SPECIAL REPORT 224

RADON POTENTIAL IN THE PALOS VERDES AREA, CALIFORNIA

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CALIFORNIA GEOLOGICAL SURVEY
Department of Conservation

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SPECIAL REPORT 224

RADON POTENTIAL IN PALOS VERDES AREA, CALIFORNIA

By

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2012

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PLATE: Radon Potential Zone Map for the Palos Verdes Area, Los Angeles County, California

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 out from underlying soil and rock into houses and become concentrated in the indoor air, posing a significant lung cancer risk for the residents. The U.S. Environmental Protection Agency (EPA, 2007) estimates indoor radon exposure results in 21,000 lung cancer deaths annually in the United States.

Between December 2008 and June 2009, the California Department of Public Health Indoor Radon Program (CDPH-Indoor Radon Program) conducted an indoor-radon survey of 481 homes in the Palos Verdes area of Los Angeles County using short-term radon detectors. Radon survey test results range from 0.3 picocuries per liter (pCi/L), the detection limit, to 39.2 pCi/L for a home basement. The highest first-floor measurement obtained within a room normally occupied in a residence, a living room in a multi-level house, was 31.5 pCi/L. The U.S. EPA recommended radon action level is 4.0 pCi/L.

A radon potential zone map for Palos Verdes area, California, was developed by the California Geological Survey (CGS) utilizing:

- The 1:24,000 scale 1999 *Palos Verdes Peninsula* Dibblee Foundation Geologic Map (Map DF-70) in combination with information from the 1:70,300 scale 1987 *Bedrock distribution of the lithofacies of the Monterey Formation of the Palos Verdes Peninsula* map by Conrad and Ehlig

- 2008-2009 CDPH-Indoor Radon Program Palos Verdes area indoor-radon survey data and 39 additional 2006 to 2010 indoor-radon test data for residences that CDPH had but which were not part of the 2008-2009 survey

- Information from the USGS Open-File Report 2004-1050, Geology and Indoor Radon in Schools of the Palos Verdes Peninsula Unified School District, Palos Verdes Peninsula, California http://pubs.usgs.gov/of/2004/1050/

- Surficial background uranium data from studies by Fukumoto and others (2005) and Fukumoto (2010)

The Palos Verdes indoor-radon data were linked to area geologic units using a geographic information system (GIS). The associated radon data characteristics were used to rank geologic unit radon potential.

Four radon potential categories defined by the percentage of homes with indoor radon likely to equal or exceed 4.0 pCi/L were used: high (≥ 20 percent), moderate (≥ 5.0 to 19.9 percent), low (< 5 percent), and unknown (for geologic units with few or no data). Geologic unit occurrences with the same radon potentials were grouped to define the radon potential zones for the Palos Verdes area radon map. A final map development step involved statistical comparison of indoor-radon data populations for the resulting radon potential zones to confirm that each zone represents a distinct radon potential.

The 1:48,000 scale (1 inch equals 0.758 miles) radon potential zone map developed by this study for the Palos Verdes area, California, 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 level of a particular building. All radon zones will contain some homes testing above 4 pCi/L and some homes testing below 4 pCi/L. The only way to identify specific buildings with indoor-radon levels exceeding 4 pCi/L is through testing.

Based on indoor-radon survey results, the radon potential zone map for the Palos Verdes area developed in this study, and 2010 U.S. census data, an estimated 28,175 people in the Palos Verdes area live in residences with indoor air radon concentrations likely to equal or exceed 4.0 pCi/L. An estimated 4,954 people live in houses that will likely test at 10 pCi/L or more radon, and about 1,898 are estimated to live in houses that will likely test at 20 pCi/L or higher.

Because about 61 percent of the Palos Verdes study area consists moderate to high radon potential areas, indoor-radon testing should be encouraged. Individuals planning new home construction in Palos Verdes may wish to consider incorporating radon-resistant features into their building plans, particularly if the building site is located in a higher-radon potential area. If necessary, radon mitigation after construction is still possible but it will be more costly. Information on radon remediation and radon resistant construction is available on the CDPH-Indoor Radon Program website at:
http://www.cdph.ca.gov/healthinfo/environhealth/Pages/Radon.aspx

INTRODUCTION

Purpose

This report describes radon potentials for geologic formations in the Palos Verdes area of Los Angeles County, California. Additionally, this report documents the procedures and data used by the California Department of Conservation, California Geological Survey (CGS) to produce the 2012 radon potential zone map for the Palos Verdes area of Los Angeles County. CGS produced the map for the California Department of Public Health Indoor Radon Program (CDPH-Indoor Radon Program) through an interagency agreement. Only minimal background information on radon and radon health issues is included in this report and detailed radon testing and remediation practices are not discussed. The following websites contain information about radon and health issues, testing and remediation:

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

Background Information on 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 levels of five to several tens of ppm and occasionally higher. While all buildings have some potential for elevated indoor-radon levels, buildings located on rocks and associated soils containing higher concentrations of uranium often have an increased likelihood of elevated indoor radon levels. Breathing air with elevated radon gas abundance 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, 2007) estimated 21,000 people die in the United States annually from lung cancer attributed to radon exposure.

Radon in indoor-air is measured in units of picocuries per liter (pCi/L) in the U.S. The average radon concentration for indoor air in American homes is about 1.3 pCi/L (U.S. EPA, 2007). The average radon concentration in outdoor air is about 0.4 pCi/L. The U.S. EPA recommends that individuals avoid long-term exposures to radon concentrations ≥ 4.0 (*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 1 out of 15 homes (6.7 percent) in the United States have radon levels ≥ 4.0 pCi/L.

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

Radon gas readily moves through rock and soil along micro-fractures and through 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 the soil into buildings in various ways. It can move through cracks in slab foundations or basement walls, pores and cracks in concrete blocks, through-going floor-to-wall joints, and openings around pipes. Radon enters buildings from the soil when air pressure inside the buildings is lower than air pressure in the soil. When exhaust fans are used, inside air is heated, or wind is blowing across a building, the building's internal air pressure is lowered. Because radon enters buildings from the adjacent soil, radon levels are typically highest in basements and ground floor rooms. Radon can also enter a building in water from private wells. All ground water contains some dissolved radon gas. The travel time of water from an aquifer to a home in a private well is usually too short for much radon decay so radon is available to be released in the house during water usage, for example through use of a bathroom shower. However, normal water usage typically adds only about 1 pCi/L 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-doesn't 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 detectors are exposed to the air in a building according to the manufacturer's instructions and then sent to a laboratory for analysis. Charcoal detectors are usually exposed for a few days under closed building conditions (i.e., a short-term test), while alpha-track detectors are typically exposed for periods of weeks, months or as long as a year under normal (open) building conditions (i.e., a long-term test). These tests are simple and inexpensive and homeowners can do this testing themselves. Test results are reported in pCi/L. Long-term tests (alpha-track detector measurements) have an advantage because they "average out" short-term fluctuations in radon levels that relate to factors such as weather changes. Consequently, long-term measurements should be more representative of 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 is several pCi/L above 4 pCi/L, follow-up short-term tests or long-term tests will also be above 4 pCi/L (e.g. Appendix D).

Radon Potential Maps

Radon potential maps indicate areas where the likelihood of a house exceeding 4 pCi/L (the U.S. EPA recommended radon action level) is relatively higher or lower. They may also be used with population data to estimate the number of individuals exposed to excessive radon levels within the area of map coverage. Radon potential maps and related population estimates can help government agencies and private organizations identify priority areas for future radon testing and public education efforts.

Use and Limitations of Radon Potential Maps

Radon potential maps developed by CGS for the CDPH-Indoor Radon Program identify areas where geologic conditions are more likely to contribute to excessive indoor radon levels. They are advisory, not regulatory, intended to assist federal, state and local government agencies, and private organizations in targeting their radon program activities and resources. These maps are not intended for determining which buildings have excessive indoor radon levels. In addition to geology, local variability in soil permeability and climatic conditions, and factors such as building design, construction, condition, and usage may influence indoor radon levels. Radon levels for a specific building can only be determined accurately by indoor radon testing of that building, regardless of what radon zone it is located within. All radon zone categories will likely have some buildings with indoor radon levels ≥ 4.0 pCi/L.

Development of the Palos Verdes Area Radon Potential Map

Palos Verdes area radon potential zones were developed utilizing data from the following data and information sources:

- The 1:24,000 scale 1999 *Palos Verdes Peninsula* Dibblee Foundation Geologic Map (Map DF-70) in combination with the 1:70,300 scale *Bedrock distribution of the lithofacies of the Monterey Formation of the Palos Verdes Peninsula* map by Conrad and Ehlig (Conrad and Ehlig, 1987)

- 2008-2009 CDPH-Indoor Radon Program Palos Verdes area indoor-radon survey data and 39 additional 2006 to 2010 indoor-radon test data for residences that CDPH had, but which were not part of the 2008-2009 survey

- The CDPH-Indoor Radon Program's radon tests sorted by Zip Code database (May 4, 2010 update) http://www.cdph.ca.gov/HealthInfo/environhealth/Documents/Radon/CaliforniaRadonDatabase.pdf

- Information from the USGS Open-File Report 2004-1050, Geology and Indoor Radon in Schools of the Palos Verdes Peninsula Unified School District, Palos Verdes Peninsula, California (see the reference section for a web address for this report)

- Information from Fukumoto and others, 2003, Classroom Radon Measurements in the Palos Verdes Peninsula Unified School District, Palos Verdes Estates, California: Proceedings of the 2003 International Radon Symposium--Volume I (see the reference section for a web address for this report)

- Information from Duval and others (2003), Fukumoto and others (2003), Fukumoto and others (2005) and Fukumoto (2010) on background uranium abundance in soil and rocks in the Palos Verdes area

The Palos Verdes area radon potential map development steps are as follows:

1) Utilizing a geographic information system (GIS), indoor-radon and background uranium data for the Palos Verdes area were grouped by geologic unit.

2) Geologic units with associated indoor-radon data were preliminarily assigned to one of 4 radon potential categories based on the percentage

of radon data at or exceeding 4 pCi/L, the number and magnitude of radon data per unit exceeding 10 pCi/L, and the total number of data. Background uranium data were examined and found to have a geographic trend similar to the indoor-radon data.

3) Using the information from steps 1 and 2, final radon potentials were assigned to all geologic units in the Palos Verdes area, based on the percentages of short-term tests likely to exceed 4.0 pCi/L as follows:

- High--20 percent or more ≥ 4.0 pCi/L indoor measurements
- Moderate--5 to 19.9 percent ≥ 4.0 pCi/L indoor measurements
- Low--0-4.9 percent ≥ 4.0 pCi/L indoor measurements
- Unknown--areas with insufficient data for estimating the percent of ≥ 4.0 pCi/L indoor measurements

4) Geologic unit areas with similar radon potentials were grouped to form radon potential zones.

5) The indoor-radon data for each radon zone were compared statistically with other zones to confirm that each zone represents a statistically distinct indoor-radon data population.

6) The final radon zones were compared with 2010 census block data to estimate indoor radon impacts on the Palos Verdes area population.

The data and information utilized and the results for each of these steps are provided and discussed in more detail in the following sections of this report.

Portions of radon potential zones underlain by faults and shear zones sometimes have increased potential for elevated indoor-radon because such features provide pathways for radon flow. However, faults and shear zones are not shown on the 1:48,000 scale Palos Verdes Area Radon Potential Zone map because uncertainties in fault locations on the Dibblee 1:24,000 scale Palos Verdes Area map. These location uncertainties relate to soil and alluvium cover as well as urban development at Palos Verdes. Consequently, it is better to base indoor radon testing priorities on zone designation rather than attempt to target fault and shear zone locations. Where situations require detailed information about indoor-radon and fault or shear zone relationships, well designed site-specific studies would be required. In some of these cases, studies of radon concentration in soil gas may be useful for fault and shear zone identification and tracking.

THE PALOS VERDES AREA SHORT-TERM INDOOR-RADON SURVEY AND OTHER AVAILABLE INDOOR-RADON DATA

Overview

The CDPH-Indoor Radon Program conducted a survey of indoor-radon in Palos Verdes area homes between December 2008 and April 2009. The CDPH-Radon Indoor Program solicited participation via direct mailing to 11,862 homeowners in the Palos Verdes area. Four hundred and sixty-five homeowners (3.9 percent) participated in the survey. Survey participants received a free short-term charcoal detector with instructions for placement and exposure, which they subsequently mailed to the Indoor Radon Program contract lab for measurement. Test results were provided directly to the survey participants by the contract lab within several weeks of detector receipt. The primary survey goal was to obtain sufficient indoor-radon data for homes located on specific geologic units to evaluate the radon potentials of those units. Indoor-radon test data for an additional 39 homes, voluntarily provided to CDPH by several radon testing labs between 2006 and 2010, were included with the survey data to create the final indoor-radon database utilized in this study. The percentage of homes exceeding the 4.0 pCi/L U.S. EPA recommended radon action level was used to evaluate Palos Verdes geologic unit radon potentials. The results of this evaluation are presented below in Tables 3a, 3b, 3c, 3d on pages 24 to 26 (also see Appendices E.1 and E.2).

Figure 1 shows the geographic distribution of the CDPH radon survey homes in the Palos Verdes area. One hundred and one homes tested ≥ 4.0 pCi/L and their geographic distribution is shown in Figure 2. The survey indoor-radon concentrations range from 0.3 pCi/L, the detection limit, to 39.2 pCi/L-- in the basement of a house in San Pedro. The next highest measurements, 31.5 pCi/L and 26.6 pCi/L, are on the first floors in houses in Rancho Palos Verdes. The highest radon survey measurement for a house in Palos Verdes Peninsula is 22.6 pCi/L for a first floor test.

