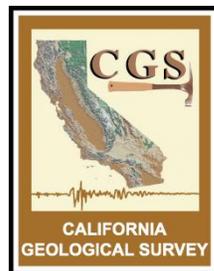


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RADON POTENTIAL IN MONTEREY COUNTY

2007



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By

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2007

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EXECUTIVE SUMMARY

During winter 2006, the Department of Health Services-Radon Program conducted an indoor-radon survey of 1,059 residences in Monterey County using short-term charcoal detectors. In Zip Code area 93924 (Carmel Valley), 24.5 percent of the residences had radon levels at or above 4 picocuries per liter, the U.S. EPA recommended action level. In two other Zip Code areas, 93905 (Salinas) and 93923 (Carmel), 9.5 and 5.3 percent of the residences measured at or above 4 picocuries per liter respectively. Based on survey results, not weighted for location, an estimated 15,668* individuals out of 401,754 (3.9 percent) live in residences with radon levels at or above 4 picocuries per liter in Monterey County

Through a cooperative agreement with the Department of Health Services Radon Program, the California Geological Survey compared the radon survey data with available geology, soil and uranium geochemical information for Monterey County. Portions of Monterey County having either high, moderate or low potential for residences with radon levels at or above 4 picocuries per liter were identified during this activity. These radon potential “zones” are shown on the 1:100,000-scale (1 inch = 1.58 miles) maps of western and eastern Monterey County included as Plate 1 and Plate 2 of this report.

High radon potential zone areas relate to a group of Monterey Formation geologic units and adjacent related alluvial units covering 10.9 percent of the county (361 square miles total). Survey results suggest 25.0 percent of residences in the high potential zone have radon levels at or above 4 picocuries per liter. An estimated 2,828 individuals live in residences in this zone with radon levels at or above 4 picocuries per liter, 549 of which may live in residences with radon levels exceeding 20 pCi/l. Moderate radon potential areas are related to certain portions of Monterey Formation geologic units, middle Pleistocene fluvial terrace deposits, and the Paso Robles Formation and cover approximately 20.2 percent of the county (671 square miles total). Survey results suggest 6.0 percent of residences in the moderate potential zone have radon levels at or above 4 picocuries per liter. An estimated 3,950 individuals live in residences with radon levels at or above 4 picocuries per liter within moderate zone areas. Low radon potential areas cover about 68.9 percent of the county (2,290 square miles total) and are comprised of a number of different geologic units. Survey results suggest 1.2 percent of residences in the low potential zone have radon levels at or above 4 picocuries per liter. An estimated 3,895 individuals live in residences with radon levels at or above 4 picocuries per liter within low zone areas. Using the radon potential zone population estimates, 10,683 individuals out of 401,754 (2.66 percent) are estimated to live in residences with indoor radon levels at or above 4 picocuries per liter in Monterey County.

*All population figures are based on 2000 census data.

The only way to identify buildings with indoor radon levels exceeding 4 picocuries per liter is through testing. The map of radon potential zones for Monterey County in this report can be used as a guide to prioritize areas for public education on radon and for targeting additional indoor radon testing activities. This report includes the data and information utilized and describes the approach taken to develop the radon potential zone map for Monterey County. It also identifies radon data gaps for Monterey County that could be addressed in the future if resources become available.

INTRODUCTION

Purpose

This report documents the procedures used by the California Department of Conservation, California Geological Survey (CGS), to produce the 2007 radon potential map of Monterey County for the California Department of Public Health (CDPH). This report also describes radon potentials for geologic formations in Monterey 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. Typical concentrations of uranium and thorium for many rocks and soils are on the order of a few parts-per-million (ppm). The average uranium content for the earth's continental crust is about 2.5-2.8 ppm. Certain rock types, such as 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, radon gas from water typically accounts for only about 5 percent of the total radon in indoor air (WRRTC, 1997).

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 15,000 to 22,000 according to the U.S. Environmental Protection Agency (U.S. EPA) (U.S. EPA, 2002). The average radon concentration for indoor air in American homes is about 1.3 pCi/l, (picocuries per liter) based on a 1991 national survey (U.S. EPA, 1992). The average radon concentration in outdoor air is about 0.4 pCi/l. The U.S. EPA recommends that individuals avoid long-term exposures to radon concentrations ≥ 4.0 pCi/l. Based on long-term radon test statistics, the U.S. EPA estimates that more than 6 million houses (about 1 out of 15) in the United States have radon levels ≥ 4.0 pCi/l and more than 60,000 homes have radon levels above 20 pCi/l (U.S. EPA, 1992).

Although radon levels are used as a guide for acceptable levels of exposure and for action levels, it is primarily the inhalation of two radon daughter elements polonium-218 and polonium-214 that leads to lung cancer. These elements have very short half-lives and when they enter the lungs they attach to lung tissue or trapped dust particles and quickly undergo radioactive decay. This is in contrast to the longer-lived radon-222 that is mostly exhaled before it undergoes radioactive decay. The alpha particles emitted 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 common 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 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 MONTEREY 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 probability for indoor-air with ≥ 4.0 pCi/l radon levels. Since 2005 (Churchill, 2005 and 2006), radon zones for these maps 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. In the previous approach, qualitative ranking of zones on a county by county basis, sometimes resulted in situations where zone classification in one county would have dramatically different ≥ 4.0 pCi/l percentage than the same zone classification in an another county. For the example cited here, this alternative approach would have classified the highest zone for County C in the high radon potential category as for Counties A and B, even though the County C high zone has a much lower percentage of ≥ 4.0 pCi/l indoor-measurements.

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 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 while fractures of an inch width or less can be significant pathways for radon movement to a buildings foundation. Soil and alluvium may obscure fault 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 in 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 ≥ 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.

MONTEREY COUNTY SHORT-TERM INDOOR-RADON SURVEY RESULTS

Overview

A survey of 1,059 Monterey County homes conducted by the California Department of Public Health--Radon Program between January 10 and May 12, 2006 generated the indoor-radon data for this project. The CDPH Radon Program solicited participation in this survey via direct mailing to 34,958 homeowners in Monterey County. Three percent of homeowners (1,059) agreed 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 Monterey County. Forty-one locations had results that equaled or exceeded 4.0 pCi/l and these are shown in *Figure 2*. The data range from 0.2 pCi/l (the detection limit) to 25.1 pCi/l. *Table 1* summarizes survey results by Zip Code Zone.

Radon Survey Data Exposure Information and Quality

Most residents (81.5%) exposed their detector kits for 48 hours (Appendix A). Eighty-nine duplicate tests were made during the survey and the results are listed in Appendix B. For 20 sites below 1 pCi/l, 78.4 % of the test pairs differ by 0.3 pCi/l or less with an overall range of 0.0 to 0.8 pCi/l. For 51 sites with measurements between 1 and 10 pCi/l, 50% of test pairs differ by 0.6 pCi/l or less with an overall range of 0.1 to 1.2 pCi/l. For the one site above 10 pCi/l the test pair results were 25.1 pCi/l and 8.3 pCi/l. The placement of these two detectors with respect to each other at this site is not known and may be a factor here. A single charcoal detector previously placed at this site tested 16.5 pCi/l.

Follow-up Testing

Twenty-five radon survey sites had follow-up indoor radon tests (Appendix C). The period between the initial site test and follow-up testing ranged from 3 days to 57 days. Eighty-four percent of retested sites did not change in status from the initial test with regard to being ≥ 4 pCi/l or < 4 pCi/l. Of 12 sites initially testing > 4 pCi/l, 8 retested ≥ 4 pCi/l and 4 sites retested < 4 pCi/l. One site initially testing 22.1 pCi/l retested 19.2 pCi/l 49 days later.

Two sites initially testing of 44.9 and 28.4 pCi/l were retested with 4 detectors 39 days later and 2 detectors 29 days later respectively. The 6 follow-up detectors ranged from 0.2 (detection limit) to 0.8 pCi/l. These two sites are located within the Qe geologic unit (Eolian deposits, i.e., coastal dunes) on BbC (Baywood) soil. As is reported in Table 3 below, 142 additional sites on this geologic unit and soil were tested during the Monterey County indoor-radon survey and all results were less than 2.5 pCi/l. Three of the 142 sites are within 200 and 400 feet of these

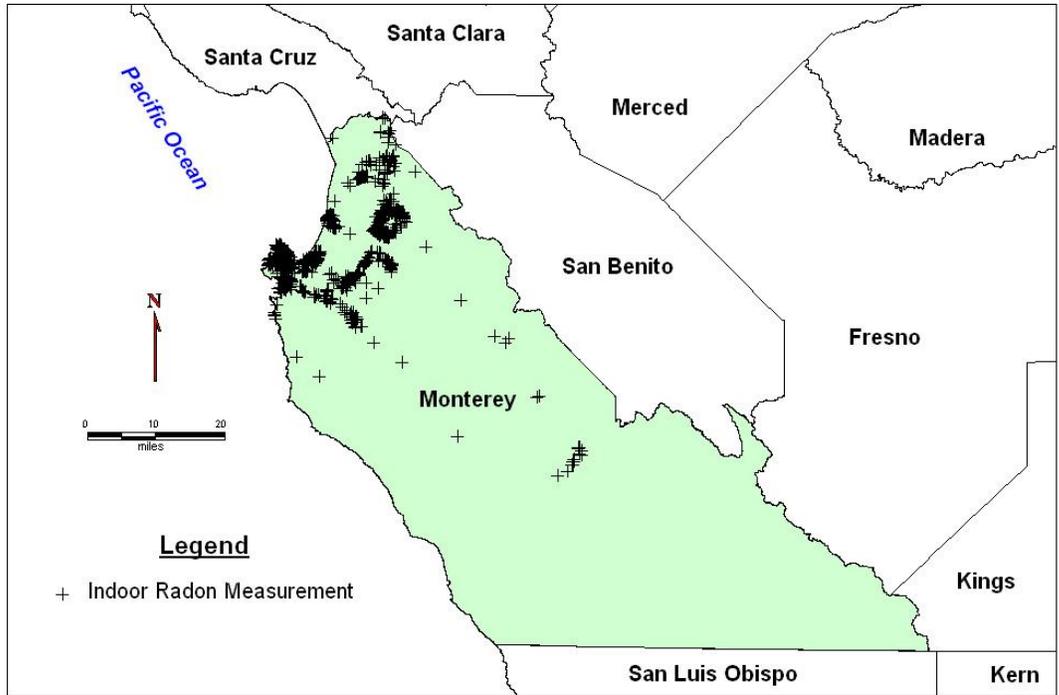


Figure 1. CDPH Short-Term Radon Tests for Monterey County

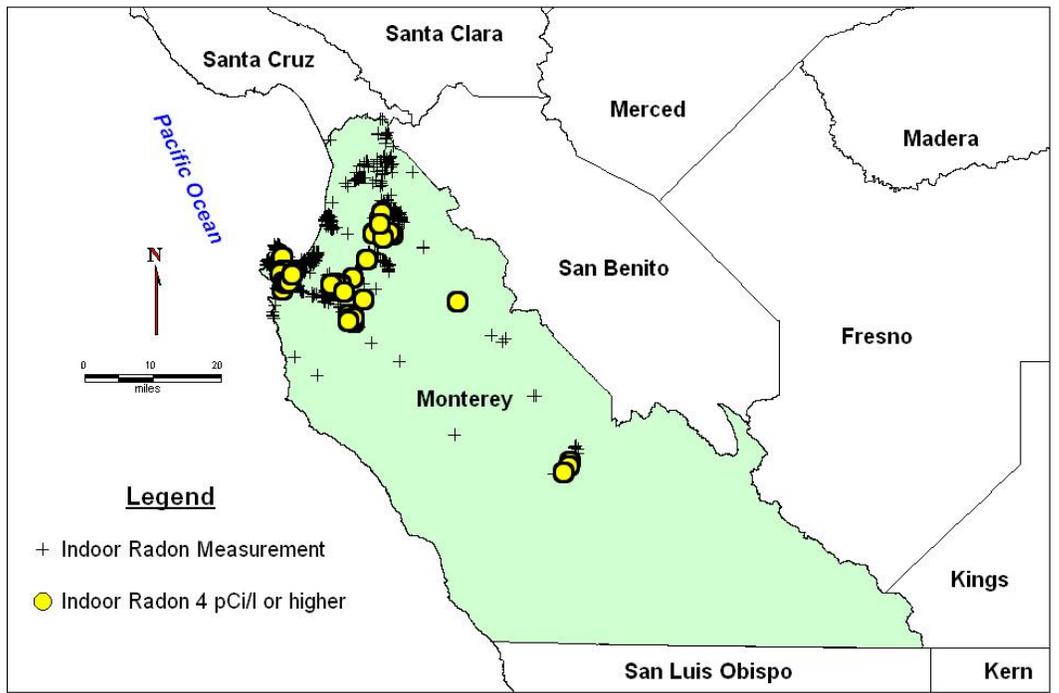


Figure 2. CDPH Short-Term Radon Test Results—4.0 pCi/l or Greater

Zip Code	City/Region	Number of Measurements	Measurements ≥ 4.0 pCi/l	Percent ≥ 4.0 pCi/l
93426	Bradley	0*	--	--
93451	San Miguel	0*	--	--
93901	Salinas	91	4	4.4
93902	Salinas	0*	--	--
93905	Salinas	21	2	9.5
93906	Salinas	85	2	2.4
93907	Salinas	80	1	1.3
93908	Salinas	98	3	3.1
93920	Big Sur	0*		
93921	Carmel	1	0	0
93922	Carmel	0*		
93923	Carmel	100	5	5.3
93924	Carmel Valley	53	13	24.5
93925	Chualar	0*	--	--
93926	Gonzales	1	1	100
93927	Greenfield	3	0	0
93930	King City	15	3	20
93932	Lockwood	0*	--	--
93933	Marina	55	0	0
93940	Monterey	178	6	3.4
93950	Pacific Grove	138	0	0
93953	Pebble Beach	56	1	1.8
93955	Seaside	62	0	0
93960	Solidad	3	0	0
93962	Spreckels or Salinas	0*	--	--
95004	Aromas	14	0	0
95012	Castroville	4	0	0
95039	Moss Landing	1	0	0
95076**	Watsonville**	0*	--	--
	<i>total</i>	<i>1,059</i>	<i>41</i>	<i>3.9</i>

*No respondents to CDPH Indoor-Radon testing solicitation.

**Portion of Zip Code area in Monterey County

Table 1. CDPH Indoor-radon Short-term Test Results for Monterey County by Zip Code Zone.

two sites and tested 0.2, 0.4, and 0.6 pCi/l. On the basis of site retest results and results from the 142 sites with the same geologic and soil units present, the initial test results at these two sites were considered in error and were replaced with the retest results in the Monterey County survey database.

