SPECIAL REPORT 226

RADON POTENTIAL IN SAN MATEO COUNTY, CALIFORNIA

2014

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RADON POTENTIAL IN SAN MATEO COUNTY, CALIFORNIA

By

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PG #4265

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EXECUTIVE SUMMARY

Radon is a radioactive gas formed by decay of small amounts of uranium and thorium naturally present in rock and soil. Sometimes radon gas can move from underlying soil and rock into homes and become concentrated in the indoor air, posing a significant lung cancer risk for the residents. The U.S. Environmental Protection Agency (U.S. EPA, 2012) estimates indoor radon exposure results in 21,000 lung cancer deaths annually in the United States.

Between November, 2007 and May, 2008, the California Department of Public Health-Indoor Radon Program (CDPH-Indoor Radon Program) conducted an indoor-radon survey of 478 homes in San Mateo County using short-term radon detectors. Radon survey test results range from 0.1 picocuries per liter (pCi/L), the detection limit, to 94.8 pCi/L for a home with a slab-on-grade foundation (room unspecified). Follow-up tests in this home produced measurements of 83.7 pCi/L and 60.0 pCi/L for first-floor rooms. The next highest measurements, 35.9 pCi/L and 28.3 pCi/L, were obtained for first-floor rooms in two other slab-on-grade homes. The U.S. EPA recommended radon action level is 4.0 pCi/L.

A radon potential zone map for San Mateo County, California, was developed by the California Geological Survey (CGS) utilizing:

- CDPH-Radon Program 2007-2008 San Mateo County indoor-radon survey test data
- NURE Project Airborne Survey data for equivalent uranium (eU)
- The 1:62,500 scale U.S. Geological Survey Geologic Map of San Mateo County, California (USGS OFR 98-137)
- The Oakland Museum of California San Francisquito Creek Watershed and Alluvial Fan Map (approximately 1:57,600 scale)
- San Mateo County soil unit data and maps from the Natural Resources Conservation Service (NRCS).

The county indoor-radon data were linked to area geologic units and soil units using a geographic information system (GIS). Geologic units were ranked for radon potential based on the characteristics of their associated radon data, with consideration given to NURE eU data, soil permeability and shrink-swell character, and previous rankings of geologic units in Santa Cruz and other California counties. Four radon potential categories, defined by the percentage of survey data equal to or exceeding 4.0 pCi/L, were used to rank San Mateo geologic units: high (≥ 20 percent), moderate (5 percent to 19.9 percent), low (< 5 percent), and unknown (for geologic units with few or no data). Geologic units with the same radon potentials were grouped together to define the radon potential zones for the San Mateo County radon potential map (i.e., all high potential occurrences collectively define the high radon potential zone, etc.). A final step in radon potential zone development involved statistical comparison of indoor-radon data populations for the resulting radon potential zones to confirm each zone represents a distinct radon potential.

The 1:100,000 scale (1 inch equals 1.578 miles) radon potential zone map for San Mateo County, 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 in a particular building. All radon zones 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 developed in this study, and 2010 U.S. Census data, an estimated 34,853 people in San Mateo County live in residences with indoor-air radon concentrations likely to equal or exceed 4.0 pCi/L. An estimated 9,222 people live in homes that will likely test 10 pCi/L or more, and about 4,050 people are estimated to live in homes that will likely test at 20 pCi/L or higher.

Indoor-radon testing should be encouraged in San Mateo County in high and moderate radon potential zone areas, which represent 30 percent of the county, and within unknown potential areas where insufficient data are currently available to estimate radon potential. A significant portion of CDPH survey ≥ 4.0 pCi/L measurements (14 out of 35) are associated with the San Francisquito Creek alluvial fan (Menlo Park and Atherton area). Consequently, indoor-radon testing should be encouraged in homes and buildings within the San Francisquito Creek alluvial fan area and watershed (the fan alluvium source area). 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 possible, if necessary, but will be more expensive than the cost of adding radon reducing features during house construction. In recent years some south Bay Area homes have been remodeled to add basements. Homes with basements tend to have increased incidence of indoor-radon concentrations exceeding the U.S. EPA action level. Indoor-radon testing should be encouraged in homes with recently added basements and radon-resistant new construction practices should be considered for basement additions to homes.

