SPECIAL REPORT 232

RADON POTENTIAL IN ORANGE COUNTY, CALIFORNIA

2015

CALIFORNIA GEOLOGICAL SURVEY
Department of Conservation

STATE OF CALIFORNIA
EDMUND G. BROWN, JR.
GOVERNOR

THE NATURAL RESOURCES AGENCY
JOHN LAIRD
SECRETARY FOR RESOURCES

DEPARTMENT OF CONSERVATION
MARK NECHODOM
DIRECTOR

CALIFORNIA GEOLOGICAL SURVEY
JOHN G. PARRISH, PH.D., *STATE GEOLOGIST*

SPECIAL REPORT 232

RADON POTENTIAL IN ORANGE COUNTY, CALIFORNIA

By

Ronald K. Churchill, Ph.D.
PG #4265

2015

CALIFORNIA GEOLOGICAL SURVEY'S PUBLIC INFORMATION OFFICES:

Southern California Regional Office
888 S. Figueroa Street, Suite 475
Los Angeles, CA 90017
(213) 239-0878

Library and Headquarters Office
801 K Street, MS 14-31
Sacramento, CA 95814-3531
(916) 445-5716

Bay Area Regional Office
345 Middlefield Road, MS 520
Menlo Park, CA 94025
(650) 688-6327

Page Intentionally Blank

TABLE OF CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

Radon is a radioactive gas formed by decay of small amounts of uranium and thorium naturally present in rock and soil. Sometimes radon gas can move from underlying soil and rock into homes and concentrate in the indoor air, posing a significant lung cancer risk for the residents. The U.S. Environmental Protection Agency (U.S. EPA, 2012) estimates indoor-radon exposure results in 21,000 lung cancer deaths annually in the United States. The U.S. EPA recommended action level for indoor radon concentration is 4.0 picocuries per liter (pCi/L).

Between November 2007 and May 2008, the California Department of Public Health (CDPH), Indoor Radon Program, surveyed 1,136 homes in Orange County for indoor-radon using short-term radon detectors. Survey results range from 0.5 pCi/L, the detection limit, to 22.0 pCi/L. The highest indoor-radon measurement in CDPH records for an Orange County home is 25.6 pCi/L. It was made in January 2010 in a slab-on-grade foundation house and was added to the survey data for Orange County.

This report documents the data and procedures used by the California Geological Survey to develop the radon potential map for Orange County. Data used are:

- 2007-2008 CDPH-indoor-radon survey data for Orange County
- National Uranium Resource Evaluation (NURE) Airborne gamma-ray survey data for uranium in soil and rocks
- Surface gamma-ray survey data
- Laboratory data for uranium in soil samples
- California Geological Survey and U.S. Geological Survey 1:100,000 scale geologic maps (1 inch on the map equals 1.58 miles)
- Natural Resources Conservation Service (NRCS) Orange County soil maps and permeability and shrink-swell data

To evaluate radon potentials of individual geologic units, indoor-radon data, uranium data, geologic units and soil units were linked to individual geologic units and soil units using a geographic information system (GIS). A preliminary radon potential was then assigned to each geologic unit based on percent of indoor-radon data at or exceeding 4.0 pCi/L:

- High potential—20 percent or more
- Moderate potential—5 to 19.9 percent
- Low potential—less than 5 percent; and
- Unknown potential—insufficient data to assign a potential.

Next, NURE (National Uranium Resource Evaluation program), surface and soil uranium data, NRCS (Natural Resource Conservation Service)

soil permeability and shrink-swell data, and geologic unit radon potentials determined in previous California radon studies were reviewed. The preliminary radon potential became the final unit potential unit unless the data review supported a different radon potential. Geologic units were assigned to either moderate, low or unknown radon potential categories. Available indoor-radon data do not support a high potential ranking for any Orange County geologic unit.

To create radon potential zone areas for the Orange County map, areas of different geologic units with the same radon potential ranking were grouped together to define the radon potential zones. All moderate radon potential geologic unit areas collectively define the moderate potential zone areas, low potential unit areas the low potential zone areas, and unknown potential unit areas the unknown potential zone areas. A final validity check of these radon potential zones involved statistical comparison of their indoor-radon data populations to confirm each zone represents a distinct radon population. The resulting map shows moderate potential zone areas comprise 14.8 percent of Orange County, low potential zone areas 57.4 percent, and unknown potential areas 27.8 percent, much of the latter being located in low population or unpopulated east-central and south-east portions of the county.

The CGS 1:100,000-scale radon potential zone map for Orange County is informational, not regulatory. It is intended as a guide to prioritize areas for public education about radon and for targeting additional indoor-radon testing activities. The map cannot be used to determine the indoor-air radon concentration in a particular building. All radon zones contain some homes with radon above 4 pCi/L and some homes below 4 pCi/L. The only way to identify specific homes and buildings with indoor-radon exceeding 4 pCi/L is through testing.

Based on CDPH indoor-radon survey results, the radon potential zone map developed in this study, and 2010 U.S. Census data, an estimated 106,727 people in Orange County live in residences with indoor-air radon concentrations likely to equal or exceed 4.0 pCi/L. An estimated 5,410 people live in homes that will likely test 10 pCi/L or more, and about 3,113 people are estimated to live in homes that will likely test at 20 pCi/L or higher. Indoor-radon testing should be encouraged in Orange County, especially in moderate radon potential zones areas, which represent 14.8 percent of the county, and within unknown potential areas where insufficient data are currently available to estimate radon potential. Those considering new home construction may wish to consider radon resistant new construction practices, particularly at sites within moderate radon potential areas. Post construction radon mitigation is possible, if necessary, but will be more expensive than the cost of adding radon-reducing features during home construction.

INTRODUCTION

Purpose

This report documents the data and procedures used by the California Department of Conservation, California Geological Survey (CGS) to develop the 2015 radon potential zone map for Orange County. CGS produced the map for the California Department of Public Health Indoor Radon Program (CDPH-Indoor Radon Program) through an interagency agreement. The report includes radon potentials for individual geologic units and estimates of the county population exposed to 4 picocuries per liter (pCi/L) or higher indoor-radon concentrations. The report contains only minimal radon background, health issue and testing information. No information on radon remediation of homes and buildings is included in the report.

The following websites have information about radon and health issues, testing and remediation:

http://www.cdph.ca.gov/healthinfo/environhealth/Pages/Radon.aspx
and http://www.epa.gov/radon/pubs/index.html.

Background Information about Radon and Health

Radon gas is a naturally occurring odorless and colorless radioactive gas. It forms from the radioactive decay of small amounts of uranium and thorium naturally present in rocks and soils. The average uranium content for the earth's continental crust is about 2.5-2.8 parts per million (ppm). Typical concentrations of uranium and thorium for many rocks and soils are a few ppm. Certain rock types, such as organic-rich shales, some granitic rocks, and silica-rich volcanic rocks may have uranium and thorium present at concentrations of five to several tens of ppm and occasionally higher. While all buildings have some potential for elevated indoor-radon levels because radon is always present in the underlying soils and rocks, buildings located on those rocks and soils containing higher concentrations of uranium often have an increased likelihood of elevated indoor-radon levels. Breathing air with elevated radon gas abundance over long periods of time increases one's risk of developing lung cancer. Not everyone exposed to radon will develop lung cancer. However, the U.S. Environmental Protection Agency (U.S. EPA, 2012) estimated 21,000 people die in the United States annually from lung cancer attributed to radon exposure.

Indoor-radon concentrations are reported in picocuries per liter (pCi/L) in the U.S. The average indoor-radon concentration in American homes is about 1.3 pCi/L (U.S. EPA, 2012). Average outdoor air radon concentration is about 0.4 pCi/L. The U.S. EPA recommends that individuals avoid long-term exposures to radon concentrations ≥ 4.0 pCi/L (*4.0 pCi/L is the U.S. EPA recommended indoor-radon action level*). Based on long-term radon test statistics, the U.S. EPA estimates about one out of 15 homes (6.7 percent) in the United States has radon levels ≥ 4.0 pCi/L.

Indoor-radon concentration is a guide for acceptable exposure and for remedial action. However, it is inhalation of two radon radioactive decay products, polonium-218 and polonium-214, that is thought to primarily lead to lung cancer. These polonium isotopes have very short half-lives (see Table 1). When they enter the lungs, they attach to lung tissue or trapped dust particles and quickly undergo radioactive decay, emitting high-energy alpha particles. The alpha particles are thought to damage lung tissue cell DNA (deoxyribonucleic acid), causing cancer (Brookins, 1990). In contrast, most longer-lived radon-222 is exhaled before undergoing radioactive decay.

Radon gas readily moves through rock and soil along micro-fractures and interconnected pore-spaces between mineral grains. Radon movement away from its site of origin is typically limited to a few feet to tens of feet 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-219), but movement may be hundreds of feet 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 of uranium-238, see Table 1) has the longest half-life of the several radon isotopes, it is usually the predominant radon isotope in indoor air rather than shorter-lived radon-220 (a radioactive-decay product of thorium-232) or radon-219.

Radon gas moves from underlying soil into buildings when air pressure inside the buildings is lower than air pressure in the soil, and pathways for radon entry are available. Heating indoor air, using exhaust fans and wind blowing across a building will lower a building's internal air pressure. Pathways include cracks in slab foundations or basement walls, pores and cracks in concrete blocks, through-going floor-to-wall joints, and openings around pipes. Because radon enters buildings from the adjacent soil, indoor-radon concentrations are typically highest in basements and ground floor rooms. Radon can also enter a building in water from private wells. All ground water contains some dissolved radon gas. The travel time of water from an aquifer to a home in a private well is usually too short for much radon decay, so radon is available to be released in the house during water usage, for example through use of a bathroom shower. However, normal water usage typically adds only about 1 pCi/L of radon to indoor air per 10,000 pCi/L of radon in water (Grammer and Burkhart, 2004).

Nuclide (Isotope)	**Principal mode of radioactive decay**	**Half-life**
Uranium-238	Alpha	$4.5X10^9$ years
Thorium-234	Beta	24.1 days
Protactinium-234	Beta	1.2 minutes
Uranium-234	Alpha	$2.5X10^5$ years
Thorium-230	Alpha	$7.5X10^4$ years
Radium-226	Alpha	1,602 years
Radon-222	**Alpha**	**3.8 days**
Polonium-218	Alpha	3.1 minutes
Lead-214	Beta	26.8 minutes
Astatine-218	Alpha	1.5 seconds
Bismuth-214	Alpha	19.9 minutes
Polonium-214	Alpha	$1.6\text{-}10^{-4}$ seconds
Thallium-210	Beta	1.3 minutes
Lead-210	Beta	22.6 years
Bismuth-210	Beta	5.0 days
Polonium-210	Alpha	138.4 days
Thallium-206	Beta	4.2 minutes
Lead-206	Stable	Stable

Table 1. The uranium-238 radioactive decay series.

(Generalized-does not show branching or some short-lived isotopes. Modified from Appleton, 2005, p. 229)

The most common indoor-radon testing methods utilize either charcoal or alpha-track type detectors. These tests are simple to perform, inexpensive and homeowners can do this testing themselves. Following manufacturer instructions, these detectors are exposed to home indoor-air and sent to a laboratory for analysis. Test results, in pCi/L, are sent directly to the homeowner. Laboratory analysis is typically included in the cost of a detector.

Long-term tests (alpha-track detector measurements) have advantages over short-term tests (charcoal detector measurements). Longer exposure time “averages out” short-term fluctuations in radon levels such as those caused by weather changes. Also, long-term tests are done under open-house conditions. Consequently, long-term measurements should be more representative of a person’s annual average indoor-radon levels. However, short-term measurements are more commonly used because of the shorter time required. More often than not, if a short-term indoor radon test result is several pCi/L above 4 pCi/L, follow-up short-term tests or long-term tests will also be above 4 pCi/L (see Appendix D).

Radon Potential Map Characteristics, Use and Limitations

Radon potential maps developed by CGS for the CDPH-Indoor Radon Program show areas where geologic conditions create higher or lower likelihoods for homes exceeding 4 pCi/L. Also shown are areas lacking data for radon potential determination. The number of individuals exposed to excessive radon levels for an area can be estimated using U.S. Census track data and a radon zone map.

Radon potential maps are advisory, not regulatory. They are intended to help federal, state and local government agencies and private organizations target and prioritize radon program activities and resources. Radon potential maps cannot be used to identify which homes have excessive indoor radon levels. In addition to geology, local variability in soil permeability, climatic conditions, and factors such as home design, construction, condition, and usage preferences may influence indoor radon levels. Regardless of what radon zone it is in, testing is the only way to determine the radon concentration in a specific home accurately. All radon zones typically have some homes with indoor radon levels $\geq$ 4.0 pCi/L as well as homes with radon levels $<$ 4 pCi/L.

Development of the Orange County Radon Potential Map

Orange County radon potential zones were developed utilizing data from the following data and information sources:

- CDPH-Radon Program 2007-2008 Orange County indoor-radon survey test data for 1,137 residences and the 2010 CDPH-Radon Zip Code Database.

- NURE (National Uranium Resource Evaluation) Project Airborne Survey data for equivalent uranium (eU).

- The Geologic Map of the Oceanside 30’ x 60’ Quadrangle, California; California Geological Survey (Kennedy and Tan, 2007).

- The Geologic Map of the San Bernardino and Santa Ana 30’ x 60’ quadrangles, California, version 1.0; U.S. Geological Survey (Morton and Miller, 2006).

- The Geologic Map of the Long Beach 30’ x 60’ Quadrangle, California, version 1.0; California Geological Survey (Saucedo and others, 2003).

- Orange County soil unit data and maps from the Natural Resources Conservation Service (NRCS) (NRCS, 2008; Watchell, 1978).

The Orange County radon potential map development steps were:

1) Using a geographic information system (GIS), 2007-2008 CDPH-Radon Program indoor-radon survey data for Orange County were grouped by geologic unit.

2) Using associated indoor-radon data, geologic units were preliminarily assigned to one of four radon potential categories based on the percentage of indoor-radon measurements at or exceeding 4 pCi/L (see step 7 for categories), the number and magnitude of indoor-radon measurements per unit exceeding 10 pCi/L, and the total number of measurements.

3) Using GIS, NURE project airborne equivalent uranium (eU) data were grouped by geologic unit.

4) Using NURE data, geologic units were rated as more likely or less likely to be related to problem radon homes based on the percentage of eU data exceeding 5 ppm uranium (twice the average crustal uranium abundance of 2.5 ppm).

5) Using GIS, 2007-2008 CDPH-Radon Program indoor-radon survey data were grouped by NRCS soil unit.

6) Permeability and shrink-swell character information and indoor radon data for soil units were reviewed to see if these soil characteristics relate to higher or lower indoor-radon concentration homes.

7) Using information from steps 2, 4 and 6, assign final radon potentials were assigned to all geologic units in Orange County using categories defined by percentages of short-term tests likely to exceed 4.0 pCi/L as follows:

   - High—20.0 percent or more ≥ 4.0 pCi/L indoor measurements
   - Moderate—5 to 19.9 percent ≥ 4.0 pCi/L indoor measurements
   - Low—0 to 4.9 percent ≥ 4.0 pCi/L indoor measurements
   - Unknown—units with insufficient data for estimating the percent of ≥ 4.0 pCi/L indoor measurements

8) Using GIS, geologic unit areas with similar radon potentials were grouped to form radon potential zones.

9) Indoor radon data for each radon zone were compared statistically with other zones to confirm that each zone represented a distinct indoor-radon data population.

10) Final radon zones were compared with 2010 census block data to estimate radon impacts on the Orange County population.

Following sections of this report provide more details on data utilized and the results of these steps.

Portions of radon potential zones with faults and shear zones often have increased potential for elevated indoor-radon concentrations because such features provide pathways for radon flow. However, the 1:100,000 scale Orange County radon potential zone map does not show fault and shear zone locations. The reason is fractures less than an inch wide can be significant radon pathways but cannot be accurately represented on a 1:100,000 scale map. On a 1:100,000-scale map, the minimum size of a feature that can be depicted is about 100-200 feet and the accuracy of that feature's location is commonly +/- tens to hundreds of feet. Additionally, soil and alluvium may obscure faults and shear zones, especially smaller ones, or prevent their precise location. Consequently, at 1:100,000-scale mapping, it is better to base radon testing priorities on zone designation rather than attempt to target fault and shear zone locations. Detailed investigations of indoor-radon and fault or shear zone relationships require use or development of 1:24,000 or more detailed scale geologic maps.

THE ORANGE COUNTY SHORT-TERM INDOOR-RADON SURVEY AND OTHER AVAILABLE INDOOR-RADON DATA

Overview

The CDPH-Radon Program conducted a survey of indoor-radon in Orange County homes between November 2007 and May 2008. The CDPH-Radon program solicited participation via direct mailing to 40,000 Orange County homeowners. One thousand one hundred thirty-six homeowners (2.8 percent) participated in the survey. Each participant received a free charcoal detector with instructions for placement and exposure. After exposure, participants mailed their detector to the Radon Program contract lab for measurement. The contract lab provided test results directly to survey participants within several weeks of detector receipt.

The primary goal of this survey was to obtain sufficient indoor-radon data for homes located on specific geologic units to evaluate the radon potentials of these units. The percentage of homes exceeding the 4.0 pCi/L U.S. EPA recommended radon action level was used to evaluate geologic unit radon potential. Survey results are presented below in the section titled: *Orange County Geologic Unit Radon Potentials* (page 16).

Figure 1 shows the geographic distribution of the CDPH radon survey homes in Orange County. Areas of high and low survey sample densities in Figure 1 reflect high and low population density variations in the county. Figure 2 shows the geographic distribution of fifty-eight survey homes testing ≥ 4.0 pCi/L. Table 2 provides foundation type, test floor, test room and the name of the geologic unit present for Orange County homes with radon measurements of 8.0 pCi/L or above.

The survey radon concentrations range from 0.5 pCi/L, the reported detection limit, to 22.0 pCi/L, the latter for a first floor guest bedroom in a slab foundation house. The highest indoor-radon measurement in CDPH records for an Orange County home that has sample location and foundation type information is 25.6 pCi/L, for a downstairs bedroom in a slab-on-grade house tested in January 2010. Because of its significance, this measurement has been included in the Orange County CDPH radon database (see Home 1 in Table 2). The next highest survey measurements are in slab foundation houses, 12.9 pCi/L, in a first floor guest room, and 9.0 pCi/L, in a basement living room.

Figure 1. CDPJ 2007-2008 Orange County radon survey test locations.

City abbreviations: A, Anaheim; F, Fullerton; HB, Huntington Beach; I, Irvine; LB, Laguna Beach; MV, Mission Viejo; SC, San Clemente; SJC, San Juan Capistrano; T, Tustin; YL, Yorba Linda

Table 3 summarizes Orange County indoor-radon survey results by Zip Code zone and City/Region. For comparison, Table 4 summarizes CDPH on-line Zip Code radon database test data for Orange County Zip Code zones accumulated by CDPH between 1989 and 2010. The CDPH on-line database includes the 2007-2008 Orange County radon survey data in Table 3. Table 4 data cannot be used for evaluating geologic unit radon potentials because: 1) many data are only located by Zip Code, and 2) many geologic unit occurrences are smaller than Zip Code areas. Geologic unit evaluation requires more precise location information for radon test homes than just Zip Code area. Table 4 data also contains multiple radon measurements for some homes (e.g., follow-up measurements, simultaneous measurements in multiple rooms, or even measurements after radon mitigation) and multiple measurements from

Figure 2. CDPH 2007-2008 Orange County radon survey test locations with 4.0 pCi/L or greater sites shown as yellow circles.

City abbreviations: A, Anaheim; F, Fullerton; HB, Huntington Beach; I, Irvine; LB, Laguna Beach; MV, Mission Viejo; SC, San Clemente; SJC, San Juan Capistrano; T, Tustin; YL, Yorba Linda

multi-story apartment or condominium units. Unfortunately, the database does not include documentation to identify multiple measurements at given locations or pre or post mitigation data. In spite of these limitations, comparison of Table 4 data with Table 3 data shows the CDPH on-line Zip Code radon data are still useful for pointing out which Zip Codes may contain radon problem areas, and suggesting general indoor-radon trends for Orange County. Percentages of ≥ 4 pCi/L homes are often similar in Tables 3 and 4 for Zip Codes with at least 20 measurements. The overall percentage of Orange County homes ≥ 4 pCi/L is 5.2 for the 2007-2008 CDPH survey (1,137 measurements) and 4.2 for the CDPH 1989-2010 Zip Code database (3,435 measurements).

Home	Radon pCi/L	Foundation Type	Test Floor	Test Room	Geologic Unit Name and [Map Symbol]
1	25.6	Slab-On-Grade	1	Downstairs Bedroom	Old alluvial fan deposits [Qof]
2	22.0	Slab	1	Bedroom	Young landslide deposits [Qyls]
3	12.9	Slab	1	Lower Guest Room	Topanga Group, undifferentiated [Tt]
4	9.0	Slab*	Basement*	Living Room	Very old alluvial fan deposits [Qvof]
5	8.5	Slab	1	Bedroom	Young landslide deposits [Qyls?]
6	8.3	Crawlspace	Not Provided	Family Room	Young alluvial fan deposits [Qyf]
7	8.3	Slab	1	Family Room	Young alluvial fan deposits [Qyf]
8	8.2	Slab	1	Living Room	Young alluvial fan deposits [Qyf]
9	8.2	Slab	1	Bedroom	Young alluvial fan deposits [Qyf]
10	8.1	Slab	1	Living Room	Very old alluvial fan deposits [Qvof]
11	8.0	Slab	1	Dining Room	Young alluvial fan and valley deposits-clay [Qyfc]

Table 2. Orange County indoor-radon measurements ≥ 8.0 pCi/L: home foundation type, floor, room and geologic unit.

*As reported to the lab by the homeowner

Zip Code	City/Region	Measurements	Measurements ≥ 4 pCi/L	Percent ≥ 4 pCi/L
90620	Buena Park	4	0	0
90621	Buena Park	1	1	100.0
90623	La Palma	7	0	0
90630	Cypress	20	1	5.0
90631	La Habra	14	2	14.3
90680	Stanton	6	0	0
90720	Los Alamitos	16	0	0
90740	Seal Beach	13	0	0
92602	Irvine	6	1	16.7
92603	Irvine	7	0	0
92604	Irvine	13	2	15.4
92606	Irvine	7	0	0
92610	Foothill Ranch/El Toro	9	0	0
92612	Irvine	5	0	0
92614	Irvine	7	0	0
92617	Irvine	1	0	0
92618	Irvine	4	0	0
92620	Irvine	21	2	9.5
92624	Capistrano Beach	1	0	0
92625	Corona Del Mar	13	0	0
92626	Costa Mesa	25	3	12.0
92627	Costa Mesa	13	1	7.7
92629	Dana Point	11	0	0
92630	Lake Forest	39	0	0
92637	Laguna Woods	6	0	0
92646	Huntington Beach	31	0	0
92647	Huntington Beach	26	1	3.9
92648	Huntington Beach	17	0	0
92649	Huntington Beach	16	0	0
92651	Laguna Beach	13	1	12.9
92653	Laguna Hills	24	0	0
92655	Midway City	1	0	0
92656	Aliso Viejo	23	1	4.4
92657	Newport Coast	8	0	0
92660	Newport Beach	23	0	0
92663	Newport Beach	6	0	0
92672	San Clemente	15	2	13.3
92673	San Clemente	23	1	4.4
92675	San Juan Capistrano	15	3	20.0
92676	Silverado	1	0	0
92677	Laguna Niguel/ Laguna Beach	58	5	8.6
Table 3 continues on next page				

Table 3 ***(page 1 of 2)*****. CDPH indoor-radon short-term test results for November 2007 to May 2008 Orange County radon survey—by Zip Code Zone.**

Table 3 continued				
Zip Code	**City/Region**	**Measurements**	**Measurements ≥ 4 pCi/L**	**Percent ≥ 4 pCi/L**
92679	Coto De Caza/ Dove Canyon/ Trabuco Canyon	19	0	0
92683	Westminster	17	0	0
92688	Rancho Santa Margarita	35	0	0
92691	Mission Viejo	33	0	0
92692	Mission Viejo	41	1	2.4
92694	Ladera Ranch	7	0	0
92701	Santa Ana	1	0	0
92704	Santa Ana	2	0	0
92705	Santa Ana/Tustin	17	1	5.9
92706	Santa Ana	4	0	0
92707	Santa Ana	3	0	0
92708	Fountain Valley	25	0	0
92780	Tustin	20	1	5.0
92782	Tustin	12	2	16.7
92801	Anaheim	9	0	0
92802	Anaheim	3	0	0
92804	Anaheim	8	0	0
92805	Anaheim	8	0	0
92806	Anaheim	9	1	11.1
92807	Anaheim	21	1	4.8
92808	Anaheim	14	0	0
92821	Brea	15	0	0
92823	Brea	4	2	50.0
92831	Fullerton	22	2	9.1
92832	Fullerton	6	0	0
92833	Fullerton	15	1	6.7
92835	Fullerton	12	2	16.7
92840	Garden Grove	19	0	0
92841	Garden Grove	7	0	0
92843	Garden Grove	2	0	0
92844	Garden Grove	9	0	0
92845	Garden Grove	11	0	0
92861	Villa Park	6	1	16.7
92865	Orange	10	2	20.0
92866	Orange	6	0	0
92867	Orange	26	3	11.5
92868	Orange	1	0	0
92869	Orange	20	0	0
92870	Placentia	21	5	23.8
92886	Yorba Linda	31	5	16.1
92887	Yorba Linda	17	2	11.8
	total	1137	59	5.2