The two other sites with ≥ 4 pCi/l initial tests and < 4 pCi/l follow-up tests had test results of 5.2 and 3.6 (17 days apart) and 5.0 and 3.3 (36 days apart).

Of 13 sites testing < 4 pCi/l, all retested < 4 pCi/l (i.e., no sites initially testing < 4 pCi/l retested > 4 pCi/l). Retesting at these sites occurred between 3 and 35 days after initial testing.

Monterey County Geologic/Soil Unit Radon Potentials

Indoor-radon data from the CDPH Radon Program 2006 survey of Monterey 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 by Rosenberg (2001) was used to determine the geologic unit present at radon measurement locations. The NRCS digital soil map for Monterey County (NRCS, 2007) was used to determine soil type at each measurement location and is available for downloading at:

<http://soildatamart.nrcs.usda.gov/Survey.aspx?County=CA053date>

Table 2 lists six geologic units, with their associated soil types, likely to have high and moderate radon potential based in indoor-radon measurement results. The status of four of these units is provisional (indicated by “High?” or “Moderate?”)—less certain because they have few associated indoor-radon measurements. Other data (airborne radiometric data, uranium data from soil samples and sediment samples, and soil property 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 combinations of geologic and soil units having 25 or more indoor radon measurements and few or no measurements ≥ 4.0 pCi/l (i.e., units with sufficient radon measurement data to statistically support their low radon potential classification).

Geologic Unit (From Rosenberg, 2001)	Soil Type (from NRCS)	Incidence Rate (R) of CDPH Indoor-Radon Measurements \geq 4 pCi/l, in percent	Radon Potential Designation
Tm-Monterey Formation (siliceous mudstone, Miocene)	SfE, SfF, Sg (Santa Lucia)	R=21.1%, N=38 N \geq 4.0 = 8 Maximum = 25.1 pCi/l	High R \geq 20%
Tmdi-Monterey Formation (diatomite, Miocene)	SfE, SfF, Sg (Santa Lucia)	R uncertain (<i>too few data</i>), N=4 N \geq 4.0 = 3 Maximum = 22.1 pCi/l	High? Max=22.1 pCi/l Apparent R > 20% Unit similar to other high potential units in California
Tmi-Monterey Formation (semi-siliceous mudstone, middle Miocene)	SfE, SfF (Santa Lucia)	R uncertain (<i>too few data</i>), N=6 N \geq 4.0 = 1 Maximum = 8.2 pCi/l	High or Moderate? Apparent R > 5% Unit similar to other high and moderate potential units in California
Qt-Fluvial terrace deposits (undifferentiated, Pleistocene and Holocene)– <u>those Qt areas adjacent to or surrounded by Monterey Fm.</u>	LeC (Lockwood) and SfE, SfF, Sg (Santa Lucia)	R uncertain (<i>too few data</i>), n=9 N \geq 4.0 = 3 Maximum = 11.2 pCi/l	High? Apparent R > 20%
Qal-Alluvial deposits (undifferentiated, Holocene)- <u>those Qal areas adjacent to or surrounded by Monterey Formation areas)</u>	RaA (Rincon) and SfF, Sg (Santa Lucia)	R= uncertain (<i>too few data</i>) N=7 N \geq 4.0 = 2 Maximum = 7.5 pCi/l	High? Apparent R > 20%
Qtmp-Fluvial terrace deposits (middle Pleistocene)	AeA and AeC (Antioch) and CnA and CnC Cropley	R = 8% N=36 Data \geq 4.0 = 3 Maximum = 7 pCi/l	Moderate R \geq 5 % and < 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 and Soil Units in Monterey County Based on 2006 CDPH Short-term Indoor Radon Data

Geologic Unit (Rosenberg, 2001)	Soil Type (NRCS)	Incidence Rate (R) of CDPH Indoor-Radon Measurements ≥ 4 pCi/l, in percent	Radon Potential Designation
Kgdm-Porphyritic granodiorite of Monterey	NcC (Narlon)	R=2.4% N=41 N ≥4.0 = 1 Maximum = 8.1 pCi/l	Low R < 5 %
Qa-Aromas Sand, undifferentiated (Pleistocene)	AkD, AkF (Arnold)	R=0% N=64 Maximum = 2.6 pCi/l	Low R < 5 %
Qct-Coastal terraces, undifferentiated (Pleistocene)	BbC (Baywood)	R=0% N=32 Maximum = 2 pCi/l	Low R < 5 %
	NcC (Narlon)	R=0% N=115 Maximum = 2.4 pCi/l	Low R < 5 %
Qe-Eolian Deposits, undifferentiated (Pleistocene)	BbC (Baywood)	R=0% N=142 Maximum = 2.4	Low R < 5 %
	TaC (Tangoir)	R=0% N=28 Maximum = 1.2 pCi/l	Low R < 5 %
Qfp-Flood-plain deposits, undifferentiated (Holocene)	GkB (Gorgonio)	R=3.1% N=32 N ≥4.0 = 1 Maximum=5.2 pCi/l	Low R < 5 %
	SbA (Salinas)	R=4.4% N=68 N ≥4.0 = 3 Maximum = 5.5 pCi/l	Low R < 5 %
Qfpl-Alluvial fans (late Pleistocene)	CbA (Chualar)	R=2.0 N=50 N ≥4.0 = 1 Maximum = 5.2 pCi/l	Low R < 5 %

Table 3. Low Radon Potential Geologic and Soil Units in Monterey County Based on 2006 CDPH Short-term Indoor Radon Data (with more than 25 measurements)

NURE DATA REVIEW

Background

During the 1970s and early 1980s, the federal government funded the National Uranium Resource Evaluation Project (NURE). 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 uranium are 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 in radon mapping projects, particularly where indoor-radon measurements are sparse or lacking.

Airborne Radiometric Data

Figure 3. shows the approximately 1,387 miles of flight lines flown within Monterey County during the 1980 NURE airborne radiometric surveys and uranium anomaly locations. About 999 miles of flight lines were part of the NURE Santa Cruz 1X2 degree quadrangle survey and about 338 miles were part of the NURE San Luis Obispo 1X2 degree survey. The flight-line grid pattern consists of east-west flight-lines, 3-6 miles apart, and north-south flight-lines, 12 miles apart. Along the flight lines a specially equipped helicopter recorded approximately 57,000 gamma-ray spectral measurements. Data collection occurred at an average flight speed of 86 miles per hour and an average altitude of 336 feet. Such measurements typically represent uranium content within the upper 18 inches of surficial material over an area of approximately 48,000 square feet (High-Life Helicopters, 1981a). 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 used to estimate of the soil-rock uranium content in parts-per-million (ppm) at each of the 57,000 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). eU data can be impacted by soil moisture (Grasty, R.L., 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.

A problem with the NURE airborne radiometric survey digital files for the Santa Cruz 1X2 degree quadrangle prevented the creation of a digital data layer of flight-line uranium data for comparison, using GIS methods, with geologic units from the 1:100,000-scale map used in this radon mapping project.

Consequently, the 1981 NURE report (High Life Helicopters, Inc., 1981b) for this quadrangle was reviewed for information on the uranium content of geologic formations and the locations and geologic characteristics of flight-line segments with anomalously high uranium. Information summarizing flight-line uranium data for geologic units from this 1981 report is provided in Appendix F. A list of flight-line uranium anomalies from this 1981 report for the Monterey County portion of the Santa Cruz 1X2 degree quadrangle is provided in Appendix G. Airborne radiometric data for the San Luis Obispo 1X2 degree quadrangle portion of Monterey County were suitable for creation of a digital layer for detailed comparison with the 1:100,000-scale map geologic units by GIS methods. Results of this comparison are summarized in Appendix H. Airborne equivalent uranium anomalies used in this study are defined as follows:

- 1) For Santa Cruz quadrangle data--*by 1X2 degree quadrangle geologic map unit (using the definition from the 1980 NURE report, High Life Helicopters, Inc., 1981b)* two consecutive averaged eU samples each being two or more standard deviations above the mean or three consecutive average 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. For example, for Monterey Formation units the anomaly thresholds would be about 6 to 10.4 ppm eU.
- 2) For the San Luis Obispo data (from the NURE flight-line digital database)—eU data equal to or exceeding 7.5 ppm (3 times the average uranium content of the earth's crust and within the range of anomaly thresholds for Monterey Formation units in the 1980 NURE report).

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:

- Tm-Monterey Formation;
- Tml-Monterey Formation, semi-siliceous mudstone;
- Other Monterey Formation units-Tmdi (diatomite), Tmc (clay shale) Tmd (Devilwater member)
- QTp-Paso Robles Formation
- Tpo-- Pancho Rico Formation, diatomaceous mudstone;
- Kqdj-Quartz diorite-granodiorite of Johnson Canyon
- Tvd-Intrusive dacitic felsite
- Tvp-Pinnacles Formation-dacitic breccia and tuff breccia

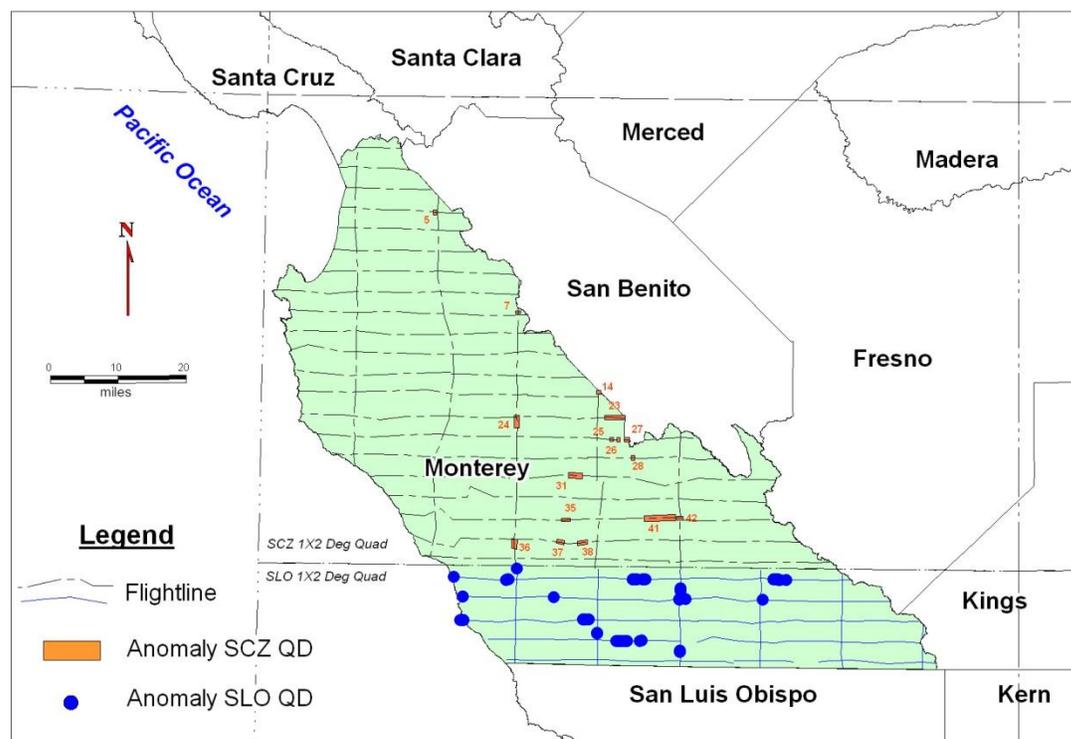


Figure 3. NURE Project Flight lines and Equivalent Uranium Anomalies

Blue flight lines and anomalies are from the San Luis Obispo 1X2 degree quadrangle NURE study, black flight lines and orange anomalies are from the Santa Cruz 1X2 degree quadrangle NURE study. Geologic information for the numbered anomalies is provided in Appendix G.

Uranium in Soil, Stream Sediment and Talus Samples

NURE activities in Monterey County also resulted in the collection and analysis of 134 soil samples, 415 stream sediment, and 26 talus samples for total uranium. The distribution of the soil, stream sediment and talus samples in Monterey County are shown in Figure 4. Figure 5 shows those samples (24 percent) that equal or exceed 5.0 ppm total uranium (i.e., approximately twice the average uranium content of the earth's crust).

Uranium data for the samples, grouped by the geologic unit present at the sample collection site, are listed in Appendix I. Seventy-four geologic units have NURE uranium data available. Four units have 25 or more associated NURE samples, the Tm (Monterey Formation)- stream sediment, Qal (Alluvial deposits)-stream sediment, Qfp (Flood-plain deposits)- stream sediment and soil, and QTp (Paso Robles Formation)-stream sediment. Median value of Uranium in stream sediment associated with Tm is 6.3 ppm, significantly higher than median uranium values for stream sediment and soil associated with Qal, Qfp or QTp which range from 2.2 to 3.6 ppm. The highest individual uranium analyses for these units, in order from high to low, are as follows: Qal—stream sediment,