Table 2a summarizes CDPH survey results by Zip Code zone and City/Region. For comparison, Table 2b summarizes the 2010 CDPH on-line Zip Code radon database test data, accumulated since 1989, for Palos Verdes area Zip Code zones. The CDPH on-line database includes the 2008-2009 radon survey data and the additional 39 data from 2006-2010 in Table 2a. Table 2b data cannot be used for evaluating the radon potential of particular geologic units because the only available location information is the Zip Code for many of the houses tested. Another complication with the Table 2b data is that it likely includes multiple radon measurements for some homes (e.g., follow-up measurements or simultaneous measurements in multiple rooms) that cannot be identified as such. In spite of these limitations, Table 2b data are still useful for identifying which Palos Verdes area Zip Codes may contain radon

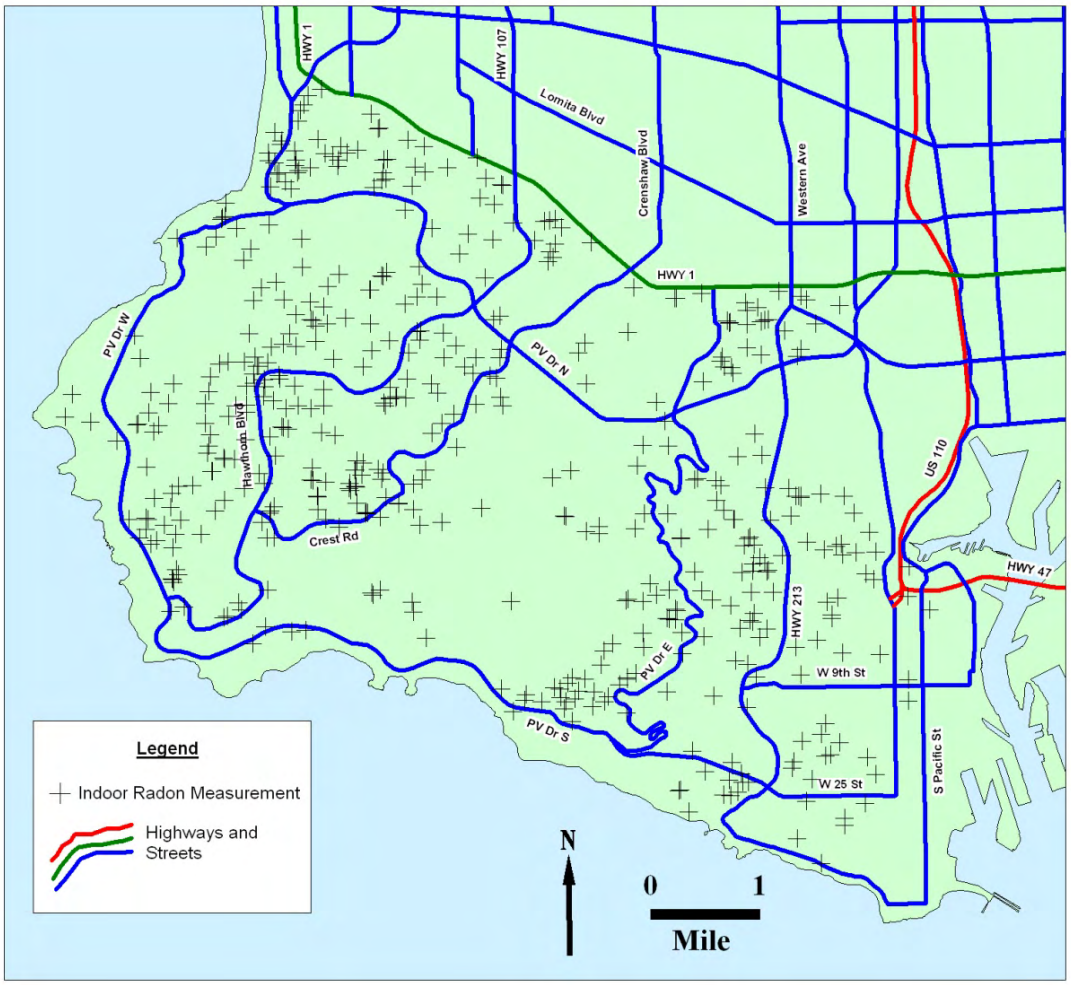

FIGURE 1. CDPH 2008-2009 Palos Verdes area radon survey test locations (includes additional 39 non-survey locations)

problem areas, and for suggesting general indoor-radon trends for the Palos Verdes area. Both the 2008-2009 survey and the Zip Code radon data sets show reasonably close agreement on the overall percentage of homes in the Palos Verdes area ≥4 pCi/L (i.e., 20.0 percent for the 2008-2009 survey data versus 17.8 percent for the online Zip Code data).

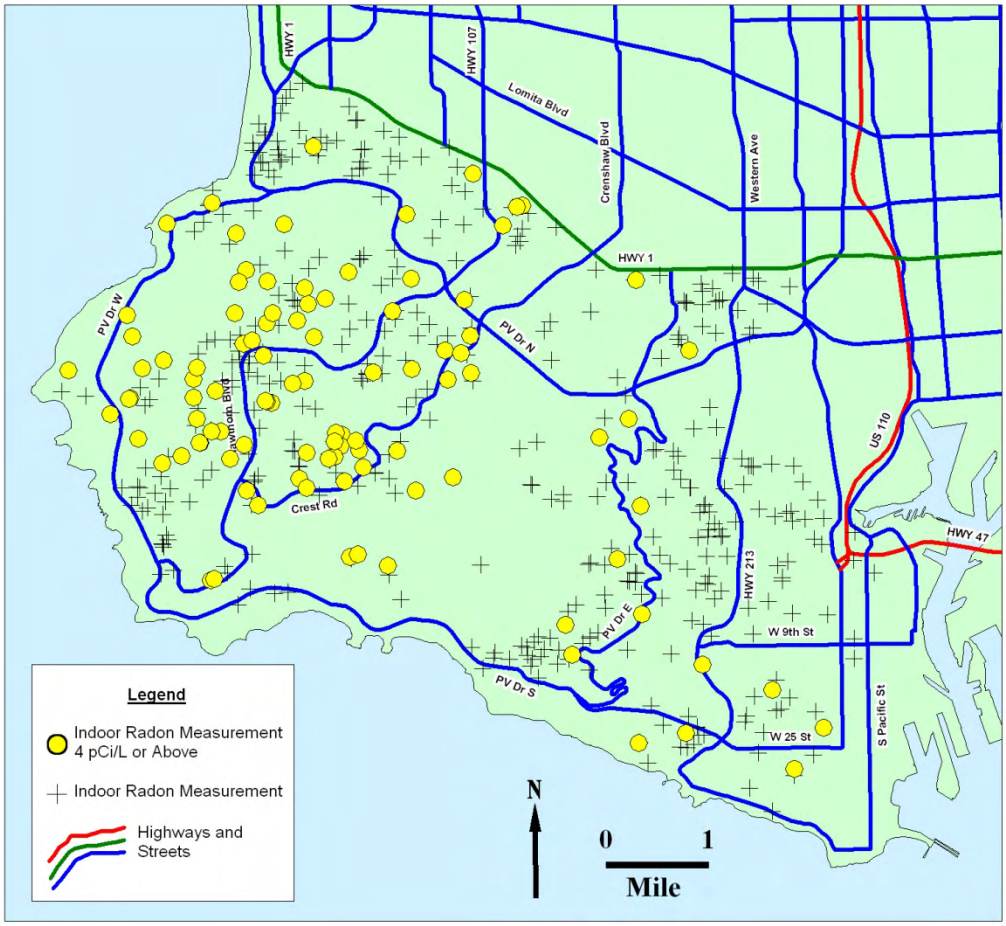

FIGURE 2. CDPH 2008-2009 Palos Verdes area radon survey test locations with 4.0 pCi/L or greater sites shown as yellow circles
(Includes 39 additional non-survey locations)

Figure 2 displays the spatial distribution of radon survey data ≥ 4 pCi/L and data < 4 pCi/L across the Palos Verdes peninsula. It shows a higher density of ≥ 4 pCi/L measurements in the western portion of the Palos Verdes peninsula indicating higher radon potential there. Indoor-radon data in Tables 2a and 2b also suggest increased radon potential in western Palos Verdes Peninsula. Duval and others (2004) found that the Altamira Shale phosphatic lithofacies (of Conrad and Ehlig, 1987), principally located in western Palos Verdes peninsula, is more likely than other geologic units to have higher concentrations of radon in soil gas, higher concentrations of uranium, and, consequently more likely to produce elevated levels of indoor radon than other Palos Verdes geologic units.

In summary, both the 2008-2009 indoor-radon survey data and the Zip Code radon data indicate that much of the Palos Verdes area has high or

Zip Code	City/Region	Number of Measurements	Measurements ≥ 4.0 pCi/L	Percent ≥ 4.0 pCi/L
90274	Palos Verdes Peninsula	102	32	31.4
90275	Rancho Palos Verdes	244	55	22.4
90277	Redondo Beach	28	2	7.1
90503	Torrance	1	1	--
90505	Torrance	32	4	12.5
90710	Harbor City	7	0	0
90717	Lomita	16	1	6.3
90731	San Pedro	25	3	8.3
90732	San Pedro	49	3	6.1
Totals for Zip Codes within the Palos Verdes Study Area				
		504	101	20.0

TABLE 2a. CDPH indoor-radon short-term test results for 2006-2009 Palos Verdes area radon data--By Zip Code Zone

Zip Code	City/Region	Number of Measurements	Measurements ≥ 4.0 pCi/L	Percent ≥ 4.0 pCi/L
90274	Palos Verdes Peninsula	303	83	27.4
90275	Rancho Palos Verdes	407	80	19.7
90277	Redondo Beach	81	4	4.9
90503	Torrance	20	3	15.0
90505	Torrance	63	5	9.5
90710	Harbor City	16	0	0
90717	Lomita	29	3	10.3
90731	San Pedro	51	5	9.8
90732	San Pedro	94	6	6.4
Totals for Zip Codes within the Palos Verdes Study Area				
		1064	189	17.8

TABLE 2b. Radon test results for the Palos Verdes Area Zip Code Zones from the CDPH on-line Radon Zip Code Database for California (1989-2010)

moderate potential for homes to exceed the U.S. EPA recommended radon action level of 4 pCi/L. These data also suggest a regional trend of increasing radon potential from San Pedro in the eastern Palos Verdes area to Rancho Palos Verdes and Palos Verdes Estates in the west.

Radon Survey Data--Exposure Duration and Data Quality

Most Palos Verdes area radon survey participants exposed their radon tests for two days as instructed, but a few exposed them for 3 or 4 days. Differences between two-day, three-day and four-day exposure test results should be negligible.

Appendix A lists results for 28 concurrent (duplicate) tests made during the survey. These results are summarized in Table 2c, which shows consistency between duplicate test results.

High Measurement Group Range pCi/L	Associated Concurrent Group Measurement Ranges pCi/L	Differences pCi/L
9.6-24.7	9.3-24.4	0.3-2.5
3.0-5.4	1.3-3.3	0.0-2.2
1.3-2.8	1.5-2.6	0.1-1.5
0.6-0.8	0.5-0.6	0.1-0.3
<0.5	<0.5	<0.4

TABLE 2c. Comparison of Palos Verdes area radon survey duplicate (concurrent) test results

Appendices B and C show the analytical results for 3 field blank radon detectors (i.e., not exposed to radon) and 10 spiked radon detectors (exposed to a known concentration of radon). The 3 field blank samples measured below 0.5 pCi/L. Eight of 10 spiked samples differed by between) 0.3 to 3.4 pCi/L from the mean chamber radon concentration of 18.2 pCi/L. One spiked sample measured 4.8 pCi/L and another measured 11.8 pCi/L above the average chamber radon concentration. All detectors exposed to air averaging 18.2 pCi/L radon measured above 4.0 pCi/L, the U.S. EPA recommended action level.

In summary, duplicate, blank and spiked sample test results support the validity of the CDPH-Indoor Radon Program Palos Verdes area radon survey data.

Follow-up Radon Testing Results

Sixteen follow-up radon tests at 12 different locations were made and are shown in Appendix D. The number of days between tests range from 11 to 196. In 11 of the 16 instances, the follow-up tests confirmed the original test result of either > 4.0 pCi/L or < 4.0 pCi/L. One of the 5 follow-up test pairs dropped from 31.5 pCi/L to 0.5 pCi/L with 196 days between tests. Possibly this house underwent radon remediation but no information documenting this is available. Two of the 5 follow-up tests missed confirming a previous ≥ 4 pCi/L or < 4 pCi/L test by 0.4 pCi/L.

In summary, the follow-up tests related to the Palos Verdes area radon survey usually (69% of the time) confirmed the initial test result of either > 4.0 pCi/L or < 4.0 pCi/L.

Indoor Radon Data and Geologic Unit Information

Indoor-radon data from the CDPH Indoor Radon Program 2008-2009 survey of Palos Verdes area homes are tabulated by geologic unit in Appendices E.1 and E.2. The Conrad and Ehlig (1987) Bedrock distribution of the lithofacies of the Monterey Formation of Palos Verdes geologic map, at approximately 1:70,300, and the Dibblee (1999) Palos Verdes Peninsula and Vicinity geologic map, at 1:24,000 scale, were used to determine which geologic unit is present at each radon test location.

INDOOR RADON AT PALOS VERDES AREA SCHOOL SITES

The following information has been summarized from reports for indoor radon and background uranium studies conducted during 2003 at Palos Verdes Peninsula Unified School District school sites by Fukumoto and others (2003) and Duval and others (2004).

Between February 15 and June 6, 2003, 335 classrooms in 17 Palos Verdes Peninsula Unified School District schools were tested for indoor-radon concentrations using short-term activated charcoal detectors (Fukumoto and others, 2003). 10.5 percent of the classrooms tested exceeded the U.S. EPA recommended action level of 4.0 pCi/L. Nine schools had one or more rooms exceeding 4.0 pCi/L. Eight of these schools are located in western and northwestern Palos Verdes. Three schools had more than three classrooms exceeding 4.0 pCi/L: Silver Spur Elementary with 14, Palos Verdes High School with 9 and Montemalaga Elementary with 8. The highest classroom radon concentration measured was 48.3 pCi/L at Palos Verdes High School.

At Palos Verdes High School most of the measurements exceeding 4.0 pCi/L, including the 48.3 pCi/L measurement, were from rooms in the science wing. This building had an unventilated crawlspace below its slab foundation where radon could concentrate. This sub-slab crawlspace is unique to the science wing at Palos Verdes High School and not found at any other school site in the school district. Two crawlspace radon tests using short-term detectors produced measurements of 544 and 590 pCi/L. An initial mitigation attempt using foam to seal openings around drainage and gas lines passing through the science wing's slab was unsuccessful in lowering room radon concentrations. A second mitigation attempt used a sub-slab ventilation approach that involved placing perforated hoses in the

crawlspace covered by a tear-resistant polymer sheet that was sealed along the crawl space walls to act as a radon barrier. The perforated hoses below the polymer sheet were connected to pipes with fans to vent the trapped radon above roof level where it rapidly dissipated. This mitigation approach reduced room radon levels in the science wing to typical outdoor (ambient background) radon levels.

At Silver Spur Elementary School, 14 out of 21 classrooms (including 1 portable classroom) tested above 4.0 pCi/L. The highest indoor-radon concentration measured at this site was 14.2 pCi/L. Silver Spur Elementary site is unusual in that virtually all of the soil surface area between classroom wings is covered with asphalt or concrete. This surface covering might be a factor in the large number of above 4.0 pCi/L classrooms at this site. It may act as a seal or cap and prevent radon escaping to the atmosphere between classroom wings and thus result in increased radon concentration in soil underlying the classrooms.

At Montemalaga Elementary School, eight rooms exceeding 4.0 pCi/L were measured during one weekend. Follow-up testing two-weeks later, under different weather conditions, measured five rooms exceeding 4.0 pCi/l. The highest classroom indoor-radon concentration measured at this site was 16.3 pCi/L. Some detectors placed in cabinets, beneath sinks and near wall heaters measured radon levels significantly higher than in the center of the room. For example, 40 pCi/L under a sink versus 3.7 pCi/L in the center of one room, and 57.4 pCi/L associated with a heater and 54.7 pCi/L associated with a sink versus 10.7 pCi/L in the center of another room. These results indicate that significant amounts of radon were entering some rooms through openings in the slab associated with plumbing fixtures.

Initial attempts to reduce indoor-radon levels at Montemalaga and Silver Spur elementary schools involved re-programming the HVAC systems to maximize the intake of outdoor air to positively pressurize classrooms to reduce radon entry and dilute the entering radon (Fukumoto and others, 2003). This approach was ultimately unsuccessful and sub-slab ventilation systems were required to reduce indoor-radon to acceptable levels (Joseph Fukumoto, 2011, oral communication). Detailed radon information for other school sites can be found in Duval and others (2004).