Table 3 *(page 2 of 2)*. **CDPH indoor radon short-term test results for November 2007 to May 2008 Orange County radon survey—by Zip Code zone**

Zip Code	City/Region	Measurements	Measurements ≥ 4 pCi/L	Percent ≥ 4 pCi/L
90620	Buena Park	21	0	0
90621	Buena Park	7	1	14.3
90623	La Palma	19	0	0
90630	Cypress	50	1	2.0
90631	La Habra	36	5	13.9
90680	Stanton	9	0	0
90720	Los Alamitos	34	0	0
90740	Seal Beach	24	1	4.2
90743	Surfside	1	0	0
92602	Irvine	5	1	20.0
92603	Irvine	15	0	0
92604	Irvine	41	4	9.8
92606	Irvine	15	0	0
92607	Laguna Niguel	1	0	0
92610	Foothill Ranch	21	1	4.8
92612	Irvine	13	0	0
92614	Irvine	72	2	2.8
92615	Huntington Beach	4	0	0
92617	Irvine	3	0	0
92618	Irvine	24	0	0
92620	Irvine	45	3	6.7
92624	Capistrano Beach	3	1	33.3
92625	Corona Del Mar	43	5	11.6
92626	Costa Mesa	70	5	7.1
92627	Costa Mesa	44	2	4.6
92628	Costa Mesa	1	0	0
92629	Dana Point	35	0	0
92630	Lake Forest	90	0	0
92637	Laguna Woods	8	0	0
92646	Huntington Beach	69	0	0
92647	Huntington Beach	97	1	1.0
92648	Huntington Beach	64	2	3.1
92649	Huntington Beach	48	2	4.2
92651	Laguna Beach	46	2	12.9
92653	Laguna Hills	111	5	4.5
92654	Laguna Hills	6	0	0
92655	Midway City	10	0	0
92656	Aliso Viejo	74	2	2.8
92657	Newport Coast	19	0	0
92660	Newport Beach	57	0	0
92663	Newport Beach	60	8	13.3
92672	San Clemente	47	4	8.5
92673	San Clemente	63	1	1.6
Table 4 continues on next page				

Table 4 *(page 1 of 3)*. **Radon test results for Orange County Zip Code Zones from the CDPH on-line Radon Zip Code Database for California (1989-2010).**

Table 4 continued				
Zip Code	**City/Region**	**Measurements**	**Measurements ≥ 4 pCi/L**	**Percent ≥ 4 pCi/L**
92674	San Clemente	1	1	100.0
92675	San Juan Capistrano	41	4	9.8
92676	Silverado	3	0	0
92677	Laguna Niguel	136	9	6.6
92679	Trabuco Canyon	102	0	0
92683	Westminster	50	0	0
92684	Westminster	1	0	0
92685	Westminster	55	0	0
92688	Rancho Santa Margarita	84	0	0
92690	Mission Viejo	4	0	0
92691	Mission Viejo	99	4	4.0
92692	Mission Viejo	117	3	2.6
92693	San Juan Capistrano	3	0	0
92694	Ladera Ranch	14	0	0
92697	Irvine	2	0	0
92698	Irvine	1	0	0
92701	Santa Ana	8	0	0
92703	Santa Ana	4	0	0
92704	Santa Ana	14	2	14.3
92705	Santa Ana	64	5	7.8
92706	Santa Ana	13	0	0
92707	Santa Ana	14	0	0
92708	Fountain Valley	56	0	0
92728	Fountain Valley	1	0	0
92780	Tustin	42	1	2.4
92782	Tustin	24	4	16.7
92801	Anaheim	29	2	6.9
92802	Anaheim	17	0	0
92804	Anaheim	30	0	0
92805	Anaheim	27	1	3.7
92806	Anaheim	29	1	3.5
92807	Anaheim	56	5	8.9
92808	Anaheim	32	0	0
92814	Anaheim	1	0	0
92817	Anaheim	2	0	0
92821	Brea	58	1	1.7
92823	Brea	5	2	40.0
92831	Fullerton	42	3	7.1
92832	Fullerton	12	0	0
92833	Fullerton	26	2	7.7
92834	Fullerton	8	0	0
92835	Fullerton	23	2	8.7
92840	Garden Grove	58	0	0
Table 4 continues on next page				

Table 4 *(page 2 of 3).* **Radon test results for Orange County Zip Code zones from the CDPH on-line Radon Zip Code Database for California (1989-2010).**

Table 4 continued				
Zip Code	**City/Region**	**Measurements**	**Measurements ≥ 4 pCi/L**	**Percent ≥ 4 pCi/L**
92841	Garden Grove	9	0	0
92843	Garden Grove	5	0	0
92844	Garden Grove	13	0	0
92845	Garden Grove	23	0	0
92860	Norco	1	0	0
92861	Villa Park	12	4	33.3
92865	Orange	146	4	2.7
92866	Orange	18	0	0
92867	Orange	43	3	7.0
92868	Orange	4	0	0
92869	Orange	37	1	2.7
92870	Placentia	63	9	14.3
92885	Yorba Linda	1	0	0
92886	Yorba Linda	79	7	8.9
92887	Yorba Linda	46	4	8.7
	total	3435	143	4.2

Table 4 *(page 3 of 3).* **Radon test results for Orange County Zip Code zones from the CDPH on-line Radon Zip Code Database for California (1989-2010).**

Radon Survey Data—Exposure Duration and Data Quality

Most Orange County CDPH radon survey participants exposed their radon tests for two days as instructed, but some exposed them for 3 or 4 days. Differences between two-day and three-day or four-day test results should be negligible. Appendix A lists results for 44 duplicate (concurrent) tests made during the survey and summarized in Table 5, which shows consistency between groups of concurrent (duplicate) tests.

Measurement Group Range pCi/L	Associated Concurrent Group Measurement Ranges pCi/L	Differences pCi/L
4.2-8.3	2.5-8.1	0.2-1.7
2.1-3.1	1.3-3.1	0.0-1.0
1.0-1.9	0.5-1.7	0.0-1.2
0.5-0.9	0.5-0.8	0.0-0.4

Table 5. Comparison of Orange County radon survey duplicate (concurrent) test results.

Appendices B and C show the analytical results for three field blank radon detectors (i.e., not exposed to radon) and eight spiked radon detectors (exposed to a known concentration of radon). The three blank detector results measured below the reported lab detection limit of 0.5 pCi/L. Five of the eight laboratory spike samples measured within 10 percent of the maximum (16.1 pCi/L) and minimum (12.7 pCi/L) radon concentrations for the test chamber in which they were exposed. Three detectors measured higher than 10 percent above the chamber maximum, 23.0 percent or 3.7 pCi/L higher, 14.3 percent or 2.3 pCi/L higher, and 12.4 percent or 2.0 pCi/L higher. No spiked samples measured below the minimum test chamber radon concentration.

In summary, duplicate, blank and spiked sample test results support the validity of the CDPH-Radon Program Orange County radon survey data.

Follow-up Radon Testing Results

Appendix D shows six follow-up radon tests in five home sites initially testing above 4 pCi/L. The number of days between tests range from 22 to 131. In three of these homes, the follow-up tests confirmed the original test result of ≥ 4.0 pCi/L. In one home two follow-up tests were 11 pCi/L lower 34 days later. This large difference suggests the follow-up test locations may not coincide with the original test location, or that installation of a radon mitigation system may have occurred between the tests.

ORANGE COUNTY GEOLOGIC UNIT RADON POTENTIALS

Indoor Radon Data and Geologic Unit Information

Appendix E shows the Orange County indoor-radon survey data tabulated by geologic unit. This tabulation includes a later (2010) home measurement of 25.6 pCi/L. Of 154 geologic units, 60 have indoor-radon data and 10 have more than 25 measurements. Ninety-four geologic units do not have indoor-radon data, but some of these in the unincorporated eastern and southeastern parts of the county may have few or no associated homes. The following 1:100,000-scale geologic maps were used to determine which geologic unit is present at each indoor-radon test location: the geologic map of the Oceanside 30’ x 60’ Quadrangle, California (Kennedy and Tan, 2007); the geologic map of the San Bernardino and Santa Ana 30’ x 60’ quadrangles; California (Morton and Miller, 2006); and the geologic map of the Long Beach 30’ x 60’ Quadrangle, California (Saucedo and others, 2003).

Preliminary Geologic Unit Radon Potentials

Geologic units were assigned preliminary radon potentials based upon associated indoor-radon data and definitions of radon potential categories, (page 6, step 7). Appendix E lists these preliminary unit radon potentials. No Orange County geologic units met the high radon potential criteria during the indoor-radon data review. Tables 6 and 7 list the most likely moderate and low radon potential geologic units. Some unit radon potentials in Tables 6 and 7 are provisional—less certain because they have fewer than 25 indoor-radon measurements. Provisional status may also be assigned where previous county studies support a different unit radon potential if a unit has few or no indoor-radon data available within Orange County. Geologic unit radon potentials from Churchill, 2005, 2006, 2007, 2008, 2010, 2012 and 2014, were considered in choosing provisional radon potentials for Orange County geologic units. A (P) after

Geologic Unit [unit symbol](unit time period)	**Incidence Rate (R) and other statistics***	**Radon Potential Designation** Justification for preliminary moderate ranking
Capistrano Formation—Siltstone Facies [Tcs](early Pliocene and Miocene)	**R* = 7.7 %** N** = 78 N ≥ 4 pCi/L*** = 6 Maximum = 7.8 pCi/L	**Moderate** 5% ≤ R < 20%
Monterey Formation [Tm](middle Miocene) **Monterey Formation** with closely associated **Young axial-channel deposits** [Qya](Holocene and late Pleistocene)	**R = 2.9 %** N = 34 N ≥ 4 pCi/L = 1 Maximum = 4.0 pCi/L **R = 5.0 %** N = 40 N ≥ 4 pCi/L = 2 Maximum = 5.8 pCi/L	**Moderate (P)** Unit assigned moderate or high potential in coastal county studies from Los Angeles to San Mateo **Moderate** Unit and adjacent Qya indoor radon data meet moderate potential criteria 5% ≤ R < 20%
Puente Formation—La Vida Member [Tplv](Miocene)	**R = uncertain⁺** N = 1 N ≥ 4 pCi/L = 0 Maximum = 0.9 pCi/L	**Moderate (P)** Unit assigned moderate potential in Los Angeles County
Puente Formation—Sycamore Canyon Member [Tpsc](early Pliocene and Miocene)	**R = 9.1 % uncertain** N = 11 N ≥ 4 pCi/L = 1 Maximum = 4.1 pCi/L	**Moderate (P)** Puente Formation assigned moderate potential in Los Angeles County

Table 6. Moderate radon potential geologic units in Orange County based on 2007-2008 CDPH short-term indoor-radon data.

*R% = [(N ≥ 4 pCi/L)/ N] X 100
**N = the number of indoor radon measurements
***N ≥ 4 pCi/L = the number of indoor radon measurements at or above 4 pCi/L
⁺uncertain = the geologic unit incident Rate (R) % is less certain because of the small number of associated indoor-radon measurements

Geologic Unit [unit symbol](unit time period)	**Incidence Rate (R) and other statistics***	**Radon Potential Designation**
Capistrano Formation—Oso Member [Tco](early Pliocene and Miocene)	**R = 0 %** N = 19 N ≥ 4 pCi/L = 0 Maximum = 1.7 pCi/L	**Low** 0% ≤ R < 4.9%
Volcanic intrusive rocks associated with El Modeno Volcanics—Diabasic [Tiemd](middle Miocene)	**R = % uncertain** N = 2 N ≥ 4 pCi/L = 0 Maximum = 0.8 pCi/L	**Low(P)** 0% ≤ R < 4.9%
Niguel Formation [Tn](Pliocene)	**R = 0 %** N = 36 N ≥ 4 pCi/L = 0 Maximum = 3.4 pCi/L	**Low** 0% ≤ R < 4.9%
Puente Formation—Soquel member [Tpsq](early Pliocene and Miocene)	**R = 0 % uncertain** N = 10 N ≥ 4 pCi/L = 0 Maximum = 1.9 pCi/L	**Low(P)** 0% ≤ R < 4.9%
Sespe Formation [Ts](early Miocene, Oligocene, and late Eocene)	**R = 0 %** N = 17 N ≥ 4 pCi/L = 0 Maximum = 1.4 pCi/L	**Low(P)** 0% ≤ R < 4.9%
Santaigo Formation [Tsa](middle Eocene)	**R = 0 % uncertain** N = 7 N ≥ 4 pCi/L = 0 Maximum = 0.8 pCi/L	**Low(P)** 0% ≤ R < 4.9%
San Onofre Breccia [Tso or Tsob](middle Miocene)	**R = 0 % uncertain** N = 8 N ≥ 4 pCi/L = 0 Maximum = 0.8 pCi/L	**Low(P)** 0% ≤ R < 4.9%
Topanga Group, undifferentiated [Tt](middle Miocene)	**R = 6.7 % uncertain** N = 15 N ≥ 4 pCi/L = 1 Maximum = 12.9 pCi/L	**Low (P)** 14 of 15 measurements range from 0.5 pCi/L to 1.7 pCi/L
Topanga Group—Bommer Formation [Ttb](middle Miocene)	**R = 0 % uncertain** N = 4 N ≥ 4 pCi/L = 0 Maximum = 1.1 pCi/L	**Low(P)** 0% ≤ R < 4.9%
Topanga Group—Los Trancos Formation [Ttlt](middle Miocene)	**R = 0 % uncertain** N = 4 N ≥ 4 pCi/L = 0 Maximum = 0.7 pCi/L	**Low(P)** 0% ≤ R < 4.9%
Table 7 continues on the next page		

Table 7 *(page 1 of 2)*. **Low radon potential geologic units in Orange County based on 2007-2008 CDPH short-term indoor-radon data**

Table 7 continued		
Geologic Unit [unit symbol](unit time period)	**Incidence Rate (R)* and other statistics**	**Radon Potential Designation**
Vaqueros Formation [Tv](early Miocene, Oligocene, and late Eocene)	**R = 0 % uncertain** N = 4 N ≥ 4 pCi/L = 0 Maximum = 1.4 pCi/L	**Low(P)** 0% ≤ R < 4.9%
El Modeno Volcanics—andesitic [Tvema](middle Miocene)	**R = 0 % uncertain** N = 4 N ≥ 4 pCi/L = 0 Maximum = 0.8 pCi/L	**Low(P)** 0% ≤ R < 4.9%
El Modeno Volcanics—tuff and tuff breccias [Tvemt](middle Miocene)	**R = 0 % uncertain** N = 3 N ≥ 4 pCi/L = 0 Maximum = 1.1 pCi/L	**Low(P)** 0% ≤ R < 4.9%
Vaqueros and Sespe Formations, undifferentiated [Tvs](early Miocene, Oligocene, and late Eocene)	**R = 0 % uncertain** N = 5 N ≥ 4 pCi/L = 0 Maximum = 2.1 pCi/L	**Low (P)** 0% ≤ R < 4.9%

Table 7 *(page 2 of 2)*. **Low radon potential geologic units in Orange County based on 2007-2008 CDPH short-term indoor radon data**

*See Table 6 footnotes for definitions of R, N, N ≥ 4 pCi/L, and uncertain

the radon potential designation indicates provisional radon potential status in the third column in Tables 6 and 7. Average rock-type uranium abundance was also considered in assigning provisional status for units with few or no data. For example: for volcanic rocks, rhyolite often exceeds basalt in background uranium abundance so rhyolite typically has higher radon potential.

In addition to indoor-radon data, other data useful for estimating geologic unit radon potentials are available for Orange County: NURE airborne radiometric data; surface radiometric data; and soil data. Following sections discuss these data, their review results and their use to establish the final geologic unit radon potentials.

Surficial Geologic Deposits, Indoor Radon Data and Radon Potential

Surficial geologic deposits consist of unconsolidated alluvial or residual geologic material (e.g., sand, silt, clay, gravel, cobbles, and boulders). They include the following Orange County geologic map units — axial-channel alluvium, alluvial fan, colluvium, landslide deposits, eolian deposits, flood-plain deposits and paralic deposits. Some of these deposits have different radon potentials at different locations. The reason is that some surficial units have multiple sources of material with significantly different radon potentials. For example, an alluvial fan deposit composed only of material eroded from moderate radon potential source rocks will likely have a different radon potential than an alluvial fan deposit composed only of material from low radon potential source rocks. Standard geologic maps do not indicate source information for surficial geologic units and one map unit could include both fans if they are similar in material characteristics and age. However, different radon potential areas within surficial units may be approximately located by:

- Considering watershed and topographic constraints on material transported from source rock areas with known radon potentials

- Using surficial unit indoor-radon data.

Forty-six of the 59 Orange County ≥ 4 pCi/L measurements (78 percent) occur in homes on surficial geologic units (Appendix E). Moderate radon potential status was assigned to surficial unit areas predominantly composed of material from moderate potential sources. Surficial unit occurrences received a low potential designation when composed of material predominantly derived from low potential source units. Boundaries between moderate potential and low potential areas are based on source rock potentials, topography and indoor-radon data. Table 8 shows that 33 of the 46 ≥ 4 pCi/L surficial indoor-radon measurements occur in portions of five surficial deposit types likely to have moderate radon potential. Table 9 compares surficial unit indoor-radon data for moderate and low radon potential areas.

Surficial unit Indoor-radon data for moderate and low potential were statistically compared and results of this comparison are given in Appendix F. The radon data populations for both moderate and low radon potential areas of Qya are significantly different statistically. So are the radon data populations for moderate and low radon potential areas of Qyf deposits. Apparent differences in radon data populations for moderate and low radon potential areas for units Qls + Qls?, Qvof, and Qyls + Qyls? may not be significantly different and instead be due to random sampling variability. However, this statistical result, for these three groups of geologic units, may result from their small numbers of data, especially for the low radon potential portions of these groups.

Surficial Unit (selected areas)	**Indoor-Radon Statistics**	**Radon Potential and Justification**
Very young landslide deposits [Qls + Qls?*]	**R = 5.9 %** N = 17 N ≥ 4 pCi/L = 1 Maximum = 4.2 pCi/L	**Moderate (P)** Apparent 5% ≤ R < 20%
Very old alluvial-fan deposits [Qvof]	**R = 13.3 %** N = 83 N ≥ 4 pCi/L = 11 Maximum = 9.0 pCi/L	**Moderate** 5% ≤ R < 20% with N ≥ 25
Young axial-channel deposits [Qya]	**R = 10.5 %** N = 19 N ≥ 4 pCi/L = 2 Maximum = 5.8 pCi/L	**Moderate (P)** Apparent 5% ≤ R < 20%
Young alluvial-fan deposits [Qyf]	**R = 17.3 %** N = 81 N ≥ 4 pCi/L = 14 Maximum = 8.3 pCi/L	**Moderate** 5% ≤ R < 20% with N ≥ 25
Young landslide deposits [Qyls + Qyls?*]	**R = 45.5 % uncertain** N = 11 N ≥ 4 pCi/L = 5 Maximum = 22.0pCi/L	**Moderate (P)** Apparent 5% ≤ R < 20% and High maximum pCi/L

Table 8. Indoor-radon data for portions of surficial deposits assigned to moderate radon potential status.

* “?” indicates less certainty that these areas actually are very young landslide deposits or young landslide deposits.

Geologic Unit	Moderate Potential Portion	Low Potential Portion
Very young landslide deposits [Qls + Qls?*]	**R = 5.9 %** N = 17 N ≥ 4 pCi/L = 1 Maximum = 4.2 pCi/L	**R = uncertain** N = 2 N ≥ 4 pCi/L = 0 Maximum = 0.7 pCi/L
Very old alluvial-fan deposits [Qvof]	**R = 13.3 %** N = 83 N ≥ 4 pCi/L = 11 Maximum = 9.0 pCi/L	**R = 0 % uncertain** N = 15 N ≥ 4 pCi/L = 0 Maximum = 2.3 pCi/L
Young axial-channel deposits [Qya]	**R = 10.5 %** N = 19 N ≥ 4 pCi/L = 2 Maximum = 5.8 pCi/L	**R = 2.3 %** N = 43 N ≥ 4 pCi/L = 1 Maximum = 5.3pCi/L
Young alluvial-fan deposits [Qyf]	**R = 17.3 %** N = 81 N ≥ 4 pCi/L = 14 Maximum = 8.3 pCi/L	**R = 0.5 %** N = 210 N ≥ 4 pCi/L = 1 Maximum = 5.8 pCi/L
Young landslide deposits [Qyls + Qyls?*]	**R = 45.5 % uncertain** N = 11 N ≥ 4 pCi/L = 5 Maximum = 22.0 pCi/L	**R = uncertain** N = 3 N ≥ 4 pCi/L = 0 Maximum = 1.4 pCi/L

Table 9. Comparison of indoor-radon data for assigned moderate and low radon potential portions of Orange County surficial deposits.

* “?” indicates less certainty that these areas actually are very young landslide deposits or young landslide deposits.

NURE PROJECT URANIUM DATA

Background

Between 1975 and 1983, the United States government funded the National Uranium Resource Evaluation (NURE) project. The NURE goal was to identify new domestic uranium sources (ore deposits) for energy and national defense. NURE uranium exploration activities included airborne gamma-ray spectral surveys that estimated the uranium content of soils and rocks at points along a grid of flight lines. Flight-line segments with anomalously high uranium concentrations became targets for additional uranium exploration work. Such anomalies also suggest areas with increased potential for indoor-radon problems because radon concentrations in soil gas are likely elevated at these locations.

Additionally, NURE project soil and stream sediment samples were collected in some California 1X2 degree quadrangles for laboratory uranium analyses. When available, these uranium data may also indicate areas likely to have anomalously elevated soil radon concentrations. Unfortunately, such sampling did not include Orange County.

Airborne Radiometric Data

NURE airborne radiometric data used in this study were compiled from the original data files by Duval (2000). A total of 242.6 miles of NURE flight-line data are available for Orange County. The flight-line grid pattern, shown in Figure 3, consists of east-west flight lines 2.1 to 4.3 miles apart and north-south flight lines 11.6 to 11.9 miles apart covering the eastern and central portions of Orange County. No airborne radiometric data are available for western Orange County because the NURE program did not survey major urban areas. A specially equipped helicopter flew a few hundred feet above the ground at about 90 miles per hour along these flight lines and recorded 10,788 gamma-ray spectral measurements. The average distance between data measurements along a flight line varies between 40 feet and 180 feet.

Energy from the isotope bismuth-214 is one of the gamma-ray energies measured during the NURE airborne radiometric survey. It forms soon after radon-222 decays and quickly decays to Polonium-214 (see Table 1). The NURE program used bismuth-214 gamma-ray data to estimate the soil-rock uranium content, in parts-per-million (ppm), at each flight line measurement location. Under the NURE survey conditions, each airborne uranium measurement represents the average uranium content within the upper 18 inches of surficial material (rock or soil) over an area of approximately 48,000 square feet, or about 1.1 acres (High-Life Helicopters, 1980a and 1980b). Uranium concentrations calculated from bismuth-214 gamma-ray data are in parts-per-million (ppm) and called equivalent uranium data, abbreviated eU. This distinguishes them from uranium data determined by direct chemical methods for rock or soil samples in a laboratory, abbreviated U. The most common laboratory methods for uranium analyses employed by NURE project laboratories were delayed neutron activation and fluorescence.

Soil moisture, atmospheric inversion and other conditions can negatively impact airborne eU data measurements (Grasty, 1997). Consequently, elevated eU data concentrations are used in this study as qualitative indicators of rock or soil areas with increased radon potential.

Figure 3 shows flight-line data locations where eU equal or exceed 5.0 ppm. The average uranium content of the earth’s crust is about 2.5 ppm.

Figure 3. NURE project flight lines and elevated equivalent uranium (eU) locations. "GE" in the map legend represents "greater than or equal to." City abbreviations: A, Anaheim; F, Fullerton; HB, Huntington Beach; I, Irvine; LB, Laguna Beach; MV, Mission Viejo; SC, San Clemente; SJC, San Juan Capistrano; T, Tustin; YL, Yorba Linda

For rocks and soils, uranium concentrations two or more times the crustal average (i.e., 5 ppm or more), are commonly considered anomalously high. Blue circles indicate ≥ 5.0-ppm eU locations along NURE flight lines in Figure 3. These locations are assumed more likely to have ≥ 4.0 pCi/L homes because of increased uranium abundance in local rocks and soils.

Appendix G summarizes NURE airborne eU data for 98 geologic units in Orange County (70 county units do not have NURE eU data available). These data suggest the following geologic units are more likely to have moderate radon potentials:

Marine sedimentary rocks

Tcs-Capistrano Formation, siltstone facies
Tm-Monterey Formation
Tplv-Puente Formation, La Vida Member

Interbedded marine and non-marine sedimentary rocks

Tsi-Silverado Formation
Tvs-Vaqueros (marine) and Sespe Formations (non-marine), undifferentiated

Certain Portions of Surficial geologic units

Qls-Very young landslide deposits
Qya-Young axial-channel deposits
Qyf-Young alluvial-fan deposits
Qyls-Young landslide deposits

Airborne eU data in Appendix F also suggest the following geologic units are more likely to have low radon potentials:

Jbc-Bedford Canyon Formation, undifferentiated
Khg-Heterogeneous granitic rocks
Klbc-Baker Canyon Conglomerate member
Klhs-Ladd Formation, Holtz Shale member-zone of concentrated sandstone and conglomerate beds
Ktr-Trabuco Formation
Kvsp-Santiago Peak Volcanics
Kvspi-Intrusive rocks associated with Santiago Peak Volcanics
Kwsr-Williams Formation, Schulz Ranch Member
Kwsrl-Williams Formation, Schulz Ranch Member, lower member
Kwst-Williams Formation, Starr Member
Qls-Landslide Deposits
Qvop-Very old paralic deposits
Qw-Very young wash deposits
Tco-Capistrano Formation, Oso Member
Qyf-Young alluvial-fan deposits
Tfl-Fernando Formation-lower member
Tfu-Fernando Formation-upper member
Tpsc-Puente Formation-Sycamore Canyon Member
Tt-Topanga Group, undifferentiated
Ttlt-Topanga Formation-Los Trancos Formation
Tv-Vaqueros Formation

ORANGE COUNTY SURFACE URANIUM DATA

Orange County Surface eU Data

Fukumoto and others (2006) completed a surface eU survey of 68 Mission-Viejo-Laguna Niguel area sites in 2006. Table 10 summarizes their survey results for geologic units and Figure 4 shows gamma-ray measurement locations. For these measurements, a 1.4-liter thallium activated sodium iodide gamma-ray spectrometer was placed directly on the ground at each location and a 5 minute counting time utilized. Survey results suggest that units Tcs, Tm, and surficial deposit occurrences of Qya and Qyls? near Tcs and Tm, commonly contain more than 5 ppm uranium in this part of Orange County. Consequently, these Mission Viejo-Laguna Niguel area units are more likely to have moderate or high potential for elevated radon homes.

