppm, with a median value of 12.4 ppm uranium. Samples from 19 of these sites exceed 5 ppm in uranium content (see Figure 5) and represent the following Monterey Formation subunits—Tm, Tml, Tmd, Tmg, and Tmw (*units from Rosenberg, 2007*). Along with Monterey Formation samples, three Santa Margarita Sandstone samples from San Luis Obispo County were also analyzed in Durham's study. Their uranium contents are: 10.7 ppm (porcelanite), 39.9 ppm (phosphorite), and 9.45 ppm (vitreous tuff).

According to Durham, the Monterey Formation and other similar occurrences of diatomaceous, porcelaneous and cherty (siliceous) marine rocks generally contain more uranium than most other sedimentary rocks. The uranium in these rocks was probably derived from seawater and is adsorbed by organic material or incorporation in organic complexes. Where present in the Monterey Formation, phosphatic material adds to the total uranium content of diatomaceous sediments because it also concentrates uranium from seawater. Durham observed that cherty and dolomitic rocks, and rocks having a high proportion of terrigenous clastic material, generally have the lower uranium contents within the Monterey Formation.

In summary, NURE Data and Durham's study indicate the Monterey Formation and similar rocks included with the Santa Margarita Sandstone contain relatively high background concentrations of uranium. Consequently, houses in San Luis Obispo County located on these geologic units likely have increased risk for elevated indoor-air radon concentrations compared to houses on other geologic units.

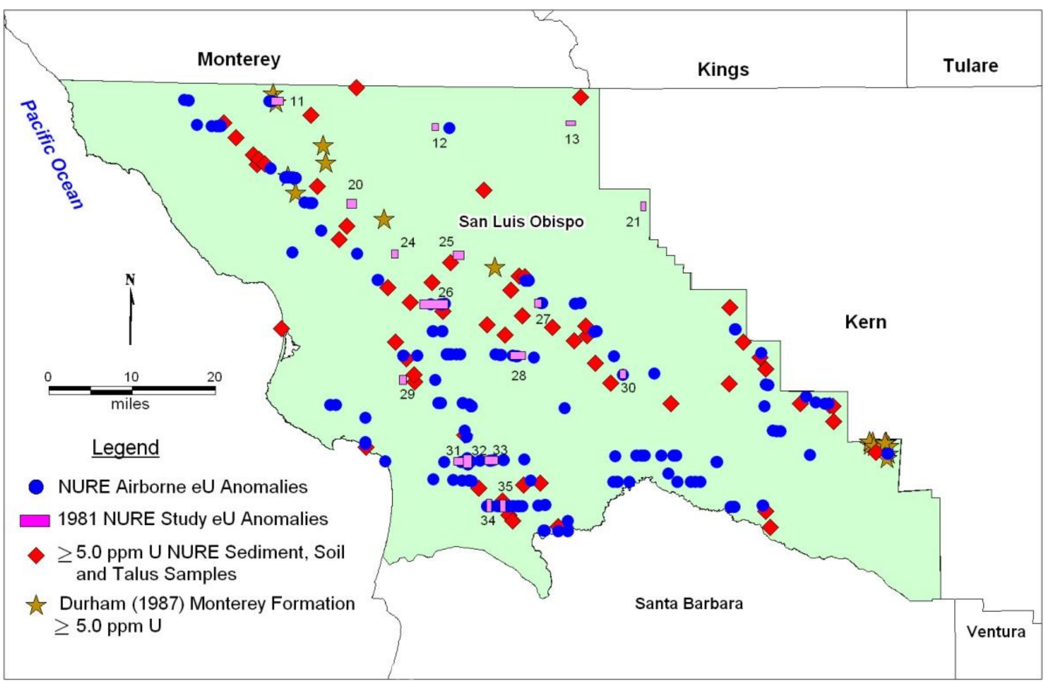

Figure 6. Comparison of NURE Airborne eU Anomaly Locations (Figure 3) with ≥ 5ppm U Soil, Sediment, and Monterey Formation (Durham, 1987) Sites (Figure 5).

NURE sediment-soil-talus data do not support the increased radon potential for Qa, QTp and Tss, implied by the airborne radiometric surveys, and are inconclusive for Tsm and Ku because of limited data.

Figure 6 shows locations of anomalous airborne equivalent uranium data, anomalous sediment-soil-talus uranium data, and Monterey Formation sample data from Durham (1987) exceeding 5 ppm uranium within San Luis Obispo County. Spatial distribution of these anomalous data groups is roughly similar except in the central southern portion of the county (Brown Canyon-Gypsum Canyon vicinity) where there are no sediment-soil-talus uranium anomalies associated with a group of airborne uranium anomalies.

NRCS SOIL DATA

Soil Properties and Indoor-Radon

The few relatively high uranium analyses for geologic units other than the Monterey Formation, listed in Table 4 and Appendix I, suggest that areas of uranium concentration with increased radon potential occur within these other units, but are small and scattered rather than continuous. Whether or not these areas of increased uranium concentration have increased radon potential depends, in part, on the permeability and other characteristics of the soils units present. Interconnected voids between mineral grains and fractures formed during drying of swelling clays are the primary forms of soil permeability and pathways for radon between its source and a building. Although not ideal, soil permeability data for water and shrink-swell behavior provides a qualitative gauge of soil permeability for radon gas (e.g., Brookins, 1990, Figure 7.2, p. 128).

Soil developed on the Paso Robles Formation provides an example of how soil shrinkage fractures may facilitate radon transport to a foundation. A study by Fierer and others (2005) contains information on radon in the upper two meters of soil in Santa Barbara County developed on the Paso Robles Formation. They found samples at 2 meters depth at 6 sites had soil gas radon levels ranging from about 1,000 pCi/l to 2,000 pCi/l. Shrinkage fractures 3 to 4 meters deep have been noted in soil derived from the Paso Robles Formation (Rosenberg, L.I., San Luis Obispo County Planning Department, written communication, 2007). Thus, soil fractures can be significant pathways for radon gas moving to a building's foundation. Swelling clays may also cause cracks in foundations and slabs, facilitating radon entry into buildings.

Appendix J lists representative permeability and shrink-swell properties of those San Luis Obispo County soils associated with at least one indoor-radon measurement ≥ 4 pCi/l. From the information in Appendix J, San Luis Obispo County soils with horizons with the following characteristics appear more likely to be associated ≥ 4 pCi/l indoor air sites than soils with other combinations of permeability and shrink/swell characteristics:

- Moderate permeability and moderate or low shrink/swell
- Moderately-slow permeability and moderate or low shrink/swell
- Slow permeability and high shrink/swell
- Very-slow permeability and high shrink/swell

Of the 54 sites having ≥ 4 pCi/l, 48 have soils with the aforementioned characteristics.

The following soils with these permeability and shrink-swell characteristics are associated with the Tml Monterey Formation subunit: Gazos shaly clay loam, Linne-Calodo complex, Linne-Zakme complex, Millsholm-Dibble complex, San Andreas-Arujo and Santa Lucia-Lopez complex. Typically, these soils are 20 to 40 inches thick and rest on weathered or hard shale. Ten out of 21 houses (48 percent) on Tml and these soils exceeded 4 pCi/l.

Rapid to moderately rapid permeability and low shrink-swell soils appear less likely to be associated with ≥ 4 pCi/l indoor air sites. Only 6 of the 54 ≥ 4 pCi/l sites have rapid permeability low shrink-swell soils. Note that Baywood and Oceano soils have these properties and are associated with the Table 3 low radon potential geologic units Qs, Qos and Qso (recent and older dune sand, see Appendix E). Only two of the 222 houses on these geologic units and soils exceeded 4 pCi/l.

RADON POTENTIAL ZONES

Final San Luis Obispo County Geologic Unit Radon Potentials

San Luis Obispo County high and moderate radon potential zones are based on locations of geologic units classified as having high or moderate radon potential. Table 5a summarizes the strengths of four categories of supporting data for "high" and "moderate" radon potential for various Monterey Formation geologic units: 1) indoor radon data; 2) NURE airborne gamma-ray survey data for equivalent uranium; 3) NURE sediment, soil and talus uranium data; and 4) NRCS soil permeability and shrink-swell data. In Table 5a, because of similarities in uranium content, physical characteristics, and the properties of associated soils, other Monterey Formation subunits with few or no indoor radon data (Tm, Tmu, Tmw, Tmmb, Tmmc, Tmmd, Tma, Tmb, Tmc, Tmd, and Tmg) are listed as having high radon potential at this time. Future radon testing of houses located on these Monterey Formation units may change their radon potential status.

Table 5b indicates the strength of supporting data for high or moderate radon potential classifications for four non-Monterey Formation geologic units: Qoa (where it likely contains a significant component of Monterey Formation alluvium), and Ka, QTp and Tsm.

Geologic Unit	Indoor Radon Survey Data	NURE Project Airborne Survey Data for eU	NURE Project and Other Sediment, Soil and Talus Data for U	NRCS Soil Perm. and Shrink-Swell Data	Assigned Radon Potential
Monterey Formation—combined data (Tml+Tm+Tmu+Tmw)	XX	x	x+	X	High
Tml-Monterey Formation-lower or Monterey Formation semi-siliceous mudstone	XX	x	x+	X	High
Tmu-Monterey Formation siliceous shale	x	x	x	X	High
Tm-Monterey Formation-undifferentiated	x?	x	+	X	High?
Tmmb-Monterey Formation-silty shale	x?			X	High?
Tmmc-Monterey Formation-resistant bedded chert	ND		x?	X	High?
Tmmd-Monterey Formation-diatomite	x?			X	High?
Tma-Monterey Formation, Saltos Member	ND			x	High?
Tmb-Monterey Formation-basal member siltstone, dolomitic claystone, and siliceous sandstone	ND			X	High?
Tmc-Monterey Formation-siliceous shale	ND			X	High?
Tmd-Monterey Formation-Devilwater Shale Member	ND		+	X	High?
Tmg-Monterey Shale-Gould Shale member	ND		+	x	High?
Tmw-Monterey Shale-Whiterock Bluff Shale Member	ND	x	+	x	High?

Table 5a. San Luis Obispo County Geologic Units and Strength of Supporting Data for Increased Radon Potential—Monterey Formation Units.

XX = more than 25 indoor radon measurements with ≥ 20% at 4 pCi/l or higher)
X = more than 25 indoor radon measurements (with ≥ 5% and < 20% at 4pCi/l or higher); or uranium analyses (with median ≥ 5 ppm U); or soils greatly facilitating radon migration
x = less than 25 indoor radon measurements (with ≥ 5 at 4 pCi/l or greater); or units with NURE airborne survey eU anomalies; or uranium analyses with median ≥ 5 ppm
+ = Uranium data in Durham (1987) supporting increased radon potential
ND = no indoor-radon data
? = confidence level somewhat uncertain (additional data needed)

Geologic Unit	**Indoor Radon Survey Data**	**NURE Project Airborne Survey Data for eU**	**NURE Project Sediment, Soil and Talus Data for U**	**NRCS Soil Perm. and Shrink-Swell Data**	**Assigned Radon Potential**
Qoa-Early to late Pleistocene alluvial deposits, undifferentiated (*where near Monterey Formation units*)	X		x	?	High?
Ka-Atascadero Formation	X			x	Moderate
QTp, TQp and Qpr-Paso Robles Formation	X	x	x	?	Moderate
Tsm-Santa Margarita Sandstone	X	x	+	?	Moderate

Table 5b. San Luis Obispo County Geologic Units and Strength of Supporting Data for Increased Radon Potential—Non-Monterey Formation Units.

X = more than 25 indoor radon measurements (with ≥ 5% and < 20% at 4pCi/l or higher); or uranium analyses (with median ≥ 5 ppm U); or association with soils facilitating radon migration
x = less than 25 indoor radon measurements (with ≥ 5 at 4 pCi/l or greater); or units with NURE airborne survey eU anomalies; or uranium analyses with median ≥ 5 ppm; or soils somewhat facilitating radon migration
+ = Uranium data in Durham (1987) supporting increased radon potential
ND = no indoor-radon data
? = confidence level somewhat uncertain (additional data needed)

Table 5c lists geologic units where there is some indication of increased radon potential, but available data are insufficient to justify a high or moderate radon potential classification. At this time, Table 5c units and all other geologic units in San Luis Obispo County not listed in Tables 5a and 5b are assigned low radon potential. Future studies to obtain additional indoor radon measurements related to these geologic units should be considered and may result in reclassification of some units to Moderate or High radon potential status.