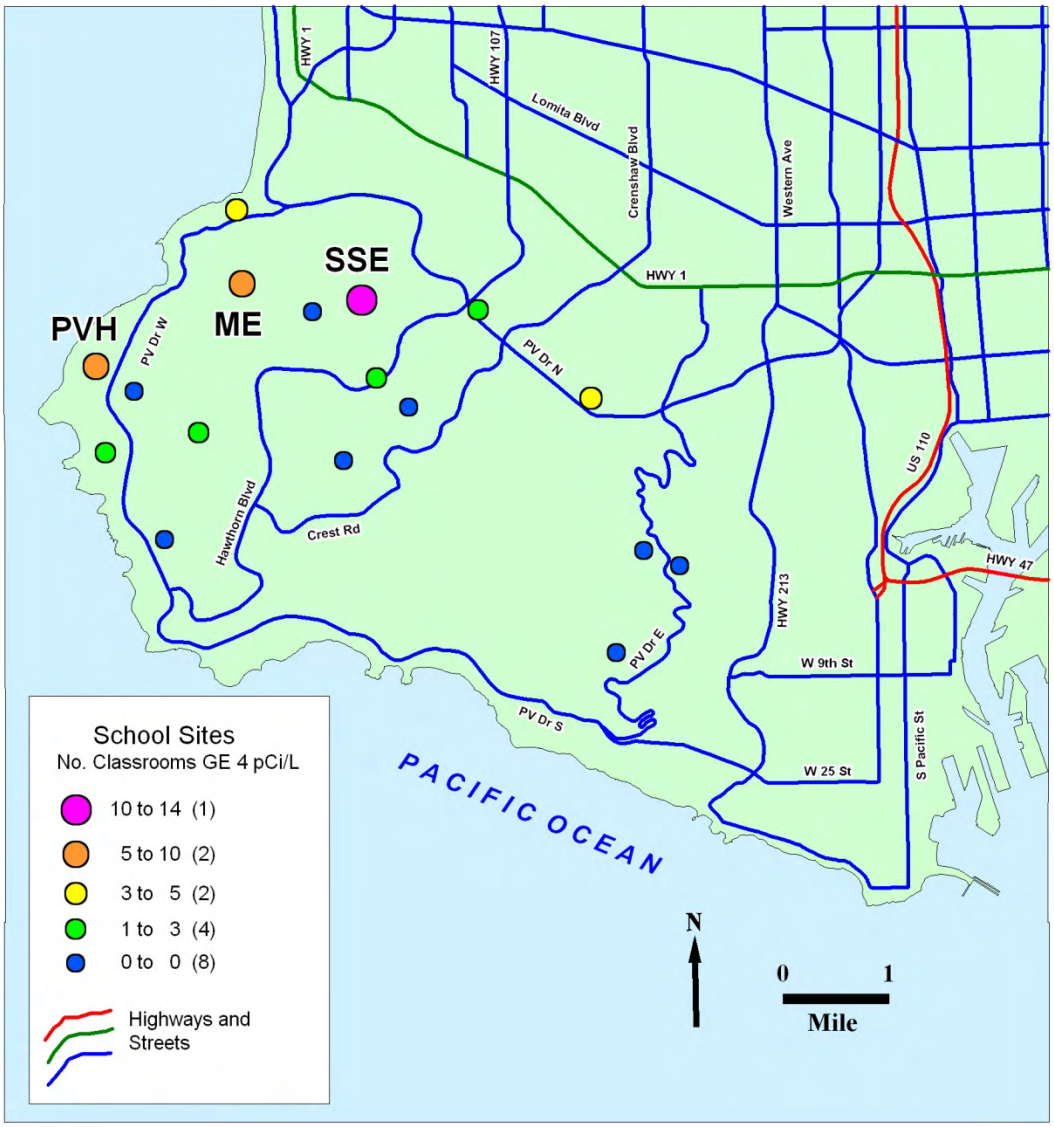

FIGURE 3. Number or classrooms at Palos Verdes Peninsula Unified School District school sites at or exceeding 4 pCi/L during 2003 2-day indoor-radon tests (ME-Montemalaga Elementary; **PVH**-Palos Verdes High; **SSE**-Silver Spur Elementary**)**

Duvall and others (2004) contains a graph showing estimated soil gas concentrations versus average indoor radon in classrooms for 17 Palos Verdes school sites they studied. It shows estimated soil gas radon concentrations for these sites range from approximately 200 pCi/L to 1250 pCi/L (this latter estimate is for Montemalaga Elementary). Unfortunately, most of the data points in the graph are not identified by school site, so it is not possible to determine if there is a geographic trend in estimated soil gas radon concentrations.

Based on school site investigations, Duvall and others (2004) concluded that the Monterey Formation is a source of radon that can produce indoor-radon levels above the US EPA action level of 4 pCi/L at Palos Verdes. They also concluded that the upper part of the Altamira Shale member of the Monterey Formation, the phosphatic lithofacies as denoted by Conrad and Ehlig, 1987, is more likely to produce elevated levels of indoor radon because it contains higher concentrations of uranium and, consequently, is more likely to produce higher concentrations of radon in soil gas than other Palos Verdes geologic units.

BACKGROUND URANIUM DATA IN THE PALOS VERDES AREA

Because indoor-radon is ultimately derived from uranium, uranium abundance data for soil and rocks are useful for identifying areas more likely to have houses with elevated radon concentrations. Uranium data from the National Uranium Resource Evaluation (NURE) project, funded by the Federal Government between 1975 and 1993, have been utilized in previous CGS radon mapping studies for other locations in California. Unfortunately, NURE data are unavailable for the Palos Verdes area because the NURE project did not collect data in urban areas. However, field analyses of background uranium abundance in soil and rock at school sites and other locations in the Palos Verdes area are available from studies by Duval and others (2004), Fukumoto and others (2003), Fukumoto and others (2005) and Fukumoto (2010) and their data are summarized in Appendices E.3 (For Dibblee geologic units) and E.4 (for Conrad and Ehlig lithologic units). These analyses were made using portable gamma-ray spectrometers and results are reported as parts-per-million equivalent uranium (ppm eU). The highest eU measurement , 15.7 ppm, is located on Dibble unit Tma near a contact with Tmv. The next highest measurement, 15.3 ppm, is on Dibble unit Tmv at the Montemalaga Elementary School site, 150 feet from a contact with Tma. The lowest eU measurement, 0.7 ppm, is on Dibblee unit Qoa at Point Vicente Elementary School.

Figure 4 shows the spatial distribution of eU data in the Palos Verdes area available from the listed studies. Figure 5 shows eU data from these studies that equals or exceeds 5 ppm. 5 ppm is approximately twice the average uranium abundance in the earth's continental crust and can be considered a boundary between "typical" and "anomalous" background uranium concentrations. Figure 5 shows 5 ppm eU or higher measurements in western Palos Verdes area but absent in eastern Palos Verdes. This pattern suggests a higher probability for indoor-radon concentrations to exceed the US EPA recommended action level of 4 pCi/L in western and north-central Palos Verdes, and lower probability in eastern Palos Verdes. This geographic trend in background uranium data

is generally similar to the indoor-radon survey data and school site data previously mentioned.

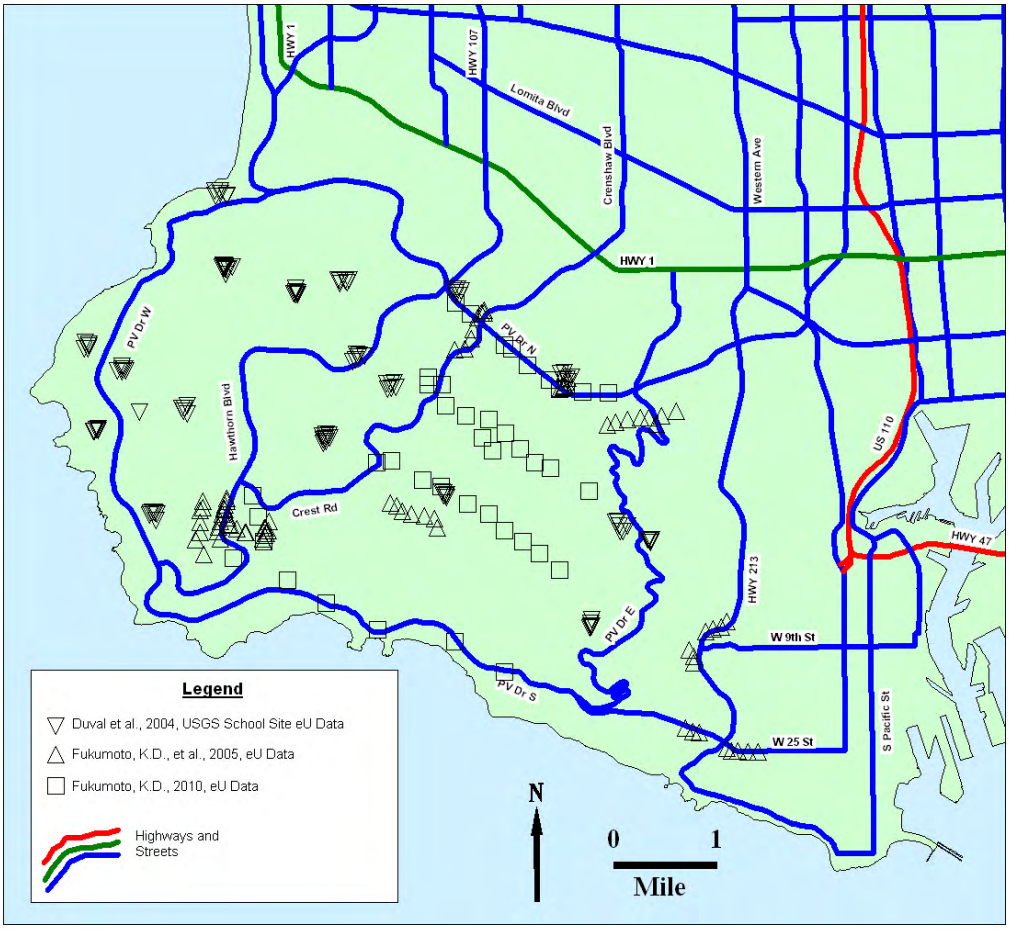

FIGURE 4. Location of eU (equivalent uranium) measurements of background uranium abundance in Palos Verdes area rocks and soil

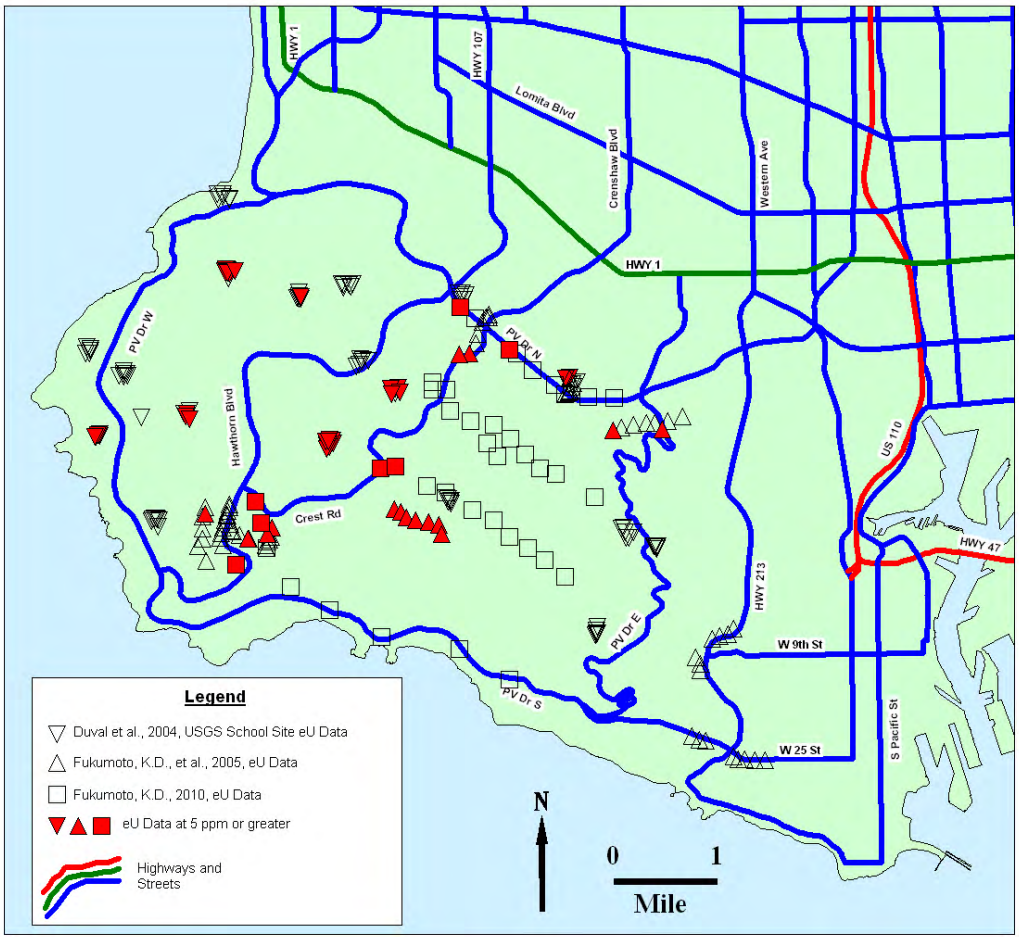

FIGURE 5. eU measurements at 5 ppm or greater in Palos Verdes area rocks and soil

PALOS VERDES AREA SOIL DATA

Soil property data are sometimes useful in identifying areas with higher radon potential. Radon is more easily released from host minerals and can migrate further within higher permeability soils. In soils with low permeability, radon release and migration can be significantly restricted. Soil moisture is also an important factor. Soils exhibiting moderate to high shrink-swell character may be associated with indoor-radon problems. 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. Cracks in slabs and basement walls are pathways for radon moving from the soil into a home. 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).

A search for Palos Verdes area soil information identified a 1969 U.S. Department of Agriculture, Natural Resource Conservation Service (NRCS) document titled *Report and General Soil Map Los Angeles County California*. The soil map in this document shows the Palos Verdes Peninsula divided into five different soil associations. However, the following information on this report, and other historical soils documents was obtained via a 2011 written communication with Mr. Randy Riddle, soil scientist, USDA-NRCS Carson Soil Survey Office:

> *The 1969 Report and General Soil Map Los Angeles County does not provide data that is considered to be up to our current standards. Any data that could be provided from the historical reports would be misleading and not considered accurate. Many of the soils mapped in these historical surveys are not being correlated in the area anymore and major difference in mapping concepts as well as understanding of important soil characteristics have changed since that time. Furthermore, there is no COLE data for the shrink-swell data available in this document and our definition of defining the depth to bedrock has been refined. The area (Palos Verdes) is considered unmapped because of this and will be mapped with the initial mapping of the Soil Survey of Los Angeles County, Southeastern Past which is currently in progress.*

NRCS staff has indicated that the soil mapping project that includes the Palos Verdes area is currently scheduled for completion in about four years.

Because of this NRCS communication, an evaluation of possible soil property impacts on indoor-radon was not undertaken for the Palos Verdes area. Based on previous radon potential mapping of Monterey Formation areas in California, information on soil permeability, shrink-swell character and depth to bedrock may suggest sub areas within high and moderate radon potential zones that are slightly higher or lower in radon potential when it becomes available in the future. However, it is unlikely that future soil information would result in large portions of radon potential zones developed during this study being changed to another radon potential category.