The surface eU data for Tn are too few to be conclusive about its uranium content. However, the limited data suggest this unit may have lower radon potential for indoor-radon problems than Tcs or Tm in the Mission Viejo-Laguna Niguel area.

Geologic Unit Symbol	Geologic Unit name	N	N ≥ 5 ppm eU	% N ≥ 5 ppm eU	Low ppm	High ppm	Median U ppm
Qya	Young axial-channel deposits	16	12	75.0	3.2	8.9	6.0
Qyls?	Young landslide deposits—uncertain	2	2	--	6.6	7.2	6.9
Tcs	Capistrano Formation—siltstone facies	28	20	71.4	3.8	8.2	5.55
Tm	Monterey Formation	18	13	72.2	4.2	8.6	5.7
Tn	Niguel Formation	3	0	--	3.0	4.5	3.9
Tn?	Niguel Formation—uncertain	1	1	--		5.3	5.3

Table 10. Surface equivalent uranium (eU) data for selected geologic units between Laguna Beach and Mission Viejo. (Data from Fukumoto, 2006)

Orange County Soil Uranium Data

Smith and others (2013) contains soil uranium data for C-horizon samples at two Orange County sites. Figure 4 includes the locations of these sites. The uranium data from Smith and others, along with geologic unit and NRCS (Natural Resource Conservation Service) soil unit, permeability, shrink-swell and soil depth information, are contained in Table11. Uranium analysis was by ICP-MS with a detection lower limit of 0.1 mg/kg.

Both soil samples are from occurrences of Qya (young axial-channel deposits) dominated by alluvium derived from suspected lower radon potential source rocks. Their uranium contents are below the 2.5 ppm crustal average, suggesting Qya deposits in these areas have relatively low potential for elevated indoor-radon.

USGS Sample Number	**Sample Depth cm**	**U ppm**	**Geologic Unit**	**NRCS Soil Unit**	**Perm**	**Sh-Sw**	**Soil Depth Inches (*cm*)**
C-358460	50-75	1.4	Qya	146-Corralitos loamy sand	rapid	low	203+ (*516+*)
C-358463	30-40	2.3	Qya	198-Soboba gravelly loamy sand	very rapid	low	152+ (*386+)*

Table 11. Soil properties and uranium data for two Orange County C-horizon soil samples. (Data from Smith and others, 2013; and NRCS, 2008)

Table abbreviations: Perm = soil permeability; Sh-Sw = soil shrink-swell characteristics

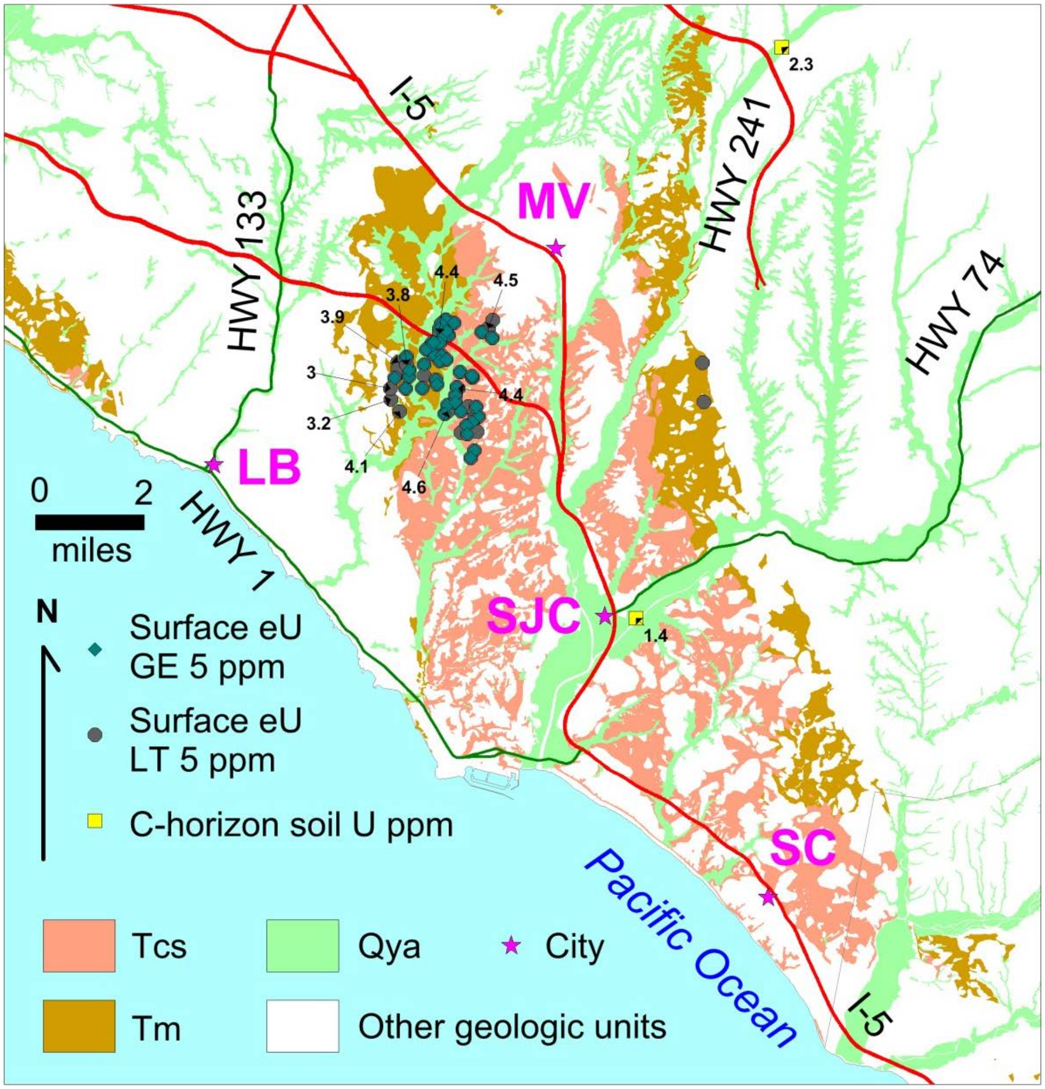

Figure 4. Locations of surface gamma-ray spectrometer measurements for eU and two C-horizon soil U determinations. (Fukumoto and others, 2006; Smith and others, 2013)

eU data for sites within Tcs or Tm areas are summarized in Table 5. Labeled uranium concentrations (in parts-per-million for both eU and U) in the figure are for sites not located on Tcs or Tm. "GE" in the map legend represents "greater than or equal to." "LT" in the map legend represents "less than." City abbreviations: LB = Laguna Beach; MV= Mission Viejo; SC = San Clemente; SJC = San Juan Capistrano.

ORANGE COUNTY SOIL DATA

Soil Properties and Indoor Radon

Appendix H provides information on the relationship between different soil types and Orange County geologic units. Soil property data from NRCS county soil reports are sometimes useful in identifying areas with higher radon potential. Higher permeability soils facilitate radon release from host minerals and increased migration distances. In soils with low permeability, radon release and migration can be significantly restricted. Soil moisture is also an important factor relating to indoor-radon problems, especially for homes on moderate to high shrink-swell soils. These soils change permeability, exhibiting low permeability during periods of precipitation and high permeability (cracks) during dry periods because they contain clays that expand or contract in relation to soil moisture content. High shrink-swell soils also stress and sometimes crack foundations, creating radon entry pathways into homes. However, radon is more readily released from its point of origin and may migrate further in dry soils than wet soils because it is captured (dissolved) and held in the water (Brookins, 1990, Appleton, 2005).

Appendix I lists representative permeability, shrink-swell and depth to bedrock information for Orange County soils associated with at least one indoor-radon measurement. It is compiled from the NRCS soil survey and map for Orange County and the western part of Riverside County, California (NRCS, 2008; also see Wachtell, 1978).

Tables 12 and 13 summarize soil permeability, shrink-swell and radon data relationships for Orange County soils. Data in these tables suggest:

- Soils with moderate to slow permeability tend to have more ≥ 4 pCi/L homes than soils with rapid to very rapid permeability

- Soils with moderate to high shrink-swell character tend to have more ≥ 4 pCi/L homes than soils with low shrink-swell character

Table 14 lists those Orange County soil units more often associated with ≥ 4 pCi/L homes, based on related indoor-radon data, along with their permeability and shrink-swell characteristics, depth to bedrock, geologic unit associations and related indoor-radon data. Figure 5 shows the location of soil units listed in Table 14. Table 15 lists soil units less often associated with ≥ 4 pCi/L homes along with information on their soil properties, geologic unit associations and related indoor-radon data. Tables 14 and 15 only include those soil units having associated indoor-radon data. Consequently, they may not include all Orange County soils more likely or less likely for elevated indoor-radon concentrations.

Soil Permeability (multiple horizons listed in order from shallow to deep)	**% all soil permeability groups in terms of radon measurements**	**N**	**N ≥ 4 pCi/L**	**% ≥ 4 pCi/L**	**Maximum pCi/L**
Very Rapid	0.2	2	0	0	0.6
Rapid	5.5	60	0	0	3.0
Rapid over Moderate	3.7	40	1	2.5	5.8
Rapid over Moderate over Moderately Slow to Moderate	1.9	21	0	0	3.0
Rapid over Moderately Slow over Rapid	2.6	28	0	0	1.9
Rapid over Slow over Rapid	0.2	2	0	0	2.2
Moderately Rapid over Very Rapid	2.7	30	0	0	2.2
Moderately Rapid	12.9	141	2	1.0	5.1
Moderate to Moderately Rapid over Slow over moderate	1.7	19	0	0.0	2.7
Moderately Rapid over Very Slow over moderate	16.1	176	13	7.4	25.6
Moderate	13.7	150	11	7.3	8.5
Moderate over Moderately Slow	1.0	11	0	0.0	1.9
Moderate over Moderately Slow over Moderate	5.9	65	8	12.3	8.3
Moderate over Slow to Moderately Slow	2.4	26	2	7.8	5.3
Moderately Slow	12.1	133	6	5.0	12.9
Moderately Slow or Slow	0.1	1	0	0	1.2
Moderately Slow over Slow over Moderately Slow	0.6	6	2	33.3	4.3
Slow	16.9	185	8	4.4	22.0
total	100.2	1096*	53		

Table 12. Soil permeability and home indoor-radon data.

*N = 1096 instead of 1137 because NRCS soil permeability is not provided in NRCS soil reports for certain soil units, such as artificial fill.

Soil Shrink-Swell Character (multiple horizons listed in order from shallow to deep)	**% all soil shrink-swell groups in terms of radon measurements**	**N**	**N ≥ 4 pCi/L**	**% ≥ 4 pCi/L**	**Maximum pCi/L**
High	18.7	205	10	4.9	22.0
Moderate	17.2	189	10	5.3	12.9
Low	30.2	331	3	0.9	5.8
Low over Moderate	6.8	75	7	9.3	8.2
Low over Moderate over Low	6.5	71	2	2.8	8.3
Low over high over low	16.1	176	13	7.4	25.6
Moderate over High	0.6	7	0	0	1.2
Moderate over High over Moderate	0.6	6	2	33.3	4.3
Moderate over Low	3.3	36	6	0	0.8
	100.0	1096*	53		

Table 13. Soil shrink-swell character and indoor-radon data.

*N = 1096 instead of 1137 because NRCS soil shrink-swell information is not provided in NRCS soil reports for certain soil units, such as artificial fill.

Soil Unit Map Symbols	**Soil Unit Name (*principal geologic units*)**	**Permeability; Shrink-Swell; Depth to Bedrock**	**N Rn Data**	**% ≥ 4 pCi/L**	**Highest Indoor Rn pCi/L**
126, 127, 128	**Bosanko clay** (*Capistrano Fm, Monterey Fm and related surficial units*)	Slow; High; < 60 inches	31	6.5	6.1
134	**Calleguas clay loam** (*Capistrano Fm, Monterey Fm, Puente Fm and related surficial units*)	Moderate; Moderate; < 60 inches	54	7.4	8.5
166, 167	**Mocho loam** (*young alluvial fan deposits*)*	Moderate; Low to Moderate; > 60 inches	63	11.1	8.2
172,173, 175,176	**Myford sandy loam** (*old and very old alluvial fan, channel and paralic deposits**)	Moderately Rapid (12”) over Very Slow (37”) over Moderate (30”; Low over High over Low; > 60 inches	124	10.5	25.6
206, 207	**Sorrento loam** (*in alluvium from sedimentary rocks on fans and flood plains**)	Moderate (12”) over Moderately Slow to Moderate (50”) over Moderate (10”); Low over Moderate over Low; > 60 inches	29	6.9	8.3
208, 209	**Sorrento clay loam** (*in alluvium from sedimentary rocks on fans and flood plains**)	Moderate (12”) over Moderately Slow to Moderate (50”) over Moderate (10”); Moderate over Moderate over Low; > 60 inches	36	16.7	8.3
219, 220	**Xerothents, loamy, cut and fill areas**	Uncertain; Uncertain; ≤ 60 inches	21	19.1	6.1

Table 14. Orange County soil types more often associated with indoor-radon levels ≥ 4 pCi/L.

*****Where a significant component of these sediment is derived from bedrock units with higher radon potentials (e.g., Capistrano Formation-Siltstone Facies; Monterey Formation; Puente Formation La Vida Member, etc.).

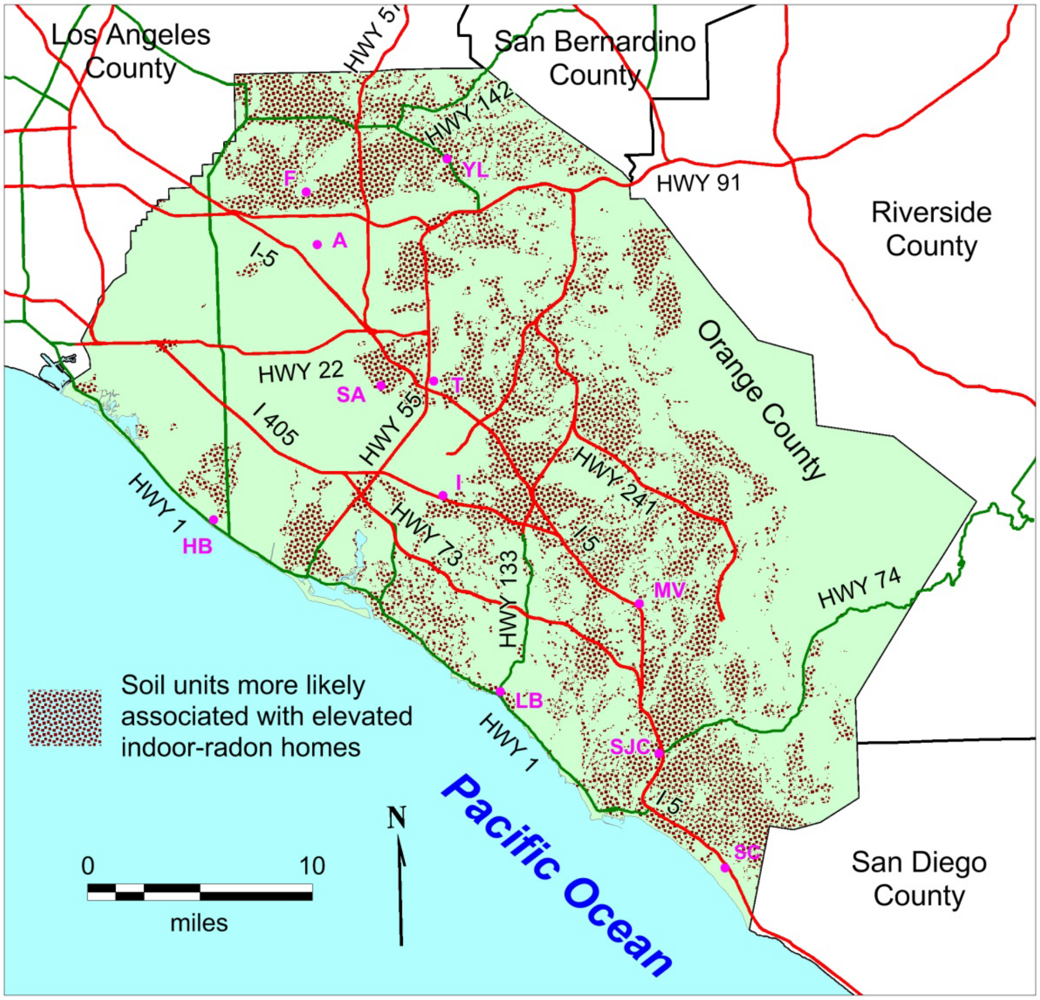

Figure 5. Location of soil units more likely associated with elevated indoor-radon homes. *City abbreviations: A, Anaheim; F, Fullerton; HB, Huntington Beach; I, Irvine; LB, Laguna Beach; MV, Mission Viejo; SC, San Clemente; SJC, San Juan Capistrano; T, Tustin; YL, Yorba Linda*

Soil Unit Map Symbols	**Soil Unit Name (*principal associated geologic units*)**	**Permeability; Shrink-Swell; Depth to Bedrock**	**N Rn Data**	**% ≥ 4 pCi/L**	**Highest Indoor Rn pCi/L**
122, 123,124, 125	**Bolsa silt loam or silty clay loam** (*in young axial channel and alluvial fan deposits**)	Moderately Slow; Moderate; > 60 inches	79	1.3	8.0
141, 142, 145	**Cineneba sandy loam** (*in mostly low radon potential marine Miocene and Pliocene sedimentary units**)	Moderately Rapid; Low; ≤ 19”	54	1.9	4.1
157, 158	**Hueneme fine sandy loam** (*in young alluvial fan deposits**)	Moderately Rapid; Low; > 60”	76	1.3	5.1
161, 162	**Marina loamy sand** (*in old and very old paralic deposits-eolian sands**)	Moderate; Low; > 60”	25	0.0	1.1
168, 169, 170, 171	**Modjeska gravelly loam** (*in old and very old alluvial fan and axial channel deposits**)	Moderately Rapid (63”)over Very Rapid (8”); Low; > 60”	30	0.0	2.2
174, 177, 178, 179	**Myford sandy loam** (*old and very old alluvial fan, channel and paralic deposits**)	Moderately rapid (12”) over very slow (37”) over moderate (30”); Low over High over low; > 60”	52	0.0	3.7
194,195, 196	**San Emigdio fine sandy loam** (*in old and young alluvial fan deposits**)	Rapid (60” or Rapid (40” over Moderately Slow (3”) over Rapid (18”); Low; > 60”	78	0.0	3.0

Table 15. Orange County soil types less often associated with indoor-radon levels ≥ 4 pCi/L.

***Where a significant component of sediment is **<u>not</u>** derived from bedrock units with higher radon potentials (e.g., Capistrano Formation-Siltstone Facies; Monterey Formation; Puente Formation La Vida Member, etc.)

RADON POTENTIAL ZONES

Final Orange County Geologic Unit Radon Potentials

Final Orange County geologic unit radon potentials zones were assigned using review results for:

1) Indoor-radon data;
2) NURE airborne eU data;
3) Surface eU and lab U data; and
4) NRCS soil data for permeability and shrink-swell characteristics and depth.

Some Orange County geologic units have few or no data available for ranking their radon potential. These units received the same radon potentials as assigned in previous studies of Los Angeles and other California Counties, if radon ranking data were available in the previous studies. A unit received an unknown ranking if few or no data suitable for radon ranking are available in this study or previous studies.

Tables 16 and 17 list Orange County geologic units with assigned moderate radon potentials for bedrock and surficial units respectively. These tables provide information about which data support the assigned radon potential for individual geologic units. Table 17 shows information only for the portions of surficial units having moderate radon potential. The remaining portions of these surficial units are composed of low potential areas, unknown potential areas or a combination of both. Appendix J lists geologic units ranked as low or unknown radon potential.

Geologic Unit (symbol and name)	**Indoor Radon Data**	**NURE Airborne eU Data**	**Surf. eU Data**	**NRCS Soil Perm., Shrink-Swell and Depth Data**	**Assigned Radon Potential** (additional considerations)
Tcs-Capistrano Formation-Siltstone Facies	XX	XX	XX	X	Moderate 5% ≤ R < 20%
Tm-Monterey Formation	XX	XX	XX	XX	Moderate 5% ≤ R < 20% Includes related Qya-Young axial-channel deposits (Moderate to high radon potential in other California coastal Counties.)
Tplv-Puente Formation-La Vida Member	ID	XX	ND	ID	Moderate 5% ≤ R < 20% Moderate radon potential in Los Angeles County. Unit could serve as source rock for moderate radon potential surficial units down slope.)
Tpsc-Puente Formation-Sycamore Canyon Member	X	--	ND	X	Moderate 5% ≤ R < 20%

Table 16. Data supporting bedrock geologic units being ranked as having moderate radon potential in Orange County.

R = Radon Potential in percent homes ≥ 4 pCi/L
XX = supports radon potential ranking
X = appears to support radon potential ranking but limited data
-- = data do not support radon potential ranking
ID = insufficient data to determine if supports radon potential ranking or not
ND = no data

Geologic Unit (symbol and name)	**Indoor Radon Data**	**NURE Airborne eU Data**	**Surf. eU Data**	**NRCS Soil Perm., Shrink-Swell and Depth Data**	**Assigned Radon Potential**
Qls + Qls?	X	XX	ND	XX	Moderate 5% ≤ R < 20%
Qof	X	--	ND	X	Moderate 5% ≤ R < 20%
Qof3	X	ID	ND	X	Moderate 5% ≤ R < 20%
Qvof-Very old alluvial-fan deposits	XX	--	ND	XX	Moderate 5% ≤ R < 20%
Qya-Young axial-channel deposits	X	XX	XX	XX	Moderate 5% ≤ R < 20%
Qyf-Young alluvial fan deposits	XX	XX	ND	XX	Moderate 5% ≤ R < 20%
Qyls + Qyls?—Young landslide deposits	X	XX	X	XX	Moderate 5% ≤ R < 20%

Table 17. Data supporting portions of surficial geologic units being ranked as having moderate radon potential in Orange County.

R = Radon Potential in percent homes ≥ 4 pCi/L
XX = supports radon potential ranking
X = appears to support radon potential ranking but limited data
-- = data do not support radon potential ranking
ID = insufficient data to determine if supports radon potential ranking or not
ND = no data

Radon Potential Zone Creation

A radon potential zone for a county is the collection of all the areas with similar radon potential for display on a base map of the county. As previously discussed, Orange County has geologic units with moderate, low or unknown radon potential, so it will have moderate, low and unknown radon potential zones. These zones are created by simply combining the county's geologic units into moderate, low or unknown radon potential groups based on their final assigned radon potential. The moderate potential zone is all of the occurrences of moderate potential geologic units. Some occurrences adjoin each other creating a larger moderate potential area; others are isolated creating a smaller moderate potential area. Low potential and unknown potential zone areas are similarly defined. This radon zone development process relies on GIS procedures. Figure 6 is a miniature and simplified version of the Orange County radon potential map showing the moderate, low and unknown zones. Figure 7 shows the radon potential zones with supporting data.