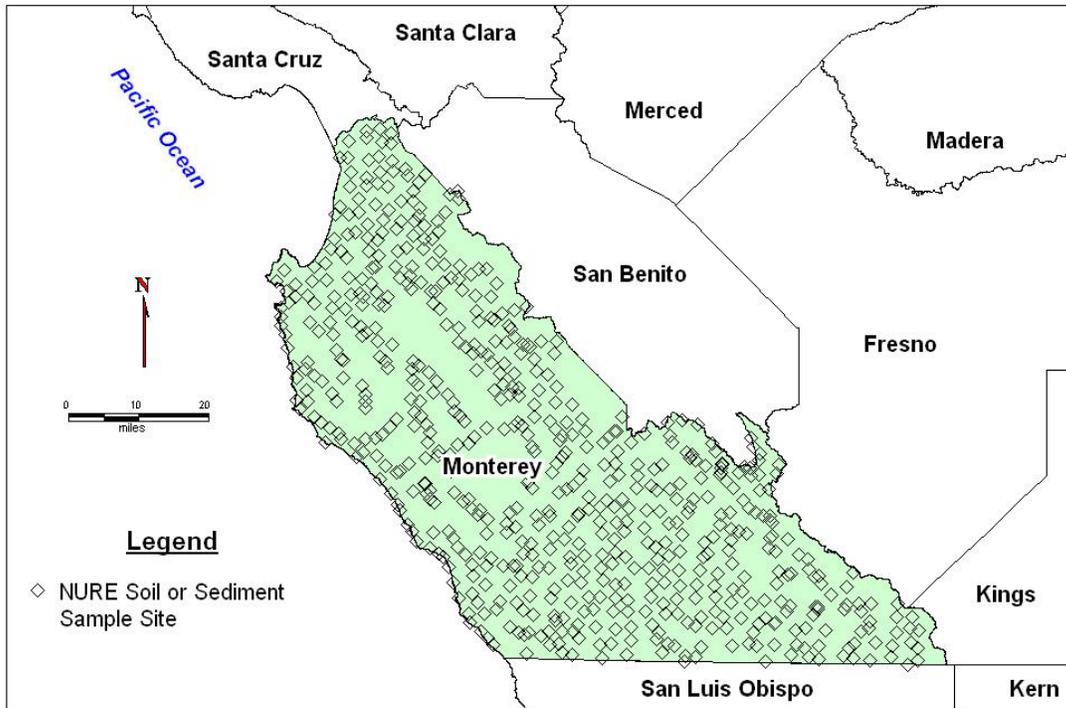


Figure 4. NURE Soil, Stream Sediment and Talus Sample Locations

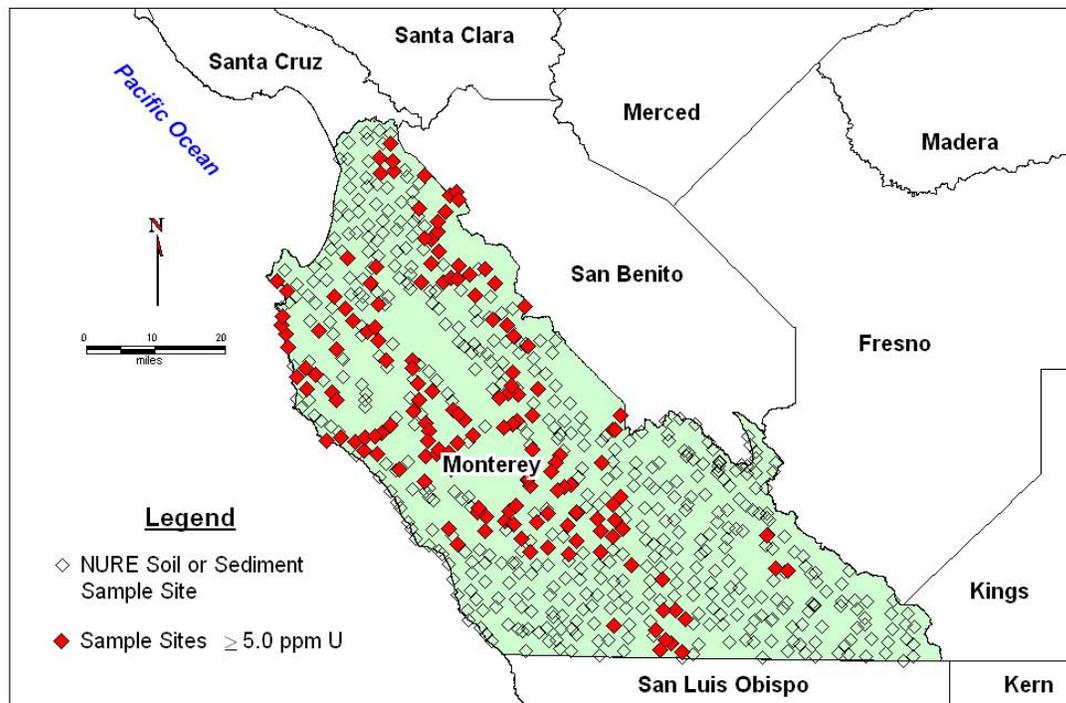


Figure 5. NURE Soil, Stream Sediment and Talus Locations with ≥ 5.0 ppm Uranium

21.9 ppm; Tm—stream sediment, 12.2 ppm; Qfp-soil, 7.2 ppm; Qfp-stream sediment, 6.3; and QTp-stream sediment, 4.32 ppm. The remaining 70 units have too few uranium data to reliably determine their uranium population characteristics. However, 17 geologic units (besides Qal and Tm, previously mentioned) have at least one associated NURE uranium analysis exceeding 10 ppm, suggesting that at least small areas within these units may have higher radon potential (see Table 4 and Appendix I). These high uranium sample sites

Geologic Unit and NURE sample type	Highest NURE U analysis (ppm)	Geologic Unit and NURE sample type	Highest NURE U analysis (ppm)
Kqmf-stream sed	51.2	pKqf-soil	12.3
pKm-soil	33.9	Tm-stream sed	12.2
Qal-stream sed	21.9	Tss-talus	12.1
Qc-stream sed	20.7	Kqmp-stream sed	11.8
Qhf-stream sed	20.1	pKqf-stream sed	11.3
Kqds-stream sed	18.2	Kqdj-talus	10.9
Qhf-soil	17.8	pKg-stream sed	10.9
Tm-talus	15.4	pKc-soil	10.7
Kgdn-stream sed	13.5	pKg-stream sed	10.2
Qls-talus	13.2		

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

are located in sparsely populated rural portions of Monterey County. Using 5 ppm uranium (twice the average crustal uranium content) as a screening boundary between geologic units with higher and lower radon potential, NURE uranium data for stream sediment, soil and talus samples suggest the most likely geologic units to have areas with elevated radon potentials in Monterey County are:

- Tm-Monterey Formation
- Kqmf-Quartz Monzonite of Brickmore Canyon
- Kqds-Hornblende-biotite diorite of Soberanes Point
- Kqdj-Quartz diorite-granodiorite of Johnson Canyon
- pKqf-Quartzofeldspathic rocks-gneiss, granofels, quartzite, minor schist
- Tss-Unnamed marine sandstone (Paleocene)
- Qhf-Alluvial fan deposits (Holocene)

Note that both the NURE airborne radiometric data and the soil-stream sediment-talus data support increased radon potential status for the following geologic units:

- Tm-Monterey Formation
- Kqdj-Quartz diorite-granodiorite of Johnson Canyon

The sediment-soil-talus data do not support the increased radon potential for Tpo and QTp implied by the airborne radiometric surveys, but the data are too few to be conclusive. Little can be concluded about the status of Tml (Monterey Formation, semi-siliceous mudstone) with only two uranium analyses of sediment available.

Figure 6 shows locations of anomalous airborne equivalent uranium data and anomalous sediment-soil-talus uranium data within Monterey County. These groups appear to be somewhat mutually exclusive in location with the many of the sediment-soil-talus anomalies being in areas of granitic or metamorphic rocks while the airborne equivalent uranium anomalies appear more closely associated with areas of Cenozoic marine and non-marine sediments. One possibility for this pattern is that radon emanation from granitic and metamorphic rocks in Monterey County is lower than from the Cenozoic sediments. Radon emanation is the percent of radon that escapes from minerals where it formed into surrounding pore spaces and fractures. If true, this suggests that higher total uranium in granitic and metamorphic rocks in Monterey County may be less a problem for elevated indoor-radon than lower moderate total uranium levels in Cenozoic sediments. Additional research is required to confirm or reject this possibility.

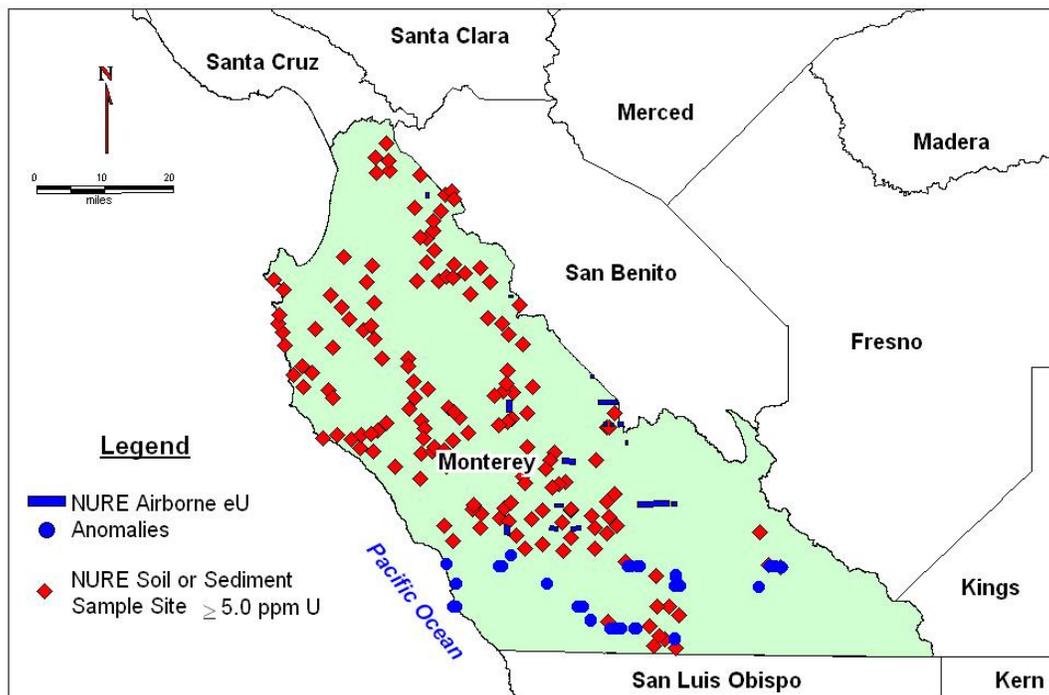


Figure 6. Comparison of NURE Airborne Survey eU Anomaly Locations with NURE Soil and Sediment Sample U Anomaly Locations

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 small areas of uranium concentration with increased radon potential occur within these other units. Whether or not these areas of 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 related to 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 related to the Paso Robles Formation. They found samples at 2 meters depth at 6 sites had soil gas radon levels ranging from about 500 pCi/l to 1,600 pCi/l. Shrinkage fractures 3 to 4 meters deep have been noted in soil associated with the Paso Robles Formation (Rosenberg, County of San Luis Obispo, 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 Monterey County soils associated with at least one indoor-radon measurement ≥ 4 pCi/l. From the information in Appendix J, Monterey 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 41 ≥ 4 pCi/l sites, 39 have soils with horizons with these characteristics (note that some soils have multiple horizons with different characteristics). The Santa Lucia soil is an example of a moderate permeability and low shrink/swell soil, associated with the Monterey Formation. Eight of the 41 home sites with 4 pCi/l or higher indoor-data in Monterey County are on Santa Lucia soil. Additional factors connecting Santa Lucia soil to elevated radon sites may be its

thickness and the physical condition of the underlying Monterey Formation. The representative Santa Lucia soil profile is only 24 inches thick and the soil rests on hard fractured Monterey (Formation) shale (Cook, 1978, p. 70). If this thickness and the fracturing are typical, radon should have numerous short and easy pathways available to move from its point of generation, within the Monterey Formation or the Santa Lucia soil, to the foundation of an overlying building.

Moderately-rapid, rapid or very rapid permeability soils appear less likely to be associated with ≥ 4 pCi/l indoor air sites. Only 9 of 41 of the ≥ 4 pCi/l sites have soils with at least one moderately-rapid, rapid or very rapid soil horizon. In Table 3, listing low-radon potential geologic and soil units based on indoor radon test results, note that Arnold, Baywood, Gorgonio and Tangoir soils have only moderately-rapid to rapid permeability and low shrink-swell soil horizons. NURE soil and stream sediment data for the geologic units in Table 3 are not abnormally low for the geologic units listed in Table 3, ranging from 2.1 ppm (slightly below the crustal uranium average) to 9.9 (almost 4 times the crustal uranium average). However, no information is available on the emanation efficiencies (the percent of radon that escapes from minerals and rocks) for these geologic units. Consequently, it remains uncertain if lower indoor-radon levels result from higher soil permeability, perhaps by facilitating dilution of soil gas in the subsurface by low radon atmospheric air or facilitating the flow of radon around buildings instead into buildings, or from low radon emanation efficiencies for these geologic units and soils

RADON POTENTIAL ZONES

Final Monterey County Geologic Unit Radon Potentials

Monterey County high and moderate radon potential zones are based on locations of geologic units classified as having high or moderate radon potential. As discussed in previous sections and summarized in Table 5, indoor radon measurements, NURE airborne gamma-ray survey and stream sediment, soil and talus uranium data, and NRCS soil data, support the high potential zone for Monterey County being based on the distribution of Monterey Formation occurrences in the county. Because of similarities in uranium content and soil properties, characteristics and geologic origin, other Monterey Formation subunits—Tml, Tmdi, Tmc and Tmd, will be treated as having high radon potential at this time. Geologic units Qtmp and QTp are classified as having moderate radon potential based on currently available indoor-radon data. While no indoor data are currently available for QTp in Monterey County, review of QTp associated indoor-data for San Luis Obispo County Data suggest ≥ 4 pCi/l rate of about 6 to 8 percent and, consequently, a moderate radon potential classification. A moderate zone classification for QTp is also supported by NURE Airborne Survey data and soil permeability-shrink/swell data. There are insufficient data to reliably classify the remaining geologic units listed in Table 5

Geologic Unit	Indoor Radon Survey Data	NURE Project Airborne Survey Data for eU	NURE Project Stream Sediment, Soil and Talus Sample data for U	NRCS Soil Permeability and Shrink-Swell Data
Tm-Monterey Formation	XX	x	X	X
Qtmp-Fluvial terrace deposits (middle Pleistocene)	X			X
Tml-Monterey Formation Siltstone	x	x		X
Tmdi-Monterey Formation Diatomite	x	x		X
Qt-Fluvial terrace deposits (those assoc. w Monterey Fm units)	x			
Qal-Alluvial deposits (those assoc. w Monterey Fm units)	x			
Tmc-Monterey Formation clay shale	ND	x		X
Tmd-Monterey Formation Devil Water member	ND	x		X
QTp-Paso Robles Formation	+	x		X
Tpo-Pancho Rico Formation	ND	x		X
Kqdj-Quartz diorite-granodiorite of Johnson Canyon	ND	x	x	
Tvd-Intrusive dacite felsite	ND	x		
Tvp-Pinnacles Formation-dacitic breccia and tuff breccia	ND	x		
Kqmf	ND		x	
Kqds	ND		x	
pKqf	ND		x	
Tss	ND		x	
Qhf	ND		x	

Table 5. Monterey County Geologic Units and Strength of Supporting Data for Increased Radon Potential.

XX = more than 25 indoor radon measurements with $\geq 20\%$ at 4 pCi/l or greater)

X = more than 25 indoor radon measurements (with $\geq 5\%$ and $< 20\%$ at 4pCi/l or greater); or uranium analyses (with median ≥ 5 ppm U); or strong 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

+ = more than 25 indoor radon measurements on geologic unit in an adjacent county with $\geq 5\%$ and $< 20\%$ at 4 pCi/l or greater)

ND = no indoor-radon data

as having moderate or high radon potential. Future studies to obtain 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. All other geologic units in Monterey County are assigned low radon potential at this time based on currently available data.

Radon Potential Zone Boundaries

Monterey Formation unit areas (Tm, Tml, Tmdi, Tmd, and Tmc) and immediately adjacent alluvial areas within a 0.2 mile wide buffer having Santa Lucia or Lockwood soils are classified as high radon potential. Monterey Formation/buffer areas with other soil types are classified as moderate radon potential.