SELECTION OF PALOS VERDES AREA GEOLOGIC MAPS TO USE FOR RADON POTENTIAL MAP DEVELOPMENT

Introduction

The following geologic maps were initially identified as potentially suitable to use for radon potential map development for the Palos Verdes area:

- Palos Verdes Peninsula and Vicinity 1:24,000-scale, Dibblee Foundation Map DF-70 by Dibblee (1999)

- Bedrock distribution of the lithofacies of the Monterey Formation of the Palos Verdes Peninsula map, approximately 1:70,300-scale by Conrad and Ehlig (1987), see Figure 6. *Note: This is a bedrock map and does not show surficial deposits such as recent of older alluvium, landslide deposits, sand dune deposits, etc. Also, it is focused on the Monterey Formation so it does not show younger geologic units such as the Fernando Formation, San Pedro Sand, Timms Point Silt, and Lomita Marl that are included on the Dibblee Foundation map*)

- Geologic Map of the Northwest Part of the Palos Verdes Hills, Los Angeles County, California, California Division of Mines and Geology (now the California Geological Survey), Map Sheet 27, 1:12,000-scale by Cleveland (1976). *Note: This map only covers part of Palos Verdes. It apparently was compatible with a map of the remainder of Palos Verdes by Richard H. Jahns that was never published. An unpublished copy of Jahns' map could not be located during this study*.

- Geologic Map of the Long Beach 30'X60' Quadrangle, California, Map No. 5, Regional Geologic Map Series, California Geological Survey 1:100,000 scale by Saucedo and others (2003)

The geologic unit contacts in some parts of these maps may be approximately located because of poor exposure.

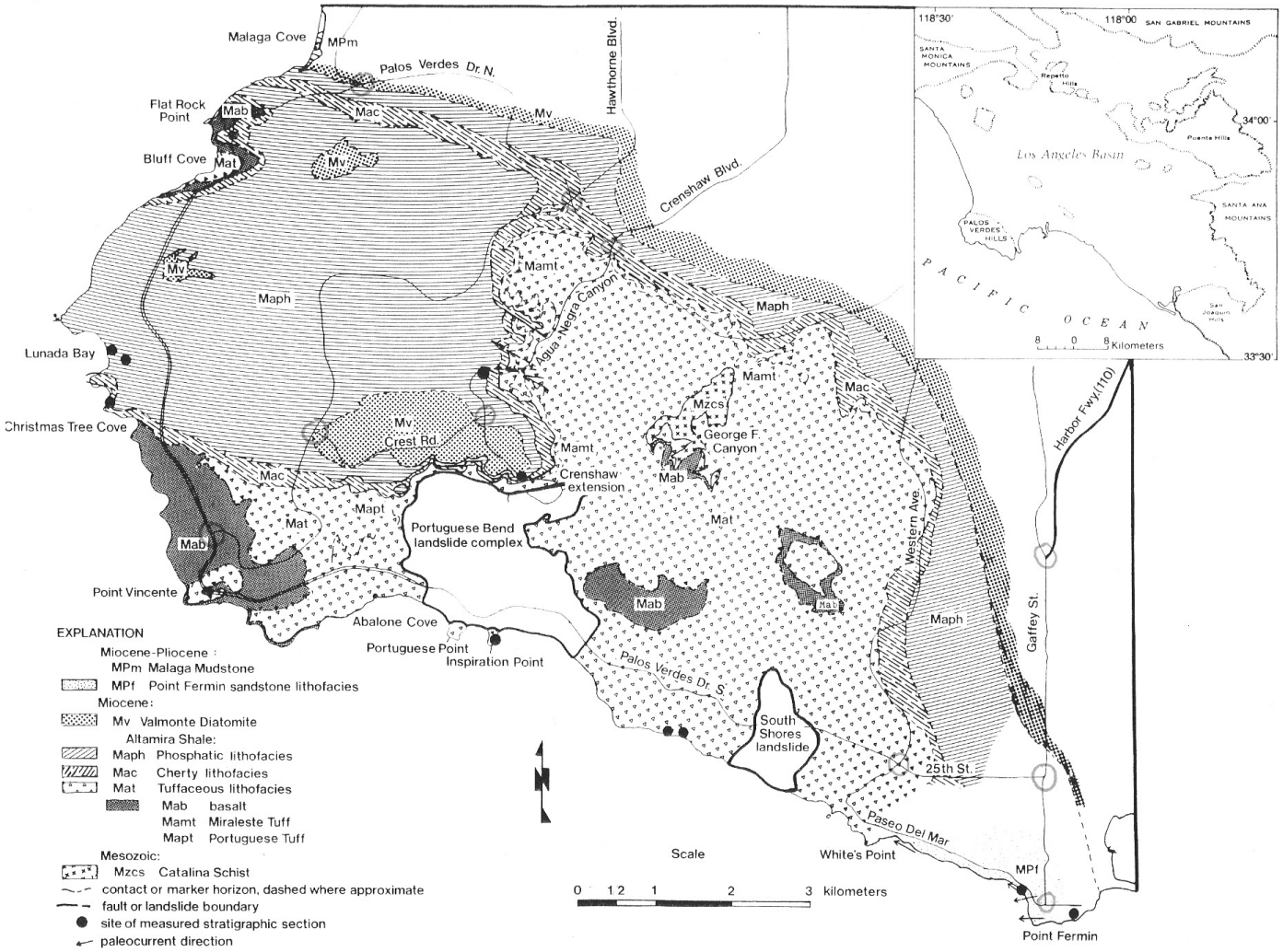

FIGURE 6. Bedrock distribution of the lithofacies of the Monterey Formation of the Palos Verdes Peninsula by Conrad and Ehlig (1987) *Reproduced at smaller than original scale with permission from Pacific Section SEPM (Society for Sedimentary Geology).*

Geologic Map Evaluation

Map evaluation for Palos Verdes radon mapping suitability involved the following steps and criteria:

1. After indoor radon and background uranium data were subdivided by geologic unit for each of the geologic maps:

- Indoor-radon statistics including the percentage of data equal to or exceeding 4 pCi/L (R) were compiled for each geologic unit
- Background eU statistics were compiled for each geologic unit
- Indoor radon and eU data populations for geologic units of each map were compared to determine if they were statistically similar or different using the Mann-Whitney rank sum test
- Geographic trends for R (percentages of indoor-radon data ≥ 4 pCi/L) and background uranium abundance, by geologic unit, were determined for each geologic map

2. The geologic maps were considered viable to use for development of a radon potential map if:

- Indoor-radon and eU data populations for geologic units of the map fall into statistically multiple distinct radon potential categories (e.g., high, moderate, or low)

- Geologic unit indoor-radon and background uranium data populations reflect the observed geographic trend of showing higher R percents and eU abundance in western Palos Verdes

3. If more than one map meets the requirements in step 2, then the map having the highest R for the combined indoor-radon data for all the high radon potential units is considered the best geologic map to use for radon potential mapping.

Map Selection and Preliminary Radon Potential Ranking of Geologic Units

Based on the approach described in the previous section, the CGS Long Beach 30'X60' Quadrangle and CGS Map Sheet 27 geologic Maps were determined unsuitable for Palos Verdes radon mapping. Neither would produce derivative radon potential maps showing the westerly increase in radon potential that indoor radon data and eU data support. Also, Map sheet 27 had incomplete coverage of the Palos Verdes area and the indoor-radon data populations of its geologic units were found not to be significantly different. Evaluation of Long Beach 100k geologic unit indoor-radon populations found them also not to be statistically distinct

from each other. Because neither Map Sheet 27 nor the Long Beach Quadrangle geologic maps were viable for radon map preparation, details regarding their geologic unit statistics for indoor-radon and eU data have not been included in this report.

The Conrad and Ehlig[1] map and Dibblee map geologic units have statistically distinct indoor-radon and eU data populations, and Rs for high radon potential units (see Tables 3a to 3e, Appendix E.1 to E.4 and Appendix F.1 to F.6). However, both maps have portions of their high radon potential units extending through eastern Palos Verdes, contrary to available indoor-radon and eU data trends, not meeting this requirement for map selection.

In comparing the Conrad and Ehlig geologic map with the Dibblee geologic map, it becomes evident that Dibblee's Tma unit is equivalent to the Conrad and Ehlig Maph unit and Mac unit in the western Palos Verdes area and the belt Maph and Mac occurrences extending eastward and southward. The Conrad and Ehlig Mv areas generally correspond to the Dibblee Tv areas with some differences in unit contact locations. Finally, Conrad and Ehlig's Mat unit areas generally correspond to Dibblee's Tmat unit areas.

The Conrad and Ehlig and Dibblee maps differ in how their high radon potential units are depicted. Dibblee shows the high radon potential Tma unit as a large occurrence in western Palos Verdes and extending continuously from northwest to east then southeast around Palos Verdes to Pt. Fermin. Tmv is shown as isolated occurrences in western Palos

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1-- *The Conrad and Ehlig geologic map has several limitations:*

- *It is in the form of an 8.5 by 11 inch page size figure in their report,*
- *Information about the base map and map projection is not provided*
- *There are no latitude and longitude labeled reference points for map registration*

Geocoding of this map for GIS work required cross-referencing map features by the latitude and longitudes of the same features on other maps with a documented projection and accurate GIS registration. Even though the Conrad and Ehlig map can only be "roughly" registered, it appears superior to the Dibblee map for isolating the high potential zone at Palos Verdes (i.e., the Conrad and Ehlig circular area Maph contains 38.8 percent ≥ 4 pCi/L measurements compared with 32.7% for the Dibblee Tma area.

To overcome its limitations, the Conrad and Ehlig map was visually compared to the Dibblee Foundation map and adjustments were made to Dibblee map geologic unit boundaries Tma and Tmat to make them appear in closer accord with the Conrad and Ehlig map. The radon potential zone boundaries follow these adjusted geologic unit contacts when they are present.

Verdes and as a belt, in contact with Tma to the south, extending from northern to southeastern Palos Verdes. Conrad and Ehlig show high radon potential units Maph and Mv separated into western area occurrences and belts extending from the northwest to east to southeast around Palos Verdes toward Pt. Fermin (see Figure 6, note mapping ends before the Pt. Fermin is reached). The Maph and Mv occurrences are separated by the moderate radon potential Mac unit (Table 3b).
The radon potentials of the western area and belt occurrences of Maph and Mv are shown in Table 3e and the western area and belt radon populations are significantly different (also see Appendices F.5 and F.6). Maph and Mv within the western area have high radon potentials while the belt Mv has moderate potential and belt Maph has low or possibly moderate potential.

Lithologic Characteristics of High, Moderate and Low Radon Potential Geologic Units

The lithologic characteristics of high, moderate and low radon potential geologic units in the Palos Verdes area are summarized in Appendix G for the Conrad and Ehlig bedrock lithologic units and the Dibblee geologic units.

Geologic Unit	Incidence Rate (R) of ≥ 4 pCi/L Indoor Measurements (in Percent)	Radon Potential Designation
Conrad and Ehlig (1987) Map Geologic Units		
Valmonte Diatomite [Mv](Miocene)	R = 26.2% N = 42 N ≥ 4 pCiL = 11 Maximum = 9.3 pCi/L	High (R ≥ 20%)
Altamira Shale: Phosphatic lithofacies [Maph](Miocene)	R = 32.9% N = 161 N ≥ 4 pCiL = 53 Maximum = 31.5 pCi/L	High (R ≥ 20%)
Combined Mv and Maph Units	R = 32.0% N = 203 N ≥ 4 pCiL = 64 Maximum = 31.5 pCi/L	High (R ≥ 20%)
Dibblee (1999) Map Geologic Units		
Monterey Formation-Valmonte Diatomite-deep marine [Tmv](Miocene)	R = 36.0% N = 50 N ≥ 4 pCiL = 18 Maximum = 9.6 pCi/L	High (R ≥ 20%)
Monterey Formation-Altamira Shale-upper part-deep marine [Tma]	R = 31.2% N = 154 N ≥ 4 pCiL = 48 Maximum = 39.2 pCi/L	High (R ≥ 20%)
Combined Tmv and Maph Units	R = 32.4% N = 204 N ≥ 4 pCiL = 66 Maximum = 39.2 pCi/	High (R ≥ 20%)

TABLE 3a. High radon potential geologic units in the Palos Verdes area based on 2008-2009 CDPH short-term indoor radon data

Geologic Unit	Incidence Rate (R) of ≥ 4 pCi/L Indoor Measurements (in Percent)	Radon Potential Designation
Conrad and Ehlig (1987) Geologic Units		
Altamira Shale: Cherty lithofacies [Mac](Miocene)	R = 15.4% N = 26 N ≥ 4 pCiL = 4 Maximum = 5.2 pCi/L	Moderate (5% ≥ R < 20%)
Altamira Shale Tuffaceous lithofacies [Mat](Miocene)	R = 12.9% N = 124 N ≥ 4 pCiL = 16 Maximum = 11.7 pCi/L	Moderate (5% ≥ R < 20%)
basalt [Mab](Miocene)	R = 13.0%?* N = 23 N ≥ 4 pCi/L = 3 Maximum = 10.4 pCi/L	Moderate?* (5% ≥ R < 20%) (*4 pCi/L results may relate to the underlying or adjacent Mat unit*)
Valmonte Diatomite (*NW-SE PV Belt Only*)	R = 9.1%? N = 11 N ≥ 4 pCiL = 1 Maximum = 5.0 pCi/L	Moderate?? (5% ≥ R < 20%)
Dibblee (1999) Geologic Units		
alluvium-elevated and dissected [Qae](Holocene)	R = 16.0% N = 25 N ≥ 4 pCiL = 4 Maximum = 9.7 pCi/L	Moderate (5% ≥ R < 20%)
landslide debris [Qls](Holocene-Pleistocene?)	R =%? N = 11 N ≥ 4 pCiL = 4 Maximum = 8.8 pCi/L	Moderate? (5% ≥ R < 20%) (*almost entirely in Monterey Fm-Tmat areas so probably similar to Tmat potential, moderate*)
older alluvium-nonmarine terrace [Qoa](Pleistocene)	R = 11.1% N = 72 N ≥ 4 pCiL = 8 Maximum = 17.3 pCi/L	Moderate (5% ≥ R < 20%)
Monterey Formation-Altamira Shale-lower part-deep marine [Tmat](Miocene)	R = 11.7% N = 107 N ≥ 4 pCiL = 16 Maximum = 11.7 pCi/L	Moderate (5% ≥ R < 20%)

TABLE 3b. Moderate radon potential geologic units in the Palos Verdes area based on 2008-2009 CDPH short-term indoor radon data
*"?" = somewhat uncertain because of limited indoor data

Geologic Unit	Incidence Rate (R) of ≥ 4 pCi/L Indoor Measurements (in Percent)	Radon Potential Designation
Conrad and Ehlig (1987) Map Geologic Units		
Part of the Altamira Shale: Phosphatic lithofacies ***See Table 3e***		
Dibblee (1999) Map Geologic Units		
older stabilized dune and drift sand [Qos](Pleistocene)	R = 2.4% N = 42 N ≥ 4 pCiL = 1 Maximum = 5.0 pCi/L	Low
San Pedro Sand-shallow marine [Qsp](Pleistocene)	R =%?* N =12 N ≥ 4 pCiL = 0 Maximum = 3.9 pCi/L	Low?*
Basalt-submarine [Tb] (Miocene)	R = 5.6%? N = 18 N ≥ 4 pCiL = 1 Maximum = 5.5 pCi/L	Low? (5% ≥ R < 20%) (*4 pCi/L result may relate to the underlying or adjacent Tmat unit*)