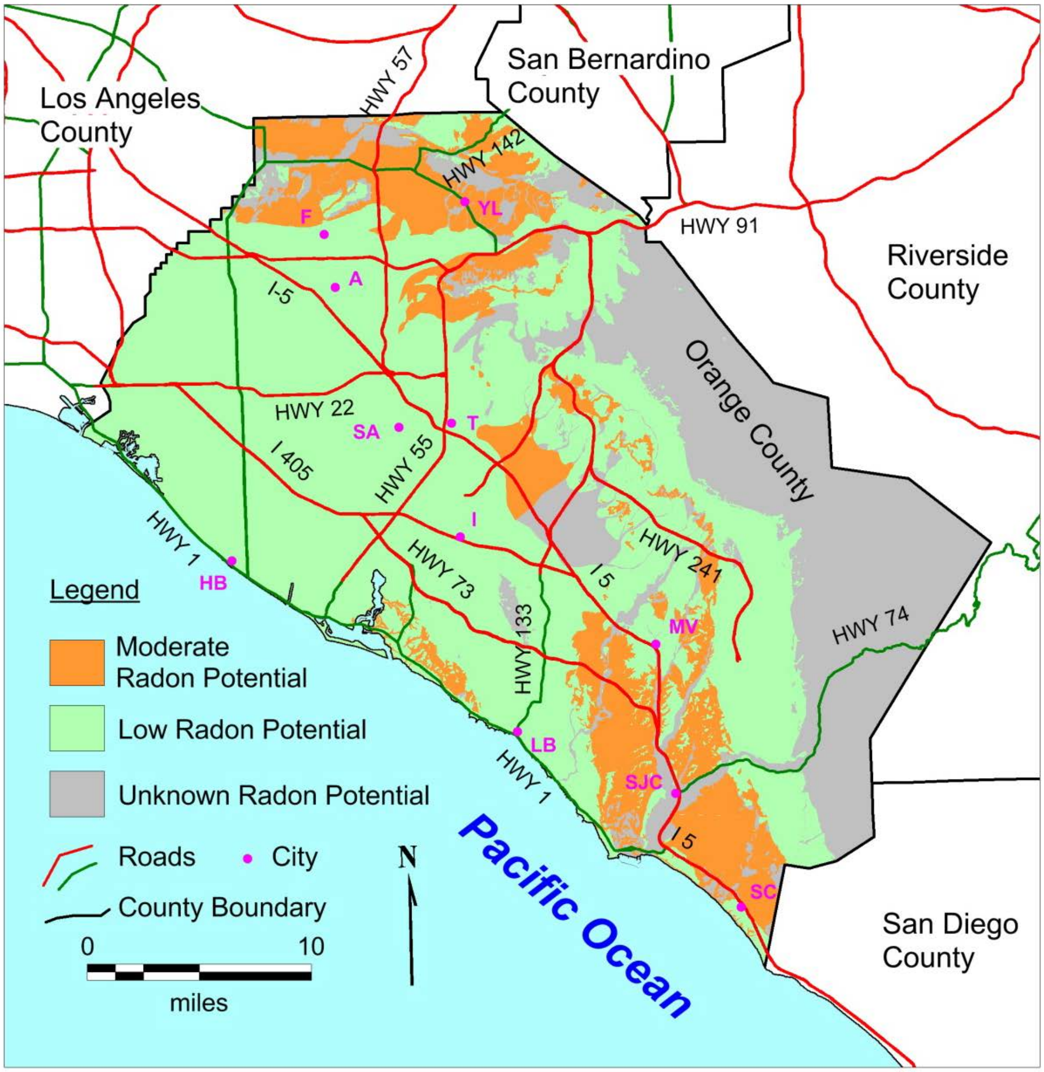

Figure 6. Orange County radon potential zones.

City abbreviations: A, Anaheim; F, Fullerton; HB, Huntington Beach; I, Irvine; LB, Laguna Beach; MV, Mission Viejo; SC, San Clemente; SJC, San Juan Capistrano; T, Tustin; YL, Yorba Linda

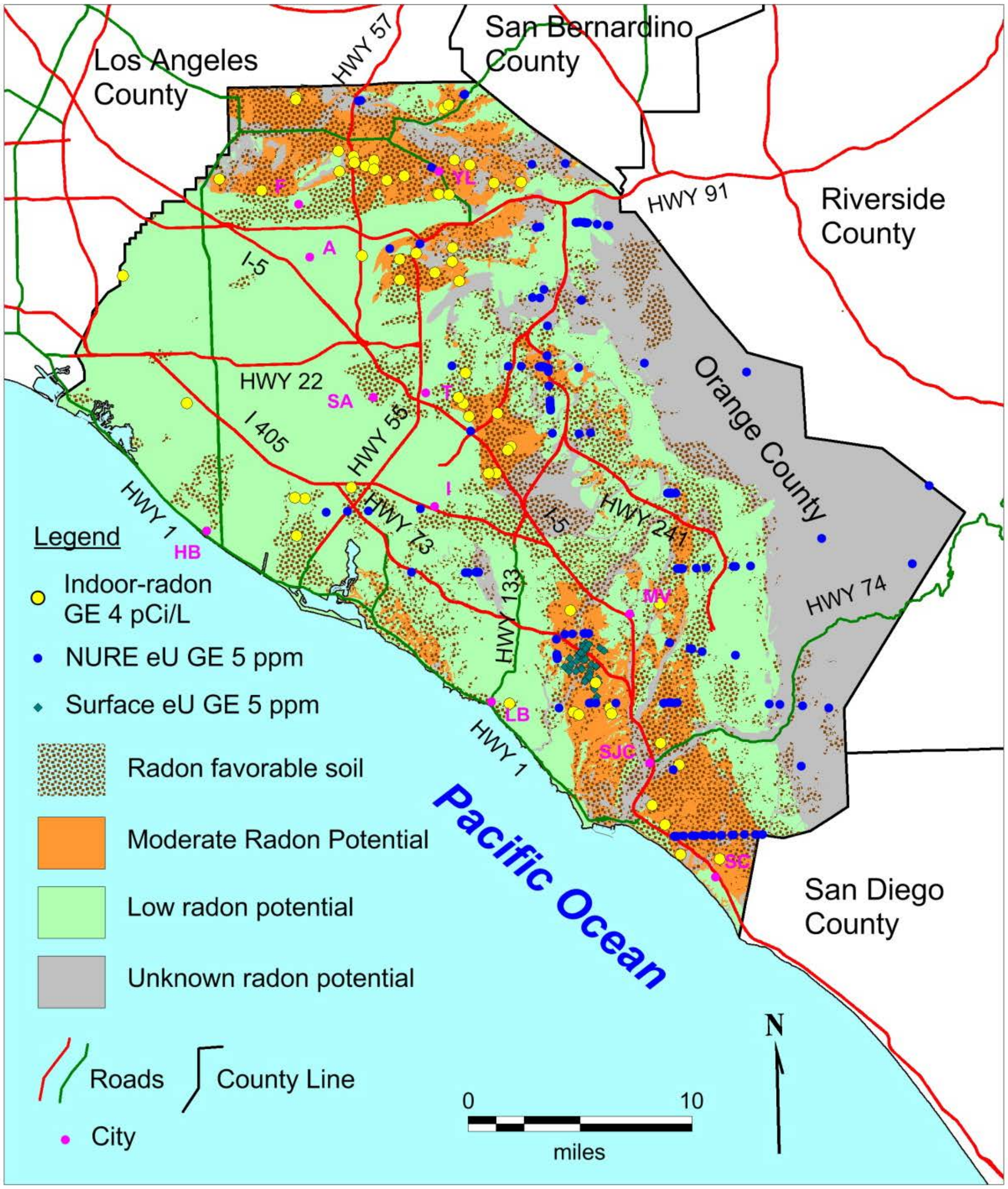

Figure 7. Orange County radon potential zones with supporting data.

"GE" in map legend represents "greater than or equal to." City abbreviations: A, Anaheim; F, Fullerton; HB, Huntington Beach; I, Irvine; LB, Laguna Beach; MV, Mission Viejo; SC, San Clemente; SJC, San Juan Capistrano; T, Tustin; YL, Yorba Linda

Most radon potential zone boundaries are geologic unit boundaries between units of different radon potential. However, as previously discussed, some surficial geologic units may be divided into moderate or low radon potential portions based on material source potential. Such boundaries may be a "best guess" about predominance of moderate or low potential material at a particular location within a surficial unit occurrence based upon available data. An example is a boundary between merging alluvial fans, each with different radon potential source rocks. Additional data in the future could lead to the revision of such boundaries.

Figure 8 shows an occurrence of an Orange County surficial unit with parts assigned to either moderate or unknown radon potential. Note the location of the area, along and east of I-5 oriented northwest to southeast. It is about 9 miles long and 2 to 3 miles wide and includes the Orange County Great Park (and the former El Toro Marine Corps air station). The area is composed of alluvial fan deposits. Moderate radon potential bedrock occurs at higher elevations within the watershed to the east. Eroded material from these units is likely included in the alluvial fans, and may result in their increased radon potential status. However, the northwest part of this area was mapped as moderate radon potential and the southeast part as unknown radon potential. Why were these areas assigned different radon potentials? Indoor-radon data support a moderate radon potential status for the northern portion of this area but no radon data are available in the southern portion. Additionally, moderate radon potential source rocks feeding these fan deposits are less prevalent in the south than to the north. The dividing boundary between the moderate potential and the unknown potential areas is based on fan topography and the presence of indoor-radon data. Obviously, if indoor-radon data became available for the unknown potential area in Figure 8, its potential status could change.

Radon Potential Zone Characteristics

Tables 18, 19, 20 and 21 list various Orange County radon zone characteristics.

Table 18 shows the number of radon measurements and the median, 25 percent and 75 percent quartile radon concentrations, and the minimum and maximum radon concentrations for each radon potential zone and Orange County as a whole.

Table 19 shows the number and percentage of ≥ 4.0 pCi/L, ≥ 10.0 pCi/L and ≥ 10.0 pCi/L radon measurements and the area, in square miles, for each radon potential zone and for Orange County.

Table 20 shows the percentages of ≥ 4.0 pCi/L, ≥ 10.0 pCi/L and ≥ 10.0 pCi/L measurements distributed between the radon potential zones, and the percent land area for each zone. It also shows the cumulative percent of ≥ 4.0 pCi/L measurements and land area for each zone from moderate to unknown. Note that the moderate zone represents only 14.9 percent of

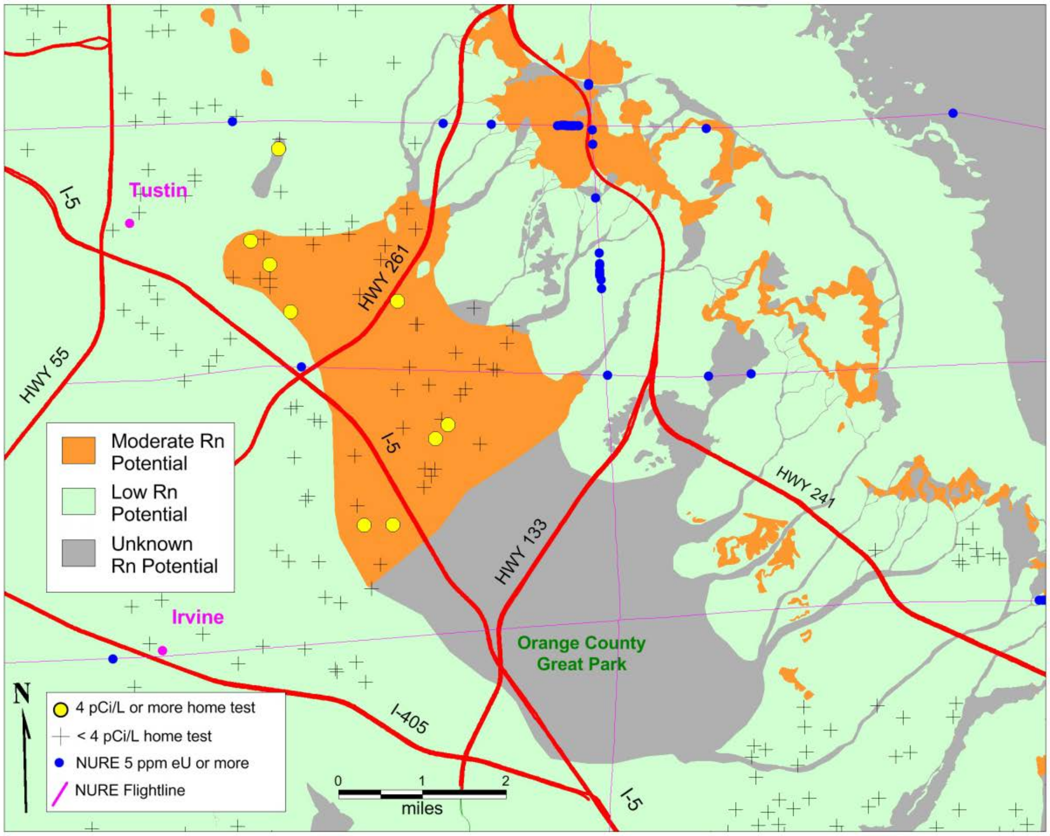

Figure 8. Moderate and unknown radon potential portions of an alluvial fan deposit area in Orange County.

County land area but contains 76.3 percent of all ≥4.0 pCi/L home measurements.

Table 21 shows, for the radon data available for this study, the number of ≥ 4.0 pCi/L measurements per square mile and the total number of radon measurements per square mile in Orange County. Orange County averages about 1.4 radon measurements per square mile.

Potential Zone	N	Median pCi/L	pCi/L at 25%	pCi/L at 75%	Min pCi/L	Max pCi/L
Moderate	340	1.1	0.6	2.3	0.5	25.6
Low	705	0.7	0.5	1.1	0.5	12.9
Unknown	92	0.8	0.5	1.8	0.5	8.3
All	1137	0.8	0.5	1.4	0.5	25.6

Table 18. Orange County radon zone data characteristics.

Potential Zone	N	N ≥ 4.0 pCi/L	% data ≥ 4.0 pCi/L	N ≥ 10.0 pCi/L	% ≥ 10.0 pCi/L	N ≥ 20.0 pCi/L	% ≥ 20.0 pCi/L	Area (sq-mi) land only
Moderate	340	45	13.2	2	0.6	2	0.6	118.7
Low	705	8	1.1	1	0.1	0	0.0	456.3
Unknown	92	6	6.5	0	0.0	0	0.0	221.6
All	1137	59	5.2	3	0.3	2	0.2	796.6

Table 19. ≥ 4.0 pCi/L data incidence per radon potential zone.

Zone	% of all N ≥ 4.0 pCi/L	% of all N ≥ 10.0 pCi/L	% of all N ≥ 20.0 pCi/L	% Area	Cumulative % of ≥ 4.0 pCi/L measurements	Cumulative % of Orange County Land Area
Moderate	76.3	66.7	100.0	14.9	66.7	14.9
Low	13.6	33.3	0	57.3	89.9	72.2
Unknown	10.2	0	0	27.8	100.0	100.0
All	100.0	100.0	100.0	100.0		

Table 20. Distribution of ≥ 4.0 pCi/L, ≥ 10.0 pCi/L and ≥ 20 pCi/L Orange County indoor-radon data by radon potential zone.

Zone	Average number of ≥ 4.0 pCi/L radon measurements per square mile	Average number of all radon measurements per square mile
Moderate	0.3791	2.86
Low	0.0175	1.55
Unknown	0.0271	0.42
All	0.0741	1.43

Table 21. Radon data per square mile in Orange County by radon potential zone.

RADON POTENTIAL ZONE STATISTICS

Indoor Radon Measurement Data Population Characteristics

Appendix K and Appendix L list indoor-radon population statistics for each Orange County radon potential zone. Appendix L provides statistics for non-transformed radon data and Appendix L provides statistics for log-transformed radon data.

Indoor Radon Measurement Frequency Distributions

Frequency distributions of trace element concentration data, such as for uranium and radon in rocks and soils, are often approximated using a lognormal distribution. However, because of the variety of geologic units and complex history of processes affecting them, trace element geochemical data cannot always be fit to a specific frequency distribution (Rose and others, 1979, p. 33). The indoor-radon data for Orange County are an example of this situation. Taken as a whole, the indoor radon test data from the CDPH Orange County survey fail the Shapiro-Wilk normality test in both untransformed and log-transformed modes (Appendix M). Consequently, neither a normal distribution nor a log-normal distribution represents the Orange County radon survey data well. This failure likely arises because the Orange County radon data are a combination of samples from multiple populations with each rock unit having its own unique distribution of indoor-radon data frequencies. On an individual basis, the rock-unit related indoor-radon populations may be log-normal but the aggregate indoor-radon data population is not log-normal.

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) data populations. This study uses the Mann-Whitney rank sum test for comparing individual radon potential zone data populations for this reason. Non-normality also has negative consequences for predictions of percentages of homes with indoor radon levels exceeding 4.0 pCi/L where such predictions incorrectly assume a log-normal population distribution for radon data. Consequently, this study used percentages of Orange County radon survey data at or above 4 pCi/L, 10 pCi/L and 20 pCi/L the radon potential zone population estimates (see Tables 9b and 12).

Statistical Comparison of Indoor Radon Data by Radon Potential Zone

Appendix N lists the Mann-Whitney rank sum test statistical comparison results for the moderate and low radon potential zone indoor-radon data populations. The results show that the indoor-radon data populations for each radon potential zone are statistically distinct. This outcome, along with the fact that the medians for each radon zone population decrease with rank order (moderate>low), is evidence supporting the validity of the Orange County radon potential zone definitions.

Estimated Population Exposed to 4.0 pCi/L or Greater Indoor Air Radon Concentrations in Orange County

The estimates in Tables 22 and 23 provide some perspective about the significance of the indoor-radon issue in Orange County.

Table 22 shows estimates for the resident population and the number of homes in each radon potential zone and within Orange County. Census tract boundaries were compared with radon potential zone boundaries using GIS to make the radon zone population estimates. A census tract's population was assigned entirely to a radon potential zone if the census tract area was entirely within that radon zone. A census tract located in multiple zones had its population divided among the zones in proportion to the percentage of census tract area within each zone. The number of homes per radon potential zone was calculated by dividing the estimated zone population by 2.99, the average number of persons per household in Orange County between 2007 and 2011 (U.S. Department of Commerce, 2013).

Table 23 contains estimates of the number of residents residing in homes with radon at or above 4, 10 and 20 pCi/L for each radon potential zone and for the entire county. These estimates were made by multiplying the percentages of ≥ 4.0 pCi/L, ≥ 10.0 pCi/L, and ≥ 20.0 pCi/L measurements for each zone (from Table 19) by the estimated total population for each zone.

Radon Potential Zone	Estimated Total Population within Zone — 2010 Census Statistics	Estimated Household Population and Total Homes within Zone in 2010	
Orange County		Average Household Population*	Number of Homes**
Moderate	519,626	2.99	173,788
Low	2,291,730	2.99	766,465
Unknown	198,876	2.99	66,514
Total	3,010,232	2.99	1,006,767

Table 22. Estimated population and number of homes in each Orange County radon potential zone.

*Persons per household, 2007-2011, for Orange County, California *from* U.S. Census Bureau, State & County QuickFacts – http://quickfacts.census.gov/qfd/states/06/06059.html

**Zone population ÷ average household population

Table 23 contains two groups of total population estimates for radon exposure in Orange County. In the first, under table heading "*Population Estimates Weighted by Radon Zone and Population Distribution*," the population estimates are the totals of the moderate, low and unknown potential zone population estimates for ≥ 4.0 pCi/L, ≥ 10.0 pCi/L, and ≥ 20.0 pCi/L exposure categories. The second estimate, under table heading *"Population Estimate by Radon Survey Results Un-weighted by Radon Zone or Population Distribution"* was calculated by multiplying the total Orange County population by the Table 19 row "All" percentages for ≥ 4.0 pCi/L, ≥ 10.0 pCi/L, and ≥ 20.0 pCi/L measurement incidence. Note that the un-weighted by zone estimates are significantly higher than the weighted by zone estimates. This situation may result from sample bias with more measurements from higher radon potential areas than lower potential areas. The CDPH Orange County radon survey did target

Radon Potential Zone	**Estimate Total Population for Zone**	**Estimated Population at ≥ 4.0 pCi/L**	**Estimated Population at ≥ 10.0 pCi/L**	**Estimated Population at ≥ 20.0 pCi/L**	**% Area**	**Sq. Miles**
Moderate	519,626	68,591 13.2%	3,118 0.6%	3,118 0.6%	14.9	118.7
Low	2,291,730	25,209 1.1%	2,292 0.1%	0 0.0%	57.3	456.3
Unknown	198,876	12,927 6.5%	0 0.0%	0 0.0%	27.8	221.6
County-Wide Radon Exposure Estimates						
Population Estimate Weighted by Radon Zone and Population Distribution						
Totals *(weighted, i.e., sum of zone population estimates)*	3,010,232*	106,727 3.6%	5,410 0.18%	3,113 0.10%	100	796.6
Population Estimate by Radon Survey Results Un-weighted by Radon Zone or Population Distribution						
Totals for Orange County	3,010,232*	156,532 5.2%	9,031 0.3%	6,020 0.2%	100	796.6

Table 23. Estimates of Orange County population exposed to 4.0 pCi/L or greater indoor-radon levels in residences. (Based on 2010 U.S. Census Data)

*Orange County 2010 population

homes on suspected higher radon potential geologic units over homes on suspected lower radon potential units. Consequently, the weighted population estimates are likely more representative of actual radon exposure in Orange County than the un-weighted population estimates.

ORANGE COUNTY RADON MAPPING PROJECT SUMMARY

This project developed an Orange County radon potential map using short-term indoor-radon test data for homes, airborne radiometric data, surficial gamma-ray spectral data, soil data, and a map of geologic units. County radon potential maps indicate the relative likelihood that indoor air in a home at a particular location will exceed the U.S. EPA recommended radon action level of 4 pCi/L. Radon potential maps do not predict the indoor-radon concentrations in homes or buildings at particular locations.

The principal steps in creating the Orange County radon potential map were:

1. Compiling Orange County indoor-radon, uranium and soil data by geologic unit.
2. Using the compiled data to estimate geologic unit radon potentials.
3. Grouping occurrences of geologic units with similar potentials to define radon potential zones.

Steps 1 and 3 were completed using GIS procedures. Step 2 included consideration of geologic unit radon potentials in other California county radon studies. The Orange County moderate and low radon potential zones were defined using these 3 steps. Definitions used for potential zones are: moderate, 5 percent to 20 percent of home radon measurements expected to be at or above the U.S. EPA action level of 4 pCi/L; low, less than 5 percent of home radon measurements expected to be at or above 4 pCi/L.

This project did not identify any high radon potential geologic units in Orange County. Some geologic units had few or no data and radon potential information was not available for them in previous radon studies. The combined occurrences of these units make up the “unknown” radon potential zone in Orange County.

The finalized Orange County radon potential zones have the following characteristics:

Moderate Radon Potential Zone

- Comprises 14.9 percent (118.6 square miles) of Orange County.
- Contains 76.3 percent of the Orange County ≥ 4.0 pCi/L CDPH indoor-radon survey measurements and 100.0 percent of the ≥ 20.0 pCi/L home measurements.
- The maximum home radon measurement in this zone is 25.6 pCi/L (for a bedroom on the first floor of a slab-on grade foundation home).

Low Radon Potential Zone

- Comprises 57.3 percent (456.1 square miles) of Orange County.
- Contains13.6 percent of the Orange County ≥ 4.0 pCi/L CDPH indoor-radon survey measurements and no ≥ 20.0 pCi/L measurements.
- The Maximum home radon measurement in this zone is 12.9 pCi/L (for a guest room on the first floor of a slab foundation home).

Unknown Radon Potential Zone

- Comprises 27.8 percent (221.6 square miles) of Orange County.
- Contains 10.2 percent of the Orange County ≥ 4.0 pCi/L CDPH indoor-radon survey measurements and no ≥ 20.0 pCi/L measurements.
- The maximum home radon measurement in this zone is 8.3 pCi/L (for a family room, floor not specified, of a crawlspace foundation home).

This study did not identify any high radon potential geologic units or areas in Orange County.

This study did find both homes with indoor-radon concentrations exceeding the U.S. EPA recommended actions level of 4 pCi/L and homes with concentrations below the action level within each radon potential zone in Orange County. Consequently, the only way to know the indoor-radon concentration in a particular home or building is by testing the indoor-air for radon, regardless of the zone in which the home or building is located.

Statistical comparison of the indoor-radon data populations for moderate and low radon potential zones, using the Mann-Whitney rank sum test, shows these zones differ from each other statistically. The P value for this test (the probability of being wrong in concluding that there is a true difference between the groups) is less than 0.001. This is strong statistical support for moderate radon potential areas in Orange County having higher percentages of homes exceeding the U.S. EPA action level than do low radon potential areas.

RECOMMENDATIONS

Indoor-radon testing should be encouraged in Orange County, especially in moderate radon potential zone areas which represent almost 15 percent of the county. Additional indoor-radon measurements in homes within unknown radon potential areas should also be encouraged. Those considering new home construction, particularly at sites within moderate radon potential areas, may wish to consider radon resistant new construction practices. Post construction radon mitigation is possible, if necessary, but will be more expensive than the cost of adding radon reducing features during house construction.

ACKNOWLEDGEMENTS

Milton Fonseca (CGS) produced the final GIS file of the Orange County Radon Potential Map and provided GIS support during the development of this map and report. Kathryn Fukumoto graciously provided the author data from her 2006 surface gamma-ray survey of the Aliso Viejo, Mission Viejo and Laguna Niguel area for use in this study. George Faggella, CDPH Radon program, provided information about the Orange County indoor-radon survey, test results and survey QQ/QC information. John Clinkenbeard (CGS) reviewed the map and report and provided helpful suggestions to improve the text.

REFERENCES

Appleton, J.E., Radon in Air and Water, 2005, in Selinus, Olle, ed., Essentials of Medical Geology, Elsevier Academic Press, Amsterdam, pp. 227-262.

Brookins, D.G., 1990, The Indoor Radon Problem; Columbia University Press, New York, 229 p.

Churchill, R.K, 2014, Radon Potential in San Mateo County, California; California Geological Survey, Special Report 226, 83 p.

Churchill, R.K, 2012, Radon Potential in the Palos Verdes Area, California; California Geological Survey, Special Report 224, 64 p.

Churchill, R.K, 2010, Radon Potential in Santa Cruz County, California; California Geological Survey, Special Report 216, 92 p.

Churchill, R.K, 2008, Radon Potential in San Luis Obispo County, California; California Geological Survey, Special Report 208, 72 p.

Churchill, R.K, 2007, Radon Potential in Monterey County, California; California Geological Survey, Special Report 201, 71 p.

Churchill, R.K, 2006, Radon Potential in Ventura County, California; California Geological Survey, Special Report 194, 42 p.

Churchill, R.K, 2005, Radon Potential in southern Los Angeles County, California; California Geological Survey, Special Report 182, 52 p.