Paso Robles Formation areas and associated 0.2 mile wide buffer areas are classified as moderate radon potential. A buffer zone is used here because no indoor-radon data are available for the Paso Robles Formation in Monterey County and the majority of associated soils are not included in Appendix J.

Note that buffer zones were not created for areas of Monterey Formation units or Paso Robles Formation areas having a width less than 0.2 miles unless these occurrences were less than 0.2 miles apart.

Middle Pleistocene fluvial terrace deposit (QTmp) areas with Antioch or Salinas soils are classified as moderate radon potential. Soil data and available indoor radon data did not support use of a buffer zone in this case.

Sometimes high or 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.

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

Table 6a and Table 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.

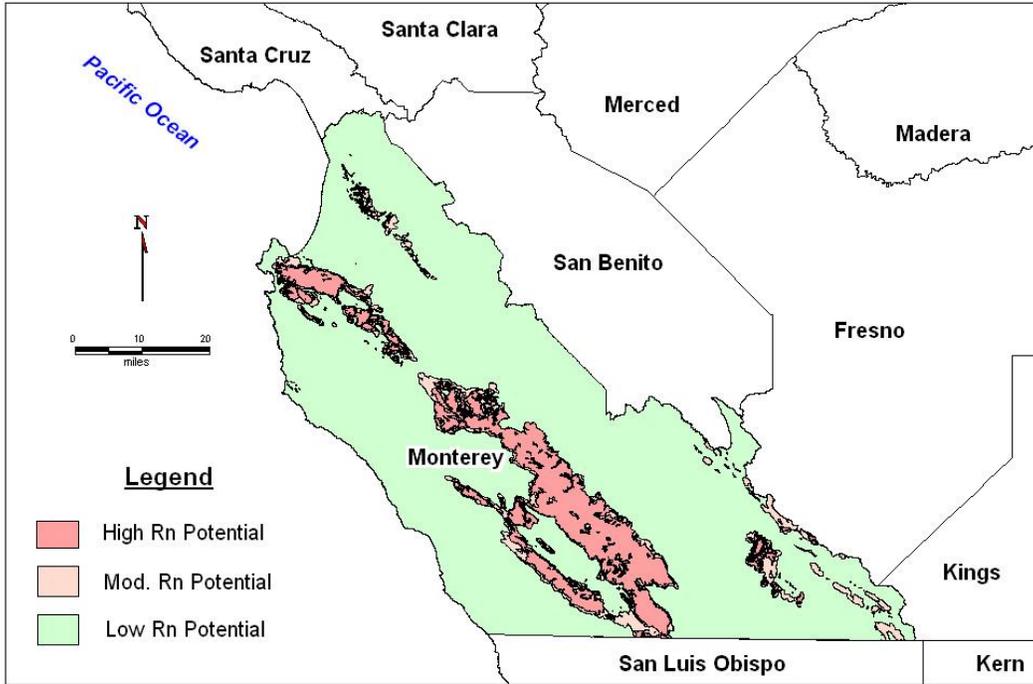


Figure 7. Radon Potential Zones for Monterey County.

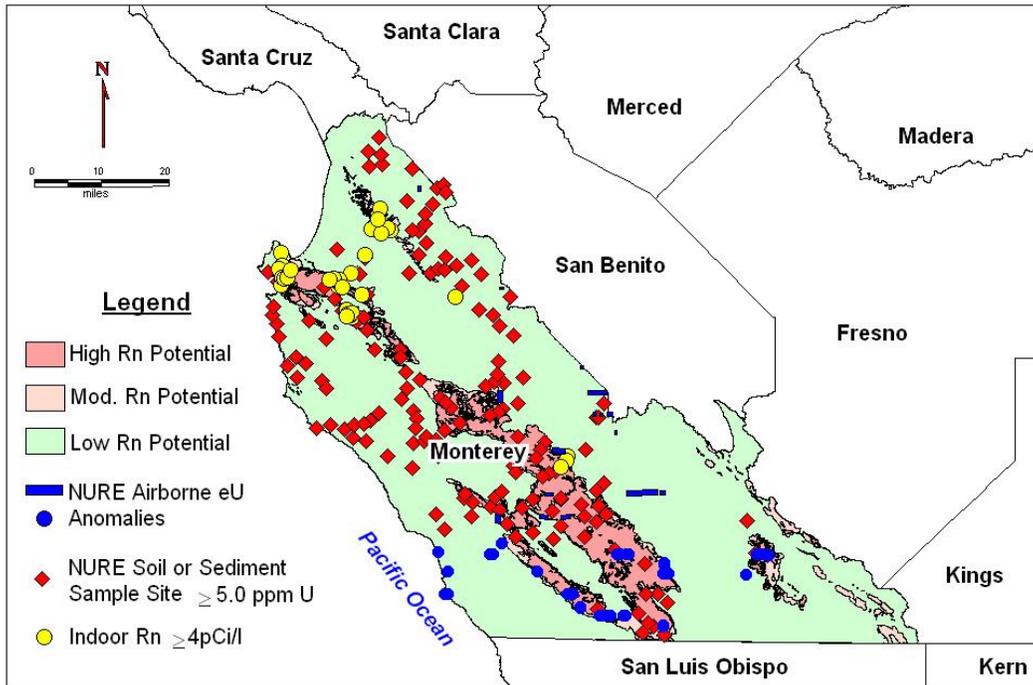


Figure 8. Comparison of Radon Potential Zones, Anomalous NURE Data and Indoor Radon Data ≥ 4 pCi/l.

Zone	n	Median pCi/l	pCi/l at 25%	pCi/l at 75%	Min pCi/l	Max pCi/l
High	84	1.65	0.6	3.85	0.2	25.1
Moderate	166	0.85	0.3	1.6	0.2	7.0
Low	809	0.6	0.2	1.1	0.2	8.7
All	1059	0.6	0.2	1.2	0.2	25.1

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	84	21	25.0	7	8.3	4	4.8	361
Moderate	166	10	6.0	0	0	0	0	671
Low	809	10	1.2	0	0	0	0	2290
All	1059	41	3.9	7	0.7	4	0.4	3322

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 Monterey County Area
High	51.2	100	100	10.9	51.2	10.9
Moderate	24.4	0	0	20.2	73.2	31.1
Low	24.4	0	0	68.9	100.0	100.0
All	100.0	100.0	100.0	100.0		

Table 7a. ≥ 4.0 pCi/l Incidence Rates for Monterey 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	0.058	0.23
Moderate	0.015	0.25
Low	0.004	0.35
All	0.012	0.32

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 Monterey 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 Monterey 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. A 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 Monterey 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	1059	0.311	<0.001	Failed
All Data—Log (10) Transformed	1059	0.151	<0.001	Failed
High Zone—Untransformed	84	0.263	>0.001	Failed
High Zone—Log(10) Transformed	84	0.113	=0.010	Failed
Moderate Zone— Untransformed	166	0.221	<0.001	Failed
Moderate Zone—Log(10) Transformed	166	0.121	<0.010	Failed
Low Zone—Untransformed	809	0.233	<0.001	Failed
Low Zone—Log(10) Transformed	809	0.172	<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

<i>Mann-Whitney Rank Sum Test</i>					
<i>Group</i>	<i>N</i>	<i>Missing</i>	<i>Median</i>	<i>25%</i>	<i>75%</i>
High Zone	84	0	1.65	0.6	3.85
Moderate Zone	166	0	0.85	0.3	1.6
<i>Result</i>	T = 12567.000 n(small)=84 n(big)=166 (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)				
<i>High Zone</i>	84	0	1.65	0.6	3.85
<i>Low Zone</i>	809	0	0.60	0.2	1.1
<i>Result</i>	T = 52312.000 n(small)=84 n(big)=809 (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)				
<i>Moderate Zone</i>	166	0	0.85	0.30	1.6
<i>Low Zone</i>	809	0	0.60	0.20	1.1
<i>Result</i>	T = 93382.500 n(small)=166 n(big)=809 (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

Estimated Population Exposed to 4.0 pCi/l Radon or Greater Indoor Air in Monterey County

Population estimates for each radon potential zone were obtained by overlaying the Monterey County radon potential zones with 2000 census tract data. For census tracts not completely within a radon potential zone, a portion of census tract population proportional to the percent area of the census tract falling within the radon potential zone was used as the population contribution of that census tract to the total population of the radon potential zone. The estimated populations for the different radon potential zones are listed in Table 10.

Radon Potential Zone	Estimated Total Population within Zone— 2000 Census Statistics	Estimated Total Houses within Zone— 2000 Census Statistics
High	11,351	4,918
Moderate	65,834	19,917
Low	324,569	106,876
All Monterey County	401,754	131,711

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

Table 11 shows the estimated populations of residents for each radon potential zone and the estimated number of residences exposed to different radon levels. These estimates are based on the estimated population for each zone multiplied by the ≥ 4.0 pCi/l percentages for each zone from Table 6b.

Potential Radon Impacts on the Population of Monterey County

The High and Moderate radon potential zones contain 31.1 percent of the Monterey County area and 19.21 percent of the county population. These two zones also contain:

- 63.54% of the Monterey County population estimated to live in residences with indoor radon levels of ≥ 4.0 pCi/l
- Available data suggest most or all of the Monterey County residences with indoor radon levels ≥ 10.0 pCi/l area are within the High Zone

These results indicate that geology based radon potential zones can target areas within Monterey 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 Monterey County. Factors other than geology, such as soil permeability, building condition, design and usage also have important impacts on indoor radon levels. Therefore, anyone concerned about possible exposure to radon in his or her residence should test, regardless of location.—The U.S. EPA recommends testing of all residences regardless of location.

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	11,351 ¹	2,838	942	549	10.9%
	2.83% ²	26.57%	100.00%	100.00%	361 mi ²
		25.0% rate ³	8.3% rate	4.8% rate	
Moderate	65,834	3,950	0	0	20.2%
	16.39%	36.97%	0.00%	0.00%	671 mi ²
		6.0% rate	0.0% rate	0.0% rate	
Low	324,569	3,895	0	0	68.9%
	80.79%	36.46%	0.00%	0.00%	2,290 mi ²
		1.2% rate	0.0% rate	0.0% rate	
Population Estimates Weighted by Radon Zone					
Totals (weighted by zone)	401,754	10,683	942	549	100.00%
	100.00%	100.00%	100.00%	100.00%	3,322 mi ²
		2.66% rate	0.23% rate	0.14% rate	
Population Estimates by Radon Level Without Regard to Data Location or Zone					
All Monterey County (not weighted by zone)**	401,754	15,668	2,812	1,607	100.00%
		3.9% rate	0.7% rate	0.4% rate	3,322 mi ²

Table 11. Estimates of Monterey 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

**Based only on radon test results, not weighted for location

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 Monterey 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 and 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 Monterey 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 Monterey Formation unit areas and the Paso Robles Formation 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. Buffer zones were not used with middle Pleistocene fluvial terrace deposits to establish associated moderate potential zone areas because available indoor-radon data and soil data did not support their use in this case.

The final radon potential zones have the following characteristics:

High Radon Potential Zone: this zone comprises 10.9 percent (361 square miles) of Monterey County and contains 51.2 percent of ≥ 4.0 pCi/l short-term radon data in the CDPH database.

Moderate Radon Potential Zone: this zone comprises 20.2 percent (671 square miles) of Monterey County and contains 24.4 percent of ≥ 4.0 pCi/l short-term radon data in the CDPH database.

Low Radon Potential Zone: this zone comprises 68.9 percent (2290 square miles) of Monterey County and contains 24.4 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, 25.1 pCi/l; Moderate, 7.0 pCi/l; and Low, 8.7 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 2,838 individuals within High Radon Potential Zone areas and 3,950 individuals within Moderate Radon Potential Zone areas live in residences likely to measure ≥ 4.0 pCi/l in short-term tests. An additional 3,895 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 68.9 percent of the Monterey County area. An estimated 549 individuals live in dwellings with indoor-radon levels measuring ≥ 20 pCi/l on short-term tests in Monterey County. Available data suggest that ≥ 20 pCi/l dwellings may be confined to High Radon Potential Zone areas.

Recommendations for Future Studies

Indoor radon data are lacking or minimal for Big Sur, Bradley, portions of Carmel (Zip Codes 93921, 93922), Castroville, Chualar, Gonzales, Greenfield, Lockwood, Moss Landing, portions of Salinas (Zip Code 93902), San Miguel, Solidad, Spreckels and Watsonville (portion of Zip Code 95076 in Monterey County). Future radon testing efforts should consider targeting these communities. The rural southern half of Monterey County also lacks indoor-radon measurements and future activities to encourage testing residences there should be considered.

Priority geologic units for additional indoor-radon testing should be: Monterey Formation-siltstone, Monterey Formation-diatomite, Monterey Formation-clay shale, Monterey Formation-Devil Water member, Paso Robles Formation, Pancho Rico Formation, and Quartz Diorite-granodiorite of Johnson Canyon. Acquisition of additional indoor-radon data for associated houses and schools would allow better evaluation of the radon potential status of these geologic units.

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APPENDIX A

Charcoal Detector Exposure

Detector exposure	Number of detectors	Percent of detectors
1 day	32	2.4
2 days	1,078	81.5
3 days	190	14.4
4 days	22	1.7
<i>total</i>	1,322*	100

* 1059 sites were tested but multiple detectors were placed at some sites

APPENDIX B

Indoor-Measurement Field Duplicate Results

Differences between field duplicate indoor-measurements for the Monterey County radon survey, January to May 2006.