Radon Potential Zone Boundaries

Monterey Formation unit areas (Tml, Tm, Tmu, Tmw, Tmmb, Tmmc, Tmmd, Tma, Tmb, Tmc, Tmd, and Tmg) and immediately adjacent areas within a 0.2 mile wide buffer (especially Qoa areas) are classified as having high radon potential.

QTp, TQp, Qpr (the three Paso Robles Formation units), Ka and Tsm and additional areas within a 0.2 mile wide surrounding buffer are classified as having moderate radon potential.

Occurrences of the high radon potential and moderate radon potential units just mentioned with minimum dimensions less than 0.2 miles were not assigned the 0.2 mile wide buffer except were such occurrences are less than 0.2 miles apart.

Sometimes high and moderate potential geologic units are close enough that their buffer zones overlap each other. When this situation occurs high zone buffer areas receive priority over moderate zone buffer areas. Figure 7 shows the radon zone locations and Figure 8 shows the radon zones in relationship to anomalous NURE data and ≥ 4 pCi/l indoor measurements.

Geologic Unit	**Indoor Radon Survey Data**	**NURE Project Airborne Survey Data for eU**	**NURE Project Sediment, Soil and Talus Data for U**	**NRCS Soil Perm. and Shrink-Swell Data**	**Assigned Radon Potential**
gr*	ND		x	?	?
Kgr*	? n=2	x	x	-	?
Ku	ND	x		?	?
Qa	x? n=15	x		x	?
Qls	ND		x?	X	?
Qrs	x? n=3			X?	?
Qya	x? n=18		x	X?	?
sp	? n=4			-	?
Td	ND		x?	x	?
Tss	ND	x		?	?

Table 5c. San Luis Obispo County Geologic Units with Insufficient Supporting Data for an Increased Radon Potential Classification.

X = soils facilitating radon migration
x = less than 25 indoor radon measurements (with ≥ 5 at 4 pCi/l or greater); or units with NURE airborne survey eU anomalies; or uranium analyses with median ≥ 5 ppm; or soils somewhat facilitating radon migration
ND = no indoor-radon data
- = soil properties do not support elevated radon potential
? = confidence level uncertain (additional data needed)

* Units “Kgr” and “gr” are the same rock unit--the dual nomenclature results from different geologists using different map symbols in parts of SLO County (Rosenberg, 2008, written communication). Unfortunately, areas mapped as “gr” do not have indoor-radon data available.

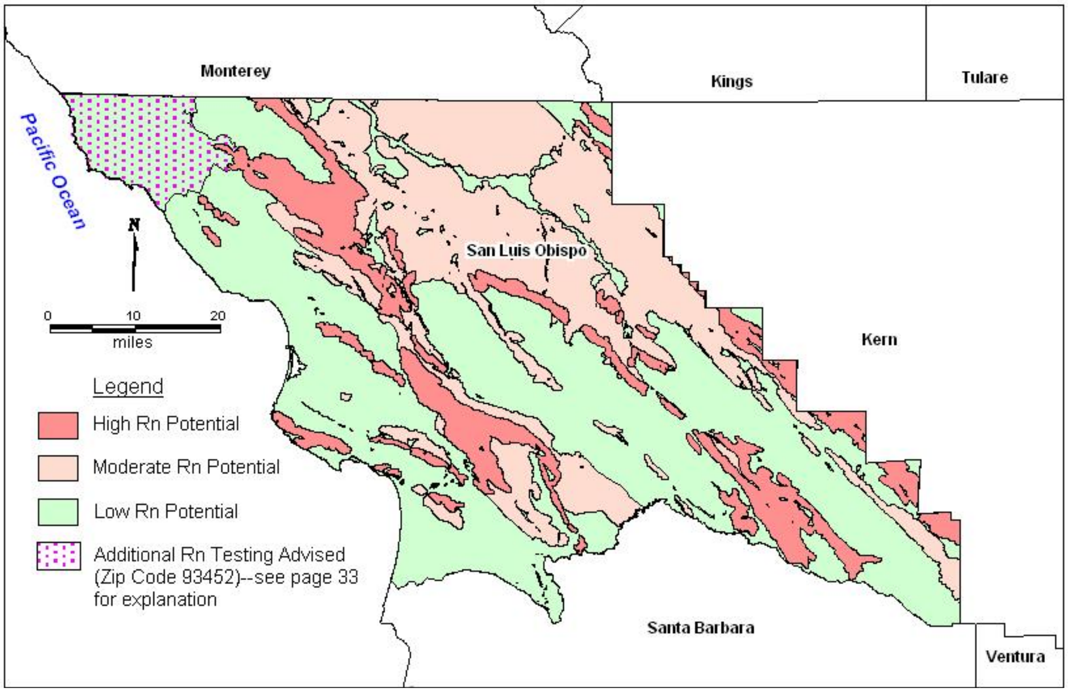

Figure 7. Radon Potential Zones for San Luis Obispo County.

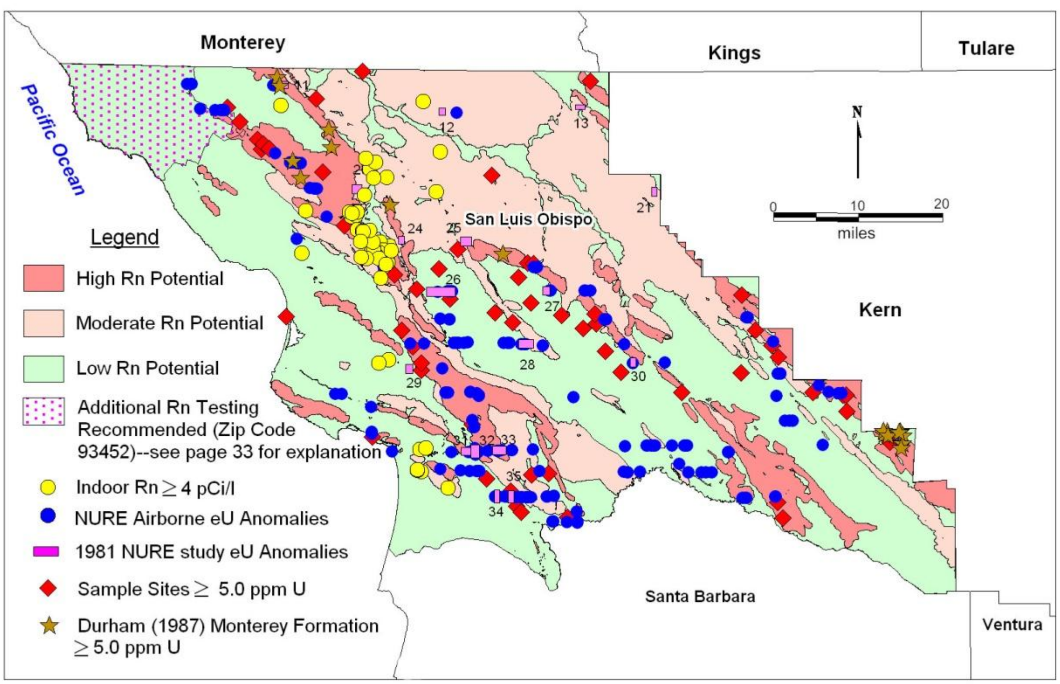

Figure 8. Comparison of Radon Potential Zones, Anomalous Uranium Data (Figure 6) and Indoor Radon Data ≥ 4 pCi/l (Figure 2).

All portions of San Luis Obispo County not classified as High or Moderate radon potential areas, as defined above, are considered to have Low radon potential at this time.

Tables 6a and 6b contain information about the radon data characteristics for each radon zone. Table 7a and Table 7b provide information about the incidence rates of ≥ 4 pCi/l indoor measurements and the density of indoor-radon survey measurements per radon zone.

Zone	n	Median pCi/l	pCi/l at 25%	pCi/l at 75%	Min pCi/l	Max pCi/l
High	114	2.0	0.900	3.900	0.300	57.6
Moderate	201	1.2	0.700	2.400	0.300	12.0
Low	603	0.5	0.300	1.000	0.300	10.8
All	918	0.7	0.300	1.400	0.300	57.6

Table 6a. 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	114	28	24.6	5	4.4	2	1.8	590
Moderate	201	17	8.5	1	0.5	0	0.0	1025
Low	603	9	1.5	1	0.2	0	0.0	1689
All	918	54	5.9	7	0.8	2	0.2	3304

Table 6b. ≥ 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 % of San Luis Obispo County Area
High	51.9	71.4	100.0	17.8	51.9	17.8
Moderate	31.5	14.3	0.0	30.9	83.4	48.7
Low	16.7	14.3	0.0	51.4	100.1	100.0
All	100.1	100.0	100.0	100.1		

Table 7a. ≥ 4.0 pCi/l Incidence Rates for San Luis Obispo County by Radon Potential Zone

Zone	Average Rate: n ≥ 4.0 pCi/l measurements per square mile	Average Rate: All measurements per square mile
High	0.0475	0.1932
Moderate	0.0166	0.1961
Low	0.0053	0.3537
All	0.0163	0.2778

Table 7b. Radon Data Distribution by Radon Potential Zone

RADON POTENTIAL ZONE STATISTICS

Indoor-Radon Measurement Data Characteristics

The statistical characteristics of the untransformed and log(10) transformed CDPH indoor radon data for San Luis Obispo County radon potential zones are provided in Appendix K and Appendix L).

Indoor-Radon Measurement Frequency Distributions

Frequency distributions of trace elements, such as uranium and radon, in rocks and soils are often 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 San Luis Obispo County are an example of this. Taken as a whole, the indoor radon test data from CDPH fail the Kolmogorov-Smirnov normality test in both untransformed and log-transformed modes (Table 8). Consequently, the data are neither normally nor lognormally distributed. The non-normal frequency distribution may be because the data are a combination of samples from several different populations—each rock unit radon population having its own unique distribution. On an individual basis, the rock unit radon populations may be lognormal, but the aggregate population is not lognormal.

Data non-normality has important implications for certain 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 study and the results are discussed in a following section. 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.

Statistical Comparison of Indoor Radon Data by Radon Potential Zone

The results of the statistical comparisons of indoor-radon data for the San Luis Obispo County radon potential zones are listed in Table 9. The indoor-radon data population for each radon potential zone is statistically distinct according to the Mann-Whitney rank sum test.

Data	N	K-S Distribution	P	Result
All Data—Untransformed	918	0.340	<0.001	Failed
All Data—Log (10) Transformed	928	0.210	<0.001	Failed
High Zone—Untransformed	114	0.305	<0.001	Failed
High Zone—Log(10) Transformed	114	0.063	>0.200	Passed
Moderate Zone—Untransformed	201	0.188	<0.001	Failed
Moderate Zone—Log(10) Transformed	201	0.093	<0.001	Failed
Low Zone—Untransformed	603	0.300	<0.001	Failed
Low Zone—Log(10) Transformed	603	0.285	<0.001	Failed

Table 8. Results of the Kolmogorov-Smirnov Normality Test for Untransformed and Log(10) Transformed Indoor-Radon Data, by Radon Potential Zone

A test that fails indicates that the data varies significantly from the pattern expected if the data were drawn from a population with a normal distribution. A test that passes indicates that the data matches the pattern expected if the data were drawn from a population with a normal distribution

Estimated Population Exposed to 4.0 pCi/l Radon or Greater Indoor Air in San Luis Obispo County

Population estimates for each radon potential zone were obtained by overlaying the San Luis Obispo County radon potential zones with 2000 census tract data. For a census tract not completely within a radon potential zone, the population contribution from that tract was considered equal to the percentage area of the tract within the radon zone. Table 10 lists the estimated populations for the different radon potential zones.