INTRODUCTION

Purpose

This report describes radon potentials for geologic formations in San Mateo County, California. Additionally, this report documents the procedures and data used by the California Department of Conservation, California Geological Survey (CGS) to develop the 2013 radon potential zone map for San Mateo 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 concentrations of five to several tens of ppm and occasionally higher. While all buildings have some potential for elevated indoor-radon levels because radon is always present in the underlying soils and rocks, buildings located on those rocks and soils containing higher concentrations of uranium often have an increased likelihood of elevated indoor-radon levels. Breathing air with elevated radon gas abundance over long periods of time increases one's risk of developing lung cancer. Not everyone exposed to radon will develop lung cancer. However, the U.S. Environmental Protection Agency (U.S. EPA, 2012) estimated 21,000 people die in the United States annually from lung cancer attributed to radon exposure.

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, 2012). 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. The high energy 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 in the earth's subsurface. 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, along through-going floor-to-wall joints, and through 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	4.5×10^{9} years
Thorium-234	Beta	24.1 days
Protactinium-234	Beta	1.2 minutes
Uranium-234	Alpha	2.5×10^{5} years
Thorium-230	Alpha	7.5×10^{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 two or three 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 to perform, 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 testing that building for indoor-radon, regardless of what radon zone (high, moderate, low or unknown) it is located within. All radon zone categories will likely have some buildings with indoor radon levels ≥ 4.0 pCi/L.

Development of the San Mateo County Radon Potential Map

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

- CDPH-Radon Program 2007-2008 San Mateo County indoor-radon survey test data for 478 residences and the CDPH-Radon Zip Code Database
- NURE Project Airborne Survey data for equivalent uranium (eU)
- The 1:62,500 scale U.S. Geological Survey Geologic Map of San Mateo County, California (USGS OFR 98-137)
- The Oakland Museum of California San Francisquito Creek Watershed and Alluvial Fan Map (approximately 1:57,600 scale)
- San Mateo County soil unit data and maps from the Natural Resources Conservation Service (NRCS)

The San Mateo County radon potential map development steps are as follows:

1) Utilizing a geographic information system (GIS), 2007-2008 CDPH-Radon Program indoor-radon survey data (home test measurements) for San Mateo County were grouped by geologic unit and soil unit

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

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

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

5) 2007-2008 CDPH-Radon Program indoor-radon survey data were grouped by NRCS soil units.

6) Permeability and shrink-swell character were reviewed for soil groups with indoor-radon data to see if these soil features were associated with higher or lower indoor-radon concentration homes.

7) Using information from steps 2, 4 and 6, final radon potentials were assigned to all geologic units in San Mateo County, with categories defined by 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 to 4.9 percent ≥ 4.0 pCi/L indoor measurements
   - Unknown—units with insufficient data for estimating the percent of ≥ 4.0 pCi/L indoor measurements

8) Geologic unit areas with similar radon potentials were grouped to form radon potential zones using GIS.

9) 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.

10) The final radon zones were compared with 2010 census block data to estimate radon impacts on the San Mateo County 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 often have increased potential for elevated indoor-radon because such features provide pathways for radon flow. However, faults and shear zones are not identified on the 1:100,000 scale San Mateo County Radon Potential Zone map because the minimum fault or shear zone width that can be depicted on a map at this scale is about 100-200 feet, whereas fractures of an inch width or less can be significant pathways for radon movement into a building's foundation. Additionally, soil and alluvium may obscure faults and shear zones or prevent their precise location on geologic maps, except where detailed site-specific investigations have been conducted. Consequently, at 1:100,000-scale mapping, it is better to base priority for indoor testing on zone designation rather than attempt to target fault and shear zone locations. Where situations require a local detailed investigation of indoor radon and fault or shear zone relationships, accurate fault or shear zone maps of 1:24,000 or a more detailed scale should be used or developed to guide testing.

THE SAN MATEO SHORT-TERM INDOOR-RADON SURVEY AND OTHER AVAILABLE INDOOR-RADON DATA

Overview

The CDPH-Radon Program conducted a survey of indoor-radon in San Mateo County homes between November 2007 and May 2008. The CDPH-Radon program solicited participation via direct mailing to 12,000 homeowners in San Mateo County. Four hundred and seventy-eight homeowners (4.0 percent) participated in the survey. The survey participant received a free charcoal detector with instructions for placement and exposure, which they subsequently mailed to the 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 goal of this survey was to obtain sufficient indoor-radon data for homes located on specific geologic units to evaluate the radon potentials of these units. The percentage of homes exceeding the 4.0 pCi/L U.S. EPA recommended radon action level was used to evaluate geologic unit radon potential and the results are presented below in the section titled *Preliminary Assignment of Radon Potentials to Geologic Units Based Upon Indoor-radon Data* (page 14).