TABLE 3c. Low radon potential geologic units in the Palos Verdes area based on 2008-2009 CDPH short-term indoor radon data
*"?" = somewhat uncertain because of limited indoor data

Conrad and Ehlig lithologic units		Dibblee geologic units	
Name	**Symbol**	**Name**	**Symbol**
Monterey Formation-Malaga Mudstone	MPm	Alluvium	Qa
		Lomita Marl	Ql
Monterey Formation-Point Fermin sandstone lithofacies	MPf	San Pedro Sand	Qsp
		Fernando Formation	Tfr
		Monterey Formation diatomite in the San Pedro area	Tmad
		Malaga Mudstone	Tmg

TABLE 3d. Unknown radon potential geologic units in the Palos Verdes area based on available data at the time of this report

Geologic Unit	Incidence Rate (R) of ≥ 4 pCi/L Indoor Measurements (in Percent)	Radon Potential Designation
Conrad and Ehlig (1987) Maph and Mv Geologic Map Units by Occurrence Type		
Valmonte Diatomite (***Western PV only***)	R = 32.3% N = 31 N ≥ 4 pCiL = 10 Maximum = 9.3 pCi/L	High
Valmonte Diatomite (***NW-SE PV Belt Only***)	R = 9.1%?* N = 11 N ≥ 4 pCiL = 1 Maximum = 5.0 pCi/L	Moderate?* (5% ≥ R < 20%)
Altamira Shale: Phosphatic lithofacies (***Western PV only***)	R = 38.8% N = 134 N ≥ 4 pCiL = 52 Maximum = 31.5 pCi/L	High
Altamira Shale: Phosphatic lithofacies (***NW-SE PV Belt Only***)	R = 3.7% N = 27 N ≥ 4 pCiL = 1 Maximum = 6.6 pCi/L	Low (or Moderate?)
Combined Western PV portions of Valmonte Diatomite and Altamira Shale: Phosphatic lithofacies	**R= 37.6% N= 165 N ≥ 4 pCiL = 62 Maximum = 31.5 pCi/L**	**High**
Combined NW-SE Belt portions of Valmonte Diatomite and Altamira Shale: Phosphatic lithofacies	**R= 5.3% N= 38 N ≥ 4 pCiL = 2 Maximum = 6.6 pCi/L**	**Moderate**

TABLE 3e. Radon potentials for Conrad and Ehlig Maph and Mv units subdivided into western Palos Verdes and NW-SE belt areas
*"?" = somewhat uncertain because of limited indoor data

DEVELOPMENT OF RADON POTENTIAL ZONES

This section describes the procedures used for individual radon zone development. These approaches are based upon geologic unit data and relationships discussed in detail in the previous section.

A high radon potential zone developed by combining the western Palos Verdes area Maph and Mv areas would have an R exceeding those resulting from combing the entire Maph and Mv occurrences or Dibblee map Tma and Tmv occurrences (compare combined units in Table 3e with those in Table 3a). For this reason, it was decided to base the Palos Verdes high radon potential zone on the combined western area Maph and Mv unit areas. The eU data populations for Dibblee units Qoa and af areas overlying Tma and Tv areas were not found to be significantly different from Tma and Tv indoor-radon data populations (see Appendix F.3). Given the similarities between Dibblee units Tma and Tv with Conrad and Ehlig units Maph and Mv, eU data for Qoa and af overlying Maph and Mv areas are treated as having Maph and Mv radon potentials. Additionally, landslides within a geologic unit's area would be expected to have a somewhat similar radon potential to that of the underlying and surrounding geologic unit, being composed of the same material.

The moderate radon potential zone is based on the moderate radon potential units listed in Table 3b. The Mac unit area is combined with the Dibblee Tmat unit and Tma and Tmv unit area outside of the high radon potential zone to create the moderate potential zone. Defining the moderate potential zone this way divides Maph and Mv belt occurrences mainly between the moderate and unknown radon potential zones. Several small areas of Maph and Mv belt occurrences receive a low radon potential classification by this approach. The low and unknown areas correspond to the potentials of Dibble geologic units overlying Conrad and Ehlig bedrock Maph and Mv belt occurrences.

Low radon potential areas are based on combined low ranking Dibblee map units (Table 3c).

Unknown radon potential areas are based on Dibblee map units with insufficient indoor-radon and eU data for ranking (Table 3d).

Appendix H contains information on supporting data for radon potentials assigned to geologic units. Figures 7 and 8 show the Palos Verdes radon zone locations and supporting data. Tables 4a and 4b contain information about the radon data characteristics for each radon zone. Tables 5a and 5b provide information about the incidence rates of ≥ 4 pCi/L indoor radon measurements and the density of indoor-radon survey measurements per radon zone.

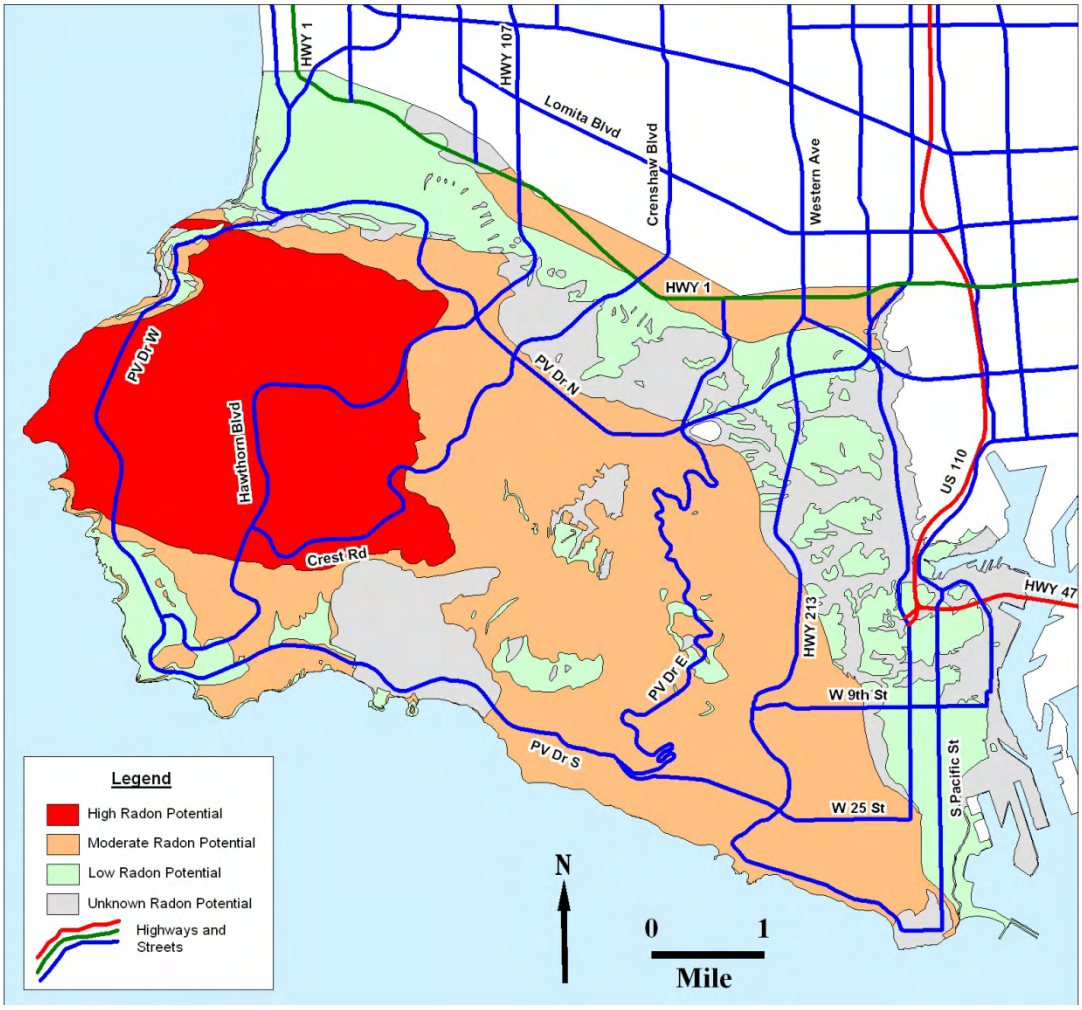

FIGURE 7. Palos Verdes Area Radon Potential Zones

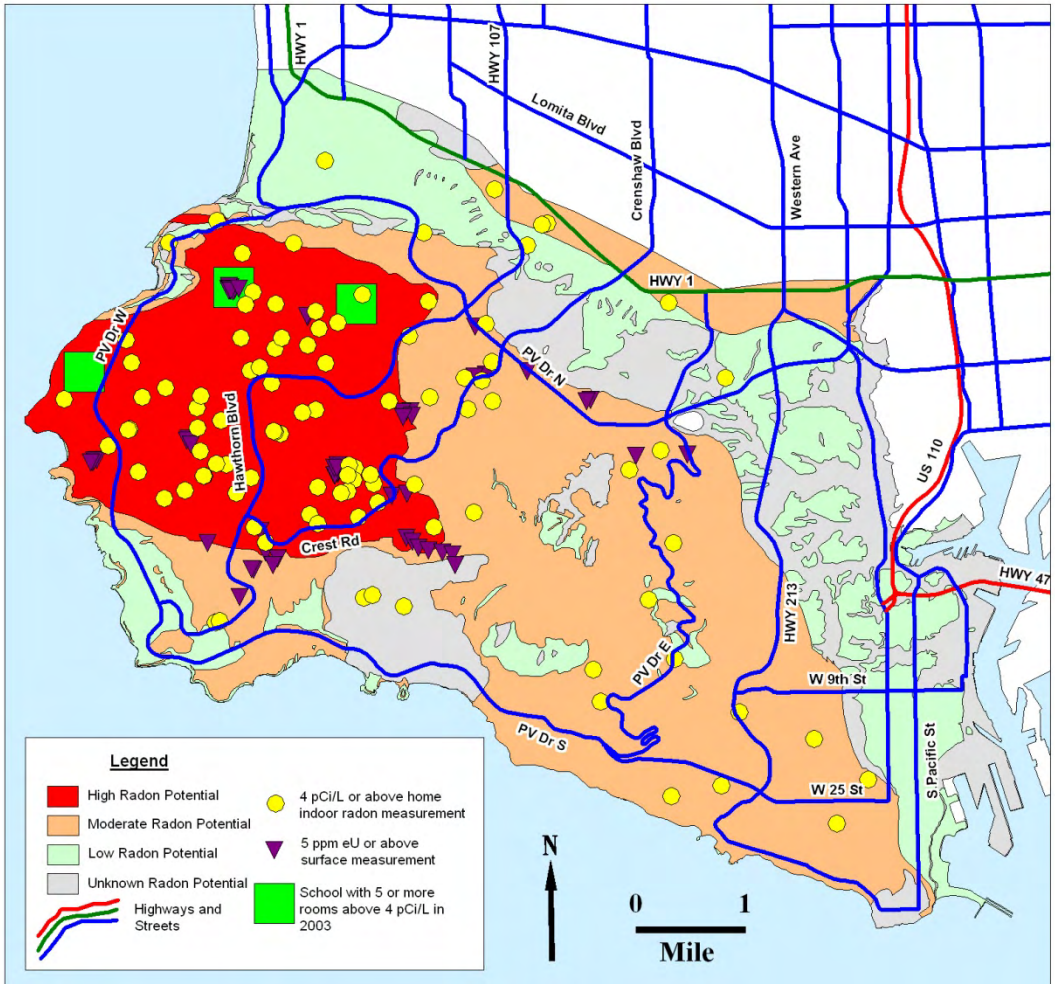

FIGURE 8. Palos Verdes area radon zones with supporting home indoor-radon survey data and eU surface measurement data

Zone	n	Median pCi/L	pCi/L at 25%	pCi/L at 75%	Min pCi/L	Max pCi/L
High	163	2.5	1.0	5.675	0.3	31.5
Moderate	197	1.4	0.7	2.9	0.3	39.2
Low	104	0.55	0.3	1.05	0.3	6.5
Unknown*	40	1.35	0.4	2.15	0.3	8.8
All	504	1.35	0.6	3.3	0.3	39.2

*Only 7 of 10 geologic units with unknown radon potential have indoor-radon measurements

TABLE 4a. Radon zone data characteristics

Zone	n	n ≥ 4.0 pCi/L	% ≥ 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
High	163	62	38.0	12	7.4	8	4.9	7.9
Moderate	197	30	15.2	5	2.5	1	0.5	16.3
Low	104	3	2.9	0	0	0	0	8.4
Unknown*	40	6	15.0	0	0	0	0	7.0
All	504	101	20.0	17	3.4	9	1.8	39.6

*Only 7 of 10 geologic units with unknown radon potential have indoor-radon measurements

TABLE 4b. n ≥ 4.0 pCi/L incidence per radon 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 Data	Cumulative % of Palos Verdes Mapped Area
High	61.4	70.6	88.9	20.0	61.4	20.0
Moderate	29.7	29.4	11.1	41.2	91.1	61.2
Low	3.0	0	0	21.2	94.1	82.4
Unknown*	5.9	0	0	17.7	100.1**	100.1**
All	100.0	100.0	100.0	100.1**		

*Only 7 of 10 geologic units with unknown radon potential have indoor-radon measurements
**Does not sum to 100.0% due to rounding error

TABLE 5a. ≥ 4.0 pCi/L incidence rates for the Palos Verdes radon map area by radon potential zone

Zone	Average Rate: ≥ 4.0 pCi/L measurements per square mile	Average Rate: All measurements per square mile
High	7.8481	20.6329
Moderate	1.8405	12.0859
Low	0.3571	12.3810
Unknown*	0.8571	5.7143
All	2.5505	12.7273

*Only 7 of 10 geologic units with unknown radon potential have indoor-radon measurements

TABLE 5b. Radon data distribution by radon potential zone

RADON POTENTIAL ZONE STATISTICS

Indoor-Radon Measurement Data Characteristics

Descriptive statistics of indoor-radon survey data for each radon potential zone, non-transformed and log-transformed, are provided in Appendix I and Appendix J respectively.

Indoor-Radon Measurement Frequency Distributions

Frequency distributions of trace elements, such as uranium and radon, in rocks and soils are often approximated using the lognormal distribution. However, because of the variety of geologic units and complex history of processes affecting them, geochemical data such as radon data cannot always be fit to a specific frequency distribution (Rose and others, 1979, p. 33). The indoor radon data for the Palos Verdes area are an example of this situation. Taken as a whole, the indoor radon test data from the CDPH Palos Verdes survey fail the Kolmogorov-Smirnov normality test in both untransformed and log-transformed modes (Appendix K). Consequently, the data population (of 504 measurements) is neither normally nor lognormally distributed. These data may be non-normally distributed because they are a combination of samples from several different populations--each rock unit radon population having its own unique indoor-radon population. On an individual basis, the rock unit radon populations may be lognormal, but the aggregate population is not lognormal. For the different Palos Verdes area radon potential zones, only the High Potential Zone appears to have a log-normally distributed indoor-radon population

Data non-normality has important implications for certain statistical operations. For example, T-test comparisons should not be used for comparing non-normal (non-parametric) populations. For this reason, the Mann-Whitney rank sum test is used for comparisons of sub-populations of the indoor-radon test data by radon zone in this study. The Mann-Whitney comparison results for the radon potential zones are discussed in the following section. Non-normality may also have negative consequences for predictions of percentages of homes with indoor radon levels exceeding 4.0 pCi/L where such predictions incorrectly assume a lognormal population distribution for radon data.