Table 11 shows the estimated populations of residents for each radon potential zone. These estimates are based on the estimated population for each zone multiplied by the ≥4.0 pCi/l percentages for each zone from Table 6b. Note the estimate for the number of individuals with homes having indoor-radon concentrations at or above 4 pCi/l, obtained by adding the data for the individual radon zones, is higher than the estimate based on overall radon survey results alone (i.e., not considering the distribution of radon zones and county population—see the lower four rows of Table 11).

Mann-Whitney Rank Sum Test					
Group	***N***	***Missing***	***Median***	***25%***	***75%***
High Zone	114	0	1.95	0.90	3.90
Moderate Zone	201	0	1.20	0.70	2.40
Result	T = 20796.000 n(small)=114 n(big)=201 (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	114	0	1.95	0.90	3.90
Low Zone	603	0	0.50	0.3	1.0
Result	T = 62403.500 n(small)=114 n(big)=603 (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	201	0	1.20	0.70	2.40
Low Zone	603	0	0.50	0.3	1.0
Result	T = 111077.500 n(small)=201 n(big)=603 (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 9. Mann-Whitney Rank Sum Test Comparisons of Indoor-Radon Data by Radon Potential Zone

Radon Potential Zone	**Estimated Total Population within Zone—2000 Census Statistics**	**Estimated Total Houses within Zone—2000 Census Statistics**
High	39,601	15,904
Moderate	48,245	19,376
Low	158,835	63,789
All San Luis Obispo County	246,681	99,069

Table 10. Population Estimates for San Luis Obispo County Radon Zones Areas (based on 2000 U.S. Census Data).

Radon Potential Zone	**Estimated Total Population* for Zone**	**Estimated Population* at ≥ 4.0 pCi/l Conditions**	**Estimated Population* at ≥ 10.0 pCi/l Conditions**	**Estimated Population* at ≥ 20.0 pCi/l Conditions**	**Percent Area/Square Miles**
High	39,601[1] 16.1%[2]	9,742 60.0% 24.6% rate[3]	1,742 75.7% 4.4% rate	713 100.0% 1.8% rate	17.9% 590 mi^2
Moderate	48,245 19.6%	4,101 25.3% 8.5% rate	241 10.5% 0.5% rate	0 0.0% 0.0% rate	31.0% 1,025 mi^2
Low	158,835 64.4%	2,382 14.7% 1.5% rate	318 13.8% 0.2% rate	0 0.0% 0.0% rate	51.1% 1,689 mi^2
Population Estimates Weighted by Radon Zone and Population Distribution					
Totals (*weighted by zone and population distribution*)	246,681 100.1%	16,225 100.0% 6.6% rate	2,301 100.0% 0.9% rate	713 100.0% 0.3% rate	100.0% 3,304 mi^2
Population Estimates by Radon Level Without Regard to Radon Zone or Population Distribution					
All San Luis Obispo County (*not weighted by zone and population distribution*)	246,681	14,554 5.9% rate	1,973 0.8% rate	493 0.2% rate	100.0% 3,304 mi^2

Table 11. Estimates of San Luis Obispo County Population Exposed to 4.0 pCi/l or Greater Indoor Radon Levels in Residences (based on 2000 U.S. Census Data)

*Information listed vertically in the population column cells: 1) Population; 2) Percent of the total county population; 3) percent of ≥ 4.0 pCi/l measurements

Potential Radon Impacts on the Population of San Luis Obispo County

The High and Moderate radon potential zones contain 31.1 percent of the San Luis Obispo County area and 35.6 percent of the county population. Currently available data suggest these two zones also contain:

- 83.4% of the San Luis Obispo County population estimated to live in residences with indoor radon levels of ≥ 4.0 pCi/l

- Most or all of the San Luis Obispo County residences with indoor radon levels ≥ 10.0 pCi/l area (within the High Zone)

These results indicate that geology based radon potential zones can target areas within San Luis Obispo 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 in San Luis Obispo County. Factors other than geology, such as soil permeability, building condition, design and usage also have important impacts on indoor radon concentration.

SUMMARY

Mapping Procedures and Results

Short-term indoor radon test data from CDPH, NURE project airborne radiometric data, and NURE soil, stream sediment and talus uranium data, were used to identify geologic units with relatively higher or lower radon potential in San Luis Obispo County. Geologic units were classified as having high, moderate or low radon potential based on the percentage of 4.0 pCi/l or higher indoor-radon data, the presence of airborne radiometric uranium anomalies, and the presence of soil, stream sediment and talus uranium data exceeding 5.0 ppm.

High radon potential zones on the San Luis Obispo County radon potential map correspond to the locations of high radon potential geologic units. Moderate radon potential zones correspond to the locations of moderate radon potential units. Low radon potential zones are composed of the remaining geologic units, which may have either low radon potential or an unknown, but likely low radon potential.

Buffer zones, 0.2 miles wide, were added to the boundaries of high and moderate radon potential unit occurrences to establish the final high and moderate radon zone boundaries. Buffer zones were not added to individual occurrences of these units where the smallest horizontal dimension is about 0.2 miles or smaller except where several of such small occurrences were clustered together at distances of less than 0.2 miles.

The final radon potential zones have the following characteristics:

> **High Radon Potential Zone:** this zone comprises 17.8 percent (590 square miles) of San Luis Obispo County and contains 51.9 percent of ≥4.0 pCi/l short-term radon data in the CDPH database.
>
> **Moderate Radon Potential Zone:** this zone comprises 30.9 percent (1,025 square miles) of San Luis Obispo County and contains 31.5 percent of ≥4.0 pCi/l short-term radon data in the CDPH database.
>
> **Low Radon Potential Zone:** this zone comprises 51.4 percent (1,689 square miles) of San Luis Obispo County and contains 16.4 percent of ≥4.0 pCi/l short-term radon data in the CDPH database.

All three radon potential zones contain short-term indoor-radon measurements above 4.0 pCi/l. The maximum measurement for each zone is: High, 57.6 pCi/l; Moderate, 12.0 pCi/l; and Low, 10.8 pCi/l.

Statistical comparison of the indoor radon data populations for the three radon potential zones, using the Mann-Whitney rank sum test, shows that the zones are statistically different from each other (note the P values, the probability of being wrong in concluding that there is a true difference in the two groups, listed in Table 9 are less than 0.001)

An estimated 9,742 individuals within High Radon Potential Zone areas and 4,101 individuals within Moderate Radon Potential Zone areas live in residences likely to measure ≥4.0 pCi/l in short-term tests. An additional 2,382 individuals are estimated to live in residences likely to measure ≥4.0 pCi/l in short-term tests within the Low Radon Potential Zone area (i.e., scattered through 51.1 percent of the San Luis Obispo County area). An estimated 713 individuals live in dwellings with indoor-radon levels measuring ≥ 20 pCi/l on short-term tests in San Luis Obispo County. Available data suggest that ≥ 20 pCi/l dwellings may be confined to High Radon Potential Zone areas.

Recommendations for Future Radon Testing and Studies

Indoor radon data are lacking or minimal for Avila Beach, Cayucos, Creston, Harmony, Oceano, San Miguel, Santa Margarita, and Shandon. Future radon testing efforts should consider targeting these communities. The rural eastern half of San Luis Obispo County also lacks indoor-radon measurements and future activities to encourage testing residences there should be considered.

Indoor-radon testing of classrooms for schools within high and moderate radon potential zone areas should be considered for schools not previously tested.

The 2007 version of the CDPH Zip Code Radon Database, available at http://www.cdph.ca.gov/HealthInfo/environhealth/Documents/Radon/CaliforniaRadonDatabase.pdf, shows that 18 out of 37 indoor tests for the San Simeon zip code (93452) area are ≥ 4 pCi/l. Data for this database are provided voluntarily to CDPH from radon testing companies and are located only by zip code zone (to protect the privacy of clients). Consequently, it is not known if the ≥ 4 pCi/l tests are associated with particular geologic units, or if a number of these tests were made at a single location. Unfortunately, there were no respondents from this zip code area to the 2004-2005 CDPH indoor-radon testing solicitation for San Luis Obispo County, so there are no indoor data that can be related to particular locations and geologic units within this area. NURE data, and indoor-test data in adjoining areas, only support the presence of high radon potential for a small sparsely populated part of the easternmost portion of this zip code area (see Plate 1). Because the 2007 CDPH Zip Code data suggest an area (or areas) of moderate or high radon potential is present, additional indoor radon testing should be a priority for the San Simeon zip code area.

Priority geologic units for future indoor-radon testing in San Luis Obispo County should be: Monterey Formation geologic units with few or no data—Tmu, Tm, Tmmb, Tmmc, Tmmd, Tma, Tmb, Tmc, Tmd, Tmg, Tmw; and the geologic units listed in Table 5c—gr, Kgr, Ku, Qa (near Monterey Formation units), Qls (near Monterey Formation units) Qrs, Qya, sp (additional testing would be expected to show sp has a low radon potential), Td and Tss (see Appendix D for the geologic unit names associated with these map unit abbreviations). In general, radon testing priorities should be those buildings located on Miocene organic rich and/or siliceous marine shale or mudstone, or on granitic or felsic volcanic rock units.

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APPENDIX A
Indoor-Measurement Field Duplicate Results

Differences between field duplicate indoor-measurements for the San Luis Obispo radon survey, October to January, 2006

High (pCi/l)	Low (pCi/l)	Difference (pCi/l)	% Difference	Location	Date	Comment
0.7	0.6	0.1	14.3	Arroyo Grande	10/29	
0.3	0.3	0.0	0.0	Arroyo Grande	11/3	At detection limit
6.6	5.8	0.8	12.1	Arroyo Grande	11/4	Tests > 4.0 pCi/l
3.1	2.9	0.2	6.5	Arroyo Grande	11/4	
1.7	1.6	0.1	5.9	Arroyo Grande	11/10	
1.7	1.0	0.7	41.2	Arroyo Grande	11/15	
0.5	0.3	0.2	40.0	Arroyo Grande	12/22	
0.6	0.6	0.0	0.0	Arroyo Grande	12/27	
1.4	1.4	0.0	0.0	Arroyo Grande	1/4	
0.3	0.3	0.0	0.0	Arroyo Grande	1/6	At detection limit
0.3	0.3	0.0	0.0	Arroyo Grande	1/6	At detection limit
2.2	1.7	0.5	22.7	Atascadero	10/29	
0.9	0.9	0.0	0.0	Atascadero	11/4	
1.5	1.2	0.3	20.0	Atascadero	11/4	
3.1	2.9	0.2	6.5	Atascadero	11/10	
1.9	1.5	0.4	21.1	Atascadero	11/15	
2.0	2.0	0.0	0.0	Atascadero	11/15	
5.8	5.2	0.6	10.3	Atascadero	12/22	Tests > 4.0 pCi/l
3.2	2.5	0.7	21.9	Atascadero	12/22	
0.6	0.3	0.3	50.0	Cambria	12/22	
1.1	0.9	0.2	18.2	Grover Beach	12/27	
0.7	0.3	0.4	57.1	Los Osos	11/3	
0.3	0.3	0.0	0.0	Los Osos	12/22	At detection limit
0.3	0.3	0.0	0.0	Los Osos	1/6	At detection limit
2.9	2.7	0.2	6.9	Nipomo	11/15	
0.3	0.3	0.0	0.0	Nipomo	12/30	At detection limit
0.9	0.6	0.3	33.3	Oceano	1/6	
0.6	0.3	0.3	50.0	Paso Robles	11/15	
0.3	0.3	0.0	0.0	San Luis Obispo	10/29	At detection limit
1.5	0.9	0.6	40.0	San Luis Obispo	10/29	
1.1	0.6	0.5	45.5	San Luis Obispo	10/29	
0.5	0.3	0.2	40.0	San Luis Obispo	10/29	
0.3	0.3	0.0	0.0	San Luis Obispo	11/1	At detection limit
0.9	0.8	0.1	11.1	San Luis Obispo	11/3	

1.2	0.7	0.5	41.7	San Luis Obispo	11/4	
0.3	0.3	0.0	0.0	San Luis Obispo	11/5	At detection limit
1.0	0.3	0.7	70.0	San Luis Obispo	12/27	
0.3	0.3	0.0	0.0	San Luis Obispo	1/4	At detection limit
0.8	0.5	0.3	37.5	San Luis Obispo	1/4	
		9.4 N=39 0.24 pCi/l average difference	**723.6 N=39 18.5% average difference**	Overall Differences for Field Duplicates		