Figure 1 shows the geographic distribution of the CDPH radon survey homes in San Mateo County. Areas of relatively high and low survey sample densities in Figure 1 reflect high and low population density areas of the county. Thirty-five homes tested ≥ 4.0 pCi/L and their geographic distribution is shown in Figure 2. The survey radon concentrations range from 0.1 pCi/L, the reported detection limit, to 94.8 pCi/L – the latter for a slab-on-grade house, room and floor unknown. Two other measurements in this house were 83.7 pCi/L and 60.0 pCi/L for first-floor rooms. The next highest measurements were 35.9 pCi/L in a first-floor bedroom of a slab-on-grade foundation house, and 28.3 pCi/L for the first-floor living room in a slab-on-grade foundation house. Foundation type, floor, and geologic unit for all San Mateo County indoor-radon measurements exceeding 10 pCi/L are shown in Table 2.

Table 3a summarizes San Mateo indoor-radon survey results by Zip Code zone and City/Region. For comparison, Table 3b summarizes CDPH on-line Zip Code radon database test data for San Mateo County Zip Code zones accumulated by CDPH since 1989. The CDPH on-line database includes the 2007-2008 San Mateo County radon survey data in Table 3a. Table 3b data cannot be used for evaluating the radon potential of particular geologic units because, for much of its data, the only available location information is the Zip Code for the house tested. More precise