Statistical Comparison of Indoor Radon Data by Radon Potential Zone

The results of Mann-Whitney rank sum test statistical comparisons of indoor-radon data populations for Palos Verdes area High, Moderate and Low radon potential zones are listed in Appendix L. These comparisons indicate the indoor-radon data populations for the Palos Verdes High,

Moderate, and Low radon potential zone are statistically distinct. This result, along with the medians for each radon zone population decreasing in rank order (High> Moderate> Low) is evidence supporting the validity of the Palos Verdes area radon potential zone definitions. The Unknown radon potential zone is not significantly different statistically from the Moderate radon potential zone (Appendix L). However, the Unknown radon potential zone may contain a number of distinct indoor-radon sub-populations with different radon potentials. Additional indoor-radon testing within Palos Verdes Unknown radon potential areas would be necessary to document the characteristics of these populations

Estimated Population Exposed to 4.0 pCi/L Radon or Greater Indoor air in Palos Verdes area

Population estimated for each radon potential zone were obtained utilizing GIS methods to overlay Palos Verdes area radon potential zones with 2010 census tract data (U.S. Census, 2010). For a census tract not completely within a radon potential zone, the population contribution from that tract was considered equal to the percentage area of the tract within the radon zone. Table 6 lists the resulting population estimates and estimated number of homes for the different radon potential zones. Table 7 contains population estimates for each radon potential zone and estimates for individuals exposed to ≥ 4.0 pCi/L, ≥ 10.0 pCi/L, and ≥ 20.0 pCi/L indoor radon concentrations. Table 7 estimates are based on the population estimated for each zone multiplied by the ≥ 4.0 pCi/L, ≥ 10.0 pCi/L, and ≥ 20.0 pCi/L percentages for each zone from Table 4b.

Table 7 contains two groups of population totals. The totals under the table heading “Population Estimates Weighted by Radon Zone and Population Distribution” are obtained by summing the data for the individual radon zones. Totals under the table heading “Population Estimates Without Regard to Radon Zone or Population Distribution” are obtained by taking the total Palos Verdes area population and multiplying it by the percentages of CDPH Palos Verdes area radon survey data that equal or exceed 4.0 pCi/L, 10.0 pCi/L, and 20.0 pCi/L. These calculated results are designated with an (*). An estimate of the population exposed to ≥ 4.0 pCi/L indoor-radon levels derived from the percentage of ≥ 4.0 pCi/L measurements listed in the CDPH Zip Code database for Palos Verdes area Zip Codes is also included and designated by a (**). The weighted and unweighted estimates for the Palos Verdes area population exposed to various indoor-radon concentrations are roughly similar in magnitude.

Radon Potential Zone	Estimated Total Population within Zone--2010 Census Statistics	Estimated Total Homes within Zone--2010	
Palos Verdes Area		**Average Household Population***	**Homes****
High	32,171	2.7	11,915
Moderate	64,350	2.7	23,833
Low	62,921	2.7	23,304
Unknown	28,360	2.7	10,504
Total	187,802	2.7	69,556

Table 6. Population and home estimates by radon potential zone
*Estimated average based on 2011 Local Profiles of SCAG Jurisdictions (see www.**scag**.ca.gov/resources/**profiles**.htm for Palos Verdes area cities.
**Zone population ÷ average household population

Radon Potential Zone	Estimated Total Population for Zone	Estimated Population at ≥ 4.0 pCi/L Conditions	Estimated Population at ≥ 10.0 pCi/L Conditions	Estimated Population at ≥ 20.0 pCi/L Conditions	% Area	Sq. miles
High	32,171	12,225 38.0%	2,381 7.4%	1,576 4.9%	19.5	7.9
Moderate	64,350	9,868 15.2%	1,609 2.5%	322 0.5%	41.7	16.9
Low	62,921	1,828 2.9%	0 0.0%	0 0.0%	21.2	8.6
Unknown	28,360	4,254 15.0%	964 3.4%	0 0.0%	17.5	7.1
Population Estimate Weighted by Radon Zone and Population Distribution						
Totals (*weighted, i.e., sum of zone population estimates*)	187,802	28,175 (15.0%)	4,954 (2.6%)	1,898 (1.0%)	100.0	40.5
Population Estimate Without Regard to Radon Zone or Population Distribution						
Totals for the Palos Verdes Area	187,802	37,560* (20.0%) 33.429** (17.8%)	6,385* (3.4%)	3,380* (1.8%)	100.0	40.5

Table 7. Estimates of the Palos Verdes area population exposed to 4.0 pCi/L or greater indoor radon levels in residences (based on 2010 U.S. Census Data)
*estimated using 2008-2009 CDPH indoor-radon survey data
**estimated using CDPH Zip Code Database indoor-radon data for Palos Verdes area Zip Codes

PALOS VERDES AREA RADON MAPPING PROJECT SUMMARY AND RECOMMENDATIONS

Procedures Summary and Results

Short-term radon test data from CDPH and surface radiometric data for background uranium abundance were used to identify geologic units with relatively higher or lower radon potential in the Palos Verdes area. Geologic units were classified as having high, moderate, low or unknown radon potential based on the percentage of 4.0 pCi/L or higher indoor-radon measurements and the presence of surface radiometric data for uranium exceeding 5.0 ppm.

The Final radon potential zones have the following characteristics:

High Radon Potential Zone: this zone comprises 20 percent (7.9 square miles) of the Palos Verdes study area and contains 61.4 percent of the ≥ 4.0 pCi/L measurements and 88.9 percent of the ≥ 20.0 pCi/L measurements in the Palos Verdes CDPH survey. The maximum radon measurement for this zone is 31.5 pCi/L (on the first floor of a house in Rancho Palos Verdes). The maximum radon survey measurement for Palos Verdes Estates is 22.6 pCi/L (for a first floor test).

Moderate Radon Potential Zone: this zone comprises 41.2 percent (16.3 square miles) of the Palos Verdes study area and contains 29.7 percent of the ≥ 4.0 pCi/L measurements and 11.1 percent of the ≥ 20.0 pCi/L measurements in the Palos Verdes CDPH survey. The maximum radon survey measurement for a home in this zone was 39.2 pCi/L (for a basement measurement in a house in San Pedro).

Low Radon Potential Zone: this zone comprises 21.2 percent (8.4 square miles) of the Palos Verdes study area and contains 3.0 percent of the ≥ 4.0 pCi/L measurements and no ≥ 20.0 pCi/L measurements in the Palos Verdes CDPH survey. The maximum radon survey measurement for a home in this zone was 6.5 pCi/L.

Unknown Radon Potential Zone: this zone comprises 17.7 percent (7.0 square miles) of the Palos Verdes study area. The CDPH indoor-radon survey was only able to obtain a total of 40 indoor radon measurements from 7 of the 10 geologic units within this zone. This zone contains 5.9 percent of the ≥ 4.0 pCi/L measurements and no ≥ 20.0 pCi/L measurements in the Palos Verdes CDPH survey. The maximum radon measurement for a home in this zone is 8.8 pCi/L.

Every radon zone contains some short-term indoor-radon measurements equal to or above 4.0 pCi/L as well as some below 4.0 pCi/L. The

maximum measurement for each zone is: High, 31.5 pCi/L; Moderate, 39.2 pCi/L; Low, 6.5 pCi/L; and Unknown, 8.8 pCi/L.

Comparison of the indoor radon data populations for the High, Moderate, and Low radon potential zones, using the Mann-Whitney rank sum test, shows the zones differ from each other statistically. Note that the P values for these tests (the probability of being wrong in concluding that there is a true difference between groups) listed in Appendix L are less than 0.001. This is strong statistical support for the different Palos Verdes area radon potential zones representing distinct indoor-radon potential populations.

Recommendations

Indoor-radon testing should be encouraged in the Palos Verdes area as high and moderate radon potential zones account for 61.2 percent of the study (mapped) area. Additional indoor-radon measurements within the unknown potential areas should be encouraged because 15 percent of the available measurements in these areas tested at or above the U.S. EPA 4.0 pCi/L recommended action level.

Those considering new home construction, particularly at sites within high radon potential areas, may wish to consider radon resistant new construction practices. Post construction radon mitigation is still possible, if necessary, but will be more expensive than the cost of adding radon reducing features during house construction.

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APPENDIX A

Concurrent Indoor-Radon Test Data

(Multiple short-term radon measurements in a residence conducted at the same time)

High (pCi/L)	Low (pCi/L)	Difference (pCi/L)	Percent Difference*
24.7	24.4	0.3	1.2
24.7	22.2	2.5	10.1
24.4	22.2	2.2	9.0
11.6	10.9	0.7	6.0
11.6	9.6	2.0	17.2
11.6	9.3	2.3	19.8
10.9	9.6	1.3	11.9
10.9	9.3	1.6	14.7
9.6	9.3	0.3	0.3
5.4	3.2	2.2	3.1
3.3	3.3	0.0	0.0
3.1	2.8	0.3	9.7
3.1	1.8	1.3	41.9
3.1	1.3	1.8	58.1
2.8	1.8	1.0	35.7
2.8	1.3	1.5	53.6
1.8	1.3	0.5	27.8
1.7	<0.5	<1.2	<70.6
1.5	1.3	0.2	13.3
1.5	1.2	0.3	20.0
1.3	1.2	0.1	7.7
0.8	0.6	0.2	25.0
0.8	0.5	0.3	37.5
0.6	0.5	0.1	16.7
0.6	0.5	0.1	16.7
<0.5	<0.5	<0.4	--
<0.5	<0.5	<0.4	--
<0.5	<0.5	<0.4	--

* Percent Difference = Difference ÷ High X 100

APPENDIX B

2008-2009 Charcoal Detector Field Blanks

Test Kit ID	Blank Results pCi/L
CA18002	<0.5
CA18014	<0.5
CA18028	<0.5

APPENDIX C

2008-2009 Charcoal Detector Laboratory Spikes

Test Kit ID	Mean Chamber Radon Conc. pCi/L	Test Result pCi/L	Percent Difference from Mean Chamber Conc. pCi/L*
CA18000	18.2	30	39.3
CA18010	18.2	23	20.9
CA18022	18.2	20.7	12.1
CA18027	18.2	19.5	6.7
CA18029	18.2	20.3	10.3
CA18031	18.2	16.3	-10.4
CA18035	18.2	17.9	-1.7
CA18052	18.2	21.6	15.7
CA18058	18.2	20.2	9.9
CA18075	18.2	17.7	-2.8

* Percent Difference = Difference ÷ High X 100

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
39.2	27.6	11.6	29.6	19	1/12/2009	1/31/2009
31.5+	0.5+	31.0	98.4	196	1/6/2009	7/21/2009
25.6**	10.4**	15.2	59.4	59	1/25/2009	3/25/2009
25.6**	15.4**	10.2	39.8	79	1/25/2009	4/14/2009
10.4**	15.4**	5.0	32.5	20	3/25/2009	4/14/2009
9.4	4.4	5.0	53.2	101	12/28/2008	4/8/2009
5.2	5.9	0.7	11.9	98	2/8/2009	5/17/2009
5	3.6	1.4	28.0	15	1/24/2009	2/8/2009
4.6	0.9	3.7	80.4	38	1/8/2009	2/15/2009
4	1.7	2.3	57.5	37	1/7/2009	2/13/2009
3.6	6.7	3.1	46.3	131	1/20/2009	5/31/2009
2.8	2.3	0.5	17.9	47	2/5/2009	3/24/2009
0.9	<0.5	>0.4	>44.4	22	12/27/2008	1/18/2009
<0.5***	1.2***	>0.7	>58.3	11	12/26/2008	1/6/2009
<0.5***	1.3***	>0.8	>61.5	11	12/26/2008	1/6/2009
<0.5***	1.5***	>1.0	>66.7	11	12/26/2008	1/6/2009

*Percent Difference = Difference ÷ the higher of Test 1 or Test 2
+Before and after mitigation?
**Multiple measurements at a house
***Multiple measurements at a house

APPENDIX E.1
Dibblee Geologic Map Units and Indoor Radon Data

Geologic Unit Description [unit symbol](Age)	**N**	**N ≥ 4 pCi/L**	**R (%)**	**Low (pCi/L)**	**High (pCi/L)**	**Cities**	**Zip Codes****
Alluvium [Qa](Holocene)	1		nd*		0.3	Palos Verdes Estates Rolling Hills Estates Torrance	90274, 90505
Alluvium, similar to Qa but slightly elevated in position [Qae](Holocene)	25	4	16.0	0.3	9.7	Torrance Harbor City Lomita	90505, 90710 90717
Landslide debris; mostly of Monterey Shale [Qls](Holocene?)	11	4	nd*	0.3	8.8	Palos Verdes Peninsula Rancho Palos Verdes San Pedro	90274 90275 90732
Lomita Marl [Ql](Pleistocene)	1	0	nd*		0.9	Rolling Hills Estates Rancho Palos Verdes San Pedro Torrance	90274,, 90275 90231, 90732 90505
Older Alluvium-nonmarine terrace cover (contains Miocene siliceous shale and limestone pebbles) [Qoa](Pleistocene)	72	8	11.1	0.3	17.3	Palos Verdes Peninsula Rancho Palos Verdes Torrance Harbor City Lomita San Pedro San Pedro	90274, 90275 90505, 90510 90717, 90731 90732
Older stable sand dune and drift sand [Qos](Pleistocene)	42	1	2.4	0.3	5.0	Palos Verdes Estates Rolling Hills Estates Redondo Beach Torrance	90274, 90277 90505

Geologic Unit Description [unit symbol](Age)	**N**	**N ≥ 4 pCi/L**	**R (%)**	**Low (pCi/L)**	**High (pCi/L)**	**Cities**	**Zip Codes****
San Pedro Sand (sand and pebble gravel, pebbles mostly from Miocene hard siliceous shale and limestone detritus) [Qsp](Pleistocene)	12	0	nd*	0.3	3.9	Torrance Lomita San Pedro San Pedro	90505, 90717 90731, 90732
Basalt (submarine flows and breccias in lower Altamira Shale-Tmat) [Tb](Miocene)	18	1	5.6?***	0.3	5.5	Palos Verdes Estates Rancho Palos Verdes Rolling Hills	90274 90275
Fernando Formation (soft gray siltstone-claystone, locally glauconitic) [Tfr](Pliocene)	2	1	nd*	0.3	4.1	Palos Verdes Peninsula	90274
Monterey Formation-Altamira Shale upper part [Tma](Miocene)	154	48	31.2	0.3	39.2	Palos Verdes Estates Rancho Palos Verdes Redondo Beach Torrance San Pedro	90274,, 90275 90277, 90503 90731, 90732
Monterey Formation-Altamira Shale lower part [Tmat](Miocene)	107	16	15.0	0.3	11.7	Palos Verdes Peninsula Rancho Palos Verdes San Pedro	90274, 90275 90732
Monterey Formation diatomite in the San Pedro area (very similar to Valmonte Diatomite) [Tmad](Miocene)	5	0	nd*	0.5	1.9	Rancho Palos Verdes San Pedro	90275, 90731 90732
Malaga Mudstone (light gray sandstone and mudstone with diatomaceous strata and limestone concretions) [Tmg](Miocene)	3	0	nd*	0.3	2.7	Torrance San Pedro	90505, 90731