% Difference = (High-Low)/High X 100

APPENDIX B

Field Blanks

Date	Number	Results pCi/l
12/13/2004	9	All <0.3
12/23/2004	2	All <0.3
12/30/2004	9	All <0.3
1/7/2005	24	All <0.3
1/11/2005	8	All <0.3

APPENDIX C

Repeated and Successive Indoor-Radon Tests at Three Locations

Test Location 1-San Luis Obispo (City)				
Test Date	**Test (pCi/l)**	**Difference* With 10/29 Test (pCi/l)**	**% Difference**	**Comment**
10/28	0.3	--	--	Consistent low measurements during a two month period
11/15	0.6	0.3	50.0	
11/15	0.3	0.0	0.0	
11/15	0.3	0.0	0.0	
11/15	0.3	0.0	0.0	
12/29	0.3	0.0	0.0	
12/29	0.3	0.0	0.0	
12/29	0.3	0.0	0.0	
Test Location 2-Paso Robles				
Test Dates	**Test pCi/l**	**Difference Between* Tests (pCi/l)**	**% Difference**	**Comment**
12/21 12/23	1.3 2.9	1.6	55.2	The difference is between successive two-day tests; both tests are below 4 pCi/l
Test Location 3-Atascadero				
Test Dates	**Test pCi/l**	**Difference Between* Tests (pCi/l)**	**% Difference**	**Comment**
10/28 12/30	8.1 20.2	12.1	59.9	The tests are two months apart; both tests are above 4 pCi/l

*% Difference = (High-Low)/High X 100

APPENDIX D

Geologic Map Units (Rosenberg, 2007, DET Lab) and Indoor Radon Data for San Luis Obispo County

Geologic Unit DET_Lab	Geologic Unit Name/Description	N	N ≥ 4 pCi/l	R %	Low pCi/l	High pCi/l
f	Franciscan Assemblage	1	0	*		1.4
fg	Franciscan Assemblage, greenstone or basalt	2	0	*	0.3	0.3
Jmv	Ophiolite, mafic volcanic rocks	1	1	*		10.8
Ka	Atascadero Formation, undivided	33	5	15.2	0.3	57.6
Kep	El Piojo Formation, undivided	7	0	*	0.3	3.3
Kgr	Granitic rocks, undivided	2	0	*	0.3	1.7
KJf	Franciscan Assemblage, undivided	53	0	0.0	0.3	2.5
KJfm	Franciscan Assemblage, melange	10	0	*	0.3	1.3
KJfme	Franciscan Assemblage, melange	15	0	*	0.3	2.8
KJt	Toro Formation	3	0	*	0.3	1.1
Ks	Unnamed Cretaceous and Lower Tertiary Sedimentary Rocks	23	0	0.0	0.3	2.1
Qa	Latest Pleistocene to Holocene alluvium, undifferentiated	15	1	6.7	0.3	5.5
Qal	Latest Pleistocene to Holocene alluvium, undifferentiated	119	2	1.7	0.3	7.3
Qoa	Early to late Pleistocene alluvial deposits, undifferentiated	70	13	18.6	0.3	12.0
Qos	Latest Pleistocene to Holocene dune sand	68	2	2.9	0.3	7.3
Qpr**	Paso Robles Formation	25	1	4.0	0.3	4.8
Qrs	Modern stream channel deposits	3	1	*	0.9	5.4
Qs	Latest Holocene beach sand	115	0	0.0	0.3	3.4
Qso	Latest Pleistocene to Holocene dune sand	74	0	0.0	0.3	2.1
Qt	Early to late Pleistocene stream terrace deposits	30	0	0.0	0.3	2.8
QTp**	Paso Robles Formation	73	5	6.9	0.3	5.6
Qya	Modern stream channel deposits	14	2	*	0.3	6.3
sp	serpentinite	8	1	*	0.3	4.0
Tm	Monterey Formation	3	1	*	0.3	13.6

Tml	Monterey Formation-lower or Monterey Formation semi-siliceous mudstone	39	12	30.8	0.3	20.2
Tmmb	Monterey Formation, silty shale	1	0	*		3.5
Tmmd	Monterey Formation, diatomite	1	0	*		3.2
Tmor	Obispo Formation, resistant tuff	1	0	*		1
Tmot	Obispo Formation, tuff	4	0	*	0.3	3.8
Tmpe2	Edna Member of Pismo Formation	4	0	*	0.7	3.6
Tmpec	Edna Member of Pismo Formation	1	0	*		0.3
Tmpm2	Miguelito Member of Pismo Formation	1	0	*		0.3
Tmu	Monterey Formation, siliceous shale	10	2	*	1.0	7.4
Tot	Obispo Formation, tuff	2	0	*		3.7
Tppb2	Belleview Member of Pismo Formation	1	0	*		0.6
Tpps	Squire Member of Pismo Formation	54	2	3.7	0.3	6.6
TQp**	Paso Robles Formation	3	1	*	0.9	4.1
Tsm	Santa Margarita Sandstone	27	2	7.4	0.3	4.3
Tv	Vaqueros and Tembler Formation	1	0	*		0.3
Tvq	Vaqueros Formation	1	0	*		1.4
Totals	***40 geologic units***	***918***	***54***	***5.9***	***0.3***	***57.6***

* Too few data to calculate a meaningful R%

**The three Paso Robles map units present in this table, QTp, Qpr and TQp, are present on the Rosenberg 2007 draft geologic map and relate to different geologic information sources Rosenberg utilized. Combining the data for these three units yields the following statistics for the Paso Robles Formation: n = 101, n ≥ 4 pCi/l = 7, R% = 6.9, low pCi/l = 0.3 and high pCi/l = 5.6.

APPENDIX E

Geologic Units (Rosenberg, 2007, DET LAB) Soil Units (NRCS) and Indoor Radon Data

Geologic Unit DET_LAB	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/l	R %	Low pCi/l	High pCi/l
f	Franciscan Assemblage	170	Millsholm-Dibble complex (CA665)	1	0	*		1.4
fg	Franciscan Assemblage, greenstone or basalt	164	Los Osos-Diablo complex (CA664)	2	0	*	0.3	0.3
Jmv	Ophiolite, mafic volcanic rocks	165	Los Osos-Diablo complex (CA664)	1	1	*		10.8
Ka	Atascadero Formation, undivided	106	Arbuckle-San Ysidro complex (CA665)	1	0	*		3.5
	“	109	Ayar and Diablo soils (CA665)	1	1	*		57.6
	“	153	Linne-Calodo complex (CA665)	1	0	*		3.3
	“	156	Linne-Zakme complex (CA665)	1	0	*		2.7
	“	162	Lompico-McMullin complex (CA665)	7	3	*	0.3	7.4
	“	169	Millsholm-Dibble complex (CA665)	10	1	*	0.3	6.0
	“	170	Millsholm-Dibble complex (CA665)	9	0	*	0.3	3.1
	“	172	Millsholm-Rock outcrop complex (CA665)	1	0	*		0.3
	“	188	Rincon clay loam (ca665)	2	0	*	1.6	2.4
Kep	El Piojo Formation, undivided	134, 135, 136	Dibble clay loam (CA665)	3	0	*	0.3	2.2
	“	173	Mocho clay loam (CA665)	1	0	*		2.3
	“	191	Ryer clay loam (CA665)	2	0	*	0.3	1.0
	“	203	Shimmon-Dibble association, steep (CA665)	1	0	*		3.3

Kgr	Granitic rocks, undivided	127	Cieneba-Andregg complex (CA665)	1	0	*		0.3
	“	128	Cieneba-Vista complex (CA665)	1	0	*		1.7
KJf	Franciscan Assemblage, undivided	121, 122	Concepcion loam (CA664)	7	0	*	0.3	1.
	“	127	Cropley clay (CA664)	4	0	*	0.3	0.8
	“	130, 131	Diablo and Cibo clays (CA664)	5	0	*	0.3	1.3
	“	147, 148	Lodo clay loam (CA664)	3	0	*	0.3	1.5
	“	158, 161	Los Osos loam (CA664)	4	0	*	0.3	0.6
	“	162, 163, 164	Los Osos-Diablo complex, (CA664)	17	0	*	0.3	2.5
	“	195	Rock outcrop-Haploxerolls complex (CA664)	5	0	*	0.3	1.0
	“	197	Salinas silty clay loam (CA664)	8	0	*	0.5	2.5
KJfm	Franciscan Assemblage, melange	104	Baywood fine sand (CA664)	2	0	*	0.3	1.1
	“	128	Cropley clay (CA664)	5	0	*	0.3	1.3
	“	130, 132	Diablo and Cibo clays (CA664)	3	0	*	0.3	0.5
KJfme	Franciscan Assemblage, melange	128	Cropley clay, 2 to 9% slopes (CA664)	3	0	*	0.3	0.3
	“	131	Diablo and Cibo clays, 15 to 30% slopes (CA664)	1	0	*		0.3
	“	148	Lodo clay loam, 15 to 30% slopes (CA664)	2	0	*	0.6	2.8
	“	159, 160	Los Osos loam (CA664)	2	0	*	0.8	1.1
	“	163, 165	Los Osos-Diablo complex (CA664)	6	0	*	0.3	1.5
	“	168	Los Osos-variant clay loam, 15 to 50% slopes (CA664)	1	0	*		0.3
KJt	Toro Formation	16	Lodo-Hambright-Millsholm families association (CA772)	2	0	*	0.3	1.1

KJt	Toro Formation cont.	50	Xerofluvents-Xerothents-Riverwash complex (CA772)	1	0	*		0.3
Ks	Unnamed Cretaceous and Lower Tertiary Sedimentary Rocks	120	Concepcion loam (CA664)	1	0	*		0.3
	"	160	Los Osos loam (CA664)	4	0	*	0.3	1.7
	"	198	Salinas silty clay loam (CA664)	1	0	*		2.1
	"	200, 201, 202	San Simeon sandy loam (CA664)	17	0	*	0.3	1.4
Qa	Latest Pleistocene to Holocene alluvium, undifferentiated	101	Arbuckle fine sandy loam (CA665)	1	0	*		1.2
	"	103	Arbuckle-Positas complex (CA665)	2	0	*	0.5	2.3
		106	Arbuckle-San Ysidro complex (CA665)	1	0	*		1.3
	"	157, 158	Lockwood shaly loam (CA665)	4	0	*	0.3	2.9
	"	166	Metz loamy sand (CA665)	2	0	*	2.8	3.1
		183	Pico fine sandy loam (CA665)	2	1	*	1.7	5.5
	"	188	Rincon clay loam (CA665)	2	0	*	0.3	0.3
	"	310	Yeguas-Pinspring complex (CA667)	1	0	*		2.7
Qal	Latest Pleistocene to Holocene alluvium, undifferentiated	104	Baywood fine sand (CA664)	2	0	*	0.3	0.7
	"	111	Camarillo sandy loam (CA664)	1	0	*		1.0
	"	112	Camarillo loam, drained (CA664)	2	0	*	2.8	3.9
	"	120, 121	Concepcion loam (CA664)	20	0	*	0.3	2.5
	"	125	Corralitos sand (CA664)	2	0	*	2.7	3.1
	"	126	Corralitos variant loamy sand (CA664)	1	0	*		0.6
	"	127, 128	Cropley clay (CA664)	34	0	0.0	0.3	2.8