Fukumoto, K.D., Fukumoto, J.M., and Uyeno, G.P., 2006, Discovery of a New Radon-Prone Metropolitan Area in Southern California; GSA annual meeting, Philadelphia, poster.

Grammer, D., and Burkhart, Dr., J.F., 2004, 16-Hour Entry Measurement Course Manual, Western Regional Radon Training Center, University of Colorado, Colorado Springs.

High Life Helicopters, Inc. and QEB Inc., 1980a, Airborne gamma-ray spectrometer and magnetometer survey, Bakersfield Quadrangle (California): U.S. Department of Energy, Open-File Report GJBX-231-80

High Life Helicopters, Inc. and QEB Inc., 1980b, Airborne gamma-ray spectrometer and magnetometer survey, Los Angeles Quadrangle (Final Report Volume 1): U.S. Department of Energy, Open-File Report GJBX-214-80

Kennedy, M.P., and Tan, S.S., 2007, Geologic Map of the Oceanside 30' x 60' Quadrangle, California, California Department of Conservation, California Geological Survey, RGM Map Series, 1:100,000 scale, Map No. 2.

Morton, D.M., and Miller, F.K., 2006, Geologic Map of the San Bernardino and Santa Ana 30' x 60' quadrangles, California, version 1.0; U.S. Geological Survey, Open-File Report 2006-1217, online version 1.0, http://pubs.usgs.gov/of/2006/1217 .

Rose, A.W., Hawkes, H.E., and Webb, J.S., 1979, Geochemistry in Mineral Exploration, second edition; Academic Press Inc., New York, 675 p.

Saucedo, G.J., Greene, H.G., Kennedy, M.P., and Bezore, S.P., 2003, Geologic Map of the Long Beach 30' x 60' Quadrangle, California, Version 1.0, California Department of Conservation, California Geological Survey http://www.conservation.ca.gov/cgs/rghm/rgm/preliminary_geologic_maps.htm

Smith, D.B., Cannon, W.F., Woodruff, L.G., Solano, F., Kilburn, J.E., and Fey, David L., 2013, Geochemical and Mineralogical Data for Soils of the Conterminous United States, U.S. Geological Survey Data Series 801, 19 p., plus .pdf, .xls and .txt digital file Appendices http://pubs.usgs.gov/ds/801/pdf/ds801.pdf

U.S. Department of Commerce, 2013, U.S. Census Bureau, State and County QuickFacts, Orange County, California http://quickfacts.census.gov/qfd/states/06/06059.html

U.S. Department of Commerce, 2012, TIGER/Line Shapefile, 2010, 2010 county, Orange County, CA, 2010 Census Tract County-based, U.S. Census Bureau, Geography Division. http://www.census.gov/geo/www/tiger

U.S. EPA, 2012, A Citizen's Guide to Radon: The guide to protecting yourself and your family from radon, U.S. EPA 402-K-12_002, 160. Available at http://www.epa.gov/radon/pdfs/citizensguide.pdf

NRCS, 2008, Soil Survey Geographic (SSURGO) database for Orange & Western Part of Riverside Counties, California, U.S. Department of Agriculture, Natural Resources Conservation Service, CA678.

Wachtell, J.K., 1978, Soil Survey of Orange County and Western Part of Riverside County, California, Natural Resource Conservation Service, CA 678, 150 p. Available as a PDF at: http://soildatamart.nrcs.usda.gov/manuscripts/CA678/0/orange.pdf

APPENDIX A

Concurrent Indoor-Radon Test Data—In decreasing order by pCi/L

High (pCi/L)	Low (pCi/L)	Difference (pCi/L)	Percent Difference*
8.3	8.1	0.2	2.4
4.2	2.5	1.7	40.5
3.1	3.1	0	0.0
2.9	2.8	0.1	3.4
2.4	2	0.4	16.7
2.3	1.3	1	43.5
2.1	1.8	0.3	14.3
1.9	1.2	0.7	36.8
1.8	1.7	0.1	5.6
1.7	0.5	1.2	70.6
1.7	1.6	0.1	5.9
1.6	1	0.6	37.5
1.6	1.3	0.3	18.8
1.5	1.1	0.4	26.7
1.4	0.9	0.5	35.7
1.4	1.1	0.3	21.4
1.3	0.9	0.4	30.8
1.2	0.9	0.3	25.0
1.2	0.8	0.4	33.3
1.2	1	0.2	16.7
1.2	1.2	0	0.0
1.2	0.8	0.4	33.3
1.2	1.2	0	0.0
1.1	0.8	0.3	27.3
1.1	0.5	0.6	54.5
1	1	0	0.0
1	0.6	0.4	40.0
1	0.5	0.5	50.0
0.9	0.5	0.4	44.4
0.9	0.6	0.3	33.3
0.9	0.7	0.2	22.2
0.8	0.6	0.2	25.0
0.8	0.8	0	0.0
0.8	0.5	0.3	37.5
0.7	0.5	0.2	28.6
0.7	0.5	0.2	28.6
0.6	0.5	0.1	16.7
0.6	0.5	0.1	16.7
0.5	0.5	0	0.0
0.5	0.5	0	0.0
0.5	0.5	0	0.0
0.5	0.5	0	0.0
0.5	0.5	0	0.0
0.5	0.5	0	0.0

* Percent Difference = (Difference ÷ High) X 100

APPENDIX B

Charcoal Detector Field Blanks

Date Analyzed	Results pCi/L
1/23/2008	0.2
1/23/2008	0.4
1/23/2008	0.2

APPENDIX C

Laboratory Spikes of Charcoal Detectors

Date Counted	Mean Chamber Radon Conc.* pCi/L	Test Result pCi/L	Difference from Mean Chamber Conc.* pCi/L	Minimum Chamber Conc.* pCi/L	Maximum Chamber Conc.* pCi/L	Test Result within 10% of the Maximum and Minimum Radon Concentrations for the Chamber?
1/24/2008	14.4	17.3	2.9	12.7	16.1	Yes
1/24/2008	14.4	19.8	5.4	12.7	16.1	No
1/24/2008	14.4	12.8	1.6	12.7	16.1	Yes
1/24/2008	14.4	16	1.6	12.7	16.1	Yes
1/24/2008	14.4	18.1	3.7	12.7	16.1	No
1/24/2008	14.4	16	1.6	12.7	16.1	Yes
1/24/2008	14.4	18.4	4.0	12.7	16.1	No
1/24/2008	14.4	15	0.6	12.7	16.1	Yes

*Conc. = Concentration

APPENDIX D

Results of Follow-up Tests in Homes

Test 1 (pCi/L)	Test 2 (pCi/L)	Difference (pCi/L)	Percent Difference*	Days Between Tests	Date Test 1	Date Test 2
5.6	5.4	0.2	3.6	131	12/01/07	04/10/08
12.9+	1.6**	11.3	87.6	34	12/30/07	02/02/08
12.9+	1.4**	11.6	89.9	34	12/30/07	02/02/08
7.8	3.6	4.2	53.9	22	01/12/08	02/03/08
8.3	4.2	4.1	49.4	60	01/03/08	03/03/08
6.8	5.4	1.4	20.6	24	01/03/08	01/27/08

*Percent Difference = (Difference ÷ the higher of Test 1 or Test 2) X100
**Multiple measurements at a house
+Possible basement measurement?—no information available

APPENDIX E

Geologic Map Units and Indoor-Radon Data for Orange County

Unit Symbol	Unit Name	N Rn Tests	N Rn Tests GE 4 pCi/L	R%*	High pCi/L	100K Quadrangle**
af, Qaf	Artificial fill	3	0	--	0.6	LB, SA
Jbc	Bedford Canyon Formation, undifferentiated	0				SA
Jbc1	Bedford Canyon Formation, Unit 1	0				SA
Jbcm	Marble and limestone	0				SA
Kc	Carbonate-silicate rock	0				SA
Kd	Diorite, undifferentiated	0				SA
Kgb	Gabbro, undifferentiated	0				SA
Kgu	Granite, undifferentiated	0				SA
Khg	Heterogeneous granitic rocks	0				SA
Klhc	Ladd Formation, Baker Canyon Conglomerate Member	0				SA
Klhs	Ladd Formation, Holtz Shale Member	1	0	--	0.8	SA
Klhsc	Ladd Formation, Holtz Shale Member-zone of concentrated sandstone and conglomerate beds	0				SA
Ks	Serpentinite	0				SA
Kt	Tonalite, undifferentiated	0				SA
Ktr	Trabuco Formation	0				OC, SA
Ktrl	Trabuco Formation-lower unit	0				SA
Ktru	Trabuco Formation-upper unit	0				SA
Kvsp	Santiago Peak Volcanics	0				SA
Kvspi	Intrusive rocks associated with Santiago Peak Volcanics	0				SA
Kwp or Kwps	Williams Formation, Pleasants Sandstone Member	0				OC, SA
Kwps?	Williams Formation, Pleasants Sandstone Member?	0				SA
Kwps1	Williams Formation, Pleasants Sandstone Member coarse grained conglomeratic sandstone	0				SA
Kwsr	Williams Formation, Schulz Ranch Member	0				OC, SA
Kwsr?	Williams Formation, Schulz Ranch Member?	0				SA
Kwsrl	Williams Formation, Schulz Ranch Member, lower member	0				SA

Unit Symbol	Unit Name	N Rn Tests	N Rn Tests GE 4 pCi/L	R%*	High pCi/L	100K Quadrangle**
Kwsru	Williams Formation, Schulz Ranch Member, upper member	0				SA
Kwst	Williams Formation, Starr Member	0				SA
Qb	Beach deposits	0				LB
Qc	Very young colluvial deposits	0				SA
Qch	Coyote Hills Formation	6	0	0	3.8	SA
Qe	Very young eolian deposits	0				SA
Qes	Very young estuarine deposits	1	0	0	0.5	SA
Qf	Very young alluvial-fan deposits	1	0	0	1.1	SA
Qlh	La Habra Formation	14	3	21.4	4.3	SA
Qls or Qls?	Landslide Deposits or Very young landslide deposits	21	1	4.8	4.2	OC, SA
Qm	Very young marine deposits	0				SA
Qmb	Marine beach deposits	0				OC
Qoa	Old axial-channel deposits	8	0		1.6	OC,SA
Qoa1-2	Old alluvial flood plain deposits, units 1-2	0				OC
Qoa2-6	Old alluvial flood plain deposits, units 2-6	0				OC
Qoa6	Old alluvial flood plain deposits, unit 6	0				OC
Qoa7	Old axial-channel deposits, unit 7 (youngest subdivision of Qoa)	0				OC, SA
Qof	Old alluvial fan deposits	29	1	3.5	25.6	SA
Qofa	Old alluvial fan and valley deposits-sand	0				LB
Qofs	Old alluvial fan and valley deposits-silt	0				LB
Qof3	Old alluvial-fan deposits, unit 3	8	3	37.5	7.3	SA
Qop	Old paralic deposits, undivided	24	1	4.2	6.6	SA
Qop1	Old paralic deposits, unit 1	3	0	--	0.8	SA
Qop1-2	Old paralic deposits, units 1-2	4	0	--	2.2	OC
Qop2	Old paralic deposits, unit 2	5	0	--	2.3	SA
Qop2-6	Old paralic deposits, units 2-6	9	0	0	2.3	OC,SA
Qop3-6	Old paralic deposits, units 3-6	2	0	--	0.9	SA
Qopa	Old paralic deposits-sand	7	0	--	0.7	LB
Qopc	Old paralic deposits-clay	0				LB
Qopf	Old paralic deposits overlain by alluvial fan deposits	40	2	5.0	6.6	SA
Qops	Old paralic deposits-silt	8	0	0	2.3	LB
Qop3	Old paralic deposits, unit 3	0				SA
Qop4	Old paralic deposits, unit 4	0				SA
Qop6	Old paralic deposits, unit 6	0				SA

Unit Symbol	Unit Name	N Rn Tests	N Rn Tests GE 4 pCi/L	R%*	High pCi/L	100K Quadrangle**
Qop6	Old paralic deposits, unit 6	0				OC
Qop7?	Old paralic deposits, unit 7?	0				SA
Qpe	Paralic estuarine deposits	0				LB
Qsp	San Pedro Formation	1	0	--	1.1	SA
Qsp1	San Pedro Formation-lower sequence siltstone and claystone	0				SA
Qsp2	San Pedro Formation-sandstone, part conglomeratic	0				SA
Qsp3	San Pedro Formation-siltstone and claystone	0				SA
Qsp4	San Pedro Formation-upper unit sandstone, part conglomeratic	0				SA
Qsw	Very young slope-wash deposits	0				SA
Qsw?	Very young slope-wash deposits?	0				SA
Qvoa	Very old axial-channel deposits	11	0	0	1.7	SA
Qvoa1	Very old axial-channel deposits, unit 1	2	0	--	0.5	SA
Qvoa1?	Very old axial channel deposits, unit 1?	0				SA
Qvoa2	Very old axial-channel deposits, unit 2	16	0	0	1.4	SA
Qvoa3	Very old axial-channel deposits, unit 3	0				SA
Qvoa4	Very old axial-channel deposits, unit 4	0				SA
Qvoa5	Very old axial-channel deposits, unit 5	0				SA
Qvoa11	Very old paralic deposits, unit 11	0				OC
Qvoa12	Very old paralic deposits, unit 12	0				OC
Qvoa13	Very old paralic deposits, unit 13	0				OC
Qvof	Very old alluvial fan deposits	103	11	10.7	9.0	SA
Qvof1	Very old alluvial fan deposits, unit 1	0				SA
Qvop	Very old paralic deposits	10	0	0	0.8	OC, SA
Qvop?	Very old paralic deposits?	0				SA
Qvop5	Very old paralic deposits, unit 5	0				OC
Qvop7-8	Very old paralic deposits, units 7-8	1	0	--	0.9	OC
Qvop9-10	Very old paralic deposits, units 9-10	0				OC

Unit Symbol	Unit Name	N Rn Tests	N Rn Tests GE 4 pCi/L	R%*	High pCi/L	100K Quadrangle**
Qvop10-13	Very old paralic deposits, units 10-13	2	0	--	0.6	OC
Qw	Very young wash deposits	1	0	--	0.5	OC, SA
Qya	Young alluvial flood plain deposits	82	4	4.9	6.1	OC, SA
Qyc	Young colluvial deposits	0				OC, SA
Qyc?	Young colluvial deposits	0				SA
Qyf	Young alluvial fan deposits	305	16	5.3	8.3	OC, SA
Qyf3	Young alluvial fan deposits, unit 3	0				SA
Qyfa	Young alluvial fan and valley deposits-sand	33	1	3.0	5.1	LB
Qyfc	Young alluvial fan and valley deposits-clay	36	1	2.8	8.0	LB
Qyfs	Young alluvial fan and valley deposits-silt	36	0	0	1.9	LB
Qyls	Young landslide deposits	9	3	33.3	22.0	SA
Qyls?	Young landslide deposits?	9	2	22.2	8.5	SA
Qype	Young paralic estuarine deposits	5	0	0	1.2	LB
Qypt	Young peat deposits	1	0	--	1.3	SA
Qyw	Young wash deposits	0				SA
Tc	Capistrano Formation	0				SA
Tcga	Conglomerate of Arlington Mountain	0				SA
Tco	Capistrano Formation, Oso Member	19	0	0	1.7	SA
Tcs	Capistrano Formation, siltstone facies	78	6	7.7	7.8	OC, SA
Tcs?	Capistrano Formation, siltstone facies	0				SA
Tct	Capistrano Formation-turbidite facies	0				OC
Tfl	Fernando Formation-lower member	2	0	--	0.7	SA
Tflc	Fernando Formation-lower member, conglomerate	1	0	--	1.8	SA
Tfu	Fernando Formation-upper member	1	1	--	6.1	SA
Tfuc	Fernando Formation-upper member, conglomerate	0				SA
Tiema	Volcanic intrusive rocks associated with El Modeno Volcanics-andesitic	0				SA
Tiema?	Volcanic intrusive rocks associated with El Modeno Volcanics-andesitic	0				SA
Tiemd	Volcanic intrusive rocks associated with El Modeno Volcanics-diabasic	2	0	--	0.8	SA

Unit Symbol	Unit Name	N Rn Tests	N Rn Tests GE 4 pCi/L	R%*	High pCi/L	100K Quadrangle**
Tiemd?	Volcanic intrusive rocks associated with El Modeno Volcanics-diabasic?	0				SA
Tm	Monterey Formation	34	1	2.9	4.0	OC, SA
Tn	Niguel Formation	36	0	0	3.4	OC, SA
Tn?	Niguel Formation?	0				
Tp	Puente Formation, undifferentiated	0				SA
Tplv	Puente Formation, La Vida Member	1	0	--	0.9	SA
Tpsc	Puente Formation, Sycamore Canyon Member	11	1	9.1	4.1	SA
Tpscc	Puente Formation, Sycamore Canyon Member, conglomeratic Zone	0				SA
Tpsq	Puente Formation, Soquel member	10	0	0	1.9	SA
Tpy	Puente Formation, Yorba Member	9	0	0	2.8	SA
Ts	Sespe Formation	17	0	0	1.4	SA
Ts?	Sespe Formation?	0				SA
Tsa	Santiago Formation	7	0	0	0.8	OC, SA
Tsi	Silverado Formation	5	0	0	0.8	OC, SA
Tsicg	Silverado Formation-basal conglomerate	0				SA
Tsis	Silverado Formation-Serrano Clay	0				SA
Tsm	San Mateo Formation	0				OC
Tso	San Onofre Breccia	1	0	--	0.6	OC
Tsob	San Onofre Breccia	7	0	0	0.8	SA
Tsoss	San Onofre Breccia-sandstone	0				OC
Tsv	Sespe and Vaqueros Formations-undivided	0				OC
Tto	Topanga Formation	0				OC
Tt	Topanga Group, undifferentiated	15	1	6.7	12.9	SA
Ttb	Topanga Group-Bommer Formation	4	0	--	1.1	SA
Ttlt	Topanga Formation-Los Trancos Formation	4	0	--	0.7	SA
Ttlt?	Topanga Formation-Los Trancos Formation?	0				SA
Ttp	Topanga Group-Paulerino Formation	0				SA
Tv	Vaqueros Formation	4	0	--	1.4	SA
Tv?	Vaqueros Formation?	0				SA
Tvem	El Modeno Volcanics, undifferentiated	0				SA

Unit Symbol	Unit Name	N Rn Tests	N Rn Tests GE 4 pCi/L	R%*	High pCi/L	100K Quadrangle**
Tvema	El Modeno Volcanics-andesitic	4	0	--	0.8	SA
Tvemb	El Modeno Volcanics-basalt	0				SA
Tvemt	El Modeno Volcanics-tuff and tuff breccia	3	0	--	1.1	SA
Tvs	Vaqueros and Sespe Formations, undifferentiated	5	0	0	2.1	SA
		1137	59	5.2		

* Radon potential is typically low for these units in California. Artificial fill could be moderate or high if moderate or high radon potential material is used for fill.

** LB=Long Beach; OC=Oceanside; SA=Santa Ana

APPENDIX F

Statistical Comparison of Indoor-Radon Data for Moderate and Low Potential Portions of Orange County Surficial Deposits

Mann-Whitney Rank Sum Test				
Group	***N***	***Median pCi/L***	***25% pCi/L***	***75% pCi/L***
Moderate Rn Potential Qls+Qls?	17	0.6	0.5	1.25
Low Rn Potential Qls+Qls?	2	0.6	0.5	0.7
Result	Mann-Whitney U Statistic =13.000 T-16.000 n(small)=2 n(big)=17 (P=0.629) The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P=0.629)			
Moderate Rn Potential Qvof	83	1.4	0.8	2.6
Low Rn Potential Qvof	15	0.9	0.6	1.4
Result	Mann-Whitney U Statistic =435.000 T=555.000 n(small)=15 n(big)=83 (P=0.064) The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P=0.064)			
Moderate Rn Potential Qya	19	1.0	0.6	2.1
Low Rn Potential Qya	43	0.6	0.5	1.1
Result	Mann-Whitney U Statistic = 264.000 T=743.000 n(small)=19 N(big)=43 (P=0.023) 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=0.023)			

Appendix F continued on next page

APPENDIX F continued				
Group	***N***	***Median pCi/L***	***25% pCi/L***	***75% pCi/L***
Moderate Rn Potential Qyf	81	1.6	0.8	2.7
Low Rn Potential Qyf	210	0.7	0.5	1.1
Result	Mann-Whitney U Statistic = 4284.000 T=16047.000 m(small)=81 n(big)=210 (P=<0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P=< 0.001)			
Moderate Rn Potential Qyls+Qyls?	14	1.1	0.725	5.275
Low Rn Potential Qyls+Qyls?	3	1.5	1.0	1.5
Result	Mann-Whitney U Statistic = 20.000 T=28.000 n(small)=3 n(big)=14 (P=0.949) The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P=0.949)			

APPENDIX G

NURE Airborne Radiometric Survey
Equivalent Uranium (eU) Data for Orange County

Geologic Unit Symbol	Geologic Unit Name	Quad	N	N ≥ 5.0 ppm eU	% N ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Med. Ppm eU*
af	Artificial fill	LB	No Data					
Jbc	Bedford Canyon Formation, undifferentiated	SA	1049	1	0.1	0.1	5.1	2.2
Jbc1	Bedford Canyon Formation, Unit 1	SA	No Data					
Jbcm	Marble and limestone	SA	No Data					
Kc	Carbonate – silicate Rock	SA	No Data					
Kd	Diorite, undifferentiated	SA	55	0	0	0.1	2.2	1.05
Kgb	Gabbro, undifferentiated	SA	No Data					
Kgu	Granite, undifferentiated	SA	No Data					
Khg	Heterogeneous granitic rocks	SA	243	1	0.4	<0.1	5.1	2.1
Klbc	Baker Canyon Conglomerate Member	SA	160	0	0	0.3	4.0	2.35
Klhs	Ladd Formation, Holtz Shale Member-zone of concentrated sandstone and conglomerate beds	SA	100	1	1.0	0.3	5.0	2.7
Klhsc	Ladd Formation, Holtz Shale Member-zone of concentrated sandstone and conglomerate beds	SA	33	0	0	0.8	3.5	2.0
Ks	Serpentinite	SA	No Data					
Kt	Tonalite, undifferentiated	SA	7	0	0	1.4	4.0	2.7
Ktr	Trabuco Formation	OC						

Geologic Unit Symbol	Geologic Unit Name	Quad	N	N ≥ 5.0 ppm eU	% N ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Med. Ppm eU*
Ktr	Trabuco Formation	SA	298	0	0	<0.1	4.4	1.8
Ktrl	Trabuco Formation-lower Unit	SA	1	0	0	3.3	3.3	3.3
Ktru	Trabuco Formation-upper Unit	SA	2	0	0	2.7	3.6	3.15
Kvsp	Santiago Peak Volcanics	SA	354	0	0	<0.1	4.9	1.6
Kvspi	Intrusive rocks associated with Santiago Peak Volcanics	SA	40	0	0	0.4	3.9	1.9
Kwp	Williams Formation, Pleasants Sandstone Member	OC	48	1	2.1	1.7	5.4	3.1
Kwps	Williams Formation, Pleasants Sandstone Member	SA	81	3	3.7	1.2	5.9	3.35
Kwps?	Williams Formation, Pleasants Sandstone Member?	SA	No Data					
Kwps1	Williams Formation, Pleasants Sandstone Member-coarse grained conglomerate sandstone	SA	No Data					
Kwsr	Williams Formation, Schulz Ranch Member	OC	134	0	0	0.9	4.4	2.5
Kwsr	Williams Formation, Schulz Ranch Member	SA	200	2	1.0	0.7	5.3	2.8

Geologic Unit Symbol	Geologic Unit Name	Quad	N	N ≥ 5.0 ppm eU	% N ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Med. Ppm eU*
Kwsr?	Williams Formation, Schulz Ranch Member?	SA	No Data					
Kwsrl	Williams Formation, Schulz Ranch Member, lower member	SA	61	0	0	0.2	4.4	26
Kwsru	Williams Formation, Schulz Ranch Member, upper member	SA	No Data					
Kwst	Williams Formation, Starr Member	SA	84	0	0	0.2	4.8	1.8
Qaf	Artificial fill	SA	27	0	0	1.1	3.7	2.55
Qaf?	Artificial fill.	SA	No Data					
Qb	Beach deposits	LB	No Data					
Qc	Very young colluvial deposits	SA	No Data					
Qch	Coyote Hills Formation	SA	No Data					
Qe	Very young eolian deposits	SA	No Data					
Qes	Very young estuarine deposits	SA	21	0	0	1.1	3.2	2.5
Qf	Very young alluvial-fan deposits	SA	4	0	0	1.5	3.1	2.45
Qlh	La Habra Formation	SA	21	0	0	1.2	4.9	3.05
Qls	Landslide Deposits	OC	119	2	1.7	1.1	5.5	3.1
Qls?	Landslide Deposits	OC	23	0	0	1.2	4.7	2.55
Qls	Very young landslide deposits	SA	173	4	2.3	0.3	6.8	2.7
Qls?	Very young landslide deposits?	SA	94	4	4.3	0.7	7.2	2.8
Qm	Very young marine deposits	SA	2	0	0	1.6	2.5	2.05