Geologic Unit Description [unit symbol](Age)	**N**	**N ≥ 4 pCi/L**	**R (%)**	**Low (pCi/L)**	**High (pCi/L)**	**Cities**	**Zip Codes****
Monterey Formation-Valmonte Diatomite [Tmv](Miocene)	50	18	36.0	0.3	9.6	Palos Verdes Estates Rancho Palos Verdes Rolling Hills Estate Torrance	90274, 90275 90505
San Onofre Breccia (unsorted, subangular clasts, up to 0.5 m, mostly blueschist debris, white vein quartz, minor greenschist, rare garnet eclogite, in greenish-gray, friable, massive micaceous sandy matrix) [Tso](Miocene)	0		nd*			Palos Verdes Estates	90274
Catalina Schist (quartz-sericite-schist, quartz-chlorite schist, and glaucophane-blueschist with white quartz veins, thick chert beds, and rare small masses of metagabbro**)** [sc](Jurassic?)	0		nd*			Rancho Palos Verdes Rolling Hills Rolling Hills Estate	90275

*nd = insufficient data to reliably estimate R(%); **Zip Code areas containing this geologic unit*** ? = R% somewhat uncertain because of limited data

APPENDIX E.2

Conrad and Ehlig Bedrock Lithologic Map Units and Indoor Radon Data

Geologic Unit Description [unit symbol](Age)	**N**	**N ≥ 4 pCi/L**	**R (%)**	**Low (pCi/L)**	**High (pCi/L)**	**Cities**	**Zip Codes****
Monterey Formation-Malaga Mudstone [MPm](Miocene-Pliocene)	0		nd*			Torrance	90505
Monterey Formation-Point Fermin sandstone lithofacies [MPf](Miocene-Pliocene)	0		nd*			San Pedro	90731
Monterey Formation-Valmonte Diatomite [Mv](Miocene)	42	11	26.2	0.3	9.3	Lomita, Rancho Palos Verdes, Rolling Hills, Rolling Hills Estates, Palos Verdes Estates, San Pedro, Torrance	90717 90731, 90732 90274, 90275
Monterey Formation-Altamira Shale-Phosphatic lithofacies [Maph](Miocene)	161	53	32.9	0.3	31.5	Rancho Palos Verdes, Rolling Hills, Rolling Hills Estates, Palos Verdes Estates, San Pedro	90731, 90732 90274, 90275
Monterey Formation-Altamira Shale-Cherty lithofacies [Mac](Miocene)	26	4	15.4	0.3	5.2	Rancho Palos Verdes, Rolling Hills, Palos Verdes Estates, San Pedro, Westfield	90731, 90732 90274, 90275
Monterey Formation-Altamira Shale-Tuffaceous lithofacies [Mat](Miocene)	124	16	12.9	0.3	11.7	Rancho Palos Verdes, Rolling Hills, Rolling Hills Estates, San Pedro	90732, 90274 90275
Monterey Formation-Altamira Shale-basalt [Mab](Miocene)	23	13	13.0?	0.3	10.4	Rancho Palos Verdes, Rolling Hills, Palos Verdes Estates	90274, 90275
Catalina Schist [Mzcs](Mesozoic)	0		nd*			Rolling Hills, Rancho Palos Verdes	90274, 90275

*nd = insufficient data to reliable estimate R(%); **Zip Code areas containing this geologic unit; *** R% somewhat uncertain because of limited data

APPENDIX E.3

Dibblee Geologic Map Units and eU Data

(Data sources: Duvall and others(2004), Fukumoto and others (2003), Fukumoto and others (2005), and Fukumoto (2010)

Geologic Unit Description [unit symbol](Age)	**N**	**N ≥ 5 ppm**	**% ≥ 5 ppm**	**Low (ppm)**	**High (ppm)**	**Cities**	**Zip Codes****
Alluvium [Qa](Holocene)	0		nd*			Palos Verdes Estates Rolling Hills Estates Torrance	90274, 90505
Alluvium, similar to Qa but slightly elevated in position [Qae](Holocene)	0		nd*			Torrance Harbor City Lomita	90505, 90710 90717
Landslide debris; mostly of Monterey Shale [Qls](Holocene?)	5	1	nd*	2.2	6.	Palos Verdes Peninsula Rancho Palos Verdes San Pedro	90274, 90275 90732
Lomita Marl [Ql](Pleistocene)	0		nd*			Rolling Hills Estates Rancho Palos Verdes San Pedro Torrance	90275, 90275 90731, 90731 90505
Older Alluvium-nonmarine terrace cover (contains Miocene siliceous shale and limestone pebbles) [Qoa](Pleistocene)	20	4	20.0	0.7	6	Palos Verdes Estates Rancho Palos Verdes Torrance Harbor City Lomita San Pedro	90274, 90275 90505, 90510 90717, 90731 90732
Older stable sand dune and drift sand [Qos](Pleistocene)	3	0	nd*			Palos Verdes Estates Redondo Beach Torrance	90274, 90277 90505

Geologic Unit Description [unit symbol](Age)	**N**	**N ≥ 5 ppm**	**% ≥ 5 ppm**	**Low (ppm)**	**High (ppm)**	**Cities**	**Zip Codes****
San Pedro Sand (sand and pebble gravel, pebbles mostly from Miocene hard siliceous shale and limestone detritus) [Qsp](Pleistocene)	0		nd*			Torrance Lomita San Pedro	90505, 90717 90731, 90732
Basalt (submarine flows and breccias in lower Altamira Shale-Tmat) [Tb](Miocene)	1	0	nd*		3.4	Palos Verdes Estates Rancho Palos Verdes Rolling Hills	90274, 90275
Fernando Formation (soft gray siltstone-claystone, locally glauconitic) [Tfr](Pliocene)	0		nd*			Palos Verdes Peninsula	90274
Monterey Formation-Altamira Shale upper part [Tma](Miocene)	83	21	25.3	0.8	15.7	Palos Verdes Peninsula Rancho Palos Verdes Redondo Beach Torrance San Pedro	90274, 90275 90277, 90503 90731, 90732
Monterey Formation-Altamira Shale lower part [Tmat](Miocene)	82	10	12.2	0.8	11.9	Palos Verdes Peninsula Rancho Palos Verdes San Pedro	90274 90275 90732
Monterey Formation diatomite in the San Pedro area (very similar to Valmonte Diatomite) [Tmad](Miocene)	0		nd*			Rancho Palos Verdes San Pedro	90275, 90731 90732
Malaga Mudstone (light gray sandstone and mudstone with diatomaceous strata and limestone concretions) [Tmg](Miocene)	0		nd*			Torrance San Pedro	90505, 90731

Geologic Unit Description [unit symbol](Age)	**N**	**N ≥ 5 ppm**	**% ≥ 5 ppm**	**Low (ppm)**	**High (ppm)**	**Cities**	**Zip Codes****
Monterey Formation-Valmonte Diatomite [Tmv](Miocene)	19	16	84.2	2.6	15.3	Palos Verdes Estates Rancho Palos Verdes Rolling Hills Estate Torrance	90274, 90275 90505
San Onofre Breccia (unsorted, subangular clasts, up to 0.5 m, mostly blueschist debris, white vein quartz, minor greenschist, rare garnet eclogite, in greenish-gray, friable, massive micaceous sandy matrix) [Tso](Miocene)	0		nd*			Palos Verdes Estates	90274
Catalina Schist (quartz-sericite-schist, quartz-chlorite schist, and glaucophane-blueschist with white quartz veins, thick chert beds, and rare small masses of metagabbro**)** [sc](Jurassic?)	0		nd*			Ranch Palos Verdes Rolling Hills Rolling Hills Estate	90275, 90274

*nd = insufficient data to reliable estimate R(%);**Zip Code areas containing this geologic

APPENDIX E.4

Conrad and Ehilg Bedrock Lithologic Map Units and eU Data

(Data sources: Duvall and others (2004), Fukumoto and others (2003), Fukumoto and others (2005), and Fukumoto (2010)

Geologic Unit Description [unit symbol](Age)	**N**	**N ≥ 5 ppm**	**% ≥ 5 ppm**	**Low (ppm)**	**High (ppm)**	**Cities**	**Zip Codes****
Monterey Formation-Malaga Mudstone [MPm](Miocene-Pliocene)	0		nd*			Torrance	90505
Monterey Formation-Point Fermin sandstone lithofacies [MPf](Miocene-Pliocene)	0		nd*			San Pedro	90731
Monterey Formation-Valmonte Diatomite [Mv](Miocene)	0		nd*			Lomita, Rancho Palos Verdes, Rolling Hills, Rolling Hills Estates, Palos Verdes Estates, San Pedro, Torrance	90717 90731, 90732 90274, 90275
Monterey Formation-Altamira Shale-Phosphatic lithofacies [Maph](Miocene)	83	36	43.4	1.8	15.1	Rancho Palos Verdes, Rolling Hills, Rolling Hills Estates, Palos Verdes Estates, San Pedro	90731, 90732 90274, 90275
Monterey Formation-Altamira Shale-Cherty lithofacies [Mac](Miocene)	36	11	30.6	1.3	5.8	Rancho Palos Verdes, Rolling Hills, Palos Verdes Estates, San Pedro	90731, 90732 90274, 90275
Monterey Formation-Altamira Shale-Tuffaceous lithofacies [Mat](Miocene)	81	9	11.1	0.8	6.5	Rancho Palos Verdes, Rolling Hills, Rolling Hills Estates, San Pedro	90732, 90274 90275
Monterey Formation-Altamira Shale-basalt [Mab](Miocene)	6	0	nd*	0.7	1.8	Rancho Palos Verdes, Rolling Hills, Palos Verdes Estates	90274, 90275
Catalina Schist [Mzcs](Mesozoic)	nd					Rolling Hills, Rancho Palos Verdes	90274, 90275

*nd = insufficient data to reliable estimate R(%); **Zip Code areas containing this geologic unit

APPENDIX F.1

Comparing Indoor-Radon Test Data Populations for Conrad and Ehlig Lithologic Units: Summary of Mann-Whitney Rank Sum Test Results

Geologic Units		Statistically Significant Difference?			Unit with Larger Indoor-radon Median
		Result	*T* statistic	*P* value*	
Comparison of Unit Radon Populations					
Maph	Mv	No	4062.5	0.515	--
Maph	Mac	Yes	1915.0	0.039	Maph
Maph	Mat	Yes	15394.0	<0.001	Maph
Maph	Mab	Yes	1482.4	0.007	Maph
Mv	Mac	No	778.0	0.135	--
Mv	Mat	Yes	4037.5	0.049	Mv
Mv	Mab	Yes	598.5	0.028	Mv
Mac	Mat	No	1962.0	0.998	--
Mac	Mab	No	521.5	0.288	--
Mat	Mab	No	1481.5	0.241	--

* *P* value--The *P* value is the probability of being wrong in concluding that there is a true difference in the two groups (i.e., the probability of falsely rejecting the null hypothesis, or committing a Type I error based on *T*. The smaller the P value, the greater the probability that the samples are drawn from different populations. Traditionally, one can conclude there is a significant difference when $P < 0.05$.

APPENDIX F.2

Comparing Indoor-Radon Test Data Populations* for Dibblee Geologic Unit Occurrences: Summary of Mann-Whitney Rank Sum Test Results

Geologic Units		Statistically Significant Difference Between Populations?			Unit with Larger Indoor-radon Median
		Result	*T* statistic	*P** value	
Tma	Tmat	Yes	12576.0	0.016	Tma
Tma	Tmv	No	5431.0	0.400	--
Tma	Tb	Yes	1111.5	0.026	Tma
Tma	Qsp	Yes	507.5	0.002	Tma
Tma	Qos	Yes	1928.5	<0.001	Tma
Tma	Qoa	Yes	6063.0	<0.001	Tma
Tma	Qls	No	1015.5	0.505	--
Tma	Qae	No	1990.5	0.281	--
Tmat	Tmv	Yes	4736.5	0.003	Tmv
Tmat	Tb	No	994.0	0.327	--
Tmat	Qsp	Yes	459.0	0.022	Tmat
Tmat	Qos	Yes	1834.5	<0.001	Tmat
Tmat	Qoa	Yes	5584.5	0.008	Tmat
Tmat	Qls	No	821.0	0.124	--
Tmat	Qae	No	1734.5	0.678	--
Tmv	Tb	Yes	214.0	0.007	Tmv
Tmv	Qsp	Yes	183.5	<0.001	Tmv
Tmv	Qos	Yes	1080.5	<0.001	Tmv
Tmv	Qoa	Yes	4005.0	<0.001	Tmv
Tmv	Qls	No	352.5	0.837	--
Tmv	Qae	No	782.0	0.060	--
Tb	Qsp	No	157.5	0.235	--
Tb	Qos	Yes	720.5	0.006	Tb
Tb	Qoa	No	885.0	0.509	--
Tb	Qls	No	205.5	0.072	--
Tb	Qae	No	351.5	0.279	--
Qsp	Qos	No	343.5	0.786	--
Qsp	Qoa	No	412.5	0.215	--
Qsp	Qls	Yes	172.5	0.014	Qls
Qsp	Qae	Yes	152.5	0.015	Qae
Qos	Qoa	Yes	1884.0	0.002	Qoa
Qos	Qls	Yes	470.0	<0.001	Qls
Qos	Qae	Yes	1228.5	<0.001	Qae
Qoa	Qls	Yes	641.5	0.016	Qls
Qoa	Qae	Yes	1519.0	0.015	Qae
Qls	Qae	No	236.0	0.272	--

*Summary of Mann-Whitney Rank Sum Test results for Dibblee geologic unit indoor-radon populations with N ≥11

** *P* value--see Appendix F.1 table footnote

APPENDIX F.3

Comparing Geologic Unit Equivalent Uranium (eU) Populations: Summary of Mann-Whitney Rank Sum Test Results

Geologic Units		Statistically Significant Difference Between Populations?			Unit with Larger Indoor-radon Median
		Result	*T* statistic	*P* value*	
Comparison of Conrad-Ehlig Bedrock Lithologic Unit Indoor-Radon Populations*					
Maph	Mac	Yes	1497.0	<0.001	Maph
Maph	Mat	Yes	4758.0	<0.001	Maph
Mac	Mat	No	2428.5	0.189	--
Comparison of Dibblee Geologic Unit Indoor-Radon Populations**					
Tma	Tmv	Yes	1586.5	<0.001	Tmv
Tma	Tmat	Yes	5300.0	<0.001	Tma
Tmv	Tmat	Yes			Tmv
Tma	Qoa overlying Tma	No	505.0	0.181	--
Tma	af overlying Tma or Qoa on Tma	No	507.0	0.443	--
Tmv	af overlying Tmv	No	193.0	0.420	--
Tmat	Tmv	Yes	1658	<0.001	Tmv