Qal	Latest Pleistocene to Holocene alluvium, undifferentiated cont.	130	Diablo and Cibo clays (CA664)	13	0	*	0.3	0.9
	"	134	Dune land (CA664)	3		*	0.3	0.6
	"	135	Elder sandy loam (CA664)	2	0	*	0.3	0.5
Qal cont.	Latest Pleistocene to Holocene alluvium, undifferentiated cont.	158, 159, 160	Los Osos loam (CA664)	9	1	*	0.3	7.3
	"	162, 163	Los Osos-Diablo complex (CA664)	5	0	*	0.3	0.3
		169	Marimel sandy clay loam, occasionally flooded (CA664)	1	0	*		0.9
	"	170	Marimel silty clay loam, drained (CA664)	5	1	*	1.7	6.3
	"	174	Mocho loam (CA664)	2	0	*	1.7	2.4
	"	175	Mocho silty clay loam (CA664)	7	0	*	0.3	3.7
		176	Mocho variant fine sandy loam (CA664)	2	0	*	0.6	2.2
	"	183	Obispo-Rock outcrop complex, 15 to 75% slopes (CA664)	1	0	*		0.8
	"	197, 198	Salinas silty clay loam (CA664)	7	0	*	0.3	1.3
Qoa	Early to late Pleistocene alluvial deposits, undifferentiated	100	Arbuckle fine sandy loam, 0 to 2 percent slopes (CA665)	1	0	*		1.1
	"	102, 103, 105	Arbuckle-Positas complex, 9 to 15% slopes (CA665)	8	2	*	0.3	10.8
	"	106	Arbuckle-San Ysidro complex, 2 to 9% slopes (CA665)	16	4	*	0.3	12.0
	"	107	Arnold loamy sand, 9 to 30% slopes (CA665)	6	0	*	0.3	1.7
	"	108	Arnold-San Andreas complex, 30 to 75% slopes (CA665)	1	0	*		3.4
	"	127, 128	Cropley clay (CA664)	2	0	*	1.1	2.9
	"	144	Gazos shaly clay loam (CA665)	1	0	*		3.1
		150	Hanford and Greenfield gravelly sandy loams (CA665)	1	0	*		1.5

Qoa	Early to late Pleistocene alluvial deposits, undifferentiated cont.	152	Linne-Calodo complex (CA665)	2	1	*	1.2	5.8
	"	158	Lockwood shaly loam (CA665)	8	2	*	0.8	7.5
	"	159, 160	Lockwood-Concepcion complex (CA665)	3	1	*	0.5	4.4
Qoa cont.	Early to late Pleistocene alluvial deposits, undifferentiated cont.	162	Los Osos-Diablo complex (CA664)	1	0	*		0.3
	"	169	Millsholm-Dibble complex (CA665)	2	1	*	1.3	7.7
	"	182	Oceano loamy sand (CA665)	5	0	*	0.3	1.5
	"	187, 188	Rincon clay loam (CA665)	7	1	*	0.3	5.1
	"	191	Ryer clay loam (CA665)	1	1	*		4.2
	"	197	San Ysidro loam (CA665)	2	0	*	0.7	2.6
	"	224	Zaca clay (CA664)	3	0	*	0.3	1.1
Qos	Latest Pleistocene to Holocene dune sand	184, 185	Oceano sand (CA664)	67	2	3.0	0.3	7.3
	"	193	Psamments and Fluvents, wet (CA664)	1	0	*		0.3
Qpr	Paso Robles Formation	109	Briones-Pismo loamy sands (CA664)	1	0	*		0.3
	"	115, 116	Chamise shaly loam (CA664)	8	0	*	0.3	3.1
	"	117	Chamise shaly sandy clay loam (CA664)	3	0	*	0.3	1.3
	"	118	Cieneba-Kinkel variant loams (CA664)	1	0	*		0.7
	"	128	Cropley clay (CA664)	4	0	*	0.8	3.4
	"	129	Diablo clay (CA664)	5	0	*	0.5	1.7
	"	189	Pismo loamy sand (CA664)	1	0	*		3.1
	"	198	Salinas silty clay loam (CA664)	1	0	*		1.0
	"	209	Still gravelly sandy clay loam (CA664)	1	1	*		4.8
Qrs	Modern stream channel deposits	113	Balcom-Calleguas complex (CA665)	2	1	*	2.4	5.4

Qrs	Modern stream channel deposits cont.	179	Nacimiento-Los Osos complex (CA665)	1	0	*		0.9
Qs	Latest Holocene beach sand	101	Aquolls, saline (CA664)	1	0	*		0.3
	"	104, 105, 106	Baywood fine sand (CA664)	114	0	0.0	0.3	3.4
Qso	Latest Pleistocene to Holocene dune sand	184, 185	Oceano sand (CA664)	70	0	0.0	0.3	2.1
	"	223	Xerothents, escarpment (CA664)	4	0	*	0.3	1.7
Qt	Early to late Pleistocene stream terrace deposits	120	Concepcion loam (CA664)	5	0	*	0.3	0.8
	"	128	Cropley clay (CA664)	4	0	*	0.3	0.7
	"	158	Los Osos loam (CA664)	1	0	*		0.3
	"	184	Oceano sand (CA664)	1	0	*		0.3
	"	199, 200, 201	San Simeon sandy loam (CA664)	12	0	*	0.3	0.8
	"	210	Still gravelly sandy clay loam (CA664)	6	0	*	0.3	2.8
	"	221	Xererts-Xerolls-Urban land complex (CA664)	1	0	*		2.1
QTp	Paso Robles Formation	102, 103, 104	Arbuckle-Positas complex (CA665)	10	0	*	0.6	3.4
	"	106	Arbuckle-San Ysidro complex (CA665)	6	0	*	0.3	2.4
	"	107	Arnold loamy sand (CA665)	1	0	*		0.3
	"	108	Arnold-San Andreas complex (CA665)	3	0	*	1.1	1.5
	"	110	Ayar and Diablo soils (CA665)	1	0	*		1.2
	"	114	Balcom-Nacimiento association, moderately steep (CA665)	2	0	*	0.8	1.7
	"	133	Cropley clay (CA665)	2	0	*	0.5	1.2

QTp	Paso Robles Formation cont.	152, 153, 154	Linne-Calodo complex (CA665)	15	1	*	0.5	5.6
	“	159	Lockwood-Concepcion complex (CA665)	2	0	*	0.9	3.9
QTp cont.	Paso Robles Formation cont.	175, 176	Nacimiento silty clay loam (CA665)	5	0	*	0.3	2.9
	“	177, 178	Nacimiento-Ayar complex, (CA665)	3	1	*	1.2	4.6
	“	179, 180	Nacimiento-Los Osos complex (CA665)	11	1	*	0.3	4.6
	“	187, 188	Rincon clay loam (CA665)	8	1	*	0.3	4.0
	“	197	San Ysidro loam (CA665)	1	0	*		1.0
	“	198	Santa Lucia-Lopez complex (CA665)	1	0	*		1.1
	“	206	Sorrento clay loam (CA665)	1	0	*		0.3
	“	212	Xerofluvents-Riverwash association (CA665)	1	1	*		4.4
Qya	Modern stream channel deposits	130	Clear Lake clay, drained (CA665)	1	0	*		1.7
	“	138	Elder Loam (CA665)	1	0	*		3.1
	“	148	Hanford and Greenfield soils (CA665)	2	0	*	1.4	2.2
	“	152	Linne-Calodo complex (CA665)	1	1	*		6.3
	“	166	Metz loamy sand (CA665)	1		*		1.0
	“	208	Still clay loam (CA665)	8	1	*	0.3	4.3
sp	serpentinite	130	Diablo and Cibo clays (CA664)	4	1	*	0.3	4.0
	“	163, 164	Los Osos-Diablo complex, (CA664)	3	0	*	0.3	1.0
	“	183	Obispo-Rock outcrop complex (CA664)	1	0	*		0.3

Tm	Monterey Formation	103	Arbuckle-Positas complex, (CA665)	1	0	*		1.4
	“	107	Arnold loamy sand (CA665)	1	0	*		0.3
	“	144	Gazos shaly clay loam (CA665)	1	1	*		13.6
Tml	Monterey Formation-lower or Monterey Formation semi-siliceous mudstone	105	Arbuckle-Positas complex (CA665)	1	0	*		3.7
Tml cont.	Monterey Formation-lower or Monterey Formation semi-siliceous mudstone cont.	106	Arbuckle-San Ysidro complex (CA665)	3	0	*	1.0	3.3
	“	107	Arnold loamy sand (CA665)	1	0	*		1.1
	“	116	Botella sandy loamCA665)	6	1	*	0.5	6.2
	“	144	Gazos shaly clay loam (CA665)	4	0	*	0.8	2.8
	“	152, 153	Linne-Calodo complex (CA665)	6	3	*	1.3	20.2
	“	156	Linne-Zakme complex (CA665)	2	1	*	2.1	6.3
	“	159	Lockwood-Concepcion complex (CA665)	4	1	*	0.6	5.4
	“	170	Millsholm-Dibble complex (CA665)	2	2	*	6.4	7.3
	“	182	Oceano loamy sand (CA665)	1	0	*		0.6
	“	192	San Andreas sandy loam (CA665)	1	0	*		0.3
	“	193	San Andreas-Arujo complex (CA665)	3	3	*	5.4	10.3
	“	198	Santa Lucia-Lopez complex (CA665)	4	1	*	1.6	5.3
	“	205	Sorrento clay loam (CA665)	1	0	*		0.3
Tmmb	Monterey Formation, silty shale	206	Santa Lucia very shaly clay loam (CA664)	1	0	*		3.5

Tmmd	Monterey Formation, diatomite	181	Nacimiento-Calodo complex (CA664)	1	0	*		3.2
Tmor	Obispo Formation, resistant tuff	115	Chamise shaly loam (CA664)	1	0	*		1.0
Tmot	Obispo Formation, tuff	204	Santa Lucia shaly clay loam (CA664)	1	0	*		3.1
	“	206	Santa Lucia very shaly clay loam (CA664)	2	0	*	0.3	3.8
	“	225	Zaca clay (CA664)	1	0	*		0.8
Tmpe2	Edna Member of Pismo Formation	125	Corralitos sand (CA664)	1	0	*		2.9
	“	137	Elder sandy loam (CA664)	1	0	*		1.3
	“	142	Gaviota fine sandy loam, (CA664)	1	0	*		3.6
	“	189	Pismo loamy sand (CA664)	1	0	*		0.7
Tmpec	Edna Member of Pismo Formation	218	Tierra loam (CA664)	1	0	*		0.3
Tmpm2	Miguelito Member of Pismo Formation	189	Pismo loamy sand (CA664)	1	0	*		0.3
Tmu	Monterey Formation, siliceous shale	144	Gazos shaly clay loam (CA665)	1	1	*		6.0
	“	193	San Andreas-Arujo complex (CA665)	4	0	*	1.0	3.6
	“	198	Santa Lucia-Lopez complex (CA665)	3	1	*	3.1	7.4
	“	207	Still gravelly loam (CA665)	1	0	*		2.8
	“	208	Still clay loam (CA665)	1	0	*		1.5
Tot	Obispo Formation, tuff	129	Diablo clay (CA664)	1	0	*		3.7
	“	152	Lodo-Rock outcrop complex (CA664)	1	0	*		0.3
Tppb2	Belleview Member of Pismo Formation	155	Lopez very shaly clay loam (CA664)	1	0	*		0.6

Tpps	Squire Member of Pismo Formation	102	Arnold loamy sand (CA664)	3	0	*	0.3	2.2
	“	108	Briones loamy sand (CA664)	1	0	*		2.9
	“	109	Briones-Pismo loamy sands (CA664)	3	0	*	0.3	1.0
	“	110	Briones-Tierra complex (CA664)	2	0	*	0.3	1.0
	“	116	Chamise shaly loam (CA664)	2	0	*	2.1	3.1
	“	117	Chamise shaly sandy clay loam (CA664)	3	0	*	1.1	2.5
	“	125	Corralitos sand (CA664)	4	1	*	0.9	6.6
Tpps cont.	Squire Member of Pismo Formation cont.	142	Gaviota fine sandy loam, (CA664)	2	0	*	0.7	1.1
	“	155	Lopez very shaly clay loam (CA664)	2	0	*	0.5	1.5
	“	159	Los Osos loam (CA664)	2	0	*	0.8	1.3
	“	189	Pismo loamy sand (CA664)	21	1	*	0.3	4.1
	“	190	Pismo-Rock outcrop complex (CA664)	2	0	*	1.7	2.1
		206, 207	Santa Lucia very shaly clay loam (CA664)	4	0	*	0.3	2.9
	“	210	Still gravelly sandy clay loam (CA664)	2	0	*	1.0	1.5
	“	216	Tierra sandy loam (CA664)	1	0	*		3.7
TQp	Paso Robles Formation	148	Hanford and Greenfield soils (CA665)	1	0	*		0.9
	“	152	Linne-Calodo complex (CA665)	2	1	*	1.0	4.1
Tsm	Santa Margarita Sandstone	107	Arnold loamy sand (CA665)	1	1	*		4.2
	“	108	Arnold-San Andreas complex (CA665)	3	0	*	0.6	1.4
	“	156	Lopez very shaly clay loam (CA664)	1	0	*		1.6

Tsm	Santa Margarita Sandstone cont.	193	San Andreas-Arujo complex (CA665)	21	1	*	0.3	4.3
	“	198	Santa Lucia-Lopez complex (CA665)	1	0	*		0.3
Tv	Vaqueros and Tembler Formation	144	Gazos-Lodo clay loams (CA664)	1	0	*		0.3
Tvq	Vaqueros Formation	135	Dibble clay loam (CA665)	1	0	*		1.4
Totals				***918***	***54***	***5.9***	***0.3***	***57.6***

* Too few data to calculate a meaningful R%

APPENDIX F

Summary of NURE Airborne Radiometric Survey Equivalent Uranium Results for the San Luis Obispo 1X2 degree Quadrangle (T*his quadrangle includes most of San Luis Obispo County and the southern portions of Monterey County*), High Life Helicopters, Inc., 1981.