Geologic Unit Symbol	Geologic Unit Name	Quad	N	N ≥ 5.0 ppm eU	% N ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Med. Ppm eU*
Qmb	Marine beach deposits	OC	No Data					
Qoa	Old Axial channel deposits	OC	22	0	0	1.5	4.5	2.6
Qoa	Old Axial channel deposits	SA	27	1	3.7	1.1	5	2.5
Qoa1-2	Old alluvial flood plain deposits, units 1-2	OC	1	0	0	4.8	4.8	4.8
Qoa2-6	Old alluvial flood plain deposits, units 2-6	OC	20	0	0	1.8	4.2	3.3
Qof6	Old alluvial flood plain deposits, unit 6	OC	24	0	0	1.6	4.2	2.7
Qoa7	Old alluvial flood plain deposits, unit 7	OC	14	0	0	1.3	3.7	2.5
Qoa7	Old axial-channel deposits, unit 7 (youngest subdivision of Qoa)	SA	No Data					
Qof	Old alluvial fan deposits	SA	226	1	0.4	<0.5	5.3	2.4
Qofa	Old alluvial fan and valley deposits-sand	LB	No Data					
Qofs	Old alluvial fan and valley deposits-silt	LB	No Data					
Qof3	Old alluvial-fan deposits, unit 3	SA	5	0	0	0.8	3.2	1.5
Qop	Old paralic deposits, undivided	SA	No Data					
Qop1	Old paralic deposits, unit 1	SA	8	0	0	1.2	2.7	2.35
Qop1-2	Old Paralic deposits, units 1 and 2 undivided	OC	27	0	0	1.5	3.5	2.3
Qop2	Old paralic deposits, unit 2	SA	6	0	0	1.8	2.9	2.3

Geologic Unit Symbol	Geologic Unit Name	Quad	N	N ≥ 5.0 ppm eU	% N ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Med. Ppm eU*
Qop2-6	Old paralic deposits, units 2-6 undivided	OC	36	0	0	<0.3	3.4	1.4
Qop2-6	Old paralic deposits, units 2-6 undivided	SA	23	0	0	0.4	3.0	1.9
Qop3-6	Old paralic deposits, units 3-6 undivided	SA	No Data					
Qopa	Old paralic deposits, sand	LB	No Data					
Qopc	Old paralic deposits, clay	LB	No Data					
Qopf	Old paralic deposits overlain by alluvial-fan deposits	SA	215	3	1.4	0.6	5.1	2.7
Qops	Old paralic deposits, silt	LB	No Data					
Qop3	Old paralic deposits, unit 3	SA	24	0	0	0.5	3.4	2.2
Qop4	Old paralic deposits, unit 4	SA	No Data					
Qop6	Old paralic deposits, Unit 6	OC	No Data					
Qop6	Old paralic deposits, unit 6	SA	No Data					
Qop7?	Old paralic deposits, unit 7	SA	No Data					
Qpe	Paralic estuarine deposits	LB	No Data					
Qsp	San Pedro Formation	SA	No Data					
Qsp1	San Pedro Formation, unit 1	SA	No Data					
Qsp2	San Pedro Formation, unit 2	SA	No Data					

Geologic Unit Symbol	Geologic Unit Name	Quad	N	N ≥ 5.0 ppm eU	% N ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Med. ppm eU*
Qsp3	San Pedro Formation, unit 3	SA	No Data					
Qsp4	San Pedro Formation, unit 4	SA	No Data					
Qsw	Very young slope-wash deposits	SA	4	0	0	1.1	2.8	2.1
Qsw?	Very young slope-wash deposits?	SA	No Data					
Qvoa	Very old axial-channel deposits	SA	89	1	1.1	0.9	5.2	2.55
Qvoa1	Very old axial-channel deposits, unit 1	SA	10	0	0	1.1	4.2	2.55
Qvoa1?	Very old axial-channel deposits, unit 1?	SA	No Data					
Qvoa2	Very old axial-channel deposits, unit 2	SA	45	1	2.2	2.0	5.6	3.1
Qvoa3	Very old axial-channel deposits, unit 3	SA	20	0	0	1.4	4.6	2.5
Qvoa4	Very old axial-channel deposits, unit 4	SA	No Data					
Qvoa5	Very old axial-channel deposits, unit 5	SA	No Data					
Qvoa11	Very old alluvial flood-plain deposits, unit 11	OC	No Data					
Qvoa12	Very old alluvial flood-plain deposits, unit 12	OC	No Data					
Qvoa13	Very old alluvial flood-plain deposits, unit 13	OC	No Data					
Qvof	Very old alluvial-fan deposits	SA	513	1	0.2	<0.2	5.1	2.5
Qvof1	Very old alluvial-fan deposits, unit 1	SA	No Data					

Geologic Unit Symbol	Geologic Unit Name	Quad	N	N ≥ 5.0 ppm eU	% N ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Med. ppm eU*
Qvop	Very old paralic deposits, undivided	OC	No Data					
Qvop	Very old paralic deposits	SA	42	0	0	0.9	4.4	2.4
Qvop?	Very old paralic deposits?	SA	No Data					
Qvop5	Very old paralic deposits, unit 5	OC	No Data (unit not in county)					
Qvop7-8	Very old paralic deposits, units 7 and 8 undivided	OC	2	0	0	2.5	4.1	3.3
Qvop9-10	Very old paralic deposits, units 9 and 10 undivided	OC	No Data					
Qvop10-13	Very old paralic deposits, units 10-13 undivided	OC	16	1	6.3	1.6	5.4	3.15
Qw	Wash deposits	OC	5	0	0	2	4.6	2.1
Qw	Very young wash deposits	SA	69	0	0	0.5	4.2	2.35
Qya	Young alluvial flood plain deposits	OC	127	2	1.6	1.0	5.9	2.75
Qya	Young axial-channel deposits	SA	594	10	1.7	0.4	6.2	2.8
Qyc	Young colluvial deposits	OC	13	1	7.7	1.6	5.8	3.2
Qyc	Young colluvial deposits	SA	7	1	14.3	2.5	6.3	3.7
Qyc?	Young colluvial deposits?	SA	No Data					
Qyf	Young alluvial-fan deposits	OC	3	0	0	3.2	4.1	3.5
Qyf	Young alluvial-fan deposits	SA	1182	10	0.9	0.7	6.3	2.8
Qyf3	Young alluvial-fan deposits, unit 3	SA	47	2	4.3	1.1	5.2	2.6
Qyfa	Young alluvial fan and valley deposits-sand	LB	No Data					
Qyfc	Young alluvial fan and valley deposits-clay	LB	No Data					

Geologic Unit Symbol	Geologic Unit Name	Quad	N	N ≥ 5.0 ppm eU	% N ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Med. ppm eU*
Qyfs	Young alluvial fan and valley deposits-silt	LB	No Data					
Qyls	Young landslide deposits	SA	357	7	2.0	0.2	6.7	2.6
Qyls?	Young landslide deposits?	SA	36	1	2.8	1.0	5.2	3.1
Qype	Young paralic estuarine deposits	LB	No Data					
Qypt	Young peat deposits	SA	No Data					
Qyw	Young wash deposits	SA	2	0	0	3.3	3.6	3.45
Tc	Capistrano Formation	SA	10	1	10.0	1.4	5	3.65
Tcga	Conglomerate of Arlington Mountain	SA	No Data					
Tco	Capistrano Formation, Oso Member	SA	96	0	0	0.6	4.8	2.5
Tcs	Capistrano Formation, siltstone facies	OC	153	7	4.6	0.5	6.0	3.4
Tcs	Capistrano Formation, siltstone facies	SA	124	6	4.8	1.3	5.6	3.1
Tcs?	Capistrano Formation, siltstone facies?	SA	No Data					
Tct	Capistrano Formation, turbidite facies	OC	No Data					
Tfl	Fernando Formation-lower member	SA	39	0	0	0.1	3.8	2.65
Tflc	Fernando Formation-lower member conglomerate	SA	No Data					
Tfu	Fernando Formation, upper member	SA	37	0	0	1.5	3.9	2.7

Geologic Unit Symbol	Geologic Unit Name	Quad	N	N ≥ 5.0 ppm eU	% N ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Med. ppm eU*
Tfuc	Fernando Formation-upper member conglomerate	SA	2	0	0	2	3.2	2.6
Tiema	Volcanic intrusive rocks associated with El Modeno Volcanics-Andesitic	SA	No Data					
Tiema?	Volcanic intrusive rocks associated with El Modeno Volcanics-Andesitic?	SA	No Data					
Tiemd	Volcanic intrusive rocks associated with El Modeno Volcanics-Diabasic	SA	15	0	0	1.3	3.7	1.6
Tiemd?	Volcanic intrusive rocks associated with El Modeno Volcanics-Diabasic?	SA	No Data					
Tm	Monterey Formation	OC	68	4	5.9	0.5	5.6	2.8
Tm	Monterey Formation	SA	247	10	4.1	0.7	6.8	3.2
Tn	Niguel Formation	OC	12	0	0	1.4	3.6	2.6
Tn	Niguel Formation	SA	181	2	1.1	1.3	7.2	2.9
Tn?	Niguel Formation?	SA	No Data					
Tp	Puente Formation, undif.	SA	No Data					
Tplv	Puente Formation, La Vida Member	SA	202	16	7.9	0.5	7.4	2.9

Geologic Unit Symbol	Geologic Unit Name	Quad	N	N ≥ 5.0 ppm eU	% N ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Med. ppm eU*
Tpsc	Puente Formation, Sycamore Canyon Member	SA	89	0	0	1.1	4.9	2.6
Tpscc	Puente Formation, Sycamore Canyon Member, conglomeratic zone	SA	No Data					
Tpsq	Puente Formation, Soquel member	SA	208	6	2.9	1.0	6.3	2.6
Tpy	Puente Formation, Yorba Member	SA	137	3	2.2	0.1	6.1	2.5
Trmu	Rocks of Menifee Valley, undif.	SA	12	0	0	1.9	4.0	2.25
Ts	Sespe Formation	SA	377	12	3.2	0.7	6.1	2.9
Ts?	Sespe Formation?	SA	No Data					
Tsa	Santaigo Formation	OC	71	2	2.8	1.0	6.0	2.75
Tsa	Santaigo Formation	SA	204	3	1.5	0.8	5.1	2.9
Tsi	Silverado Formation	OC	12	0	0	1.9	3.3	2.65
Tsi	Silverado Formation	SA	159	8	5.0	0.7	5.8	3.2
Tsicg	Silverado Formation-basal conglomerate	SA	No Data					
Tsis	Silverado Formation-Serrano Clay	SA	No Data					
Tsm	San Mateo Formation	OC	3	0	0	1.3	2.0	1.6
Tso	San Onofre Breccia	OC	53	0	0	0.1	2.7	1.25
Tsob	San Onofre Breccia	SA	167	2	1.2	0.3	5.8	2.4

Geologic Unit Symbol	Geologic Unit Name	Quad	N	N ≥ 5.0 ppm eU	% N ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Med. ppm eU*
Tsoss	San Onofre Breccia-sandstone	OC	No Data					
Tsv	Sespe and Vaqueros Formations-undivided	OC	No Data					
Tto	Topanga Formation	OC	9	0	0	1.0	1.7	1.4
Tt	Topanga Group, undifferentiated	SA	250	1	0.4	0.5	5.0	2.1
Ttb	Topanga Group-Bommer Formation	SA	82	1	1.2	0.8	5.0	2.3
Ttlt	Topanga Formation-Los Trancos Formation	SA	60	0	0	0.5	6.2	2.5
Ttlt?	Topanga Formation-Los Trancos Formation?	SA	No Data					
Ttp	Topanga Group-Paulerino Formation	SA	9	0	0	1.7	3.7	2.7
Tv	Vaqueros Formation	SA	201	0	0	0.8	4.9	2.75
Tv?	Vaqueros Formation?	SA	3	0	0	3.0	4.6	3.0
Tvem	El Modeno Volcanics, undifferentiated	SA	No Data					
Tvema	El Modeno Volcanics, andesite	SA	9	0	0	0.8	2.1	1.5
Tvemb	El Modeno Volcanics, basalt	SA	No Data					
Tvemt	El Modeno Volcanics, tuff and tuff breccia	SA	14	0	0	0.7	2.6	1.5
Tvs	Vaqueros and Sespe Formations, undifferentiated	SA	135	7	5.2	0.5	6.6	2.9

APPENDIX H

Geologic Units, NRCS Soil Units and Indoor-Radon Data

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
af	Artificial fill	115	Beaches	3	0	--	0.5	0.6
Klhs	Ladd Formation, Holtz Shale member	134	Calleguas clay loam, 50-75% slopes, eroded	1	0	--		0.8
Qch	Coyote Hills Formation	100	Alo clay, 9-15% slopes	1	0	--		0.5
		102	Alo clay, 30-50% slopes	1	0	--		3.8
		109	Anaheim clay loam, 30-50% slopes	1	0	--		2.7
		175	Myford sandy loam, 9-15% slopes	1	0	--		0.5
		185	Pits	1	0	--		0.9
		203	Soper cobbly loam, 15-50% slopes	1	0	--		1.2
Qes	Very young estuarine deposits	115	Beaches	1	0	--		0.5
Qf	Very young alluvial-fan deposits	192	Rock outcrop-Cieneba Complex, 30-75% slopes	1	0	--		1.1
Qlh	La Habra Formation	100	Alo clay, 9-15% slopes	3	0	--	0.5	1.2
		102	Alo clay, 30-50% slopes	2	0	--	0.6	0.8
		112	Balcom clay loam, 15-30% slopes	1	0	--		0.5
		113	Balcom clay loam, 30-50% slopes	1	0	--		0.8
		173	Myford sandy loam, 2-9% slopes	1	0	--		0.5
		175	Myford sandy loam, 9-15% slopes	1	1	--		4.2
		180	Nacimiento clay loam, 15-30%	1	0	--		3.3
		181	Nacimiento clay loam, 30-50%	1	1	--		4.3
		188	Rincon clay loam, 2-9% slopes	1	1	--		4.0
		219	Xerothents, loamy, cut and fill areas, 9-15% slopes	2	0	--		0.5

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qls	Landslide Deposits or Very Young Landslide Deposits	100	Alo clay, 9-15% slopes	1	0	--		0.5
		101	Alo clay, 15-30% slopes	4	0	--	0.5	1.0
		102	Alo clay, 30-50% slopes	1	0	--		1.0
		112	Balcom clay loam, 15-30% slopes	1	0	--		0.5
		114	Balcom-Rock outcrop complex, 15-50% slopes	1	0	--		1.2
		126	Bosanko clay, 9-15% slopes	2	0	--		3.0
		128	Bosanko clay, 30-50% slopes	1	0	--		0.5
		134	Calleguas clay loam, 50-75% slopes, eroded	8	0	--		0.8
		147	Carralitos loamy sand, moderately fine substratum	1	0	--		1.3
Qls?	Landslide Deposits?	101	Alo clay, 15-30% slopes	1	1	--		4.2
Qoa	Old axial-channel deposits	127	Bosanko clay, 15-30% slopes	1	0	--		0.7
		169	Modjeska gravelly loam, 2-9% slopes	4	0	--		1.3
		170	Modjeska gravelly loam, 9-15% slopes	1	0	--		1.6
		173	Myford sandy loam, 2-9% slopes	1	0	--		0.8
		224	Yorba cobbly sandy loam, 9-30% slopes	1	0	--		1.5
Qof	Old alluvial-fan deposits	148	Cropley clay, 0-2% slopes	3	0	--	0.5	2.0
		149	Cropley clay, 2-9% slopes	1	0	--		2.6
		166	Mocho loam, 0-2% slopes	1	0	--		1.1
		168	Modjeska gravelly loam, 0-2% slopes	9	0	--	0.5	3.1
		172	Myford sandy loam, 0-2% slopes	4	1	--	0.5	25.6
		178	Myford sandy loam, thick surface, 0-2% slopes	1	0	--		0.5

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qof cont.		194	San Emigdio fine sandy loam, 0-2% slopes	9	0	--	0.5	2.8
		218	Xeralfic arents, loamy, 9-15% slopes	1	0	--		1.1
Qof3	Old alluvial-fan deposits, unit 3	132	Botella clay loam, 2-9% slopes	1	0	--		3.2
		133	Botella clay loam, 9-15% slopes	1	0	--		2.2
		173	Myford sandy loam, 2-9% slopes	1	1	--		5.2
		178	Myford sandy loam, thick surface, 0-2% slopes	1	0	--		3.7
		181	Nacimiento clay loam, 30-50%	1	1	--		7.3
		194	San Emigdio fine sandy loam, 0-2% slopes	1	0	--		0.9
		207	Sorrento loam, 2-9% slopes	1	0	--		2.6
		208	Sorrento clay loam, 0-2% slopes	1	1	--		4.6
Qop	Old paralic deposits, undivided	122	Bolsa silt loam	1	0	--		1.4
		161	Marina loamy sand, 0-2%	1	0	--		0.5
		162	Marina loamy sand, 2-9%	4	0	--	0.5	1.0
		172	Myford sandy loam, 0-2% slopes	4	1	--	0.6	6.6
		173	Myford sandy loam, 2-9% slopes	10	0	--	0.5	0.9
		177	Myford sandy loam, 15-30% slopes, eroded	1	0	--		0.5
		178	Myford sandy loam, thick surface, 0-2% slopes	2	0	--	0.5	1.6
		185	Pits	1	0	--		0.5
Qop1	Old paralic deposits, unit 1	100	Alo clay, 9-15% slopes	1	0	--		0.8
		173	Myford sandy loam, 2-9% slopes	2	0	--	0.5	0.8
Qop1-2	Old paralic deposits, units 1-2	101	Alo clay, 15-30% slopes	1	0	--		0.5
		102	Alo clay, 30-50% slopes	1		--		1.2

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qop 1-2 cont.		217	Xeralfic arents, loamy, 2-9% slopes	1	0	--		2.2
		218	Xeralfic arents, loamy, 9-15% slopes	1	0	--		0.6
Qop2	Old paralic deposits, unit 2	100	Alo clay, 9-15% slopes	2	0	--	0.5	0.5
		162	Marina loamy sand, 2-9%	1	0	--		1.0
		175	Myford sandy loam, 9-15% slopes	1	0	--		0.9
		177	Myford sandy loam, 15-30% slopes, eroded	1	0	--		2.3
Qop2-6	Old paralic deposits, units 2-6	126	Bosanko clay, 9-15% slopes	1	0	--		0.5
		142	Cieneba sandy loam, 30-75% slopes eroded	1	0	--		0.5
		162	Marina loamy sand, 2-9%	2	0	--	0.5	1.1
		173	Myford sandy loam, 2-9% slopes	3	0	--	0.8	2.3
		175	Myford sandy loam, 9-15% slopes	1	0	--		0.5
		217	Xeralfic arents, loamy, 2-9% slopes	1	0	--		0.5
Qop3-6	Old paralic deposits, units 3-6	173	Myford sandy loam, 2-9% slopes	1	0	--		0.5
		177	Myford sandy loam, 15-30% slopes, eroded	1	0	--		0.9
Qopa	Old paralic deposits-sand	162	Marina loamy sand, 2-9%	2	0	--	0.5	0.5
		173	Myford sandy loam, 2-9% slopes	2	0	--	0.5	0.5
		178	Myford sandy loam, thick surface, 0-2% slopes	1	0	--		0.7
		211	Tidal flats	2	0	--	0.5	0.5
Qopf	Old paralic deposits overlain by alluvial fan deposits	127	Bosanko clay, 15-30% slopes	1	0	--		3.5
		142	Cieneba sandy loam, 30-75% slopes eroded	1	0	--		0.5
		149	Cropley clay, 2-9% slopes	11	1	9.9	0.5	6.6

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qopf cont.		162	Marina loamy sand, 2-9%	7	0	--	0.5	0.8
		173	Myford sandy loam, 2-9% slopes	3	1	--	0.5	4.1
		174	Myford sandy loam, 2-9% slopes, eroded	4	0	--	0.5	1.3
		175	Myford sandy loam, 9-15% slopes	1	0	--		1.3
		178	Myford sandy loam, thick surface, 0-2% slopes	5	0	--	0.5	3.0
		179	Myford sandy loam, thick surface, 2-9% slopes	3	0	--	0.5	0.8
		184	Omni clay	3	0	--	0.5	1.2
		193	San Andreas sandy loam, 15-30% slopes	1	0	--		0.9
Qops	Old paralic deposits-silt	173	Myford sandy loam, 2-9% slopes	5	0	--	0.5	1.7
		178	Myford sandy loam, thick surface, 0-2% slopes	3	0	--	0.5	2.3
Qsp	San Pedro Formation	175	Myford sandy loam, 9-15% slopes	1	0	--		1.1
Qvoa	Very old axial-channel deposits	142	Cieneba sandy loam, 30-75% slopes, eroded	1	0	--		0.5
		173	Myford sandy loam, 2-9% slopes	3	0	--	0.7	1.0
		175	Myford sandy loam, 9-15% slopes	2	0	--	0.5	0.6
		177	Myford sandy loam, 15-30% slopes, eroded	3	0	--	0.5	0.9
		179	Myford sandy loam, thick surface, 2-9% slopes	1	0	--		1.3

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qvoa cont.		225	Yorba cobbly sandy loam, 9-30% slopes, eroded	1	0	--		1.7
Qvoa1	Very old axial-channel deposits, unit 1	221	Yorba gravelly sandy loam, 2-9% slopes	1	0	--		0.5
		226	Yorba cobbly sandy loam, 30-50% slopes	1	0	--		0.5
Qvoa2	Very old axial-channel deposits, unit 2	169	Modjeska gravelly loam, 2-9% slopes	11	0	--	0.5	1.0
		170	Modjeska gravelly loam, 9-15% slopes	2	0	--	0.5	0.8
		171	Modjeska gravelly loam, 15-30% slopes	1	0	--		1.4
		173	Myford sandy loam, 2-9% slopes	1	0	--		0.6
		174	Myford sandy loam, 2-9% slopes, eroded	1	0	--		0.5
Qvof	Very old alluvial fan deposits	100	Alo clay, 9-15% slopes	5	0	--	0.5	3.0
		101	Alo clay, 15-30% slopes	4	0	--	0.5	1.8
		111	Balcom clay loam, 9-15% slopes	1	0	--		0.9
		134	Calleguas clay loam, 50-75% slopes, eroded	1	0	--		2.2
		168	Modjeska gravelly loam, 0-2%	1	0	--		2.2
		173	Myford sandy loam, 2-9% slopes	45	7	--	0.5	9.0
		174	Myford sandy loam, 2-9% slopes, eroded	2	0	--	0.5	1.2
		175	Myford sandy loam, 9-15% slopes	4	0	--	0.9	2.1
		176	Myford sandy loam, 15-30% slopes	3	1	--	0.7	4.4

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qvof cont.		177	Myford sandy loam, 15-30% slopes, eroded	4	0	--	0.5	0.9
		178	Myford sandy loam, thick surface, 0-2% slopes	1	0	--		0.5
		179	Myford sandy loam, thick surface, 2-9% slopes	1	0	--		0.6
		180	Nacimiento clay loam, 15-30%	2	0	--	0.5	1.6
		188	Rincon clay loam, 2-9% slopes	5	1	--	0.5	4.3
		207	Sorrento loam, 2-9% slopes	3	0	--	0.5	1.2
		208	Sorrento clay loam, 0-2% slopes	2	0	--	1.0	1.8
		209	Sorrento clay loam, 2-9% slopes	2	0	--	0.5	2.6
		217	Xeralfic arents, loamy, 2-9% slopes	2	1	--	2.6	5.9
		218	Xeralfic arents, loamy, 9-15% slopes	2	0	--	0.6	0.8
		219	Xerothents, loamy, cut and fill areas, 9-15% slopes	6	1	--	0.5	4.1
		220	Xerothents, loamy, cut and fill areas, 15-30% slopes	2	0	--	1.1	2.9
		221	Yorba gravelly sandy loam, 2-9% slopes	2	0	--	1.4	1.5
		223	Yorba gravelly sandy loam, 15-30% slopes	1	0	--		2.7
		225	Yorba cobbly sandy loam, 9-30% slopes, eroded	2	0	--	1.7	1.8
Qvop	Very old paralic deposits	162	Marina loamy sand, 2-9%	8	0	--	0.5	0.8
		172	Myford sandy loam, 0-2% slopes	1	0	--		0.5
		175	Myford sandy loam, 9-15% slopes	1	0	--		0.5
Qvop7-8	Very old paralic deposits, units 7-8	102	Alo clay, 30-50% slopes	1	0	--		0.9

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qvop 10-13	Very old paralic deposits, units 10-13	173	Myford sandy loam, 2-9% slopes	1	0	--		0.5
		175	Myford sandy loam, 9-15% slopes	1	0	--		0.6
Qw	Very young wash deposits	158	Hueneme fine sandy loam, drained	1	0	--		0.5
Qya	Young alluvial flood plain deposits	100	Alo clay, 9-15% slopes	2	0	--	1.0	1.1
		102	Alo clay, 30-50% slopes	2	0	--	0.5	2.1
		111	Balcom clay loam, 9-15% slopes	1	1	--		5.8
		122	Bolsa silt loam	1	0	--		3.3
		123	Bolsa silt loam, drained	7	0	--	0.5	1.7
		128	Bosanko clay, 30-50% slopes	2	1	--	1.8	6.1
		132	Botella clay loam, 2-9% slopes	6	0	--	0.5	1.3
		133	Botella clay loam, 9-15% slopes	2	0	--	0.5	0.5
		134	Calleguas clay loam, 50-75% slopes, eroded	3	1	--	0.5	1.0
		135	Capistrano sandy loam, 2-9% slopes	4	0	--	0.5	1.2
		136	Capistrano sandy loam, 9-15% slopes	2	0	--	0.5	0.5
		139	Chino silty clay loam	1	0	--		0.5
		140	Chino silty clay loam, drained	1	0	--		0.6
		146	Corralitos loamy sand	3	0	--	0.5	1.9
		148	Cropley clay, 0-2% slopes	2	0	--	0.5	2.0
		149	Cropley clay, 2-9% slopes	1	0	--		2.8
		163	Metz loamy sand	2	0	--	0.6	2.3
		164	Metz loamy sand, moderately fine substratum	1	0	--		1.1
		167	Mocho loam, 2-9% slopes	3	0	--	0.5	0.9
		173	Myford sandy loam, 2-9% slopes	1	0	--		2.1
		175	Myford sandy loam, 9-15% slopes	1	0	--		2.1