** P value-- APPENDIX F.1 table footnote; ** Units with N ≥ 12 eU measurements*

APPENDIX F.4

Percentages of ≥ 5.0 ppm eU Measurements for Monterey Formation Related Geologic Map Units

Geologic Unit*	Number of Measurements	% ≥ 5.0 ppm eU
Conrad and Ehlig Palos Verdes Bedrock Lithologic Map Units*		
Maph	83	43.4
Mac	36	30.6
Mat	81	11.1
Dibblee Palos Verdes Geologic Map Units		
Tma	83	25.3
Tmv	19	84.2
Tmat	82	12.2

**No eU data are available for Mv*

APPENDIX F.5

Comparing Indoor-Radon Test Data Populations for Conrad and Ehlig "West Area" and "Belt" Maph and Mv Unit Occurrences: Summary of Mann-Whitney Rank Sum Test Results

Geologic Units		Statistically Significant Difference Between Populations?			Unit with Larger Indoor-radon Median
		Result	*T* statistic	*P* value*	
Maph west area	Maph belt	Yes	1430.0	<0.001	Maph west area
Maph west area	Mv west area	No	2447.0	0.601	
Maph west area	Mac	Yes	1516.5	0.008	Maph west area
Maph west area	Mat	Yes	13519.5	<0.001	Maph west area
Maph west area	Mab	Yes	1193.0	0.002	Maph west area
Maph belt	Mv west area	Yes	606.0	0.003	Mv west area
Maph belt	Mv belt	No	222.0	0.822	
Maph belt	Mac	No	749.5	0.403	
Maph belt	Mat	No		0.331	
Maph belt	Mab	No	565.5	0.690	
Mv west area	Mv belt	Yes	165.5	0.044	Mv west area
Mv west area	Mac	Yes	615.0	0.026	Mv west area
Mv west area	Mat	Yes	3008.5	0.008	Mv west area
Mv west area	Mab	Yes	482.5	0.009	Mv west area
Mv belt	Mac	No	189.0	0.517	
Mv belt	Mat	No	688.0	0.632	
Mv belt	Mab	No	203	0.713	

** P value-- APPENDIX F.1 table footnote*

APPENDIX F.6

Geologic Unit R (percentage of indoor-radon data ≥ 4 pCi/L)
(*Only for Geologic Units with N ≥ 11 Radon Measurements*)

Geologic Unit	Number of Measurements	R(%)
Conrad and Ehlig Palos Verdes Bedrock Lithologic Map Units		
Maph	161	32.9
Mv	42	26.2
Mac	26	15.4
Mat	124	12.9
Mab	23	13.0
Maph west area only	134	38.8
Maph belt only	27	3.7
Mv west area only	31	32.3
Mv belt only	11	9.1
Dibblee Palos Verdes Geologic Map Units		
Tma	154	31.2
Tmv	50	36.0
Tmat	107	15.0
Tb	18	5.6
Qsp	12	0
Qos	42	2.4
Qoa	72	11.1
Qls	11	36.4
Qae	25	16.0

APPENDIX G

LITHOLOGIC CHARACTERISTICS OF HIGH, MODERATE AND LOW RADON POTENTIAL GEOLOGIC UNITS

High radon potential units

Conrad and Ehlig bedrock lithologic map units:

- Mv (western PV area occurrence)--Monterey Formation, Valmonte Diatomite--diatomite and phosphatic diatomaceous shale, 125 m thick in type area
- Maph (western PV area occurrence)--Monterey Formation, Altamira Shale, phosphatic lithofacies--phosphatic diatomaceous shale and phosphatic mudstone about 25 m thick

Dibblee geologic units:

- Tmv--Monterey Formation, Valmonte Diatomite--soft, white, punky, laminated diatomaceous shale and mudstone, in places up to 125 m thick
- Tma--Monterey Formation, Altamira shale upper part--white-weathering, thin-bedded siliceous and phosphatic shale with interbeds of limestone and siltstone, locally organic and diatomaceous, 40 m thick; with cherty and porcelaneous shale at base up to 15 m thick

Moderate radon potential unit

Conrad and Ehlig bedrock lithologic map units:

- Mac--Monterey Formation, Altamira Shale, Cherty lithofacies--porcelanite and chert 16 m thick in type area
- Mat--Monterey Formation, Altamira Shale, Tuffaceous lithofacies--porcelanite, silty and sandy shale, basalt and tuff, 275 m thick in type area
- Mv (belt occurrence)--Monterey Formation, Valmonte Diatomite--diatomite and phosphatic diatomaceous shale

Dibblee geologic units:

- Qae--Surficial sediment, alluvium, similar to Qa but slightly elevated and locally dissected
- Qls--Surficial sediment, landslide debris, mostly of Monterey Shale
- Qoa--Older surficial sediment, older alluvium, nonmarine terrace cover, sandy loam and loamy clay, includes sand and pebble gravel

in Palos Verdes Hills, with pebbles derived mostly from Miocene hard siliceous shale and limestone, includes Palos Verdes Sand of Woodring and others, 1946
- Tmat--Monterey Formation, Altamira shale lower part, mostly light gray shale and mudstone with tuffaceous and dolomitic strata throughout, with total thickness up to 275 m

<u>Low radon potential units</u>

Conrad and Ehlig bedrock lithologic map units:

- Maph (belt occurrence)--Monterey Formation, Altamira Shale, phosphatic lithofacies--phosphatic diatomaceous shale and phosphatic mudstone

Dibblee geologic units:

- Qos--Surficial sediments, older, stabilized dune and drift sand, mostly unconsolidated fine-grained sand
- Qsp--Shallow marine sediments, San Pedro Sand, light gray to reddish-tan sand and pebble gravel, pebbles derived mostly from Miocene hard siliceous shale and limestone detritus, massive to locally cross-bedded
- Tb (low or moderate potential-uncertain)--Basalt, submarine flows, pillowed flows and breccias in Tmat (Lower Altamira Shale), black, fine-grained basalt to mafic andesite, in places intruded into marine sediments as peperite breccia, rock incoherent where weathered, includes sills, dikes, and irregular discordant intrusions of basalt-diabase, associated with veins of barite, dolomite and quartz

<u>Units with insufficient data to determine their radon potential at this time</u>

Conrad and Ehlig bedrock lithologic map units:

- MPm--Monterey Formation-Malaga Mudstone
  MPf--Monterey Formation-Point Fermin sandstone lithofacies
- MZcs--Catalina Schist

Dibblee geologic units:

- Qa--Alluvium
- Ql--Lomita Marl
- Qsp--San Pedro Sand
- Tfr--Fernando Formation
- Tmad--Monterey Formation diatomite in the San Pedro area

APPENDIX H

Strength of Supporting Data for Radon Potentials Assigned to Geologic Units. Units are bedrock lithologic units of Conrad and Ehlig (1987) and geologic units of Dibblee (1999)

Geologic Unit (abbreviated unit names)	**CDPH Indoor Radon Survey Data**	**Surface eU Data**	**Assigned Radon Potential**
HIGH RADON POTENTIAL			
Conrad and Ehlig bedrock lithologic units			
Mv--Monterey Formation - Valmonte Diatomite	XXX	nd	High
Mv--Monterey Formation - Valmonte Diatomite (**western PV area only**)	XXX	nd	High
Maph--Monterey Formation--Altamira Shale-Phosphatic lithofacies	XXX	XXX	High
Maph--Monterey Formation--Altamira Shale-Phosphatic lithofacies (**western PV area only**)	XXX	XXX	High
Dibblee geologic units			
Tmv-Monterey Formation-Valmonte Diatomite	XXX	XXX	High
Tma-Altamira Shale upper part	XXX	XX	High
MODERATE RADON POTENTIAL			
Conrad and Ehlig bedrock lithologic units			
Mv-Monterey Formation-Valmonte Diatomite-(**belt occurrence only**)	XXX	nd	Moderate
Mac--Monterey Formation-Altamira Shale-Cherty lithofacies	XXX	XXX	Moderate
Mat--Monterey Formation-Altamira Shale-Tuffaceous lithofacies	XXX	X? (Moderate or High?-data at boundary)	Moderate
Dibblee geologic units			
Qae--Alluvium, similar to Qa but slightly elevated in position	XXX	nd	Moderate
Qoa--Older Alluvium-nonmarine terrace cover	XXX	U? (few data support low)	Moderate
Monterey Formation-Tma Altamira Shale-lower part	XXX	XXX	Moderate

LOW RADON POTENTIAL			
Conrad and Ehlig bedrock lithologic units			
Maph-Monterey Formation--Altamira Shale-Phosphatic lithofacies (**belt occurrence only**)	XXX	X? (few data support low to moderate)	Low
Mab-Basalt	U? (only 23 data, they support Moderate Potential)	X? (few data, they support Low Potential)	Low or Moderate?
Dibblee geologic units			
Qos--Older stable sand dune and drift sand	XXX	nd	
Tb--Basalt	X?	few data	Low or Moderate?
UNKNOWN GEOLOGIC POTENTIAL			
Conrad and Ehlig bedrock lithologic units			
MPm--Monterey Formation-Malaga Mudstone	nd	nd	Unknown
MPF--Monterey Formation-Point Fermin sandstone lithofacies	nd	nd	Unknown
Mzcs--Catalina Schist	nd	nd	Unknown
Dibblee geologic units			
Qa--Alluvium	few data	nd	Unknown
Qls--Landslide debris-mostly of Monterey Shale	few data	nd	Unknown
Ql--Lomita Marl	few data	nd	Unknown
Qsp--San Pedro Sand	few data	nd	Unknown
Tfr--Fernando Formation	few data	nd	Unknown
Tmad--Monterey Formation diatomite in the San Pedro area	few data	nd	Unknown
Monterey Formation--Malaga Mudstone	few data	nd	Unknown
Tso-San Onofre Breccia	nd	nd	Unknown
cs-Catalina Schist	nd	nd	Unknown

nd = no data
XXX = data strongly support classification
X = data support classification
U = data unsupportive of classification
? = less certain or uncertain

APPENDIX I

Descriptive Statistics and Statistical Comparison of Indoor Measurements (non-transformed) by Radon Potential Zone

	All Indoor Radon Data	High Zone Radon Data	Moderate Zone Radon Data	Low Zone Radon Data	Unknown Zone Radon
Size	504	163	197	104	40
Mean	2.734	4.432	2.413	0.959	2.005
Std. Dev.	4.111	5.517	3.500	1.131	2.261
Std. Error	0.183	0.432	0.249	0.111	0.357
C.I. of Mean	0.360	0.853	0.492	0.220	0.723
Range	38.900	31.200	38.900	6.200	8.500
Maximum	39.200	31.500	39.200	6.500	8.800
Minimum	0.300	0.300	0.300	0.300	0.300
Median	1.350	2.500	1.400	0.550	1.350
25%	0.600	1.000	0.700	0.300	0.400
75%	3.300	5.675	2.900	1.050	2.150
Skewness	4.242	2.634	6.462	2.820	1.957
Kurtosis	24.604	7.676	62.289	8.768	3.436
K-S Dist.	0.277	0.227	0.273	0.280	0.241
K-S Prob.	<0.001	<0.001	<0.001	<0.001	<0.001
Sum	1377.700	722.400	475.400	99.700	80.200
Sum of Squares	12267.710	8132.840	3548.320	227.410	360.140

APPENDIX J

Descriptive Statistics and Statistical Comparison of Indoor Measurements (Log(10)-transformed) by Palos Verdes Area Radon Potential Zone

	All Indoor Radon Data	High Zone Radon Data	Moderate Zone Radon Data	Low Zone Radon Data	Unknown Zone Radon
Size	504	163	197	104	40
Mean	0.147	0.381	0.151	-0.197	0.0679
Std. Dev.	0.492	0.501	0.441	0.361	0.463
Std. Error	0.0219	0.0392	0.0314	0.0354	0.0731
C.I. of Mean	0.0431	0.0775	0.0620	0.0701	0.148
Range	2.116	2.021	2.116	1.336	1.467
Maximum	1.593	1.498	1.593	0.813	0.944
Minimum	-0.523	-0.523	-0.523	-0.523	-0.523
Median	0.130	0.398	0.146	-0.261	0.128
25%	-0.222	0.000	-0.155	-0.523	-0.412
75%	0.519	0.754	0.462	0.0207	0.332
Skewness	0.291	-0.0757	0.183	0.888	0.188
Kurtosis	-0.639	-0.573	-0.418	-0.0293	-0.976
K-S Dist.	-0.118	0.0629	0.0942	0.259	0.149
K-S Prob.	<0.001	0.114	<0.001	<0.001	0.025
Sum	74.177	62.100	29.829	-20.467	2.715
Sum of Squares	132.903	64.284	42.663	17.428	8.527

APPENDIX K

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

A test that fails indicates that the data vary 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 match the pattern expected if the data were drawn from a population with a normal distribution

Data	N	K-S Distribution	P	Result
All Data-Untransformed	504	K-S Dist. = 0.277	<0.001	Failed
All Data-Log(10) Transformed	504	K-S Dist. = 0.118	<0.001	Failed
High Zone-Untransformed	163	K-S Dist. = 0.227	<0.001	Failed
High Zone-Log(10) Transformed	163	K-S Dist. = 0.063	= 0.114	Passed
Moderate Zone-Untransformed	197	K-S Dist. = 0.273	<0.001	Failed
Moderate Zone-Log(10) Transformed	197	K-S Dist. = 0.094	<0.001	Failed
Low Zone-Untransformed	104	K-S Dist. = 0.280	<0.001	Failed
Low Zone-Log(10) Transformed	104	K-S Dist. = 0.259	<0.001	Failed
Unknown Zone-Untransformed	40	K-S Dist. = 0.241	<0.001	Failed
Unknown Zone-Log(10) Transformed	40	K-S Dist. = 0.149	=0.025	Failed

Appendix L

Comparing Indoor-Radon Test Data Populations for High, Moderate, Low and Unknown Radon Potential Zones: Mann-Whitney Rank Sum Test Results

Mann-Whitney Rank Sum Test					
Group	*N*	*Missing*	*Median*	*25%*	*75%*
High Zone	163	0	2.500	1.000	5.675
Moderate Zone	197	0	1.400	0.700	2.900
Result	T = 33768.000 n(small)= 163 n(big)= 197 (P= <0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = <0.001)				
High Zone	163	0	2.500	1.000	5.675
Low Zone	104	0	0.550	0.300	1.050
Result	T = 8530.000 n(small)=104 n(big)= 163 (p=<0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P=<0.001)				
High Zone	163	0	2.500	1.000	5.675
Unknown Zone	40	0	1.350	0.400	2.150
Result	T = 2937.000 n(small)= 40 n(big)=163 (P= <0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P= <0.001)				
Moderate Zone	197	0	1.400	0.700	2.900
Low Zone	104	0	0.550	0.300	1.050
Result	T = 11030.000 n(small)=104 n(big)=197 (P=<0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P=<0.001)				
Moderate Zone	197	0	1.400	0.700	2.900
Unknown Zone	40	0	1.350	0.400	2.150
Result	T = 4378.500 n(small)=40 n(big)=197 (P=0.335) 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=0.335)				
Low Zone	104	0	0.550	0.300	1.050
Unknown Zone	40	0	1.350	0.400	2.150
Result	T = 3613.500 n(small)=40 n(big)=104 (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)				