1:250K Geologic Map Unit	Mean eU (ppm)	St. Dev. eU (ppm)	Data Points (N)	Population Distribution Type	Related 1:100K Geologic Map Units*
E	3.22	1.20	354	Normal	Avenal sandstone, Canoas siltstone, Gredal Fm., Kreyenhagen shale, Mabury Fm., Point of Rocks sandstone, Welcome Fm.
EP	3.75	.66	123	Unknown	Dip Creek Fm.
GR	3.66	1.11	1912	Log-normal	Santa Lucia quartz diorite, granite
JK	2.02	0.44	87	Normal	Knoxville Fm.
K	1.91	0.78	170	Log-normal	Unnamed undivided Cretaceous of Table Mt. area
KJF	1.97	0.86	7765	Normal	Franciscan Fm., San Luis Fm.
KJFV	1.49	0.61	669	Normal	Cuesta diabase, Osos basalt, altered volcanic rocks (Franciscan)
KL	3.00	1.06	2927	Normal	Marmolejo Fm., Toro Fm.
KU	3.27	1.08	9916	Normal	Asuncion group, Atascadero Fm., Jack Creek Fm., Moreno Fm., Panoche Fm.
M	3.60	1.04	131	Log-normal	Sur series, complex of metamorphic and granitic rocks
MC	3.61	0.99	225	Normal	Unnamed Miocene continental rocks--red-beds and volcanic rocks
ML	3.38	1.21	2276	Log-normal	Auga sandstone, Carneros sandstone, Hanna Fm., Media shale, Rincon Fm, Sandholt Fm., Santos shale, Temblor Fm.[middle Miocene in part], Vaqueros sandstone
MM	3.88	1.32	7688	Normal	Alferitz fm., "Buttonbed" sandstone, Escuda sandstone, Gould-Devilwater shale, Monterey shale [in part upper Miocene], Point Sal Fm., Salinas shale, Twissleman sandstone member of Monterey Fm.
MU	3.58	1.53	4003	Log-normal	Antelope shale, member of Monterey Fm., McDonald shale, McLure shale member of Monterey Fm., Pismo Fm., Reef Ridge shale, Santa Margarita Ss.

MV	3.52	1.48	351	Log-normal	Undifferentiated Miocene volcanic rocks, teschenite
MVB	2.24	1.31	43	Unknown	Miocene volcanic rocks-basaltic (diabase)
MVP	1.88	0.60	60	Unknown	Miocene volcanic rocks-Obispo tuff, rhyolite tuff
MVR	2.47	0.27	5	Unknown	? (*Typo? Miocene rhyolites ?)*
OC	3.41	0.82	739	Normal	Barry conglomerate (Oligocene nonmarine)
PC	3.61	1.18	185	Normal	Morales Fm., unnamed Pliocene nonmarine beds
PLM	3.53	0.41	34	Unknown	?, (*Typo for PLM?)*
PML	2.98	0.93	2190	Log-normal	Etchegoin Fm., Etchegoin-Jacalitos Fm. Undifferentiated, Jacalitos Fm., Pancho Rico Fm. [in part upper Miocene]
PU	3.19	0.75	297	Log-normal	San Joaquin Fm.
QAL	3.21	1.01	4760	Normal	Recent alluvium, river channel deposits
QF	3.35	0.80	1936	Log-normal	Recent alluvial fan deposits in the Great Valley
QM	2.02	0.86	494	Log-normal	Pleistocene marine terrace deposits
QP	2.88	0.76	14931	Log-normal	McKittrick Fm., Paso Robles Fm., Tulare Fm. (Pliocene-Pleistocene nonmarine sedimentary deposits)
QS	3.10	0.68	681	Normal	Dune sand
QT	3.02	0.85	2237	Log-normal	River and stream terrace deposits
TI	2.76	0.38	46	Log-normal	Tertiary intrusive rocks—plugs and dikes of quartz porphyry, andesite and dacite
UB	1.62	0.86	1457	Log-normal	Serpentine, peridotite, pyroxenite, norite, gabbro
WA	3.42	1.48	215	Log-normal	Water

*100,000-scale map Quaternary surficial deposits are not listed. Note that 1:250,000-scale map unit units are heterogeneous in regard to 100,000-scale map rock units—the 1:250,000-scale map units often including a number of 100,000 rock units-sometimes with diverse characteristics and origins. This situation results from increased detail of the 1:100,000 scale map, changes in mapping in the decades since 1:250,000–scale map completion, and problems related to registration of the two different scale maps.

APPENDIX G

NURE Airborne Radiometric Survey Equivalent Uranium Anomalies for the San Luis Obispo 1X2 Degree Quadrangle (Anomaly information from High Life Helicopters, inc., 1981; only anomalies within San Luis Obispo County are listed)

Anomaly # and 7.5 minute Quad Name	1:250K Map Geologic Unit	1:100K Map Geologic Unit	Geologic Units-Comments
11	Mm	Tml, Tm, Tmc, Tvt, Qr	Anomaly is over a fault contact between middle/lower Pliocene and middle Miocene marine rocks
12	QP	QTp, Qa	Anomaly is over Pliocene-Pleistocene nonmarine sedimentary deposits
13	QP	QTp	Anomaly over a contact between an ultrabasic intrusive and Pliocene-Pleistocene nonmarine sediments northeast of the San Andreas Fault zone.
20	QP	QTp	Anomaly is over Pliocene-Pleistocene nonmarine sedimentary deposits
21	QP/Ml	QTp	Anomaly is over Pliocene-Pleistocene nonmarine rocks northeast of the San Andreas Fault zone
24	QP	QTp, Tm, Tmu	Anomaly is over the northwest trending Rinconda fault in Pliocene-Pleistocene nonmarine sedimentary deposits
25	QP	QTp, Tsm	Anomaly is over the northwest trending Huerhuero fault in Pliocene-Pleistocene nonmarine sedimentary deposits
26	Ml/gr	Kgr, Qya, Qoa	Anomaly is over granitic rocks
27	Gr/QP	gr, QTp	Anomaly is adjacent to a fault in granitic rocks
28	Ku/Qal/Mu	Tss, Qa, QTp	Anomaly is over upper Cretaceous marine deposits
29	KJF/Ml	Qal, KJf, KJs	Anomaly is over a northwest trending fault in Franciscan rocks in the south of the survey area
30	Ku/Jl	Kss	Anomaly is over upper Cretaceous marine deposits
31	Kgf/Ub/Mv	Qoa, KJf	Anomaly is over a contact between ultrabasic intrusive rocks and Franciscan rocks
32	Ub/KGF/Mv	Qal, KJf, sp, Tcg, Tm, Qls, Ka, Tb, Tss, Tot, Toa	Anomaly occurs over a fault contact between Miocene volcanic rocks and Franciscan rocks
33	Mu/Qal	Tm, Tsm, Qya	Anomaly is over upper Miocene marine sedimentary deposits
34	Mm	Tmu	Anomaly is over middle Miocene sedimentary rocks near Miocene volcanic rocks
35	Mm	Tmu, Tob	Anomaly is over middle Miocene sedimentary rocks near Miocene volcanic rocks

APPENDIX H

San Luis Obispo County NURE Airborne Radiometric Equivalent Uranium Data Equal or Greater than 7.5 ppm within San Luis Obispo County by 1:100,000 Scale Geologic Map Unit (derived using data in Duval, L.S., 2000)

1:100,000 scale Geologic Map Unit Symbol and Name		**Number of Flight-line data points at 7.5 ppm eU or greater**	**Percent of all Flight-line data points at 7.5 ppm eU or greater**	**7.5 minute quadrangles containing 7.5 ppm eU or greater locations**
Ka	Atascadero Formation, undivided	3	1.2	Chimney Canyon
Kep	El Piojo Formation, undivided	9	3.5	Lime Mountain, Pebblestone Shut-in
Kgr	Granitic rocks, undivided	12	4.7	Lopez Mtn, Santa Margarita
Kif	Italian Flat Formation	1	0.4	Bryson
KJf	Franciscan Assemblage, undivided	3	1.2	Tar Spring Ridge
KJfm	Franciscan Assemblage, melange	1	0.4	Pebblestone Shut-in,
Ksis	Seider's "Shut-In Formation" sandstone and mudstone subunit	2	0.8	Bryson
Kss	Late Cretaceous sandstone, clay shale, and minor conglomerate (OF99-14)	1	0.4	La Panza
Ku	Upper Cretaceous marine sandstone, conglomerate and minor mudstone	14	5.5	Lopez Mtn, Santa Margarita Lake
Qa	Latest Pleistocene to Holocene alluvium, undifferentiated	14	5.5	La Panza Ranch, McKittrick Summit, Painted Rock, Panorama Hills, Pozo Summit, Santa Margarita Lake
Qls	Landslide deposits	2	0.8	Huasna Peak. Tar Spring Ridge
Qoa	Early to late Pleistocene alluvial deposits, undifferentiated	2	0.8	Atascadero
Qr	Stream sand and gravel	2	0.8	Tierra Redonda Mountain

Qt	Early to late Pleistocene stream terrace deposits	3	1.2	Huasna Peak, Pismo Beach
QTp	Paso Robles Formation	4	1.6	Camatta Ranch, Estrella, La Panza
Qya	Modern stream channel deposits	4	1.6	Huasna Peak
sc	silica carbonate rocks	1	0.4	Pismo Beach
Tcg	Unnamed conglomerate and breccias, non-marine, reworked Franciscan	1	0.4	Tar Spring Ridge
Tm	Monterey Formation	26	10.2	Arroyo Grande NE, Fellows, Lopez Mtn, Pismo Beach, Tar Spring Ridge
Tma	Saltos Member of Monterey Shale	1	0.4	La Panza
Tmg	Monterey Shale, Gould Shale Member (OF99-14)	6	2.4	McKittrick Summit, Panorama Hills, Simmler
Tml	Monterey Formation-lower or Monterey Formation semi-siliceous mudstone	34 (32?)	13.3	Adelaida, Atascadero, Lime Mountain, York Mountain
Tmmb	Monterey Formation, silty shale	1	0.4	Oceano
Tmo	Morales Formation, Valley Sediments (OF99-14)	3	1.2	Chimineas Ranch
Tmpe2	Edna Member of Pismo Formation	2	0.8	Arroyo Grande NE, Pismo Beach
Tmpm	Miguelito Member of Pismo Formation	5	2.0	Pismo Beach
Tmpssh	Monterey Formation, phosphatic or porcelaneous shale with chert and diatomite lenses	2	0.8	Arroyo Grande NE
Tmu	Monterey Formation, siliceous shale	27	10.6	Caldwell Mesa, Huasna Peak, Nipomo
Tmw	Monterey Shale, Whiterock Bluff Shale Member (OF99-14)	16	6.3	Caliente Mtn, Camatta Ranch, La Panza
Tpm	Pismo Formation, Miguelito Member—claystone and siltstone	1	0.4	Port San Luis