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qya cont.		177	Myford sandy loam, 15-30% slopes, eroded	1	0	--		0.5
		179	Myford sandy loam, thick surface, 2-9% slopes	1	0	--		0.8
		182	Omni silt loam, drained	1	0	--		0.5
		184	Omni clay	8	1	--	0.5	5.3
		191	Riverwash	1	0	--		0.5
		194	San Emigdio fine sandy loam, 0-2% slopes	1	0	--		0.9
		197	Soboba gravelly loamy sand, 0-5% slopes	1	0	--		0.6
		206	Sorrento loam, 0-2% slopes	1	0	--		0.9
		207	Sorrento loam, 2-9% slopes	13	0	--	0.5	1.9
		208	Sorrento clay loam, 0-2% slopes	1	0	--		2.9
		209	Sorrento clay loam, 2-9% slopes	4	0	--	0.5	2.3
		211	Tidal flats	1	0	--		0.5
Qyf	Young alluvial fan deposits	100	Alo clay, 9-15% slopes	1	0	--		0.5
		122	Bolsa silt loam	2	0	--	0.5	0.6
		123	Bolsa silt loam, drained	20	0	0.0	0.5	2.7
		132	Botella clay loam, 2-9% slopes	2	1	--	1.0	8.2
		134	Calleguas clay loam, 50-75% slopes, eroded	1	0	--		2.5
		135	Capistrano sandy loam, 2-9%	1	0	--		0.5
		139	Chino silty clay loam	1	0	--		0.9
		140	Chino silty clay loam, drained	10	0	--	0.5	3.0
		141	Cieneba sandy loam, 15-30% slopes	2	0	--	0.5	0.7
		145	Cieneba-Rock outcrop complex, 30-75%	1	0	--		0.5

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qyf cont.		146	Corralitos loamy sand	1	0	--		1.9
		147	Carralitos loamy sand, moderately fine substratum	1	0	--		2.2
		149	Cropley clay, 2-9% slopes	1	0	--		0.5
		154	Gabino gravelly clay loam, 15-50% slopes	1	0	--		1.2
		158	Hueneme fine sandy loam, drained	52	0	--	0.5	2.3
		163	Metz loamy sand	36	1	2.8	0.5	5.8
		164	Metz loamy sand, moderately fine substratum	12	0	--	0.5	3.0
		165	Mocho sandy loam, 0-2% slopes	3	0	--	0.5	2.6
		166	Mocho loam, 0-2% slopes	51	7	13.7	0.5	8.2
		167	Mocho loam, 2-9% slopes	7	0	--	0.8	1.8
		173	Myford sandy loam, 2-9% slopes	1	0	--		1.9
		177	Myford sandy loam, 15-30% slopes, eroded	2	0	--	0.5	0.5
		178	Myford sandy loam, thick surface, 0-2% slopes	4	0	--	0.7	1.0
		179	Myford sandy loam, thick surface, 2-9% slopes	1	0	--		2.7
		182	Omni silt loam, drained	5	0	--	0.5	1.1
		184	Omni clay	6	1	--	0.5	5.1
		194	San Emigdio fine sandy loam, 0-2% slopes	32	0	0.0	0.5	3.0
		195	San Emigdio fine sandy loam, 2-9% slopes	1	0	--		1.2
		196	San Emigdio fine sandy loam, moderately fine substratum	9	0	--	0.5	1.9

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qyf cont.		197	Soboba gravelly loamy sand, 0-5% slopes	1	0	-		0.5
		206	Sorrento loam, 0-2% slopes	8	1	--	0.5	8.3
		207	Sorrento loam, 2-9% slopes	1	0	--		0.8
		208	Sorrento clay loam, 0-2% slopes	23	4	17.4	0.5	7.3
		209	Sorrento clay loam, 2-9% slopes	2	1	--	1.9	8.3
		219	Xerothents, loamy, cut and fill areas, 9-15% slopes	2	0	--	0.5	1.1
		224	Yorba cobbly sandy loam, 9-30% slopes	1	0	--		1.4
Qyfa	Young alluvial fan and valley deposits-sand	123	Bolsa silt loam, drained	2	0	--	0.5	0.9
		146	Corralitos loamy sand	1	0	-		0.8
		158	Hueneme fine sandy loam, drained	4	1	--	0.5	5.1
		163	Metz loamy sand	2	0	--	0.5	0.5
		164	Metz loamy sand, moderately fine substratum	6	0	--	0.5	1.6
		194	San Emigdio fine sandy loam, 0-2% slopes	5	0	--	0.5	0.7
		196	San Emigdio fine sandy loam, moderately fine substratum	13	0	--	0.5	1.6
Qyfc	Young alluvial fan and valley deposits-clay	123	Bolsa silt loam, drained	6	0	--	0.5	2.2
		124	Bolsa silty clay loam	2	0	--	0.5	1.3
		125	Bolsa silty clay loam, drained	12	1	--	0.5	8.0
		158	Hueneme fine sandy loam	9	0	--	0.5	2.0
		164	Metz loamy sand, moderately fine substratum	1	0	-		0.7

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qyfc cont.		166	Mocho loam, 0-2% slopes	1	0	--		1.1
		184	Omni clay	3	0	--	0.6	3.0
		194	San Emigdio fine sandy loam, 0-2% slopes	1	0	--		1.0
		196	San Emigdio fine sandy loam, moderately fine substratum	1	0	--		0.5
Qyfs	Young alluvial fan and valley deposits-silt	123	Bolsa silt loam, drained	17	0	0.0	0.5	1.5
		124	Bolsa silty clay loam	1	0	--		1.3
		125	Bolsa silty clay loam, drained	2	0	--	0.8	1.9
		157	Hueneme fine sandy loam	1	0	--		1.5
		158	Hueneme fine sandy loam, drained	9	0	--	0.5	1.9
		164		1	0	--		0.5
		196	San Emigdio fine sandy loam, moderately fine substratum	5	0	--	0.5	1.1
Qyls	Young landslide deposits	102	Alo clay, 30-50% slopes	2	1	--	0.5	22.0
		128	Bosanko clay, 30-50% slopes	1	0	--		1.1
		129	Bosanko Balcom complex, 15-30% slopes	1	0	--		1.5
.		135	Capistrano sandy loam, 2-9% slopes	1	0	--		1.0
		180	Nacimiento clay loam, 15-30% slopes	1	0			0.8
		220	Xerothents, loamy, cut and fill areas, 15-30% slopes	3	2	--	0.5	6.1
Qyls?	Young landslide deposits?	102	Alo clay, 30-50% slopes	2	0	--	0.5	1.1
		106	Anaheim loam, 15-30% slopes	1	0			1.5
		134	Calleguas clay loam, 50-75% slopes, eroded	4	2	--	0.8	8.5

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qyls? cont.		149	Cropley clay, 2-9% slopes	2	0	--	0.8	0.8
Qype	Young paralic estuarine deposits	125	Bolsa silty clay loam, drained	5	0	--	0.5	1.2
Qypt	Young peat deposits	123	Bolsa silt loam, drained	1	0	--		1.3
Tco	Capistrano Formation, Oso Member	112	Balcom clay loam, 15-30% slopes	1	0	--		0.9
		128	Bosanko clay, 30-50% slopes	1	0	--		0.7
		129	Bosanko-Balcom complex, 15-30% slopes	2	0	--	0.5	1.4
		134	Calleguas clay loam, 50-75% slopes, eroded	2	0	--	0.5	0.5
		141	Cieneba sandy loam, 15-30% slopes eroded	1	0	--		0.5
		142	Cieneba sandy loam, 30-75% slopes eroded	9	0	--	0.5	1.7
		173	Myford sandy loam, 2-9% slopes	1	0	--		0.7
		175	Myford sandy loam, 9-15% slopes	1	0	--		1.6
		185	Pits	1	0	--		1.7
Tcs	Capistrano Formation, siltstone facies	100	Alo clay, 9-15% slopes	4	0	--	0.5	2.9
		101	Alo clay, 15-30% slopes	14	1	7.1	0.5	5.3
		102	Alo clay, 30-50% slopes	21	1	4.8	0.5	7.8
		112	Balcom clay loam, 15-30% slopes	1	0	--		0.5
		126	Bosanko clay, 9-15% slopes	1	0	--		1.0
		127	Bosanko clay, 15-30% slopes	8	1	--	0.5	4.9
		128	Bosanko clay, 30-50% slopes	4	0	--	0.9	2.6

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Tcs cont.		129	Bosanko-Balcom complex, 15-30% slopes	2	0	--	0.6	1.0
		131	Botella loam, 2-9% slopes	1	0	--		1.4
		132	Botella clay loam, 2-9% slopes	1	0	--		0.9
		133	Botella clay loam, 9-15% slopes	1	1	--		4.5
		134	Calleguas clay loam, 50-75% slopes, eroded	10	1	--	0.5	6.1
		142	Cieneba sandy loam, 30-75% slopes eroded	1	0	--		0.5
		149	Cropley clay, 2-9% slopes	1	0	--		0.5
		175	Myford sandy loam, 9-15% slopes	1	0	-		0.9
		177	Myford sandy loam, 15-30% slopes, eroded	2	0	--	0.5	0.6
		207	Sorrento loam, 2-9% slopes	2	1	--	1.7	6.6
		219	Xerothents, loamy, cut and fill areas, 9-15% slopes	1	0	--		1.3
		220	Xerothents, loamy, cut and fill areas, 15-30% slopes	2	0	--	0.7	1.7
Tfl	Fernando Formation-lower member	101	Alo clay, 15-30% slopes	1	0	--		0.7
		219	Xerothents, loamy, cut and fill areas, 9-15% slopes	1	0	--		0.7
Tflc	Fernando Formation-lower member conglomerate	225	Yorba cobbly sandy loam, 9-30% slopes, eroded	1	0	--		1.8
Tfu	Fernando Formation-upper member	219	Xerothents, loamy, cut and fill areas, 9-15% slopes	1	1	--		6.1

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Tiemd	Volcanic intrusive rocks associated with El Modeno Volcanics-diabasic	101	Alo clay, 15-30% slopes	2	0	--	0.5	0.8
Tm	Monterey Formation	101	Alo clay, 15-30% slopes	1	0	--		1.8
		102	Alo clay, 30-50% slopes	2	1	--	0.5	4.0
		106	Anaheim loam, 15-30% slopes	1	0	--		1.2
		111	Balcom clay loam, 9-15% slopes	1	0	--		0.6
		112	Balcom clay loam, 15-30% slopes	1	0	--		0.7
		114	Balcom-Rock outcrop complex, 15-50% slopes	2	0	--	0.5	0.6
		126	Bosanko clay, 9-15% slopes	2	0	--	0.6	1.1
		127	Bosanko clay, 15-30% slopes	2	0	--	0.7	3.3
		128	Bosanko clay, 30-50% slopes	2	0	--	0.5	2.0
		129	Bosanko-Balcom complex, 15-30% slopes	7	0	--	0.5	1.9
		134	Calleguas clay loam, 50-75% slopes, eroded	9	0	-	0.5	1.7
		173	Myford sandy loam, 2-9% slopes	2	0	--	0.5	3.0
		176	Myford sandy loam, 15-30% slopes	1	0	--		1.4
		179	Myford sandy loam, thick surface, 2-9% slopes	1	0	--		0.5
Tn	Niguel Formation	100	Alo clay, 9-15% slopes	1	0	--		0.5
		101	Alo clay, 15-30% slopes	10	0	--	0.5	2.7
		102	Alo clay, 30-50% slopes	5	0	--	0.5	3.1
		129	Bosanko-Balcom complex, 15-30% slopes	1	0	--		0.7
		132	Botella clay loam, 2-9% slopes	1	0	--		2.9

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Tn cont.		134	Calleguas clay loam, 50-75% slopes, eroded	3	0	--	0.8	1.2
		141	Cieneba sandy loam, 15-30% slopes eroded	1	0	--		1.5
		142	Cieneba sandy loam, 30-75% slopes eroded	2	0	--	0.5	0.5
		175	Myford sandy loam, 9-15% slopes	3	0	--	1.7	3.4
		176	Myford sandy loam, 15-30% slopes	1	0	--		1.0
		177	Myford sandy loam, 15-30% slopes, eroded	2	0	--	1.7	2.3
		191	Riverwash	1	0	--		1.9
		192	Rock outcrop-Cieneba complex, 30-75% slopes	1	0	--		0.9
		224	Yorba cobbly sandy loam, 9-30% slopes	1	0	--		0.5
		225	Yorba cobbly sandy loam, 9-30% slopes, eroded	2	0	--	0.5	1.2
		226	Yorba cobbly sandy loam, 30-50% slopes	1	0	--		0.5
Tplv	Puente Formation, La Vida Member	101	Alo clay, 15-30% slopes	1	0	--		0.9
Tpsc	Puente Formation, Sycamore Canyon Member	100	Alo clay, 9-15% slopes	1	0	--		1.2
		141	Cieneba sandy loam, 15-30% slopes eroded	1	1	--		4.1
		142	Cieneba sandy loam, 30-75% slopes eroded	4	0	--	0.7	2.0

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Tpsc cont.		145	Cieneba-Rock outcrop complex, 30-75% slopes	2	0	--	0.5	0.6
		175	Myford sandy loam, 9-15% slopes	1	0	--		0.8
		209	Sorrento clay loam, 2-9% slopes	1	0	--		0.5
		225	Yorba cobbly sandy loam, 9-30% slopes, eroded	1	0	--		1.1
Tpsq	Puente Formation, Soquel Member	131	Botella loam, 2-9% slopes	1	0	--		0.7
		134	Calleguas clay loam, 50-75% slopes, eroded	2	0	--	0.5	0.7
		136	Capistrano sandy loam, 9-15% slopes	2	0	--	0.5	1.0
		142	Cieneba sandy loam, 30-75% slopes eroded	5	0	--	0.5	1.9
Tpy	Puente Formation, Yorba Member	101	Alo clay, 15-30% slopes	3	0	--	0.6	2.8
		102	Alo clay, 30-50% slopes	3	0	--	1.1	2.4
		108	Anaheim clay loam, 15-30% slopes	1	0	--		0.5
		134	Calleguas clay loam, 50-75% slopes, eroded	1	0	--		0.8
		219	Xerothents, loamy, cut and fill areas, 9-15% slopes	1	0	--		0.9
Ts	Sespe Formation	104	Alo variant clay, 15-30% slopes	4	0	--	0.7	1.4
		105	Alo variant clay, 30-50% slopes	1	0	--		0.6
		106	Anaheim loam, 15-30% slopes	1	0	--		0.5
		134	Calleguas clay loam, 50-75% slopes, eroded	3	0	--	0.5	0.9
		135	Capistrano sandy loam, 2-9% slopes	1	0	--	0.7	

Geologic Unit	**Geologic Unit Name**	**Soil Unit**	**Soil Unit Name**	**N**	**N ≥ 4 pCi/L**	**R%**	**Low pCi/L**	**High pCi/L**
Ts cont.		142	Cieneba sandy loam, 30-75% slopes eroded	3	0	--	0.5	0.6
		201	Soper gravelly loam, 15-30% slopes	2	0	--	0.5	0.5
		204	Soper-Rock outcrop complex, 30-75% slopes	2	0	--	0.5	0.8
Tsa	Santiago Formation	101	Alo clay, 15-30% slopes	1	0	--		0.7
		142	Cieneba sandy loam, 30-75% slopes eroded	6	0	--	0.5	0.8
Tsi	Silverado Formation	132	Botella clay loam, 2-9% slopes	1	0	--		0.5
		134	Calleguas clay loam, 50-75% slopes, eroded	2	0	--	0.5	0.8
		141	Cieneba sandy loam, 15-30% slopes eroded	1	0	--		0.5
		170	Modjeska gravelly loam, 9-15% slopes	1	0	--		0.5
Tso	San Onofre Breccia	226	Yorba cobbly sandy loam, 30-50% slopes	1	0	--		0.6
Tsob	San Onofre Breccia	134	Calleguas clay loam, 50-75% slopes, eroded	1	0	--		0.8
		142	Cieneba sandy loam, 30-75% slopes eroded	1	0	--		0.7
		173	Myford sandy loam, 2-9% slopes	1	0	--		0.6
		202	Soper gravelly loam, 30-50% slopes	2	0	--	0.5	0.5
		222	Yorba gravelly sandy loam, 9-15% slopes	2	0	--	0.5	0.6
Tt	Topanga Group, undifferentiated	106	Anaheim loam, 15-30% slopes	1	0	--		0.5
		113	Balcom clay loam, 30-50% slopes	3	1	--	0.5	12.8

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Tt cont.		141	Cieneba sandy loam, 15-30% slopes eroded	2	0	--	0.6	1.7
		142	Cieneba sandy loam, 30-75% slopes eroded	1	0	--		0.5
		145	Cieneba-Rock outcrop complex, 30-75% slopes	4	0	--	0.5	1.5
		175	Myford sandy loam, 9-15% slopes	1	0	--		0.9
		176	Myford sandy loam, 15-30% slopes	1	0	--		0.5
		179	Myford sandy loam, thick surface, 2-9% slopes	1	0	--		0.5
		202	Soper gravelly loam, 30-50% slopes	1	0	--		0.5
Ttb	Topanga Group-Bommer Formation	106	Anaheim loam, 15-30% slopes	1	0	--		1.0
		108	Anaheim clay loam, 15-30% slopes	1	0	--		0.8
		145	Cieneba-Rock outcrop complex, 30-75% slopes	2	0	--	0.5	1.1
Ttlt	Topanga Formation-Low Trancos Formation	100	Alo clay, 9-15% slopes	1	0	--		0.7
		101	Alo clay, 15-30% slopes	1	0	--		0.5
		173	Myford sandy loam, 2-9% slopes	2	0	--	0.5	0.5
Tv	Vaqueros Formation	101	Alo clay, 15-30% slopes	1	0	--		0.8
		128	Bosanko clay, 30-50% slopes	1	0	--		1.4
		134	Calleguas clay loam, 50-75% slopes, eroded	1	0	--		0.5
		174	Myford sandy loam, 2-9% slopes, eroded	1	0	--		0.5
Tvema	El Modeno Volcanics, andesitic	102	Alo clay, 30-50% slopes	1	0	--		0.5

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Tvema cont.		109	Anaheim clay loam, 30-50% slopes	1	0	--		0.5
		127	Bosanko clay, 15-30% slopes	1	0	--		0.6
		145	Cieneba-Rock outcrop complex, 30-75% slopes	1	0	--		0.8
Tvemt	El Modeno Volcanics-tuff and tuff breccias	101	Alo clay, 15-30% slopes	1	0	--		0.5
		145	Cieneba-Rock outcrop complex, 30-75% slopes	1	0	--		1.1
		149	Cropley clay, 2-9% slopes	1	0	--		0.5
Tvs	Vaqueros and Sespe Formations, undifferentiated	134	Calleguas clay loam, 50-75% slopes, eroded	2		--	1.1	2.1
		192	Rock outcrop-Cieneba complex, 30-75% slopes	2	0	--	0.5	0.5
		202	Soper gravelly loam, 30-50% slopes	1	0	--		1.9
				1137	59	5.2		

APPENDIX I

Orange County NRCS Soil Units and Indoor-Radon Measurements

Soil Unit Symbols	Soil Unit Name	Permeability by Soil Sub-unit	Substratum	Shrink-Swell	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	R(%)	Min pCi/L	Max pCi/L
100, 101, 102	Alo clay, 9-15% slopes, 15-30% slopes, 30-50% slopes	Slow	Weathered interbedded shale and sandstone	High	24-40	113	5	4.4	0.5	22.0
104, 105	Alo variant clay, 15-30% slopes, 30-50% slopes	Slow	Fractured weathered soft sandstone and shale	High	24-40	5			0.6	1.4
106	Anaheim loam, 15-30% slopes	Moderate	Weathered fractured sandstone or shale	Low	20-36	5			0.5	1.5
108, 109	Anaheim clay loam, 15-30% slopes, 30-50% slopes	Moderately slow	Weathered fractured sandstone or shale	Mod	20-36	4			0.5	2.7
111, 112, 113	Balcom clay loam, 9-15% slopes, 15-30% slopes, 30-50% slopes	Moderately slow	Weathered fine grained sandstone and some calcareous shale coated with lime	Mod	24-36	12	2	--	0.5	12.9
114	Balcom-Rock outcrop complex, 15-50% slopes	Moderately slow (Balcom part)	Weathered fine grained sandstone and some calcareous shale coated with lime	Mod (Balcom)	24-36 (Balcom)	3			0.5	1.2
115	Beaches	--		--	--	4			0.5	0.6

Soil Unit Symbols	Soil Unit Name	Permeability by Soil Sub-unit	Substratum	Shrink-Swell	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	R(%)	Min pCi/L	Max pCi/L
122	Bolsa silt loam	Moderately slow	Somewhat poorly drained soils on alluvial fans	Mod	>60	4			0.5	3.3
123	Bolsa slit loam, drained	Moderately slow	Somewhat poorly drained soils on alluvial fans	Mod	>60	53	0	0.0	0.5	2.7
124	Bolsa silty clay loam	Moderately slow	Somewhat poorly drained soils on alluvial fans	Mod	>60	3			0.5	1.3
125	Bolsa silty clay loam, drained	Moderately slow	Somewhat poorly drained soils on alluvial fans	Mod	>60	19	1	5.3?	0.5	8.0
126, 127, 128	Bosanko clay, 9-15% slopes, 15-30% slopes, 30-50% slopes	Slow	Weathered shale	High	22-36	31	2	6.5	0.5	6.1
129	Bosanko-Balcom complex, 15-30% slopes	Slow	45% Bosanko clay, 40% Balcom clay loam, 5% Alo clay, 3% Cieneba sandy loam, 7% Calleguas clay loam	High	26-36	13			0.5	1.9
131	Botella loam, 2-9% slopes	Mod(8"), Moderately slow (58")	Soils formed in sedimentary alluvium	Mod	>60	2			0.7	1.4
132, 133	Botella clay loam, 2-9% slopes, 9-15% slopes	Moderately slow	Soils formed in sedimentary alluvium	Mod	>60	16	2	12.5?	0.5	8.2

Soil Unit Symbols	Soil Unit Name	Permeability by Soil Sub-unit	Substratum	Shrink-Swell	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	R(%)	Min pCi/L	Max pCi/L
134	Calleguas clay loam, 50-75% slopes, eroded	Moderate	Soft fractured shale with lime coatings	Mod	10-19	54	4	7.4	0.5	8.5
135, 136	Capistrano sandy loam, 2-9 % slopes, 9-15% slopes	Moderately rapid	Soils formed in granitic alluvium on alluvial fans and alluvial plains in small valleys and in sedimentary alluvium of the coastal foothills	Low	>60	11			0.5	1.2
139	Chino silty clay loam	Moderately slow	Soils formed in sedimentary alluvium	Mod	>60	2			0.5	0.9
140	Chino silty clay loam, drained	Moderately slow	Soils formed in sedimentary alluvium	Mod	>60	11			0.5	3
141, 142	Cieneba sandy loam, 15-30% slopes, 30-75% slopes eroded	Moderately rapid	Weathered granodiorite	Low	5-19	43	1		0.5	4.1
145	Cineneba-Rock outcrop complex, 30-75% slopes	Moderately rapid (Cieneba part)	30% granodiorite outcrop, 10-35% sandstone outcrop, 5% Vista coarse sandy loam, 5% Tollhouse soil, 5% Andreas sandy loam, 5% Anaheim loam	Low (Cieneba part)	5-15	11			0.5	1.5

Soil Unit Symbols	**Soil Unit Name**	**Permeability by Soil Sub-unit**	**Substratum**	**Shrink-Swell**	**Depth to Bed Rock (inches)**	**N**	**N ≥ 4 pCi/L**	**R(%)**	**Min pCi/L**	**Max pCi/L**
146	Corralitos loamy sand	Rapid	Soils formed in mixed coarse textured alluvium—fans in long, narrow valleys	Low	>60	5			0.5	1.9
147	Carralitos loamy sand, moderately fine substratum	Rapid (40"), slow (6"), rapid 34"	Soils formed in mixed coarse textured alluvium—fans in long, narrow valleys	Low, mod, low	>60	2			1.3	2.2
148, 149	Cropley clay, 0-2% slopes, 2-9% slopes	Slow	Soils formed in fine textured alluvium derived from sedimentary rocks—on fans and valley fill	High	>60	23	1	4.4	0.5	6.6
154	Gabino gravelly clay loam, 15-50% slopes	Moderately slow (10"), slow (28")	Weakly consolidated conglomerate	Mod, high	26-40	1				1.2
157	Hueneme fine sandy loam	Moderately rapid	Soils formed in mixed alluvium—on alluvial fans and flood plains	Low	>60	1				1.5
158	Hueneme fine sandy loam, drained	Moderately rapid	Soils formed in mixed alluvium—on alluvial fans and flood plains	Low	>60	75	1	1.3	0.5	5.1