High (pCi/l)	Low (pCi/l)	Difference (pCi/l)	%* Difference	Comment
1.0	0.8	0.2	20	
1.6	1.3	0.3	18.8	
0.8	0.5	0.3	37.5	
0.6	0.4	0.2	33.3	
0.7	0.6	0.1	14.3	
1.0	0.2	0.8	80	
0.2	0.2	0.0	0	No difference. Both tests at or below detection limit
0.5	0.2	0.3	60	
6.3	5.4	0.9	14.3	Difference above 10%**
2.1	0.6	1.5	71.4	0.6 lab measurement @ 6 days, 2.1 lab measurement @ 4 days
1.2	0.2	1.0	83.3	
0.9	0.5	0.4	44.4	
0.4	0.3	0.1	25	
0.8	0.6	0.2	25	
0.2	0.2	0.0	0	No difference. Both tests at or below detection limit
0.4	0.2	0.2	50	
4.4	3.2	1.2	27.3	Difference above 10%; Measurements above and below 4.0 pCi/l
1.3	0.9	0.4	30.8	
1.1	0.8	0.3	27.3	
0.3	0.2	0.1	33.3	
1.4	0.9	0.5	35.7	
1.6	1.4	0.2	12.5	

1.0	0.8	0.2	20	1.0 lab measurement @ 7 days, 0.8 lab measurement @ 5 days
0.5	0.5	0.0	0	No Difference
0.2	0.2	0.0	0	Both tests at or below detection limit
0.4	0.3	0.1	25	
0.7	0.3	0.4	57.1	
1.4	0.4	1.0	71.4	
0.3	0.2	0.1	33.3	
0.4	0.4	0.0	0	No difference
1.2	0.5	0.7	58.3	
0.2	0.2	0.0	0	Both tests at or below detection limit
1.1	0.4	0.7	63.6	
1.3	1.1	0.2	15.4	
0.9	0.5	0.4	44.4	
1.6	1.0	0.6	37.5	
0.8	0.3	0.5	62.5	
0.5	0.2	0.3	60	
2.0	1.1	0.9	45	2.0 lab measurement @ 5 days, 1.1 lab measurement @ 8 days
4.6	0.7	3.9	84.8	Same exposure and lab measurement days
0.4	0.2	0.2	50	
6.8	6.0	0.8	11.8	Difference slightly above 10%**
0.6	0.5	0.1	16.7	
25.1	8.3	16.8	66.9	Difference above 10%**; Same exposure and lab measurement days
9.5	8.3	1.2	13.0	Difference slightly above 10%**
1.5	0.6	0.9	40	
1.3	0.5	0.8	61.5	
0.5	0.2	0.3	60	
0.6	0.4	0.2	33.3	
0.7	0.6	0.1	14.3	
0.4	0.2	0.2	50	
0.7	0.4	0.3	42.9	
3.4	3.0	0.4	11.8	3.4 lab measurement @ 4 days; 3.0 lab measurement @ 5 days
0.5	0.3	0.2	40	
0.4	0.2	0.2	50	0.4 lab measurement @ 3 days, 0.2 lab measurement @ 7 days
0.2	0.2	0.0	0	No difference. Both tests at or below detection limit
1.2	0.8	0.4	33.3	1.2 lab measurement @ 5 days, 0.8 lab measurement @ 4 days
0.5	0.2	0.3	60	
6.2	4.8	1.2	19.4	Difference above 10%**; 6.2 lab measurement @ 6 days, 4.8 lab measurement @ 5 days
1.5	0.6	0.9	60	
0.2	0.2	0.0	0	No difference. One lab measurement @

				5 days, one @ 4 days: Both tests at or below detection limit
7.5	6.3	1.2	16.0	Difference above 10%**
1.2	1.1	0.1	8.3	
1.4	1.3	0.1	7.1	
0.2	0.2	0.0	0	No difference. Both tests at or below detection limit
0.9	0.2	0.7	77.8	
0.9	0.2	0.7	77.8	
2.3	1.9	0.4	17.4	
3.3	2.1	1.2	36.4	3.3 lab measurement @ 7 days, 2.1 lab measurement @ 4 days
0.2	0.2	0.0	0	No difference. Both tests at or below detection limit
0.9	0.2	0.7	77.8	0.9 lab measurement @ 3 days, 0.2 lab measurement @ 13 days
2.6	1.9	0.7	26.9	
1.4	1.2	0.2	14.2	
1.1	0.9	0.2	18.2	
0.2	0.2	0	0	No difference. One lab measurement @ 8 days, one @ 4 days; Both tests at or below detection limit
1.2	0.2	1.0	83.3	
0.4	0.2	0.2	50	
0.6	0.5	0.1	16.7	
1.1	1.0	0.1	9.1	
5.3	5.1	0.2	3.8	Difference less than 10%**
0.2	0.2	0.0	0.0	No difference. Both tests at or below detection limit
0.9	0.5	0.4	44.4	
1.0	0.7	0.3	30	
0.6	0.2	0.4	66.7	
1.0	1.0	0	0	
1.2	0.8	0.4	33.3	
0.9	0.8	0.1	11.1	
0.6	0.2	0.4	66.7	
		54.5 N=87 0.63 pCi/l average difference	2,994.8 N=87 34.4% average difference	Overall Differences for Field Duplicates- All sample pairs <u>except</u> 25.1 and 8.3 pCi/l
		11.0 total N=51 0.22 pCi/l average difference	1,661.0 total N=51 32.6% average difference	Overall Differences when <u>both</u> measurements are LE 1 pCi/l; range in pair differences is 0 to 0.8; 78.4% of pairs have 0.3 pCi/l difference or less

		11.5 total N=20 0.58 pCi/l average difference	366 total N=20 18.3 % average difference	Overall Differences when <u>both</u> measurements are GT 1 pCi/l and LE 10 pCi/l; range of pair differences is 0.1 to 1.2 pCi/l with 50 % of pairs have 0.6 pCi/l difference or less

* % Difference = (high-low)/high X 100

** 6 pairs are above 4 pCi/l with an average difference = 7.2 % and a range of differences from % differences = 3.8 to 19.4%. The Western Regional Radon Training Center course manual indicates the expected precision for short-term radon tests above 4.0 pCi/l is 10%. One of the six pairs differed by less than 10%, the other five differed by between 11.8% and 27.3%.)

APPENDIX C

Comparison of Original and Follow-up Indoor Radon Measurements

Test 1	Test 2	Difference	Days Apart	Comments	Site
5.2	3.6	1.4	17	Change in Status from ≥ 4 pCi/l to ≤ 4 pCi/l	1
0.2	0.2	0	6	Maintained status ≤ 4 pCi/l (at or below detection limit)	2
1.3	0.5	0.8	25	Maintained status ≤ 4 pCi/l	3
22.1	19.2	2.9	49	Maintained status-high	4
6.2	4.6	1.6	33	Maintained status-high	5
6.2	6.2	0	33	Maintained status-high	5
1.3	1.1	0.2	6	Maintained status ≤ 4 pCi/l	6
6.6	6.7	0.1	11	Maintained status-high	7
28.4	0.8	27.6	29	Change in Status-high to low	8
28.4	0.3	28.1	29	Change in Status-high to low	8
0.8	0.2	0.6	4	Maintained status ≤ 4 pCi/l (Test 2 at or below detection limit)	9
0.3	0.2	0.1	4	Maintained status ≤ 4 pCi/l (Test 2 at or below detection limit)	9
0.3	1.0	0.7	35	Maintained status ≤ 4 pCi/l	10
11.6	7.6	4.0	39	Maintained status-high	11
15.2	6.0	9.2	15	Maintained status-high	12
15.2	6.8	8.4	15	Maintained status-high	12
16.5	9.5	7.0	18	Maintained status-high	13
16.5	25.1	8.6	18	Maintained status-high	13
16.5	8.3	8.2	18	Maintained status-high	13
3.6	1.1	2.5	29	Maintained status ≤ 4 pCi/l	14
1.0	0.9	0.1	2	Maintained status ≤ 4 pCi/l	15
44.9	0.4	44.5	39	Change in Status-high to ≤ 4 pCi/l	16
44.9	0.2	44.7	39	Change in Status-high to ≤ 4 pCi/l (Test 2 at or below detection limit)	16
44.9	0.2	44.7	39	Change in Status-high to ≤ 4 pCi/l (Test 2 at or below detection limit)	16
44.9	0.2	44.7	39	Change in Status-high to ≤ 4 pCi/l (Test 2 at or below detection limit)	16
0.2	0.5	0.3	3	Maintained status ≤ 4 pCi/l (Test 1 at or below detection limit)	17
2.6	2.3	0.3	4	Maintained status ≤ 4 pCi/l	18
0.9	0.2	0.7	4	Maintained status ≤ 4 pCi/l (Test 2 at or below detection limit)	19
1.5	1.4	0.1	5	Maintained status ≤ 4 pCi/l	20
5.1	5.7	0.6	34	Maintained status-high	21
5.0	3.3	2.7	36	Change in Status-high to ≤ 4 pCi/l	22
5.5	4.0	1.5	57	Maintained status-high	23
0.6	0.2	0.4	20	Maintained status ≤ 4 pCi/l (Test 2 at or below detection limit)	24

0.9	0.5	0.4	29	Maintained status \leq 4 pCi/l	25
Totals					
				Status Category	# Sites
		8		Change in Status-high to \leq 4 pCi/l	4
		0		Change in Status-low to high	0
		12		Maintained Status-high	8
		14		Maintained Status- \leq 4 pCi/l	13
		34			
				84 % of sites did not change their initial site status during retesting. For this study, follow-up tests were always < 4pCi/l if the initial test was < 4 pCi/l for these data.	

APPENDIX D

Geologic Map Units (Rosenberg, 2001) and Indoor Radon Data for Monterey County

Geologic Unit	Description	N	N GE 4 pCi/l	R %	Low pCi/l	High pCi/l
Kgdc	Granodiorite of Cachagua	4	0			1.0
Kgdm	Porphyritic granodiorite of Monterey	73	1	1.37	0.2	8.7
Kgds	Porphyritic granodiorite of Sand Creek	1	0		0.2	1.2
Kqds	Hornblende-biotite quartz diorite of Soberanes Point	3	0		0.2	2
Kqmg	Garnetiferous quartz monzonite of Pine Canyon	1	0			0.7
Qa	Aromas Sand, undifferentiated (Pleistocene)	40	0		0.2	2.6
Qal	Alluvial deposits, undifferentiated (Holocene)	31	2	6.45	0.2	7.5
Qb	Basin deposits (Holocene)	13	0		0.2	3
Qc	Colluvium (Holocene)	11	0		0.2	2.9
Qct	Coastal terraces, undifferentiated (Pleistocene)	201	0		0.2	2.4
Qd	Dune deposits (Holocene)	6	0		0.2	0.6
Qe	Eolian deposits, undifferentiated (Pleistocene)	206	0		0.2	2.4
Qfp	Flood-plain deposits, undifferentiated (Holocene)	161	6	3.73	0.2	7.5
Qfpl	Alluvial fans (late Pleistocene)	68	2	2.94	0.2	5.2
Qfpm	Alluvial fans (middle Pleistocene)	18	0		0.2	1.9
Qhf	Alluvial fan deposits, undifferentiated (Holocene)	8	0		0.2	1.8
Qls	Landslide deposits (Quaternary)	16	4	25.0	0.2	11.6
Qt	Fluvial terrace deposits, undifferentiated (Pleistocene and Holocene)	50	8	16.0	0.2	11.2
QTc	Continental deposits, undifferentiated (Pleistocene-Pliocene?)	19	1	5.26	0.2	5.6
Qtmp	Fluvial terrace deposits (middle Pleistocene)	50	4	8.00	0.2	7
Tm	Monterey Formation, siliceous mudstone (Miocene)	47	9	19.15	0.2	25.1
Tmdi	Monterey Formation, diatomite (Miocene)	5	3	60.0	0.2	22.1
Tml	Monterey Formation, siltstone (Miocene)	14	1	7.14	0.2	8.2

Tms	Unnamed marine sandstone (late and middle Miocene)	4	0		0.2	0.9
Tsm	Santa Margarita Sandstone (late Miocene)	1	0			1.6
Tts	Marine sandstone (middle Miocene)	8	0		0.2	1.2
Totals		1,059	41	3.87	0.2	25.1

APPENDIX E

Geologic Units (Rosenberg, 2001), Soil Units (NRCS) and Indoor-Radon Data

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N GE 4 pCi/l	R %	Low pCi/l	High pCi/l
Kgdc	Granodiorite of Cachagua	CcG	Cieneba	1	0			1.0
		SoE	Sheridan	2	0		0.2	0.3
		SoG	Sheridan	1	0			0.2
Kgdm	Porphyritic granodiorite of Monterey	GfF	Gazos	1	0			3.6
		NcC	Narlon	41	1	2.44	0.2	8.1
		NcE	Narlon	6	0		0.2	0.7
		ScG	San Andreas	3	0		0.2	0.3
		SfF	Santa Lucia	1	0			0.5
		SoD	Sheridan	16	0		0.2	1.2
		SoE	Sheridan	5	0		0.2	0.4
Kgds	Porphyritic granodiorite of Sand Creek	SoG	Sheridan	1	0		0.2	1.2
Kqds	Hornblende-biotite quartz diorite of Soberanes Point	JbG	Junipero	2	0		0.4	2
		LkG	Los Gatos	1	0			0.2
Kqmg	Garnetiferous quartz monzonite of Pine Canyon	AsB	Arroyo Seco	1	0			0.7
Qa	Aromas Sand, undifferentiated (Pleistocene)	AkD	Arnold	40	0		0.2	2.6
		AkF	Arnold	24	0		0.2	1.9
		Ar	Arnold	5	0		0.2	1.8
		EeD	Elkhorn	1	0			0.9
		EeE	Elkhorn	2	0		0.4	0.6
		PnE	Placentia	1	0			1.1
		ShC	San Andreas	1	0			0.2

Qal	Alluvial deposits, undifferentiated (Holocene)	Af	Aquic Zerofluvents	2	0		0.3	0.5
		AkD	Arnold	2	0		0.5	0.9
		AvA	Arroyo Seco	2	0		0.2	0.7
		EaA	Elkhorn	4	0		0.5	1.6
		GkB	Gorgonio	3	0		0.2	2.8
		MnA	Mocho	1	0			1.1
		NcC	Narlon	5	0		0.2	1.4
		PnA	Placentia	1	0			0.5
		PnC	Placentia	1	0			0.8
		RaA	Rincon	3	1	33.3	2.6	4.4
		SfF	Santa Lucia	2	1	50.0	1.6	7.5
		Sg	Santa Lucia	2	0		0.2	3.0
		ShE	Santa Ynez	2	0		0.2	0.3
		TaC	Tangoir	1	0			0.4
Qb	Basin deposits (Holocene)	Cg	Clear Lake	13	0		0.2	3
		CnA	Cropley	11	0		0.7	3
Qc	Colluvium (Holocene)	AkD	Arnold	5	0		0.2	2.9
		AkF	Arnold	3	0		0.2	0.4
		ShE	Santa Ynez	2	0		0.5	1.1
		W	--	1	0			1.0
Qct	Coastal terraces, undifferentiated (Pleistocene)	BbC	Baywood	32	0		0.2	2
		CaD	Chamise	14	0		0.2	1.5
		CaE	Chamise	4	0		0.2	0.9
		NcC	Narlon	115	0		0.2	2.4
		NcE	Narlon	7	0		0.2	1.4
		OaD	Oceano	3	0		0.5	1.3
		PdC	Pfeiffer	2	0		0.2	0.5
		ScG	San Andreas	1	0			0.8
		SfD	Santa Lucia	3	0		0.2	1.7
		SfE	Santa Lucia	2	0		0.3	0.3