Tr	Rincon Shale-siltstone or claystone, sometimes dolomitic or calcareous; porcelaneous shale with dacite clasts in conglomerate (MF-599, MF-784)	1	0.4	York Mountain
Tsc	Simmler Formation, mostly conglomerate (OF99-14)	3	1.2	Chimney Canyon, Los Machos Hills, Taylor Canyon
Tsm	Santa Margarita Sandstone	19	7.4	Huasna Peak, La Panza Ranch, Miranda Pine Mtn, Pozo Summit, Tar Spring Ridge,
Tss	Marine sandstone, clay shale and minor conglomerate, Eocene and Paleocene (OF99-14)	26	10.2	Branch Mtn, Caldwell Mesa, Miranda Pine Mtn, Santa Margarita Lake, Pozo Summit, Tar Spring Ridge, Taylor Canyon
Ttc	Temblor Formation, clay shale (OF99-14)	1	0.4	Mckittrick Summit
Tts	Temblor Formation, sandstone (OF99-14)	1	0.4	Panorama Hills
Tvp	Vaqueros Formation, Painted Rock Sandstone Member (OF99-14)	1	0.4	California Valley
Tvs	Vaqueros Formation, sandstone (OF99-14)	1	0.4	Taylor Canyon
Tvt	Volcanic rocks, vitric tuff	1	0.4	Tierra Redonda Mountain
Totals		256	99.6	

APPENDIX I

NURE Sediment (SS), Soil (SL) and Talus Uranium Data by Geologic Unit—San Luis Obispo County

DET Unit/NURE Data Type	Unit Description	N	NURE U Data (ppm)		Mean (ppm)	Median (ppm)	Low (ppm)	High (ppm)
f-SS	Franciscan Assemblage	1	2.85					2.85
gf-SS		2	2.09 1.24		1.67	1.67	1.24	2.09
gr-SS	Granitic rocks, Cretaceous	9	8.99 8.77 6.96 6.31 5.87	4.65 4.24 3.91 3.01	5.86	5.87	3.01	8.99
gr-SL	“	1	3.95					3.95
JKch-SS		2	1.17 0.44		0.81	0.81	0.44	1.17
Jo-SS	Ophiolite (predominantly microdiorite, dikes and sills, diorite and serpentinite or altered pyroxenite)	3	3.70 1.96 1.00		2.22	1.96	1.00	3.70
Jsp-SS		1	1.46					1.46
Jvmv-SS	Unnamed volcanic and metavolcanic rocks, Jurassic, basalt or metabasalt	1	0.64					0.64
Ka-SS	Atascadero Formation, undivided	7	3.62 3.13 3.10 2.79	2.68 2.66 1.66	2.81	2.79	1.66	3.62
Ka-SL	Atascadero Formation, undivided	2	4.25 2.30		3.28	3.28	2.3	4.25
Kas-SS		1	1.64					1.64

Kas-SL		3	3.55 3.12 1.97		2.88	3.12	1.97	3.55
Kep-SS	El Piojo Formation, undivided	8	5.05 3.74 3.45 3.18	2.98 2.52 2.09 2.09	3.14	3.08	2.09	5.05
Kgr-SS	Granitic rocks, undivided	6	9.90 7.59 6.73	4.73 4.42 2.34	5.95	5.73	2.34	9.90
KJf-SS	Franciscan Assemblage, undivided	8	4.48 2.88 2.86 2.06	1.99 1.94 1.79 1.77	2.47	2.03	1.77	4.48
KJf-SL	Franciscan Assemblage, undivided	1	1.96					1.96
KJfg-SS	Franciscan Rocks, graywacke	4	2.08 1.68 1.65 1.28		1.67	1.67	1.28	2.08
KJfm-SS	Franciscan Assemblage, melange	6	2.47 1.68 1.43	1.42 1.20 1.10	1.55	1.43	1.10	2.47
KJfm-SL	Franciscan Assemblage, melange	1	1.36					1.36
KJfme-SS	Franciscan Assemblage, melange	4	2.53 1.82 1.62 0.83		1.70	1.72	0.83	2.53
KJfmv-SS	Franciscan Rocks, metavolcanic rocks (greenstone)	7	2.07 1.86 1.79 1.61	1.56 1.29 1.13	1.62	1.61	1.13	2.07
KJfv-SS		1	2.09					2.09
KJs-SS		1	2.84					2.84
KJt-SS	Toro Formation	2	1.43 1.31		1.37	1.37	1.31	1.43

KJt-TALUS	Toro Formation	1	1.53						1.53
Ks-SS	Unnamed Cretaceous and Lower Tertiary Sedimentary Rocks	2	3.54 2.87			3.21	3.21	2.87	3.54
Ksis-SS		1	1.89						1.89
Kss-SS	Late Cretaceous sandstone, clay shale and minor conglomerate	2	5.01 2.70			3.86	3.86	2.70	5.01
Kss-TALUS	“	1	2.97						2.97
KTs-SS		1	5.4						5.4
Ku-SS	Upper Cretaceous marine sandstone, conglomerate and minor mudstone	1	3.95						3.95
mv & ch-SS		1	1.75						1.75
Qa-SS	Latest Pleistocene to Holocene alluvium, undifferentiated	66	10.03 5.42 5.37 5.08 4.85 4.61 4.46 4.36 4.08 4 3.99 3.96 3.88 3.84 3.72 3.64 3.61 3.58 3.57 3.53 3.49 3.44	3.36 3.30 3.23 3.23 3.22 3.16 3.11 3.07 3.04 3.04 2.93 2.92 2.91 2.83 2.75 2.68 2.66 2.65 2.65 2.60 2.57 2.57	2.53 2.53 2.52 2.51 2.49 2.42 2.39 2.32 2.30 2.27 2.26 2.18 1.98 1.95 1.90 1.78 1.72 1.69 1.51 1.32 1.07 0.51	3.11	2.93	0.51	10.03

Qa-SL	Latest Pleistocene to Holocene alluvium, undifferentiated	52	4.65 4.24 4.05 4.03 3.98 3.82 3.67 3.65 3.60 3.45 3.36 3.33 3.32 3.30 3.26 3.12 3.12 3.09	3.09 3.06 3.02 3.00 2.99 2.98 2.96 2.95 2.92 2.88 2.83 2.79 2.75 2.72 2.70 2.55 2.54 2.52	2.49 2.43 2.39 2.26 2.25 2.10 2.08 2.03 2.01 1.87 1.85 1.76 1.76 1.55 1.52 1.38	2.85	2.94	1.38	4.65
Qa-TALUS	Latest Pleistocene to Holocene alluvium, undifferentiated	2	3.71 2.27			2.99	2.99		
Qal-SS	Latest Pleistocene to Holocene alluvium, undifferentiated	17	3.49 2.95 2.86 2.79 2.31 2.29 1.85 1.85 1.75	1.67 1.57 1.51 1.49 1.46 1.41 1.38 1.00		1.98	1.75		
Qal-SL	Latest Pleistocene to Holocene alluvium, undifferentiated	3	3.62 2.89 2.47			2.99	2.89	2.47	3.62
Qls-SS	Land Slide Deposits	6	2.99 2.17 1.35	1.27 1.15 0.96		1.65	1.31	0.96	2.99
Qls-SL	“	1	13.85						13.85

Qmt-SL	Marine Terrace Deposits (Pleistocene)	2	1.08 1.08			1.08	1.08	1.08	1.08
Qoa-SS	Early to late Pleistocene alluvial deposits, undifferentiated	36	14.23 6.92 4.95 4.35 3.92 3.62 3.45 3.43 3.40 3.21 3.05 2.99	2.91 2.88 2.80 2.74 2.65 2.46 2.41 2.30 2.28 2.28 2.21 2.08	2.07 2.05 1.98 1.97 1.95 1.95 1.89 1.85 1.76 1.68 1.68 1.55	3.05	2.44	1.55	14.23
Qoa-SL	Early to late Pleistocene alluvial deposits, undifferentiated	2	2.50 1.86			2.18	2.18	1.86	2.50
Qoa2-SS	Older Alluvium (Pleistocene)-relatively younger locally	1	1.74						1.74
Qpr-SS	Paso Robles Formation	2	3.19 2.83			3.01	3.01	2.83	3.19
Qrs-SS	Modern stream channel deposits	3	2.28 2.08 1.78			2.05	2.08	1.78	2.28
Qso-SL	Latest Pleistocene to Holocene dune sand	1	0.97						0.97
Qt-SS	Early to late Pleistocene stream terrace deposits	5	3.00 2.60 2.01	2.01 0.74		2.07	2.01	0.74	3.00
Qt-TALUS	Early to late Pleistocene stream terrace deposits	1	2.28						2.28
Qtm-SS	Marine terrace deposits (Pleistocene)	1	1.79						1.79

QTp-SS	Paso Robles Formation	65	7.04	3.19	2.21	2.98	2.60	0.73	7.04
			6.85	3.10	2.17				
			5.50	3.04	2.16				
			5.10	2.98	2.12				
			4.81	2.87	2.12				
			4.68	2.86	2.07				
			4.55	2.86	2.05				
			4.47	2.85	1.98				
			4.37	2.83	1.98				
			4.36	2.63	1.96				
			4.32	2.60	1.95				
			4.28	2.57	1.94				
			4.04	2.52	1.92				
			4.02	2.50	1.87				
			3.89	2.50	1.81				
			3.86	2.46	1.80				
			3.72	2.44	1.75				
			3.69	2.38	1.31				
			3.57	2.35	1.16				
			3.48	2.33	1.01				
			3.33	2.30	0.73				
			3.25	2.29					
QTp-SL	Paso Robles Formation	8	9.42	2.57		3.61	2.72	1.88	9.42
			4.43	2.17					
			3.48	2.04					
			2.86	1.88					
Qya-SS	Modern stream channel deposits	18	12.83	2.99	1.87	3.28	2.58	1.21	12.83
			6.31	2.91	1.87				
			4.17	2.59	1.83				
			3.48	2.56	1.82				
			3.17	2.38	1.70				
			3.06	2.35	1.21				
Qya-SL	Modern stream channel deposits	3	2.19			2.01	2.06	1.79	2.19
			2.06						
			1.79						

sp-SS	serpentinite	3	3.44 1.91 0.28	1.88	1.91	0.28	3.44
Tbw-SL	Bitterwater Creek Shale of Dibble, Miocene, Marine	1	2.88				2.88
Td-TALUS	Dacite, Tertiary	2	5.2 5.2	5.20	5.20	5.2	5.2
Tm-SS	Monterey Formation	8	10.50 2.91 8.18 2.80 4.47 2.57 3.39 1.34	4.52	3.15	1.34	10.50
Tm-SL	“	7	56.99 3.08 9.23 2.72 8.05 2.34 6.53	12.71	6.53	2.34	56.99
Tma-SL	Monterey Formation, Saltos Member	6	4.22 2.47 3.01 1.81 2.93 1.81	2.71	2.70	1.81	4.22
Tmc-SS	Monterey Formation-siliceous shale	1	1.96				1.96
Tmd-SS	Monterey Formation-Devilwater Shale Member	1	0.83				0.83
Tmg-SS	Monterey Shale, Gould Shale Member	1	3.26				3.26
Tmg-SL	“	3	6.37 4.17 3.99	4.84	4.17	3.99	6.37
Tml-SS	Monterey Formation-lower or Monterey formation semi-siliceous mudstone	12	9.02 6.74 4.22 7.69 5.24 3.96 7.15 4.67 3.62 6.89 4.32 2.01	5.46	4.96	2.01	9.02
Tmmc-SS	Monterey Formation-resistant bedded chert	1	8.92				8.92
Tmo-SS	Morales Formation (valley sediments)	6	3.62 2.85 3.48 2.62 3.15 1.84	2.93	3.00		