Figure 1. CDPH 2007-2008 San Mateo County radon survey test locations

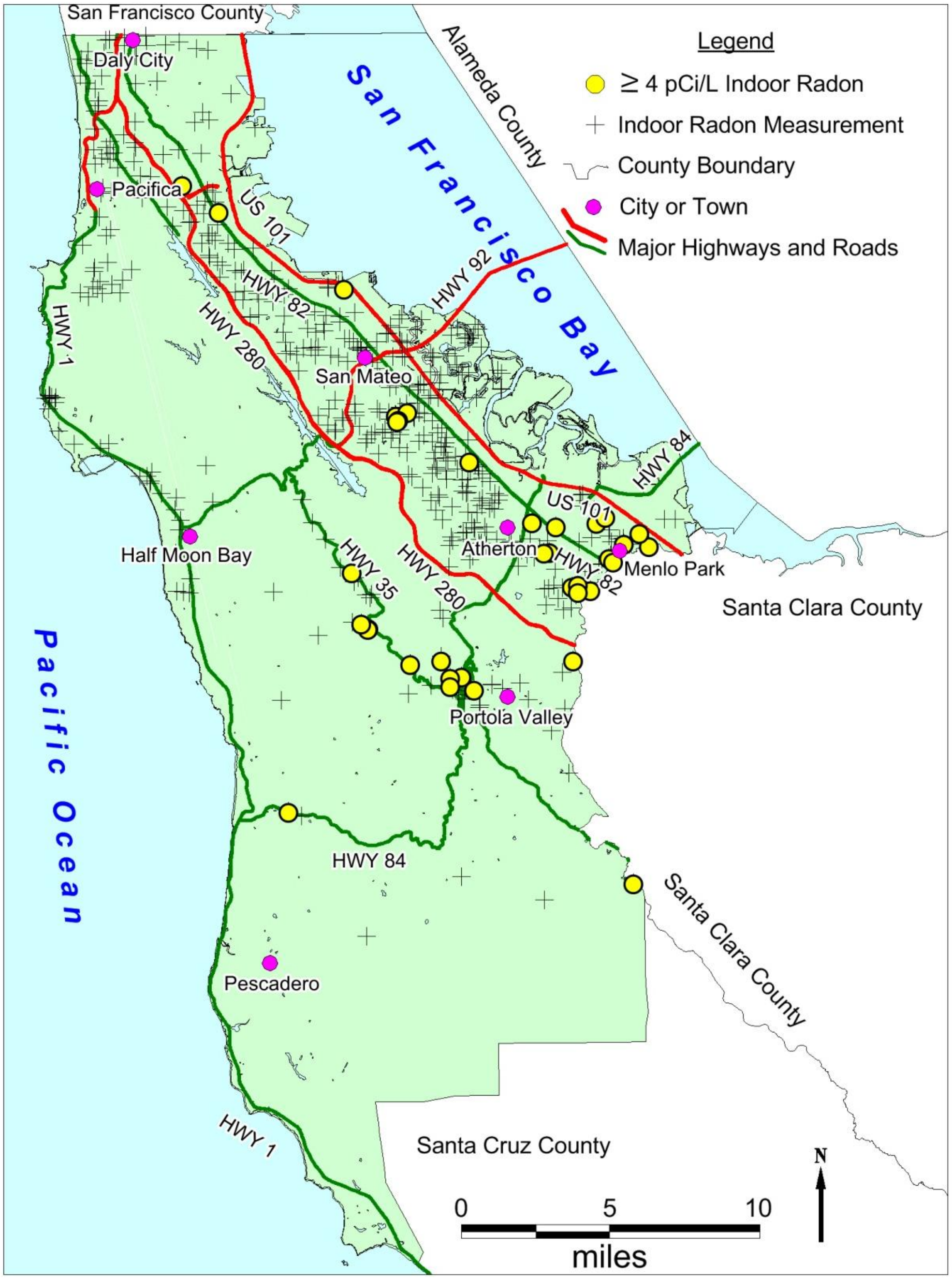

Figure 2. CDPH 2007-2008 San Mateo County radon survey test locations with 4.0 pCi/L or greater sites (shown as yellow circles)

test location information is needed for geologic unit radon potential evaluation. Another complication with Table 3b data is that it likely includes multiple radon measurements for some homes (e.g., follow-up measurements, simultaneous measurements in multiple rooms, or even measurements after radon mitigation) that cannot be identified as such. In spite of these limitations, comparison of Table 3b data with Table 3a data shows the CDPH on-line Zip Code radon data are still useful for pointing out which Zip Codes may contain radon problem areas, and suggesting general indoor-radon trends for San Mateo County. Both the 2007-2008 survey and the Zip Code radon data sets show reasonably close agreement on which Zip Code areas have radon issues and both have similar overall percentage of homes in San Mateo County ≥ 4 pCi/L (7.3 percent for the 2007-2008 survey vs. 7.2 percent for the online Zip Code data).

Home	Radon pCi/L	Foundation Type	Test Floor	Test Room	Geologic Unit Name and Map Symbol
1	94.8	Slab-on-grade	Unknown	Unknown	Lambert Shale (Tla)
	83.7		1	Play Room	
	60.0		1	Bedroom	
2	35.9	Slab-on-grade	1	Master Bedroom	Alluvial fan and fluvial deposits (Holocene) (Qhaf)
3	28.3	Slab-on-grade	1	Living Room	San Lorenzo Formation (Tsl)
	23.2		2	Bedroom	
	18.1		1	Bedroom	
4	25.9	Slab-on-grade	1	Unknown	Floodplain deposits (Holocene) (Qhfp)
5	15.3	Multi-level	1	Family Room	Lambert Shale (Tla)
6	15.2	Crawl-space?	Unknown	Unknown	Colma Formation (Qc)
7	14.1	Slab-on-grade	Unknown	Unknown	Butano Sandstone (Tb)
8	12.3	Slab-on-grade	1	Bedroom	Chert (Franciscan Formation) (fc)
9	12.1	Basement	Basement	Unknown	Natural levee deposits (Holocene) (Qhl)

Table 2. San Mateo indoor-radon measurements exceeding 10 pCi/L: home foundation type, floor, room and geologic unit

Zip Code	City/Region	Number of Measurements	Measurements ≥ 4 pCi/L	Percent ≥ 4 pCi/L
94002	Belmont	35	4	11.4
94005	Brisbane	1	0	0
94010	Burlingame	37	1	2.7
94014	Daly City	12	0	0
94015	Daly City	17	0	0
94018	El Granada	1	0	0
94019	Half Moon Bay	22	0	0
94020	La Honda	3	1	33.3
94021	Loma Mar	1	0	0
94025	Menlo Park	31	10	32.3
94027	Atherton	12	4	33.3
94028	Portola Valley	8	1	12.5
94030	Millbrae	15	0	0
94038	Moss Beach	11	0	0
94044	Pacifica	29	0	0
94061	Redwood City	17	1	5.9
94062	Redwood City	59	10	16.9
94063	Redwood City	3	0	0
94065	Redwood City	6	0	0
94066	San Bruno	18	1	5.6
94070	San Carlos	38	1	2.6
94074	San Gregorio	1	0	0
94080	South San Francisco	13	1	7.7
94303	Palo Alto	2	0	0
94401	San Mateo	6	0	0
94402	San Mateo	26	0	0
94403	San Mateo	28	0	0
94404	San Mateo	26	0	0
	Totals and average percent ≥ 4 pCi/L	478	35	7.3