		ShD	Santa Ynez	6	0		0.2	2.4
		SoD	Sheridan	4	0		0.2	1.2
		SoG	Sheridan	2	0		0.2	2.1
		Xc	Xerothents, loamy	3	0		0.2	0.4
Qd	Dune deposits (Holocene)	BbC	Baywood	1	0			0.2
		Df	Dune land	5	0		0.2	0.6
Qe	Eolian deposits, undifferentiated (Pleistocene)	AkF	Arnold	1	0			0.4
		Ar	Arnold	1	0			0.6
		BbC	Baywood	142	0		0.2	2.4
		CaD	Chamise	1	0			1.2
		EdC	Elkhorn	2	0		0.2	0.8
		EeD	Elkhorn	5	0		0.2	1.0
		EeE	Elkhorn	2	0		1.1	1.1
		NcC	Narlon	2	0		0.2	0.7
		OaD	Oceano	17	0		0.2	0.9
		ShC	Santa Ynez	1	0			0.4
		ShE	Santa Ynez	1	0			0.2
		SoD	Sheridan	3	0		0.2	0.2
		TaC	Tangoir	28	0		0.2	1.2
Qfp	Flood-plain deposits, undifferentiated (Holocene)	AvA	Arroyo Seco	1	0			1.0
		AvB	Arroyo Seco	1	0			2.9
		CbA	Chualar	1	0			0.9
		CnA	Cropley	13	1	7.7	0.5	5.0
		EaA	Elder	2	0		0.2	1.8
		EbC	Elder	6	0		0.2	1.5
		Fa	Fluvents, stony	3	0		0.4	0.8
		GkB	Gorgonio	32	1	3.1	0.2	5.2
		LeC	Lockwood	3	0		1.0	2.8
		MnA	Mocho	3	0		0.2	0.9
		MoA	Mocho	4	0		0.7	2.5

		Pa	Pacheco	5	0		0.2	1.2
		Pf	Pico	9	0		0.2	3.6
		Pr	Psamments and Fluents, occasionally flooded	1	0			0.8
		Ps	Psamments and Fluents, frequently flooded	1	0			0.3
		RaA	Rincon	3	1	33.3	0.2	7.5
		SbA	Salinas	68	3	4.4	0.2	5.5
		TbB	Tujunga	4	0		0.7	0.2
		Xc	Xerothents, loamy	1	0			0.4
Qfpl	Alluvial fans (late Pleistocene)	AsA	Arroyo Seco	2	0		1.2	1.3
		AsB	Arroyo Seco	1	0			1.2
		CbA	Chualar	50	1	2.0	0.2	5.2
		DaA	Danville	2	1	50.0	0.7	4.4
		EaA	Elder	2	0		0.4	0.9
		HbB	Hanford	3	0		0.2	2.6
		PnA	Placentia	4	0		0.2	1.3
		Xb	Xerothents, sandy	4	0		0.9	2.7
Qfpm	Alluvial fans (middle Pleistocene)	AeC	Antioch	1	0			0.9
		CbA	Chualar	6	0		0.4	1.4
		CbB	Chualar	3	0		0.2	1.9
		CbC	Chualar	2	0		0.6	0.6
		GhC	Gloria	1	0			1.4
		PnA	Placentia	3	0		0.8	1.7
		PnC	Placentia	2	0		0.4	0.8
Qhf	Alluvial fan deposits, undifferentiated (Holocene)	AsB	Arroyo Seco	1	0			0.2
		CbA	Chualar	1	0			0.5
		EaA	Elder	3	0		0.3	1.6
		HbB	Hanford	3	0		1.8	0.2

Qls	Landslide deposits (Quaternary)	EaA	Elder	1	0			0.3
		EbC	Elder	1	0			0.8
		Jc	Junipero	1	0			0.7
		NcE	Narlon	4	2	50.0	4.1	6.7
		PnD	Placentia	2	0		0.2	0.2
		ScG	San Andreas	1	0			1.4
		SfE	Santa Lucia	2	1	50.0	3.5	11.0
		Sg	Santa Lucia	4	1	25.0	0.2	11.6
Qt	Fluvial terrace deposits, undifferentiated (Pleistocene and Holocene)	AeC	Antioch	6	0		0.2	0.6
		AsB	Arroyo Seco	2	0		1.7	1.9
		AvB	Arroyo Seco	4	0		0.3	2.9
		CaD	Chamise	4	0		0.6	2.0
		CbB	Chualar	10	3	30.0	0.2	5.5
		CbC	Chualar	1	0			1.7
		CcG	Cieneba	1	0			1.0
		GkB	Gorgonio	3	1	33.3	1.7	5.7
		HaE	Haire	1	0			0.4
		Jc	Junipero	2	0		0.6	1.4
		LeC	Lockwood	4	2	50.0	0.7	11.1
		OaD	Oceano	2	0		0.2	1.5
		SfE	Santa Lucia	1	0			1.1
		SfF	Santa Lucia	3	1	33.3	0.6	5.5
		Sg	Santa Lucia	1	0			0.2
		ShD	Santa Ynez	1	0			2.7
		ShE	Santa Ynez	2	1	50.0	0.6	6.2
		Xd	Xerothents, dissected	2	0		0.7	2.3
QTc	Continental deposits, undifferentiated (Pleistocene-Pliocene?)	Am	Arnold	1	0			1.9
		LhE	Lopez	1	0			1.1

		ScG	San Andreas	1	0			0.2
		SfF	Santa Lucia	1	0			0.6
		ShC	Santa Ynez	1	0			1.4
		ShE	Santa Ynez	12	1	8.3	0.2	5.6
		Xd	Xerothents, dissected	2			0.4	3.8
Qtmp	Fluvial terrace deposits (middle Pleistocene)	AeA	Antioch	28	3	10.7	0.2	6.3
		AeC	Antioch	2	0		0.3	1.2
		Cg	Clear Lake	1	0			3.2
		CnA	Cropley	3	0		0.2	0.6
		CnC	Cropley	4	1	25.0	0.3	7.0
		DbE	Dibble	1	0			1.9
		EeD	Elkhorn	2	0		0.8	2.3
		PnA	Placentia	1	0			0.2
		ShC	Santa Ynez	2	0		0.2	0.7
		ShD	Santa Ynez	4	0		0.2	3.3
		ShE	Santa Ynez	2	0		1.0	1.1
Tm	Monterey Formation, siliceous mudstone (Miocene)	CaD	Chamise	1	1	100.0		4.6
		EbC	Elder	1	0			2.6
		Fa	Fluvents, stony	1	0			1.2
		GfE	Gazos	1	0			1.8
		NcC	Narlon	1	0			0.6
		SfE	Santa Lucia	14	2	14.3	0.2	8.1
		SfF	Santa Lucia	7	2	28.6	0.2	25.1
		Sg	Santa Lucia	17	4	23.5	0.2	22.8
		Xc	Xerothents, loamy	2	0		1.0	1.0
		Xd	Xerothents, dissected	2	0		0.3	3.4
Tmdi	Monterey Formation, diatomite (Miocene)	AkF	Arnold	1	0			0.6
		SfE	Santa Lucia	1	1	100.0		8.7

APPENDIX F

Summary of NURE Airborne Radiometric Survey Equivalent Uranium Results for the Santa Cruz 1X2 Degree Quadrangle (*this quadrangle includes most of Monterey County and portions of adjoining counties.*)

1:250K Geologic Map Unit*	Mean eU (ppm)*	St. Dev. eU (ppm)*	Events (N)*	Population Distribution Type*	Related 1:100K Geologic Map Units**
E	3.93	2.00	1,781	Log-normal	Berry Conglomerate, Church Creek Fm, Reliz Canyon Fm—The Rocks Sandstone, Lucia Shale, Junipero Sandstone
EP	3.42	1.55	1,564	Log-normal	Reliz Canyon Formation inc. Junipero sandstone, Church Creek Fm, Carmelo Formation; includes some (quartzofeldspathic rocks Cretaceous or earlier)
GR	3.68	1.80	8,347	Log-normal	Many of the granitic rock units on the 100K map, marble, mica schist, and some Monterey Fm and other Tertiary units
KJF	3.01	1.98	6,158	Log-normal	Marine sandstone-late Cretaceous, marble, some Monterey Fm and other Tertiary units
KJFV	2.89	1.97	145	Log-normal	Franciscan mafic volcanic rocks, mélangé, and undifferentiated Franciscan
KU	3.72	2.23	10,945	Log-normal	Marine sandstone-late Cretaceous, Italian Flat Formation, Gravelly Flat Formation, marble, Coastal terraces, Franciscan Complex, some granitic rocks
LS	3.93	2.03	302	Log-normal	Marble-Cretaceous or earlier, Coast Ridge belt-marble, Quartz monzonite (Fremont Peak), Quartz diorite-granodiorite (Johnson Canyon), Quartz monzonite (Bickmore

					Canyon)
M	2.92	1.45	6,114	Log-normal	Marble, gneiss-granofels-quartzite, diorite and hornblende-olivine gabbro, various granitic rock units, Marine sandstone-late Cretaceous
ML	4.19	2.26	2,056	Log-normal	Monterey Formation-siliceous mudstone, clay shale, semi-siliceous shale, Devil Water member, Temblor sandstone, Vaqueros sandstone, Marine sandstone-middle Miocene, Quartzofeldspathic rocks-Cretaceous or earlier, Berry conglomerate, Hornblend-biotite quartz diorite and some other granitic rock units
MM	5.44	2.50	4,782	Normal	Monterey Formation-siliceous mudstone, diatomite, clay shale, semi-siliceous shale, Devil Water member, Pancho Rico Formation-diatomaceous mudstone, sandstone lenses, diatomaceous siltstone, diatomite, Marine sandstone-middle Miocene, Vaqueros Formation, Santa Margarita sandstone, Temblor sandstone, Paso Robles Formation, Basaltic andesite flows, Porphyritic granodiorite and some other granitic rock units
MMC	3.02	1.64	566	Log-normal	Marine sandstone-middle Miocene, Monterey Formation-siliceous mudstone, Red beds-middle Miocene, Basaltic andesite flows, Porphyritic granodiorite and some other granitic

					rocks
MU	4.03	1.93	1,057	Log-normal	Monterey Formation-siliceous mudstone, diatomite, clay shale, semi-siliceous shale, Pancho Rico Formation-diatomaceous mudstone, sandstone lenses, diatomaceous siltstone, diatomite, Paso Robles Formation, Unnamed marine arkosic sandstone (late middle Miocene), Etchegoin Formation, Santa Margarita sandstone, Reef Ridge Shale
MV	5.01	3.55	1,170	Log-normal	Intrusive dacite felsite, Pinnacles Formation
MVB	1.74	0.37	10	Unknown	Basaltic andesite, Marine sandstone-middle Miocene
MVP	4.94	2.51	31	Unknown	Pinnacles Formation-dacitic breccia and tuff breccia
MVR	3.67	1.25	101	Log-normal	Intrusive Felsitic dacite, Dacite vent breccia, Pinnacles Formation
O	3.93	1.55	446	Log-normal	Church Creek Formation, Vaqueros Formation, Intrusive dioritic felsite, Reliz Canyon Formation—The Rocks Sandstone
OC	4.69	2.57	203	Log-normal	Berry conglomerate, Vaqueros Formation, Reliz Canyon Formation—The Rocks Sandstone, Red beds (middle Miocene)
PML	3.59	2.01	10,229	Log-normal	Paso Robles Formation-undifferentiated, Pancho Rico Formation-diatomaceous mudstone and sandstone lenses, Etchegoin Formation, Monterey Formation-siliceous mudstone, Franciscan Complex-undifferentiated, Quartz

					diorite-granodiorite (Johnson Canyon) Reef Ridge shale
PU	3.07	1.71	987	Log-normal	Merced Fm., San Joaquin Fm.
QAL	3.76	1.55	8,742	Log-normal	various alluvial deposits
QC	3.80	2.36	4,105	Log-normal	Colluvium, Aromas sand, Continental deposits-equivalent to Paso Robles Formation?, Fluvial terrace deposits, some granitic rock units
QM	3.43	1.18	499	Log-normal	Coastal terraces, marine clastic sediment (late Cretaceous)
QP	3.48	2.17	6,364	Log-normal	Paso Robles Formation, Pancho Rico Fm, Santa Margarita sandstone
QS	3.34	1.46	134	Normal	Eolian deposits, Coastal terraces, Dune deposits, Flood plain deposits, Beach sand
QT	3.60	1.60	5,551	Log-normal	Alluvial Fans (Pleistocene), Coastal Terraces (Pleistocene), Paso Robles Formation, Flood Plain deposits, Eolian deposits, Fluvial terrace deposits (Pleistocene), Aromas Sand, Colluvium, Basin deposits
TI	8.53	4.41	119	Log-normal	Intrusive dacite felsite, Quartz diorite-granodiorite of Johnson Canyon
UB	2.54	1.29	1,194	Log-normal	Serpentinite (Jurassic), Franciscan Complex-undifferentiated, mélange, greywacke sandstone, mafic volcanics, some Monterey Formation and other Tertiary units

*Data from High Life Helicopters, Inc., 1981b.