Tmo-SL	“	3	3.06 2.72 2.06			2.61	2.72	2.06	3.06
Tmof-SS	Obispo Formation-tuffaceous siltstone or claystone	1	4.17						4.17
Tmot-SS	Obispo Formation, tuff	1	2.85						2.85
Tmpe2-SS	Edna Member of Pismo Formation	2	2.73 2.22			2.48	2.48	2.22	2.73
Tmpm-SS	Miguelito Member of Pismo Formation	2	3.74 3.28			3.51	3.51	3.28	3.74
Tmu-SS	Monterey Formation, siliceous shale	11	7.53 7.21 6.61 6.28	5.38 5.35 5.13 3.59	3.51 3.10 2.97	5.15	5.35	2.97	7.53
Tmw-SS	Monterey Shale, Whiterock Bluff Shale Member	5	5.24 5.05 3.40	2.80 2.39		3.78	3.40	2.39	5.24
Tmw-SL	“	4	14.97 14.7 4.1 3.03			9.20	9.40	3.03	14.97
Tob-SS		1	1.79						1.79
Tot-SS	Obispo Formation Tuff	1	1.65						1.65
Tot Tmu-SS	Obispo Formation Tuff—Monterey Formation, siliceous shale	1	3.90						3.90
Tmp-SS		1	0.42						0.42
Tpps-SS	Squire Member of Pismo Formation	2	2.96 2.76			2.86	2.86	2.76	2.96
Tsc-SS	Simmler Formation, mostly conglomerate	5	5.19 3.51 2.84	2.46 1.89		3.18	2.84	1.89	5.19
Tsg-SL	Santa Margarita Sandstone, Miocene, marine	2	3.57 2.1			2.84	2.84	2.1	3.57
Tsi-SL		2	3.08 1.76			2.42	2.42	1.76	3.08

Tsm-SS	Santa Margarita Sandstone	10	8.46 5.04 4.55 2.96	2.83 2.71 2.46 2.19	2.07 0.71	3.40	2.77	0.71	8.46
Tsm-SL	Santa Margarita Sandstone	4	3.73 3.66 3.65 3.03			3.52	3.66	3.03	3.73
Tss-SS	Unnamed sandstone, non-marine(?) quartzofeldspathic sandstone and pebble conglomerate	22	4.19 4.15 3.96 3.52 3.35 3.05 2.99 2.99	2.99 2.80 2.64 2.54 2.51 2.50 2.39 2.26	2.25 2.14 2.09 2.04 1.87 1.73	2.77	2.59	1.73	4.19
Tss-SL	“	1	3.62						
Tss-TALUS	“	1	2.17						2.17
Tts-SS	Temblor Formation, sandstone	1	6.71						6.71
Tts-SL	“	2	5.24 2.66			3.95	3.95	2.66	5.24
Tv-SS	Vaqueros and Tembler Formation	1	2.74						2.74
Tvp-SS	Vaqueros Formation, Painted Rock Member	2	3.44 3.05			3.25	3.25	3.05	3.44
Tvp-SL	“	5	2.88 2.70 2.52	2.28 1.73		2.42	2.52	1.73	2.88
Tvt-SS	Volcanic rocks, vitric tuff	1	3.1						3.1

APPENDIX J

NRCS Soil Units with One or More ≥ 4 pCi/l Sites

Soil Unit	Soil Unit Symbol(s)	N	N ≥ 4 pCi/l	R (%)*	Permeability*** by Soil Depth Interval	Shrink-Swell Character
Arbuckle-Positas complex (CA665)	102, 103, 104,105	22	2	9.1	Moderate (Arbuckle) Moderately slow (Arbuckle) Moderately slow (Arbuckle) Moderate (Positas) Very slow (Positas) Moderately slow (Positas) Moderately slow to moderately rapid (Positas)	Low (Arbuckle, 0-29”) Moderate (Arbuckle, 29-53”) Low (Arbuckle, 53-62”) Low (Positas, 0-10”) High (Positas, 10-28”) Moderate (Positas, 28-41”) Low (Positas, 41-60”)
Arbuckle-San Ysidro complex (CA665)	106	27	4	14.8	Moderate (Arbuckle) Moderately slow (Arbuckle) Moderately slow (Arbuckle) Moderately slow (San Ysidro) Very slow (San Ysidro) Moderately slow to moderately rapid (San Ysidro)	Low (Arbuckle, 0-29”) Moderate (Arbuckle, 29-53”) Low (Arbuckle, 53-62”) Low (San Ysidro, 0-23”) High (San Ysidro, 23-38”) Moderate (San Ysidro, 38-71”)
Arnold loamy sand (CA665)	107	13	1	**	Rapid	Low (0-42”)

Ayar and Diablo soils (CA665)	109	2	1		Slow (Ayar) Slow (Diablo)	High (Ayar, 0-61”) High (Diablo, 0-50”)
Balcom-Calleguas complex (CA665)	113	2	1	**	Moderate (Balcom) Moderate (Calleguas)	Moderate (Balcom, 0-28”) Moderate (Calleugas, 0-12”)
Botella sandy loam (CA665)	116	6	1	**	Moderate (0-32”) Moderately slow (21”-65”)	Moderate (0-65”)
Corralitos sand (CA664)	125	7	1	**	Rapid	Low (0-60”)
Diablo and Cibo clays (CA664)	130, 131, 132	25	1	4.0	Slow (Diablo) Slow (Cibo)	High (Diablo, 0-58”) Slow (Cibo, 0-39”)
Gazos shaly clay loam (CA665)	144	8	2	**	Moderately slow	Moderate (0-28”)
Linne-Calodo complex (CA665)	152, 153, 154	27	7	25.9	Moderately slow (Linne) Moderately slow (Calodo)	Moderate (0 to 39”) Moderate (0-19”)
Linne-Zakme complex (CA665)	156	3	1	**	Moderately slow (Linne) Slow (Zakme)	Moderate (Linne, 0-39”) High (Zakme, 0-55”)

Lockwood shaly loam (CA665)	157, 158	12	2	**	Moderate (0-26”) Moderately slow (26-62”)	Moderate (0-62”)
Lockwood-Concepcion complex (CA665)	159, 160	9	2	**	Moderate (Lockwood, 0-26”) Moderately slow (Lockwood, 26-62”) Moderate (Concepcion) Very slow (Concepcion Slow (Concepcion) Moderate (Concepcion)	Moderate (Lockwood, 0-62”) Low (Concepcion, 0-22”) High (Concepcion, 22-36”) Moderate Concepcion, 36-51”) Low (Concepcion, 51-64”)
Los Osos Loam (CA664)	160	22	1	4.6	Moderate Slow Moderately slow	Moderate (0-14%) High (14-32”) Moderate (32-39”)
Lompico-McMullin Complex (CA665)	162	7	3	**	Moderately rapid (Lompico) Moderate (Lompico) Moderate (McMullin)	Low (Lompico, 0-10”) Moderate (Lompico, 10-36”) Low (McMullin, 0-18”)
Los Osos-Diablo complex (CA664)	162, 163, 164, 165	35	1	2.9	Moderate (Los Osos) Slow (Los Osos) Moderate (Los Osos) Slow (Diablo)	Moderate (Los Osos, 0-14”) High (Los Osos, 14-32”) Moderate (Los Osos, 32-39”) High (Diablo, 0-58”)

Millsholm-Dibble complex (CA665)	169, 170	24	4	16.7	Moderate (Millsholm) Moderately slow (Dibble) Slow (Dibble)	Moderate (Millsholm, 0-16) High (Dibble, 0-12”) High (Dibble, 12-34”)
Marimel silty clay loam, drained (CA664)	170	5	1	**	Moderately slow	Moderate (0-35”)
Nacimiento-Ayar complex (CA665)	178	3	1	**	Moderately slow (Nacimiento) Slow (Ayar)	Moderate (Nacimiento, 0-28”) High (Ayar, 0-61”)
Nacimiento-Los Osos complex (CA665)	178, 179, 180	12	1	**	Moderately slow (Nacimiento) Moderately slow (Los Osos) Slow (Los Osos)	Moderate (Nacimiento, 0-28”) Moderate (Los Osos, 0-14”) High (Los Osos, 14-24”)
Pico fine sandy loam (CA665)	183	2	1	**	Moderately rapid	Low (0-60”)
Oceano sand (CA664)	184	138	2	1.5	Rapid	Low (0-60”)
Rincon clay loam (CA665)	187, 188	19	2	**	Moderately slow Slow Moderately slow	Moderate (0-18”) High (18-64”) Moderate (64-75”)
Pismo loamy sand CA664)	189	25	1	4.0	Rapid	Low (0-19”)
Ryer clay loam (CA665)	191	2	1	**	Moderately slow Slow	Moderate (0-12”) High (12-60”)

San Andreas-Arujo complex	193	28	4	14.3	Moderately rapid (San Andreas) Moderately rapid (Arujo) Moderately slow (Arujo) Moderate (Arujo)	Low (San Andreas, 0-29”) Low (Arujo, 0-10”) Moderate (Arujo, 10-31”) Moderate (Arjuo, 31-47”)
Santa Lucia-Lopez complex (CA665)	198	9	2	**	Moderately slow	Moderate (0-72”)
Still clay loam (CA665)	208	9	1	**	Moderately slow	Moderate (0-60”)
Still gravelly sandy clay loam (CA664)	209	9	1	**	Moderately slow Rapid	Moderate (0-40”) Low (40-64”)
Xerofluvents riverwash (CA665)	212	1	1	**	--	--
Totals	26 soil units	513	54	10.5		

* R=percent of measurements at 4 pCi/l or greater

**Too few data

***NRCS Soil Permeability Definitions: very slow = <0.06 in/hr; slow = 0.06-0.2 in/hr; moderately slow = 0.2-0.6 in/hr; moderate = 0.6-2.0 in/hr; moderately rapid = 2.0-6.0 in/hr; rapid = 6.0-20.0 in/hr; very rapid >20.0

2008 RADON POTENTIAL IN SAN LUIS OBISPO COUNTY 71

APPENDIX K

Descriptive Statistics and Statistical Comparison of Indoor Measurement (non-transformed) for San Luis Obispo County Radon Zones

	All Indoor Radon Data	High Zone Radon Data	Moderate Zone Radon Data	Low Zone Radon Data
Size	918	114	201	603
Mean	1.327	3.315	1.737	0.815
Std Dev	2.489	5.899	1.623	0.981
Std Error	0.0822	0.553	0.114	0.0399
C.I. of Mean	0.161	1.095	0.226	0.0784
Range	57.3	57.3	11.7	10.5
Max	57.6	57.6	12.0	10.8
Min	0.3	0.3	0.3	0.3
Median	0.70	1.95	1.20	0.50
25%	0.30	0.90	0.70	0.30
75%	1.40	3.90	2.40	1.00
Skewness	13.804	7.290	2.469	4.376
Kurtosis	289.722	64.611	9.272	28.757
K-S Dist.	0.340	0.305	0.188	0.300
K-S-Prob.	<0.001	<0.001	<0.001	<0.001
Sum	1,218.400	377.900	349.200	491.300
Sum of Squares	7298.180	5185.390	1133.480	979.310

APPENDIX L

Descriptive Statistics and Statistical Comparison of Indoor Measurement Data (Log10-transformed) for San Luis Obispo County Radon Zones

	All Indoor Radon Data	High Zone Radon Data	Moderate Zone Radon Data	Low Zone Radon Data
Size	918	114	201	603
Mean	-0.109	0.267	0.0865	-0.246
Std Dev	0.407	0.458	0.370	0.330
Std Error	0.0134	0.0429	0.0261	0.0134
C.I. of Mean	0.0264	0.0849	0.0515	0.0264
Range	2.283	2.283	1.602	1.556
Max	1.760	1.760	1.079	1.033
Min	-0.523	-0.523	-0.523	-0.523
Median	-0.155	0.290	-0.0792	-0.301
25%	-0.523	-0.0458	-0.155	-0.523
75%	0.146	0.591	0.380	0.000
Skewness	0.736	0.0855	0.0269	1.027
Kurtosis	-0.0706	-0.0165	-0.554	0.349
K-S Dist.	0.210	0.0631	0.0945	0.287
K-S-Prob.	<0.001	0.311	<0.001	<0.001
Sum	-100.499	30.470	17.385	-148.355
Sum of Squares	162.823	31.824	28.871	102.128