Table 3a. CDPH indoor radon short-term test results for November 2007 to May 2008 San Mateo County radon survey—by Zip Code zone (Most measurements were made during winter)**.**

Zip Code	City/Region	Number of Measurements	Measurements ≥ 4 pCi/L	Percent ≥ 4 pCi/L
94002	Belmont	91	12	13.2
94005	Brisbane	5	0	0
94010	Burlingame	88	2	2.3
94014	Daly City	29	0	0
94015	Daly City	42	0	0
94018	El Granada	4	0	0
94019	Half Moon Bay	43	0	0
94020	La Honda	9	3	33.3
94021	Loma Mar	1	0	0
94022	Los Altos	60	3	5.0
94023	Los Altos	6	0	0
94024	Los Altos	44	0	0
94025	Menlo Park	101	21	20.8
94027	Atherton	51	17	33.3
94028	Portola Valley	37	4	10.8
94029	Menlo Park	1	0	0
94030	Millbrae	38	0	0
94037	Montara	15	0	0
94038	Moss Beach	16	0	0
94044	Pacifica	68	1	0
94060	Pescadero	1	0	0
94061	Redwood City	37	1	2.7
94062	Redwood City	119	27	22.7
94063	Redwood City	19	2	10.5
94065	Redwood City	17	0	0
94066	San Bruno	45	3	6.7
94070	San Carlos	88	5	5.7
94074	San Gregorio	1	0	0
94080	South San Francisco	92	2	2.2
94303	Palo Alto	22	0	0
94401	San Mateo	12	0	0
94402	San Mateo	141	6	4.3
94403	San Mateo	68	1	1.5
94404	San Mateo	48	0	0
	Totals and average percent ≥ 4 pCi/L	1532	111	7.2

Table 3b. Radon test results for San Mateo County Zip Code zones from the CDPH on-line Radon Zip Code Database for California (1989-2010).

Radon Survey Data—Exposure Duration and Data Quality

Most San Mateo county CDPH radon survey participants exposed their radon tests for two days as instructed, but some exposed them for 3 or 4 days. Differences between two-day and three-day or four-day test results should be negligible. Appendix A lists results for 49 duplicate (concurrent) tests made during the survey. These results are summarized in Table 3c, which shows consistency between most duplicate test results.

High Measurement Group Range pCi/L	Associated Concurrent Group Measurement Ranges pCi/L	Differences pCi/L
83.8*	60.0*	23.8*
15.2**	0.7**	14.5**
4.0-6.0	3.4-4.7	0.1-2.0
3.7-3.9	3.2-3.9	0.0-0.5
2.0-2.9	1.6-2.6	0.0-0.9
1.0-1.9	0.5-1.8	0.0-0.9
0.5-0.9	0.5-0.7	0.0-0.4

Table 3c. Comparison of San Mateo County radon survey duplicate (concurrent) test results
***** Different rooms on first floor of a slab-on-grade foundation house
****** Crawlspace foundation house, two tests, test locations unknown

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

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

Follow-up Radon Testing Results

Fifteen follow-up radon tests at eight different locations were made and are shown in Appendix D. The number of days between tests range from 22 to 70. In 11 of 15 instances, the follow-up tests confirmed the original test result of either ≥ 4.0 pCi/L or < 4.0 pCi/L.

Where original radon test results were not confirmed with follow up tests, one home initially measured 6.0 pCi/L while 4 follow-up tests 66 days later measured 4.0, 3.9, 3.9 and 3.4 pCi/L. Another house, initially measured 7.5 pCi/L, had a follow-up measurement of 1.9 pCi/L 34 days later. The locations of the detectors for the first and second tests in this house are unknown and could account for part or the entire measurement differences.

In summary, the follow-up tests related to the San Mateo radon survey usually (73 percent of the time) confirmed the initial test result of either ≥ 4.0 pCi/L or < 4.0 pCi/L.