**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 Santa Cruz 1X2 Degree Quadrangle (Anomaly information from High Life Helicopters, Inc., 1981; only anomalies within Monterey County are listed)

Anomaly # and 7.5 minute Quad Name	1:250K Map Geologic Unit	1:100K Map Geologic Unit	Geologic Units-Comments
# 5 San Juan Bautista	LS, GR	pKms, pKm	Anomaly over contact between marble and mica schist in the Gabilan Range
# 7 Mount Johnson	GR	Kqdj	Anomaly over quartz diorite-granodiorite of Johnson Canyon in Gabilan Range
# 14 Topo Valley	MVP	QTp, Tucs, Tpo	Anomaly over Paso Robles Formation (<i>Pleistocene-Pliocene nonmarine sediments</i>), Unnamed marine sandstone (Pliocene?), Pancho Rico Formation (<i>late Miocene to early Pliocene diatomaceous mudstone and siliceous sediments</i>)
# 23 Pinalto Canyon	QT	Kqdj, QTp, Qal, Tpo	Anomaly over quartz diorite-granodiorite of Johnson Canyon in Gabilan Range, Paso Robles Formation (<i>Pleistocene-Pliocene nonmarine sediments</i>), unconsolidated alluvial deposits, Pancho Rico Formation (<i>late Miocene to early Pliocene diatomaceous mudstone and siliceous sediments</i>)
# 24 Paraiso Springs	QT	QTp, Qfpl, Qls, Qhf	Anomaly over Paso Robles Formation, late Pleistocene alluvial fans, landslide deposits, and Holocene alluvial fans (<i>Note: alluvial fan and landslide deposits here likely contain Monterey Formation debris--RKC</i>)
# 25 Pinalto Canyon	GR	Kqdj, Tpo, QTp	Anomaly over quartz diorite-granodiorite of Johnson Canyon in Gabilan Range, Pancho Rico Formation (<i>late Miocene to early Pliocene diatomaceous mudstone and siliceous sediments</i>), Paso Robles Formation (<i>Pleistocene-Pliocene nonmarine sediments</i>)
# 26 Pinalto Canyon	GR	Kqdj, Tpo, Qt,	Anomaly over quartz diorite-granodiorite of Johnson Canyon in Gabilan Range, Pancho Rico Formation (<i>late Miocene to early Pliocene diatomaceous mudstone and siliceous sediments</i>), Fluvial terrace deposits

# 27 Pinalto Canyon	GR	Kgdg, Tpo	Anomaly over Granodiorite of Gloria Road, Pancho Rico Formation (<i>late Miocene to early Pliocene diatomaceous mudstone and siliceous sediments</i>)
# 28 San Lucas	PML	Tpo, QTp	Anomaly over Pancho Rico Formation (<i>late Miocene to early Pliocene diatomaceous mudstone and siliceous sediments</i>), Paso Robles Formation (<i>Pleistocene-Pliocene nonmarine sediments</i>)
# 31 Thompson Canyon	MM	Tm, Tps, QTp, Qfp,	Anomaly over Monterey Formation (<i>Miocene marine siliceous mudstone</i>), Pancho Rico Formation—marine sandstone lenses, Paso Robles Formation (<i>Pleistocene-Pliocene nonmarine sediments</i>), Flood-plain deposits (<i>Holocene</i>) in the Santa Lucia Range
# 35 Cosio Knob	MM	Tm	Anomaly over Monterey Formation (<i>Miocene marine siliceous mudstone</i>) in the Santa Lucia Range
# 36 Bear Canyon	M	pKqf, Kqmp	Anomaly over Quartzofeldspathic rocks (<i>gneiss, granofels, quartzite, minor schist</i>), Quartz monzonite of Pinyon Peak
# 37 Cosio Knob	QP, MU	Tm, Tps, QTp	Anomaly over Monterey Formation (<i>Miocene marine siliceous mudstone</i>), Pancho Rico Formation—marine sandstone lenses, Paso Robles Formation (<i>Pleistocene-Pliocene nonmarine sediments</i>)
# 38 Cosio Knob	MM	Tm, Tps, QTp	Anomaly over Monterey Formation (<i>Miocene marine siliceous mudstone</i>), Pancho Rico Formation—marine sandstone lenses, Paso Robles Formation (<i>Pleistocene-Pliocene nonmarine sediments</i>) in the Santa Lucia Range
# 41 San Ardo	QAL, PML	Tpo, Tucs, QTp, Qt, Qfp,	Anomaly over Pancho Rico Formation (<i>late Miocene to early Pliocene diatomaceous mudstone and siliceous sediments</i>), Unnamed marine sandstone (Pliocene?), Paso Robles Formation (<i>Pleistocene-Pliocene nonmarine sediments</i>), Fluvial terrace deposits, Flood-plain deposits (<i>Holocene</i>)
# 42 San Ardo	PML	Tpo, Qfp	Anomaly over Pancho Rico Formation (<i>late Miocene to early Pliocene diatomaceous mudstone and siliceous sediments</i>), Flood-plain deposits (<i>Holocene</i>)

APPENDIX H

**Monterey County NURE Airborne Radiometric Equivalent Uranium Data
Equal or Greater than 7.5 ppm within the San Luis Obispo 1X2 degree quad
NURE Airborne Radiometric Survey, by 1:100,000-Scale Geologic Map Unit**

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
KJfm	Franciscan Complex, melange	3	3.8	Cape San Martin
KTs	Marine clastic sedimentary rocks (sandstone, minor shale, conglomerate)	2	2.5	Alder Peak
pKqf	Quartzofeldspathic rocks (gneiss, granofels, quartzite, and minor schist)	1	1.3	Alder Peak
Qal	Alluvial deposits (Holocene)	2	2.5	Valleton
Qfp	Flood-plain deposits (Holocene)	1	1.3	Wunpost
Qls (KJfm)	Landslide deposits (<i>KJfm debris?-RKC</i>)	3	3.8	Cape San Martin
Qt	Fluvial terrace deposits (Pleistocene and Holocene)	1	1.3	Alder Peak
QTp	Paso Robles Formation, terrestrial sediments	5	6.3	Bryson, Tierra Redonda Mountain
Tm	Monterey Formation, marine siliceous mudstone	50	63.6	Bryson, Hames Valley, Jolon, Stockdale Mountain, Tierra Redonda Mountain, Valleton, Williams Hill
Tml	Monterey Formation, semi- siliceous marine mudstone	6	7.6	Bryson
Tpd	Pancho Rico Formation, diatomite	1	1.3	Bryson
Tpo	Pancho Rico Formation, diatomaceous mudstone, siltstone-sandy siliceous sediments	2	2.5	Valleton
Tucs	Unnamed marine sandstone (Pliocene?)	1	1.3	Valleton
Tvq	Vaqueros Formation, marine arkosic sandstone	1	1.3	Jolon
total		79	100.1	

APPENDIX I

NURE Sediment(SS), Soil(SL) and Talus Uranium Data by Geologic unit—Monterey County

GEN Unit/NURE Data Type	Unit Description	N	NURE U Data (ppm)	Mean	Median	Low	High
Jsp-SS	Serpentinite (Jurassic)	1	0.8				0.8
Kct-SS	Charnockitic tonalite of Compton (1960) and related(?) rocks (Cretaceous)	3	1.1 5.8 8.9	5.3	5.8	1.1	8.9
Kep-SS	El Piojo Formation (Late Cretaceous)— Marine; thick-bedded sandstone, mudstone, and conglomerate	2	1.1 3.12	2.1	2.1	1.1	3.12
Kgdg-SS	Granodiorite of Gloria Road (Ross, 1972) (Cretaceous)	1	8				8
Kgdg-SL	“	1	4.2				4.2
Kgdm-SS	Porphyritic granodiorite of Monterey (Ross, 1976) (Cretaceous)	2	5.8 2.2	4.0	4.0	2.2	5.8
Kgdm-SL	“	1	3.3				
Kgdn-SS	Quartz monzonite of Fremont Peak (Ross, 1972) (Cretaceous)	2	13.5 7.6	10.6	10.6	7.6	13.5
Kgds-SS	Porphyritic granodiorite of Sand Creek (Cretaceous)	2	5.1 4.2	4.7	4.7	4.2	5.1
Kgf-SS	Gravelly Flat Formation (Early Cretaceous)— Marine shale, sandstone at base, structurally overlies Franciscan assemblage	1	1.30				1.30
Kgh-SS	Heterogeneous granitic complex of Eiebe (1966) (Cretaceous)	1	2				2
Kgh-SL	“	2	5.4 1.8	3.6	3.6	1.8	5.4

KJf-SS	Franciscan Complex, undifferentiated (Cretaceous and Jurassic)	5	1.9 1.1 1 4.61 1.73		2.1	1.7	1	4.61
KJfm-SS	Franciscan Complex, melange (Cretaceous and Jurassic)	9	2.9 2.8 2.2 2.2 1.92	1.55 1.04 1.02 0.42	1.73	1.92	0.42	2.9
KJfm-SL	"	4	1.66 1.12 0.98 0.95		1.2	1.1	0.95	1.66
KJfv-SS	Franciscan Complex, mafic volcanic rocks (Cretaceous and Jurassic)	1	1.85					1.85
KJfv-Talus	"	1	2.9					2.9
Kms-SS	Schist of the Sierra de Salinas (Cretaceous)	1	2.7					2.7
Kms-SL	"	1	3.5					3.5
Kqdg-SS	Gneissic quartz diorite of Stonewall Canyon (Ross, 1972) (Cretaceous)	1	2.9					2.9
Kqdj-SS	Quartz diorite-granodiorite of Johnson Canyon (Ross, 1972) (Cretaceous)	7	6.2 5.8 4.9 2.8	2.8 2.6 2.2	3.9	2.8	2.2	6.2
Kqdj-Talus	"	1	10.9					10.9
Kqdp-SS	Hornblende-biotite quartz diorite of the Paraiso-Paloma area (Ross, 1976) (Cretaceous)	1	4.6					4.6
Kqds-SS	Hornblende-biotite quartz diorite of Soberanes Point (Ross, 1976) (Cretaceous)	14	18.2 10.2 9.4 6.3 6.2 6.2 5.4	4.2 3 2.9 2.7 2.6 1.8 1.2	5.7	4.8	1.2	18.2

Kqds-SL	"	2	3 2.7		2.9	2.9	2.7	3
Kqds-Talus		1	3					3
Kqdv-SS	Quartz diorite of Vergeles (Ross, 1972) (Cretaceous)	1	2.2					2.2
Kqmf-SS	Quartz monzonite of Bickmore Canyon (Ross, 1972) (Cretaceous)	3	51.2 39.8 23		38	39.8	23	51.2
Kqmp-SS	Granodiorite of Natividad Ross, 1972) (Cretaceous)	2	11.8 4.7		8.3	8.3	4.7	11.8
Kqmv-SS	Variable quartz monzonite-granodiorite of Big Pines and Island Mountain (Wiebe, 1966)_ and similar(?) mass of Willow Creek (Cretaceous)	1	4.8					4.8
Ks-SS	Marine clastic sedimentary rocks, western facies (Late Cretaceous)—Mostly sandstone	1	4.8					4.8
KTg-SS	Marine clastic sedimentary rocks (Paleocene and Late Cretaceous)—Light brown, conglomerate, minor sandstone	1	4.03					4.03
KTs-SS	Marine clastic sedimentary rocks (Paleocene and Late Cretaceous)—Light brown, hard sandstone, minor shale, and conglomerate	2	4.1 3.3		3.7	3.7	3.3	4.1
Ku-SS	Marine clastic sedimentary rocks, eastern facies (Late Cretaceous)—Mostly sandstone	4	6.2 4.3 3.8 3		4.3	4.1	3	6.2
Ku-SL	"	3	4.4 4.1 3.5		4.0	4.1	3.5	4.4
Ku-Talus	"	1	4					4
pKc-SS	Coast Ridge belt (Cretaceous or earlier)— Mostly marble	8	6.9 6.9 5 4.3	3.6 3.2 2.1 2.1	4.3	4.0	2.1	6.9

pKc-SL	"	5	10.7 6.6 3.7 3.3 0.61		5.0	3.7	0.61	10.7
pKg-SS	Graphitic and pyritic belt (Cretaceous or earlier)—Los Padres unit of Wiebe (1970)	1	10.2					10.2
pKm-SL	Marble (Cretaceous or earlier)—Mainly metamorphosed limestone, some dolomite in the Gabilan Range, Includes slide blocks near Parkfield	1	33.9					33.9
pKm-Talus	"	1	1.8					1.8
pKqf-SS	Quartzofeldspathic rocks (Cretaceous or earlier)—Gneiss, granofels, quartzite, and minor schist	15	11.3 9.2 8.9 8.3 8.3 7.2 6.1 6.1	6 5.2 3.9 3.8 3.8 2.3 0.55	6.1	6.1	0.55	11.3
pKqf-SL	"	4	12.3 6.3 5.6 4		7.1	6.0	4	12.3
pKqf-Talus	"	3	8.2 5.1 3.6		5.6	5.1	3.6	8.2
Qa-SS	Aromas Sand, undifferentiated (Pleistocene)—Heterogeneous sequence of mainly eolian and fluvial sand, silt, clay, and gravel	2	9.9 2.1		6.0	6.0	2.1	9.9
Qa-SL	"	2	2.8 2.6		2.7	2.7	2.6	2.8

Qal-SS	Alluvial deposits, undifferentiated (Holocene)—Unconsolidated, heterogeneous, moderately sorted silt and sand with discontinuous lenses of clay and silty clay	80	21.9 19 18.4 12.2 10.9 9.4 8.4 8 7.9 7 6.5 6.5 6.44 6.3 5.7 5.7 5.5 5 4.77 4.7 4.7 4.5 4.5 4.5 4.42 4.4 4.4	4.32 4.3 4 3.93 3.9 3.9 3.81 3.7 3.7 3.66 3.6 3.6 3.6 3.6 3.5 3.4 3.3 3.3 3.3 3.3 3.2 3.2 3.2 3.2 3.1 3.1	3 3 2.99 2.8 2.8 2.75 2.7 2.7 2.7 2.67 2.5 2.44 2.44 2.4 2.4 2.23 2.05 1.99 1.93 1.9 1.9 1.8 1.70 1.58 1.4 1.27	4.6	3.6	1.27	21.9
Qal-SL	“	4	6.7 4.3 2.57 1.8			3.8	3.4	1.8	6.7
Qal-Talus	“	2	4.5 2.6			3.6	3.6	2.6	4.5

Qal-Tm*	"	15	9.4 7.9 6.5 6.44 6.3 5.7 5.7 4.77	4.7 4.5 3.81 3.5 2.44 1.93 1.27	5.0	4.8	1.27	9.4
Qb-SS	Basin deposits (Holocene)—Unconsolidated, plastic clay and silty clay containing much organic material; locally contains interbedded thin layers of silt and silty sand	3	6.7 3.8 2.45		4.2	3.8	2.45	6.7
Qb-SL	"	6	3.7 3.6 3.6	3.5 3.4 3	3.5	3.6	3	3.7
Qc-SS	Colluvium (Holocene)—Unconsolidated, heterogeneous deposits of moderately to poorly sorted silt, sand, and gravel deposited by slope wash and mass movement	5	20.7 3.18 2.8 2.44 2.38		6.3	2.8	2.38	20.7
Qc-SL	"	2	3.4 2.7		3.1	3.1	2.7	3.4

Qct-SS	Coastal terraces, undifferentiated (Pleistocene)—Simiconsolidated, moderately well-sorted marine sand containing thin, discontinuous gravel-rich layers. Locally includes some terrace surfaces and debris flow deposits resting on terrace surfaces	2	5.3 2		3.7	3.7	2	5.3
Qct-SL	"	2	3.9 2.1		3.0	3.0	2.1	3.9
Qe-SS	Eolian deposits, undifferentiated (Pleistocene)—weakly to moderately consolidated, moderately to well-sorted silt and fine-to medium-grained sand deposited in extensive coastal dune field	1	5.4					5.4
Qe-SL	"	12	6.8 4.5 3.9 3.8 3.7 3.7	3.2 3 3 2.9 2.8 1.9	3.6	3.5	1.9	6.8
Qfp-SS	Flood-plain deposits, undifferentiated (Holocene)—Unconsolidated, relatively fine-grained, heterogeneous deposits of sand and silt; commonly includes relatively thin, discontinuous layers of clay	29	6.3 5.7 4.5 3.9 3.9 3.4 3.2 3.1 3 2.9 2.9 2.9 2.8 2.8 2.76	2.7 2.45 2.43 2.40 2.3 2.3 2.3 2.23 2.2 2.1 2 1.91 1.85 1.8	2.9	2.8	1.8	6.3