Soil Unit Symbols	Soil Unit Name	Permeability by Soil Sub-unit	Substratum	Shrink-Swell	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	R(%)	Min pCi/L	Max pCi/L
161, 162	Marina loamy sand, 0-2% slopes, 2-9% slopes	Moderate	Soils formed in old eolian sands on terraces near the coast	Low	>60	25			0.5	1.1
163	Metz loamy sand	Rapid (20”), moderate (43”)	Soils formed in mixed alluvium—on flood plains and alluvial fans	Low, Low	>60	40	1	2.5	0.5	5.8
164	Metz loamy sand, moderately fine substratum	Rapid (20”), moderate (20”), moderate (16”), Moderately slow to moderate (17”)	Soils formed in mixed alluvium—on flood plains and alluvial fans	Low, Low, Mod, Low	>60	21			0.5	3.0
165	Mocho sandy loam, 0-2% slopes	Moderate (12), moderate (49)	Soils formed in alluvium derived from sedimentary rocks—on alluvial fans and flood plains	Low, Mod	>60	3			0.5	2.6
166, 167	Mocho loam, 0-2% slopes, 2-9% slopes	Moderate (31), moderate (30)	from sedimentary rocks—on alluvial fans and flood plains	Low, Mod	>60	63	7	11.1	0.5	8.2
168, 169, 170, 171	Modjeska gravelly loam, 0-2% slopes, 2-9% slopes, 9-15% slopes, 15-30% slopes	Moderately rapid (63”), very rapid (8”)	Soils formed in mixed alluvium—on terraces	Low, Low	>60	30			0.5	2.2

Soil Unit Symbols	Soil Unit Name	Permeability by Soil Sub-unit	Substratum	Shrink-Swell	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	R(%)	Min pCi/L	Max pCi/L
172, 173, 175, 176	Myford sandy loam, 0-2% slopes, 2-9% slopes, 9-15% slopes, 15-30% slopes	Moderately rapid (12”), very slow (37”), moderate (30”)	Soils formed in sandy sediments—on marine terraces	Low, High, Low	>60	124	13	10.5	0.5	25.6
174, 177	Myford sandy loam, 2-9% slopes eroded, 15-30% slopes eroded	Moderately rapid (12”), very slow (37”), moderate (30”)	Soils formed in sandy sediments—on marine terraces	Low, High, Low	>60	25			0.5	2.3
178, 179	Myford sandy loam, thick surface, 0-2% slopes, 2.9% slopes	Moderately rapid (12”), very slow (37”), moderate (30”)	Soils formed in sandy sediments—on marine terraces	Low, High, Low	>60	27			0.5	3.7
180, 181	Nacimiento Clay loam, 15-30% slopes, 30-50% slopes	Moderately slow	Weathered soft sandstone or shale or both	Mod	24-36	6	2		0.5	7.3
182	Omni silt loam, drained	Moderate (12”), slow to moderately slow (48”)	Soils formed in mixed alluvium—on flood plains and in basins	Mod, High	>60	6			0.5	1.1
184	Omni clay	Moderate (17”), slow to moderately slow (43”)	Soils formed in mixed alluvium—on flood plains and in basins	High, High	>60	20	2	10.0	0.5	5.3
185	Pits	--		--	--	3			0.5	1.7

Soil Unit Symbols	Soil Unit Name	Permeability by Soil Sub-unit	Substratum	Shrink-Swell	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	R(%)	Min pCi/L	Max pCi/L
188	Rincon clay loam, 2-9% slopes	Moderately slow (11”), slow (17”), moderately slow (32”)	Soils formed in semiconsolidated alluvium derived from sedimentary rocks—on terraces	Mod, High, Mod	>60	6	2	--	0.5	4.3
191	Riverwash	--	--	--	--	2			0.5	1.9
192	Rock outcrop-Cieneba complex, 30-75% slopes	Rapid (Cieneba part)	In mountains and foothills; ≥50% Rock outcrop and ≤ Cieneba soils (formed in material weathered from granitic or sandstone rock	Low	5-15	4			0.5	1.1
193	San Andreas sandy loam, 15-30% slopes	Rapid	Weathered soft sandstone	Low	24-32	1				0.9
194, 195	San Emigdio fine sandy loam, 0-2% slopes, 2-9% slopes	Rapid	Soils formed in mixed alluvium—on flood plains and alluvial fans	Low	>60	50			0.5	3
196	San Emigdio fine sandy loam, moderately fine substratum	Rapid (40”), moderately slow (3”), Rapid (18”)	Soils formed in mixed alluvium—on flood plains and alluvial fans	Low	>60	28			0.5	1.9
197	Soboba gravelly loamy sand, 0-5% slopes	Very rapid	Soils formed in mixed alluvium—on flood plains and alluvial fans	Low	>60	2			0.5	0.6

Soil Unit Symbols	**Soil Unit Name**	**Permeability by Soil Sub-unit**	**Substratum**	**Shrink-Swell**	**Depth to Bed Rock (inches)**	**N**	**N ≥ 4 pCi/L**	**R(%)**	**Min pCi/L**	**Max pCi/L**
201, 202	Soper gravelly loam, 15-30% slopes, 30-50% slopes	Moderate (8”), moderately slow (21”)	Weathered conglomerate	Low, Mod	20-36	6			0.5	1.9
203	Soper cobbly loam, 15-50% slopes	Moderate (8”), moderately slow (21”)	Weathered conglomerate	Low, Mod	20-36	1				1.2
204	Soper-Rock outcrop complex, 30-75 % slopes	Moderate (4”), moderately slow (16”)	10-15% Rock outcrop. Weathered conglomerate	Low, Mod	20-24	2			0.5	0.8
206, 207	Sorrento loam, 0-2% slopes, 2-9% slopes	Moderate (12”), moderately slow to moderate (50”), moderate (10”)	Soil formed in alluvium derived from sedimentary rocks—on alluvial fans and flood plains	Low, Mod, Low	>60	29	2	6.9	0.5	8.3
208, 209	Sorrento clay loam, 0-2 % slopes, 2-9% slopes	Moderate (12”), moderately slow to moderate (50”), moderate (10”)	Soil formed in alluvium derived from sedimentary rocks—on alluvial fans and flood plains	Mod, Mod, Low	>60	36	6	16.7	0.5	8.3
211	Tidal flats	--	--	--	--	3			0.5	0.5
217, 218	Xeralfic Arents, loamy, 2-9% slopes, 9-15% slopes	--	--	--	>60	8	1	--	0.5	5.9

Soil Unit Symbols	Soil Unit Name	Permeability by Soil Sub-unit	Substratum	Shrink-Swell	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	R(%)	Min pCi/L	Max pCi/L
219, 220	Xerothents, loamy, cut and fill areas, 9-15% slopes, 15-30% slopes	--	--	--	10-60	21	4	19.1?	0.5	6.1
221, 222, 223	Yorba gravelly sandy loam, 2-9% slopes, 9-15% slopes, 15-30% slopes	Moderate to moderately rapid (11”), slow (29”), moderate (23”)	Soils formed in gravelly sandy sediment—on terraces	Low, Mod, Low	>60	6			0.5	2.7
224, 225, 226	Yorba cobbly sandy loam, 9-30% slopes, 9-30% slopes eroded, 30-50% slopes	Moderate to moderately rapid (11”), slow (29”), moderate (23”)	Soils formed in gravelly sandy sediment—on terraces	Low, Mod, Low	>60	13			0.5	1.8
						1137	59	5.2	0.5	25.6

APPENDIX J-1

Criteria for Low Radon Ranking of 87 Orange County Geologic Units and Groups of Units. Symbols and abbreviations are defined at the end of the table.

Geologic Unit (symbol and name)	**Indoor Radon Data**	**NURE Airborne eU Data**	**Surface eU or U Data**	**NRCS Soil Permeability, Shrink-Swell and Depth Data**	**Assigned Radon Potential**
af, Qaf, Qaf?-Artificial fill	x	X	ND	ND	L
Kc-Carbonate silicate rock	ND	ND	ND	support mixed	L (P)
Ks-Serpentinite	ND	ND	ND	support mixed	L (P)
Kwp or Kwps-Williams Formation, Pleasants sandstone member	ND	X	ND	support mixed	L and U
Qb-Beach deposits	ND	ND	ND	x	L (P)
Qc-Very young colluvial deposits	ND	ND	ND	--	L (P)
Qch-Coyote Hills Formation	x	ND	ND	--	L (P)
Qe-Very young eolian deposits	ND	ND	ND	x	L (P)
Qes-Very young estuarine deposits	x	X	ND	x	L
Qf-Very young alluvial-fan deposits	x	x	ND	X	L and U
Qls, Qls?-Landslide deposits or very young landslide deposits	X	X	ND	--	L, M, and U
Qm-Very young marine deposits	ND	x	ND	x	L
Qmb-Marine beach deposits	ND	ND	ND	X	L (P)
Qoa-Old axial-channel deposits	x	X	ND	support mixed	L and U
Qoa1-2-Old alluvial flood plain deposits, units 1-2	ND	x	ND	--	L (P)

Geologic Unit (symbol and name)	**Indoor Radon Data**	**NURE Airborne eU Data**	**Surface eU or U Data**	**NRCS Soil Permeability, Shrink-Swell and Depth Data**	**Assigned Radon Potential**
Qoa2-6-Old alluvial flood plain deposits, units 2-6	ND	X	ND	--	L and U
Qoa6-Old alluvial flood plain deposits, unit 6	ND	X	ND	--	L and U
Qoa7-Old alluvial flood plain deposits, unit 7	ND	ND	ND	support mixed	L and U (P)
Qof-Old alluvial-fan deposits	XX	X	ND	--	L and M
Qofa-Old alluvial fan and valley deposits-sand	ND	ND	ND	X	L (P)
Qofs-Old alluvial fan and valley deposits-silt	ND	ND	ND	support mixed	L (P)
Qof3-Old alluvial-fan deposits, unit 3	x	x	ND	support mixed	L, M and U
Qop-Old paralic deposits, undivided	X	ND	ND	support mixed	L
Qopa-Old paralic deposits-sand	x	ND	ND	--	L
Qopc-Old paralic deposits-clay	ND	ND	ND	support mixed	L (P)
Qopf-Old paralic deposits overlain by alluvial fan deposits	X	X	ND	support mixed	L or M?
Qops-Old paralic deposits-silt	x	ND	ND	support mixed	L
Qop1-Old paralic deposits, unit 1	x	x	ND	--	L
Qop2-Old paralic deposits, unit 2	x	x	ND	--	L
Qop1-2-Old paralic deposits, units 1-2	x	X	ND	--	L
Qop2-6-Old paralic deposits, units 2-6	x	X	ND	--	L
Qop3-Old paralic deposits, unit 3	ND	X	ND	support mixed	L
Qop4-Old paralic deposits, unit 4	ND	ND	ND	support mixed	L (P)

Geologic Unit (symbol and name)	**Indoor Radon Data**	**NURE Airborne eU Data**	**Surface eU or U Data**	**NRCS Soil Permeability, Shrink-Swell and Depth Data**	**Assigned Radon Potential**
Qop6-Old paralic deposits, unit 6	ND	ND	ND	support mixed	L (P)
Qop7?-Old paralic deposits, unit7?	ND	ND	ND	support mixed	L (P)
Qpe-Paralic estuarine deposits	ND	ND	ND	x	L (P)
Qsw, Qsw?-Very young slope wash	ND	x	ND	--	L and U (P)
Qvoa-Very old axial channel deposits	X	X	ND	--	L
Qvoa1, Qvoa1? - Very old axial-channel deposits, unit 1	x	X	ND	--	L and U
Qvoa2-Very old axial channel deposits, unit 2	X	X	ND	support mixed	L
Qvoa3-Very old axial channel deposits, unit 3	ND	X	ND	support mixed	L
Qvoa4-Very old axial channel deposits, unit 4	ND	ND	ND	support mixed	L (P)
Qvoa5-Very old axial channel deposits, unit 5	ND	ND	ND	support mixed	L (P)
Qvoa11-Very old axial channel deposits, unit 11	ND	ND	ND	--	L (P)
Qvoa12-Very old axial channel deposits, unit 12	ND	ND	ND	--	L (P)
Qvoa13-Very old axial channel deposits, unit 13	ND	ND	ND	--	L (P)
Qvof-Very old alluvial fan deposits	XX	X	ND	support mixed	L, M and U
Qvof1-Very old alluvial fan deposits, unit 1	ND	ND	ND	support mixed	L and U (P)
Qvop, Qvop?-Very old paralic deposits	X	X	ND	--	L

Geologic Unit (symbol and name)	**Indoor Radon Data**	**NURE Airborne eU Data**	**Surface eU or U Data**	**NRCS Soil Permeability, Shrink-Swell and Depth Data**	**Assigned Radon Potential**
Qvop5-Very old paralic deposits, unit 5	ND	ND	ND	--	L and U (P)
Qvop7-8-Very old paralic deposits, units 7-8	x	x	ND	--	L and U
Qvop9-10-Very old paralic deposits, units 9-10	ND	ND	ND	--	L and U (P)
Qvop10-13-Very old paralic deposits, units 10-13	x	X	ND	--	L and U
Qw-Very young wash deposits	x	X	ND	X	L and U
Qya-Young alluvial flood plain deposits	XX	X	x	support mixed	L, M and U
Qyc, Qyc?-Young colluvial deposits	ND	X	ND	X	L, U
Qyf-Young alluvial fan deposits	XX	X	ND	support mixed	L, M and U
Qyfa-Young alluvial fan and valley deposits-sand	XX	ND	ND	X	L
Qyfc-Young alluvial fan and valley deposits-clay	XX	ND	ND	x	L
Qyfs-Young alluvial fan and valley deposits-silt	XX	ND	ND	X	L
Qyf3-Young alluvial fan deposits, unit 3	ND	X	ND	support mixed	L
Qyls, Qyls? Young landslide deposits	X	X	ND	--	L, M and U
Qype-Young paralic estuarine deposits	x	ND	ND	--	L
Qypt-Young peat deposits	x	ND	ND	--	L

Geologic Unit (symbol and name)	**Indoor Radon Data**	**NURE Airborne eU Data**	**Surface eU or U Data**	**NRCS Soil Permeability, Shrink-Swell and Depth Data**	**Assigned Radon Potential**
Tco-Capistrano Formation, Oso Member	X	X	ND	--	L
Tiema, Tiema?-Volcanic intrusive rocks associated with El Modeno Volcanics-andesitic	ND	ND	ND	support mixed	L (P)
Tn, Tn?-Niguel Formation	XX	X	x	support mixed	L
Tpscc-Puente Formation, Sycamore Canyon Member, conglomeratic zone	ND	ND	ND	--	L (P)
Tpsq-Puente Formation, Soquel Member	X	X	ND	support mixed	L
Ts, Ts?-Sespe Formation	X	X	ND	support mixed	L
Tsa-Santiago Formation	x	X	ND	support mixed	L
Tsicg-Silverado Formation, basal conglomerate	ND	ND	ND	--	L (P)
Tsis-Silverado Formation-Serrano Clay	ND	ND	ND	support mixed	L (P)
Tso, Tsob-San Onofre Breccia	x	X	ND	x	L
Tsoss-San Onofre Breccia-sandstone	ND	ND	ND	support mixed	L (P)
Tsv-Sespe and Vaqueros Formations-undivided	ND	ND	ND	support mixed	L (P)
Tt-Topanga Group, undifferentiated	X	X	ND	support mixed	L (P)
Ttb-Topanga Group-Bommer Formation	x	X	ND	support mixed	L

Geologic Unit (symbol and name)	**Indoor Radon Data**	**NURE Airborne eU Data**	**Surface eU or U Data**	**NRCS Soil Permeability, Shrink-Swell and Depth Data**	**Assigned Radon Potential**
Ttlt, Ttlt?-Topanga Formation-Low Trancos Formation	x	X	ND	--	L
Tto-Topanga Formation	ND	x	ND	--	L
Ttp-Topanga Group-Paulerino Formation	ND	x	ND	support mixed	L
Tv, Tv?-Vaqueros Formation	x	X	ND	--	L
Tvem-El Modeno Volcanics, undifferentiated	ND	ND	ND	--	L (P)
Tvema-El Modeno Volcanics, andesitic	x	x	ND	support mixed	L
Tvemb El Modeno Volcanics-basalt	ND	ND	ND	--	L (P)
Tvemt-El Modeno Volcanics-tuff and tuff breccias	x	x	ND	support mixed	L
Tvs-Vaqueros and Sespe Formations, undifferentiated	x	--	ND	support mixed	L (P)

XX = more than 25 indoor radon measurements support low radon potential ranking

X = 10 to 24 indoor radon measurements support low radon potential; or NURE eU, surficial eU or soil U data support low radon potential ranking; soil characteristics support low radon potential ranking

x = <10 indoor radon measurements, support low radon potential ranking; some airborne eU data or surface eU/U data support for low ranking but small numbers of measurements; soil characteristics somewhat support a low radon potential ranking

-- = data do not support low radon potential ranking

ND = no data

(P) = provisional, confidence slightly to moderately uncertain (additional data needed); the provisional low ranking is in some cases based on similar units with data elsewhere in California

APPENDIX J-2

Orangee County Geologic Units with Unknown Radon Potential Due to Limited or No Data (all or parts of 62 units)

Unit Symbol	Unit Name and (Notes)
Jbc	Bedford Canyon Formation, undifferentiated
Jbc1	Bedford Canyon Formation, Unit 1
Jbcm	Bedford Canyon Formation, marble and limestone
Kd	Diorite, undifferentiated
Kgb	Gabbro, undifferentiated
Kgu	Granite, undifferentiated
Khg	Heterogeneous granitic rocks
Klhc	Ladd Formation, Baker Canyon Conglomerate Member
Klhs	Ladd Formation, Holtz Shale Member
Klhsc	Ladd Formation, Holtz Shale Member-zone of concentrated sandstone and conglomerate beds
Kt	Tonalite, undifferentiated
Ktr	Trabuco Formation
Ktrl	Trabuco Formation-lower unit
Ktru	Trabuco Formation-upper unit
Kvsp	Santiago Peak Volcanics
Kvspi	Intrusive rocks associated with Santiago Peak Volcanics
Kwp or Kwps/Kwps?	Williams Formation, Pleasants Sandstone Member (unknown potential and low potential areas)
Kwps1	Williams Formation, Pleasants Sandstone Member-coarse grained conglomeratic sandstone
Kwsr or Kwsr?	Williams Formation, Schulz Ranch Member
Kwsrl	Williams Formation, Schulz Ranch Member, lower member
Kwsru	Williams Formation, Schulz Ranch Member, upper member
Kwst	Williams Formation, Starr Member
Qf	Very young alluvial-fan deposits (unknown potential and low potential areas)
Qlh	La Habra Formation (additional indoor-radon data could result in change to moderate potential)
Qls or Qls?	Landslide deposits or very young landslide deposits (unknown potential, low potential and moderate potential areas)
Qoa	Old axial-channel deposits (unknown potential and low potential areas)
Qoa2-6	Old alluvial flood plain deposits, units 2-6 (unknown potential and low potential areas)
Qoa6	Old alluvial flood plain deposits, unit 6 (unknown potential and low potential areas)
Qof7	Old axial channel deposits, unit 7 (youngest subdivision of Qoa) (unknown potential and low potential areas)
Qof3	Old alluvial-fan deposits, unit 3 (unknown potential, low potential and moderate potential areas)
Qsp	San Pedro Formation
Qsp1	San Pedro Formation-lower sequence siltstone and claystone

Unit Symbol	Unit Name and (Notes)
Qsp2	San Pedro Formation-sandstone, part conglomeratic
Qsp3	San Pedro Formation-siltstone and claystone
Qsp4	San Pedro Formation-upper unit sandstone, part conglomeratic
Qsw and Qsw?	Very young slope-wash deposits (unknown potential and low potential areas)
Qvoa1	Very old axial-channel deposits, unit 1 (unknown potential and low potential areas)
Qvof	Very old alluvial fan deposits (unknown potential, low potential and moderate potential areas)
Qvof1	Very old alluvial fan deposits, unit 1 (unknown potential and low potential areas)
Qvop5	Very old paralic deposits, unit 5 (unknown potential and low potential areas)
Qvop7-8	Very old paralic deposits, units 7-8
Qvop9-10	Very old paralic deposits, units 9-10 (unknown potential and low potential areas)
Qvop10-13	Very old paralic deposits, units 10-13
Qw	Very young wash deposits (unknown potential and low potential areas)
Qya	Young alluvial flood plain deposits (unknown potential, low potential and moderate potential areas)
Qyc	Young colluvial deposits
Qyf	Young alluvial fan deposits (unknown potential, low potential and moderate potential areas)
Qyls and Qyls?	Young landslide deposits (unknown potential, low potential and moderate potential areas)
Qyw	Young wash deposits
Tc	Capistrano Formation (unknown potential and low potential areas)
Tcga	Conglomerate of Arlington Mountain
Tct	Capistrano Formation-turbidite facies
Tfl	Fernando Formation-lower member
Tflc	Fernando Formation-low member, conglomerate
Tfu	Fernando Formation-upper member
Tfuc	Fernando Formation-upper member, conglomerate
Tiemd	Volcanic intrusive rocks associated with El Modeno Volcanics-diabasic (unknown potential and low potential areas)
Tp	Puente Formation, undifferentiated
Tpy	Puente Formation, Yorba Member
Tsi	Silverado Formation
Tsicg	Silverado Formation-basal conglomerate
Tso	San Onofre Breccia

APPENDIX K

Descriptive Statistics and Statistical Comparison of Untransformed Indoor-Radon Measurements by Orange County Radon Potential Zone

	All Indoor Radon Data	Moderate Zone Radon Data	Low Zone Radon Data	Unknown Zone Radon Data
Size	1137	340	705	92
Mean	1.309	1.979	0.980	1.362
Std. Dev.	1.636	2.465	0.910	1.352
Std. Error	0.0485	0.134	0.0343	0.141
C.I. of Mean	0.0952	0.263	0.0673	0.280
Range	25.1	25.1	12.4	7.8
Maximum	25.6	25.6	12.9	8.3
Minimum	0.5	0.5	0.5	0.5
Median	0.8	1.1	0.7	0.8
25%	0.5	0.6	0.5	0.5
75%	1.4	2.3	1.1	1.775
Skewness	6.424	4.881	5.633	2.645
Kurtosis	70.089	37.042	52.539	8.58
K-S Dist.	0.310	0.274	0.299	0.264
K-S Prob.	<0.001	<0.001	<0.001	<0.001
SWilk W	0.488	0.569	0.526	0.666
SWilk Prob	<0.001	<0.001	<0.001	<0.001
Sum	1488.9	673.0	690.6	125.3
Sum of Squares	4988.85	3392.7	1259.28	336.87

APPENDIX L

Descriptive Statistics and Statistical Comparison of Ln-transformed Indoor-Radon Measurements by Orange County Radon Potential Zone

	All Indoor Radon Data	Moderate Zone Radon Data	Low Zone Radon Data	Unknown Zone Radon Data
Size	1137	340	705	92
Mean	-0.0526	0.276	-0.219	0.00394
Std. Dev.	0.699	0.836	0.553	0.716
Std. Error	0.0207	0.0453	0.0208	0.0746
C.I. of Mean	0.0407	0.0892	0.0409	0.148
Range	3.936	3.936	3.250	2.809
Maximum	3.243	3.243	2.557	2.116
Minimum	-0.693	-0.693	-0.693	-0.693
Median	-0.223	0.0953	-0.357	-0.223
25%	-0.693	-0.511	-0.693	-0.693
75%	0.336	0.833	0.0953	0.573
Skewness	1.214	0.690	1.343	0.988
Kurtosis	1.172	-0.151	1.821	0.0585
K-S Dist.	0.180	0.123	0.195	0.191
K-S Prob.	<0.001	<0.001	<0.001	<0.001
SWilk W	0.852	0.923	0.827	0.866
SWlk Prob	<0.001	<0.001	<0.001	<0.001
Sum	-59.786	93.915	-154.064	0.363
Sum of Squares	558.411	262.778	249.024	46.610

APPENDIX M

Results of the Shapiro-Wilk Normality Test for Untransformed and Ln-Transformed Indoor-Radon Data, by Radon Potential Zone.

Data	N	W-Statistic*	P	Result**
All-Untransformed	1137	0.488	<0.001	Failed
All Data-Ln Transformed	1137	0.852	<0.001	Failed
Moderate Zone-Untransformed	340	0.569	<0.001	Failed
Moderate Zone-Ln Transformed	340	0.923	<0.001	Failed
Low Zone-Untransformed	705	0.526	<0.001	Failed
Low Zone-Ln Transformed	705	0.827	<0.001	Failed
Unknown Zone-Untransformed	92	0.666	<0.001	Failed
Unknown Zone-Ln Transformed	92	0.866	<0.001	Failed

*Shapiro-Wilk Statistic (W)—tests the null hypothesis that the data was sampled from a normal distribution. Small values of W indicate a departure from normality

**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.

APPENDIX N

Mann-Whitney Rank Sum Test Comparisons of Indoor-Radon Data Between the High, Moderate, Low and Unknown Radon Potential Zones

Mann-Whitney Rank Sum Test					
Group	*N*	*Missing*	*Median*	*25%*	*75%*
Moderate Zone	340	0	1.100	0.600	2.300
Low Zone	705	0	0.700	0.500	1.100
Result	Mann-Whitney U Statistic = 77417.500 T = 220252.500 n(small) = 340 n(big) = 705 (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)				
Group	*N*	*Missing*	*Median*	*25%*	*75%*
Moderate Zone	340	0	1.100	0.600	2.300
Unknown Zone	92	0	0.800	0.500	1.775
Result	Mann-Whitney U Statistic = 12721.500 T = 16999.500 n(small) = 92 n(big) = 340 (P=0.006) 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=0.006)				
Group	*N*	*Missing*	*Median*	*25%*	*75%*
Low Zone	705	0	0.700	0.500	1.100
Unknown Zone	92	0	0.800	0.500	1.775
Result	Mann-Whitney U Statistic = 26869.500 T = 42268.500 n(small) = 92 n(big) = 705 (P=0.006) 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=0.006)				