Qfp-SL	"	28	7.2 5.6 5.5 5.06 4.5 4.2 4.1 4 4 4 3.9 3.8 3.8 3.7	3.5 3.4 3.3 3.3 3.2 3.2 3.1 3.1 3.1 2.9 2.9 2.8 2.4 2	3.8	3.6	2	7.2
Qfpl-SS	Alluvial fans (late Pleistocene)—Weakly consolidated, moderately to poorly sorted sand, silt, and gravel	10	8.6 5.8 5.6 3.6 3.57	3.54 3.3 3.28 2.8 2.1	4.2	3.6	2.1	8.6
Qfpl-SL	"	17	8.2 6.3 6.2 5.2 5.2 5 4.6 4.6 4.5	3.8 3.7 3.5 3.4 3.2 3.2 2.8 2.7	4.5	4.5	2.7	8.2
Qfpm-SS	Alluvial fans (middle Pleistocene)—Moderately consolidated, deeply weathered, moderately to poorly sorted sand, silt, and gravel, capped with moderately well drained, maximally developed soils	9	8.2 6.7 6.1 5.4 4.8	4.5 3.9 3.8 2.1	5.1	4.8	2.1	8.2
Qfpm-SL	"	1	3.9					3.9
Qfpm-Talus	"	1	2.8					2.8

Qfu-SS	Alluvial fans, undifferentiated (Pleistocene)—Weakly to moderately consolidated, moderately to poorly sorted sand, silt, and gravel deposits, but includes some fan surfaces near Lockwood. Locally divided into: Qfpl and Qfpm	6	4.48 2.39 2.38 2.09 1.67 1.36		2.4	2.2	1.36	4.48
Qfu-SL	“	1	7.17					7.17
Qhf-SS	Alluvial fan deposits, undifferentiated (Holocene)—Unconsolidated, moderately to poorly sorted sand, silt, and gravel, with layers of silty clay	13	20.1 9.8 5.6 4.1 4.1 3.8 3.7	3.1 3 2.9 2.9 2.7 2.6	5.3	3.7	2.6	20.1
Qhf-SL	“	11	17.8 13.5 10.7 10 6.3 5.8	5.6 4.8 4.1 3.3 2.8	7.7	5.8	2.8	17.8
Qls-SS	Landslide deposits (Quaternary)—Heterogeneous mixture of deposits ranging from large block slides of indurated bedrock to debris flows in semiconsolidated sand and clay	15	8 4.6 4 3.6 3.6 3.1 3 2.9	2.9 2.7 2 1.94 1.6 1.46 1.3	3.1	2.9	1.3	8
Qls-Talus	“	5	13.2 1.4 1.2	0.7 0.3	3.4	1.2	0.3	13.2
Qls-Tm-SL	“	1	3.9					3.9

Qsc-SS	Stream channel deposits, undifferentiated (Holocene)—Modern stream channels and channel deposits of the Salinas River and principal tributaries. Loose, moderately-to well-sorted gravel, coarse-to fine-grained sand and silt	1	4.2				4.2
Qsc-SL	"	1	3.2				3.2
Qscp-SS	Sandstone and conglomerate of Sims, 1990 (Pleistocene?)—Sand and gravel, olive gray, poorly sorted, poorly consolidated; contains clasts derived from Franciscan Complex	1	2.7				2.7
Qt-SS	Fluvial terrace deposits, undifferentiated (Pleistocene and Holocene)—Weakly consolidated to semiconsolidated, moderately to poorly sorted silt, silty clay, sand, and gravel deposited in a fluvial environment. Age is Pleistocene, except in near Parkfield, where map unit includes Holocene deposits. Locally divided into: Qtlp—Fluvial terrace deposits (late Pleistocene); and Qtmp—Fluvial terrace deposits (middle Pleistocene)	22	8.1 6.9 6.2 5.6 5.6 4.2 3.8 3.2 3.2 3 3	2.7 2.7 2.6 2.6 2.60 2.34 2.22 2.1 1.98 1.75 0.73	3.5	2.9	0.73 8.1
Qt-SL	"	3	3.7 2.4 2.12		2.7	2.4	2.12 3.7
QTc-SS	Continental deposits, undifferentiated (Pleistocene-Pliocene?)—Semiconsolidated, relatively fine-grained, oxidized sand and silt. Probably equivalent to Paso Robles Formation	1	6.3				6.3
QTc-SL	"	1	3.9				3.9
QTc-Talus	"	1	2.1				2.1
QTcl-SS	Paso Robles Formation, clay (Pleistocene-Pliocene?)—mainly clay	2	2.12 1.75		1.9	1.9	1.75 2.12
QTg-SS	Paso Robles Formation. Cobble gravel (Pleistocene-Pliocene?)—Cobble gravel	1	2.1				2.1

Qtmp-SL	Fluvial terrace deposits (Middle Pleistocene)—Semi-consolidated, moderately well to poorly sorted sand, silt, and clay with interbedded gravel	4	4.2 2.8 2.6 2.5		3.0	2.7	2.5	4.2
QTp-SS	Paso Robles Formation, undifferentiated (Pleistocene-Pliocene?)—Terrestrial sediments of Salinas Valley, weakly indurated pebble gravel with minor sand and clay. Locally divided into: QTcl (clay), QTm(marl), QTpc(clay and minor gravel) and QTg(cobble gravel)	27	4.32 4.19 3.3 3.3 3.02 3.00 2.84 2.81 2.66 2.42 2.25 2.24 2.18 2.18	2.06 2.04 2.02 1.95 1.95 1.95 1.86 1.82 1.8 1.73 1.58 1.51 1.46	2.4	2.2	1.46	4.32
QTp-SL	"	2	2.6 2.28		2.4	2.4	2.28	2.6
Tbe-SS	Berry Conglomerate (Oligocene)—Terrestrial red beds, sandstone, and conglomerate	1	2.3					2.3
Tcc-SS	Church Creek Formation (Eocene)—Marine; dark gray, micaceous siltstone-mudstone	3	3.7 3.1 3		3.3	3.1	3	3.7
Te-SS	Etchegoin Formation (late Miocene to Pliocene)—Marine sandstone and claystone, fossiliferous. Overlies Reef Ridge Shale or unconformable on older formations	6	2.3 2.1 2.1 1.9 1.8 1.38		1.9	2.0	1.38	2.3
Tj-SS	Junipero Sandstone (Early Eocene and Late Paleocene?)—Shallow marine; tan, arkosic; medium-grained sandstone, transgressive	2	11 7.8		9.4	9.4	7.8	11

Tm-SS	"	31	12.2 10 8.65 8.07 7.93 7.7 7.33 7.23 7 6.8 6.8 6.7 6.65 6.6 6.4 6.3	6.2 6.2 6.10 5.5 5.12 5.1 4.8 4.64 4.5 4.3 3.9 3.70 3 2.87 1.8	6.1	6.3	1.8	12.2
Tm-SL	"	7	9 7.2 4.6 4.3	3.8 3.4 0.98	5.2	4.6	0.98	9
Tm-Talus	"	3	15.4 8.2 5.26		9.6	8.2	5.26	15.4
Tml-SS	Monterey Formation, semi-siliceous mudstone (middle Miocene)—Semi-siliceous mudstone and siltstone (Sandholdt Shale Member of Durham 1968; 1974)	2	5.7 5.17		5.4	5.4	5.17	5.7
Tms-SS	Unnamed marine sandstone (late and middle Miocene)—Marine, buff to light gray, poorly to well-sorted arkosic sandstone	1	4.46					4.46
Tms-Talus	"	1	1.69					1.69
Tnt-SS	Unnamed nonmarine red beds of upper Tularcitos Canyon (age uncertain)—Terrestrial sandstone and siltstone, weakly indurated	2	6.1 2.4		4.3	4.2	2.4	6.1

Tpa-Talus	Piedras Altas Formation (Eocene or Paleocene)—Non-marine sandstone, red beds, and conglomerate	1	4.1				4.1
Tpi-SS	Pancho Rico Formation, siltstone (late Miocene to early Pliocene)—Diatomaceous siltstone to silty sandstone	1	3.5				3.5
Tpo-SS	Pancho Rico Formation, mudstone (late Miocene to early Pliocene)—Diatomaceous mudstone, siltstone to sandy siliceous sediments	13	6 4 3.3 3.3 3.1 2.8 2.8	2.7 2.7 2.6 2.3 2.2 2.11	3.1	2.8	1.65 6
Tpo-SL	"	2	3 2.39		2.7	2.7	2.39 3
Tps-SS	Pancho Rico Formation, sandstone lenses (late Miocene to early Pliocene)—Sandstone lenses	2	5.2 2.1		3.7	3.7	2.1 5.2
Tsm-SS	Santa Margarita Sandstone (late Miocene)—Marine and brackish-marine; white, friable; fine- to coarse-grained arkosic sandstone	1	2.5				2.5
Tss-SS	Unnamed marine sandstone (Paleocene)—Dark gray thin-bedded to very thick bedded sandstone and conglomerate	2	8.7 6.7		7.7	7.7	6.7 8.7
Tss-Talus	"	1	12.1				12.1
Tt-SS	Temblor Sandstone (middle Miocene)—Marine sandstone	2	1.65 0.85		1.25	1.25	0.85 1.65
Trb-SL	Red beds (middle Miocene)—Terrestrial; red to gray, poorly sorted arkosic sandstone, cobble conglomerate, and siltstone. Age of unit is probably middle Miocene	1	4.2				4.2
Ttr-SS	The Rocks Sandstone (Middle and Early Eocene)—Deep marine; tan bedded arkosic sandstone	1	5.6				5.6
Ttr-Talus	"	1	3.5				3.5

Tts-SS	Marine sandstone (middle Miocene)— Marine; buff to light gray, poorly to well- sorted arkosic sandstone, locally friable, locally conglomeratic	3	9.8 5.4 3.4		6.2	5.4	3.4	9.8
Tts-SL	"	1	3.6					3.6
Tucc-SS	Unnamed clastic sedimentary unit (probably Pliocene)—Terrestrial pebble-cobble conglomerate/gravel	1	2.52					
Tucg-SS	Unnamed clastic sedimentary unit (probably Pliocene)—Terrestrial cobble gravel	2	2.32 2.07		2.2	2.2	2.07	2.32
Tucs-SS	Unnamed clastic sedimentary unit (probably Pliocene)—Marine sandstone, locally fossiliferous	7	3.7 3.3 3.2 2.9	2.4 2.4 2.29	2.9	2.9	2.29	3.7
Tvq-SS	Vaqueros Formation (of Hamlin, 1904; Durham, 1974) (Oligocene)—Light brown marine arkosic sandstone	7	8.8 5.8 5.6 3.8	3.7 3.7 2.8	4.9	3.8	2.8	8.8
Tvq-Talus	"	1	1.81					1.81

APPENDIX J

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

Soil Unit	Soil Unit Symbol(s)	N	N \geq 4 pCi/l	R (%)*	Permeability*** by Soil Depth Interval	Shrink-Swell Character
Antioch	AeA	28	3	10.7	0-21" Moderate 21-40" Very slow 40-67" Slow 67-72" Moderately slow	0-21" Low 21-40" High 40-67" High 67-72" Low
Chamise	CaD	20	1	5.0	0-19" Moderate 19-40" Moderately slow 40-60" Moderately slow	0-19" Low 19-40" Moderate 40-60" Moderate
Chualar	CbA, CbB	71	4	5.6	0-21" Moderate 21-44" Moderately slow 44-59" Moderately slow 59-80" Moderately rapid	0-21" Low 21-44" Moderate 44-59" Low 59-80" Low
Cropley	CnA, CnC	31	2	6.5	0-69" Slow	0-69" High
Danville	DaA	2	1	**	0-18" Moderately slow 18-38" Slow 38-67" Moderately slow	0-18" Moderate 18-38" High 38-67" Moderate
Gorgonio	GkB	38	2	5.3	0-22" Rapid 22-63" Rapid	0-22" Low 22-63" Low
Lockwood	LeC	7	2	**	0-40" Moderate 40-82" Moderately slow	0-40" Moderate 40-82" High
Narlon	NcC, NcE	191	3	1.6	0-13" Moderately rapid 13-53" Very slow	0-13" Low 13-53" High
Rincon	RaA	6	2	**	0-14" Moderately slow 14-49" Slow 49-60" Moderately slow	0-14" Moderate 14-49" High 49-60" Moderate

Santa Lucia	SfE, SfF, Sg	99	16	16.2	0-24" Moderate	0-24" Low
Santa Ynez	ShE	23	2	8.7	0-18" Moderate 18-43" Very slow 43-61" Slow	0-18" Low 18-43" High 43-61" Moderate
Salinas	SbA	68	3	4.4	0-5" Moderate 5-75" Moderately Slow	Low Low
Totals		584	41			

* 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

APPENDIX K

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

	All Indoor Radon Data	High Zone Radon Data	Moderate Zone Radon Data	Low Zone Radon Data
Size	1,059	84	166	809
Mean	1.126	3.473	1.292	0.848
Std Dev	1.873	5.163	1.418	0.887
Std Error	0.0575	0.563	0.110	0.0312
C.I. of Mean	0.113	1.120	0.217	0.0612
Range	24.9	24.9	6.8	8.5
Max	25.1	25.1	7.0	8.7
Min	0.2	0.2	0.2	0.2
Median	0.60	1.65	0.85	0.60
25%	0.20	0.60	0.30	0.20
75%	1.20	3.85	1.60	1.10
Skewness	7.233	2.793	2.108	3.098
Kurtosis	74.045	8.107	4.455	15.648
K-S Dist.	0.311	0.263	0.221	0.233
K-S-Prob.	<0.001	<0.001	<0.001	<0.001
Sum	1,192.1	291.7	214.50	685.90
Sum of Squares	5,051.69	3,225.33	608.87	1,217.49

APPENDIX L

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

	All Indoor Radon Data	High Zone Radon Data	Moderate Zone Radon Data	Low Zone Radon Data
Size	1,059	84	166	809
Mean	-0.188	0.179	-0.102	-0.244
Std Dev	0.424	0.583	0.433	0.379
Std Error	0.0130	0.0636	0.0336	0.0133
C.I. of Mean	0.0256	0.127	0.0664	0.0262
Range	2.099	2.099	1.544	1.638
Max	1.400	1.400	0.845	0.940
Min	-0.699	-0.699	-0.699	-0.699
Median	-0.222	0.217	-0.0713	-0.222
25%	-0.699	-0.222	-0.523	-0.699
75%	0.0792	0.584	0.204	0.0414
Skewness	0.513	0.0535	0.189	0.3324
Kurtosis	-0.173	-0.739	-0.835	-0.830
K-S Dist.	0.151	0.113	0.121	0.172
K-S-Prob.	<0.001	0.010	<0.001	<0.001
Sum	-199.119	15.074	-16.930	-197.263
Sum of Squares	228.067	30.946	32.702	164.419