SAN MATEO COUNTY GEOLOGIC UNIT RADON POTENTIALS

Indoor Radon Data and Geologic Units

Indoor-radon data from the CDPH Radon Program 2007-2008 indoor-radon survey data for San Mateo County homes are summarized by geologic unit in Appendix E for the 36 geologic units with indoor-data. Appendix E shows the number of home radon measurements, the number of ≥ 4.0 pCi/L measurements and the maximum radon measurement for each geologic unit. The U.S. Geological Survey 1:62,500-scale Geologic Map of San Mateo County, California (Brabb, and others, 1998) was used to determine which geologic unit is present at each radon test location.

Preliminary Assignment of Radon Potentials to Geologic Units Based Upon Indoor-radon Data

Preliminary radon potentials have been assigned to geologic units based on their associated indoor-radon data listed in Appendix E and the radon potential definitions listed in step 7 on page 6. Tables 4a, 4b and 4c list geologic units likely to have high, moderate or low radon potential. Many of the unit radon potentials listed in Tables 4a, 4b and 4c are provisional—less certain because they have significantly less than 25 indoor-radon measurements. Radon potentials previously assigned to geologic units in Santa Cruz County (Churchill, 2010) were considered in choosing provisional radon potentials for the same geologic units in San Mateo County. Provisional radon potential status is indicated in Tables 4a, 4b and 4c in the following manor: “High (P)”, “Moderate (P)”, or “Low (P).” Additional discussion of high and moderate radon potential geologic units follows Table 4c below. Some alluvial units have several different radon potential designations, depending upon their location and geologic setting. The reasons for this are discussed below in this report section.

Other available data, NURE airborne radiometric data and soil data, were reviewed to see if they support either high, moderate or low designations for the provisional units, and to identify additional geologic units that may have elevated radon potential but lack indoor-radon measurements. Results of these reviews are discussed in the NURE project and soil sections of this report.

Geologic Unit	Indoor-Radon Data	Radon Potential Designation
Chert (Franciscan Formation) (fc)[Cretaceous and Jurassic] (*for area between Belmont Creek and Laurel Creek-see discussion page 18*)	R = 28.6%? N = 14 N ≥ 4 pCi/L = 4 Maximum = 12.3 pCi/L	**High** (P) R ≥ 20%
The San Francisquito Creek Alluvial Fan (Combined portions of sedimentary units Qhaf, Qhfp, Qhl, Qpaf and Qpoaf within the fan**)**	R = 34.1% N = 41 N ≥ 4 pCi/L = 14 Maximum = 35.9	**High** R ≥ 20%
Lambert Shale (Tla)[Oligocene and lower Miocene)	R = 60.0? N = 10 N ≥ 4 pCi/L = 6 Maximum = 94.8 pCi/L	**High** (P) R ≥ 20%
Lambert Shale and San Lorenzo Formation, Undivided (Tls)[lower Miocene, Oligocene, and middle and upper Eocene]	R =? N = 0 N ≥ 4 pCi/L =? Maximum =?	**High** (P) Based on Similarity to Santa Cruz County Monterey Formation and Lambert Shale
Monterey Formation (Tm)[middle Miocene]	R =? N = 1 N ≥ 4 pCi/L = 0 Maximum = 3.7 pCi/L	**High** (P) Based on Santa Cruz County Data and data for other counties
San Lorenzo Formation (Tsl)[Oligocene and upper and middle Eocene]	R =? N = 1 N ≥ 4 pCi/L = 1 Maximum = 28.3 pCi/L	**High** (P) Based on Similarity to Santa Cruz County Monterey Formation and Lambert Shale
San Lorenzo Formation: Rices Mudstone Member (Tsr)[Oligocene and middle and upper Eocene)	R =? N = 0 N ≥ 4 pCi/L =? Maximum =?	**High** (P) Based on Santa Cruz County Data

Table 4a. High radon potential geologic units in San Mateo County based on 2007-2008 CDPH short-term indoor radon data
(P)=Unit radon potential is provisional (less certain) because unit has significantly less than 25 tests

Geologic Unit	Indoor-Radon Data	Radon Potential Designation
Butano Sandstone (Tb)[middle and lower Eocene] (*Santa Cruz County upper sandstone member R = 17.7%)*	R = 12.5%? N = 8 N ≥ 4 pCi/L = 1 Maximum = 14.1 pCi/L	**Moderate** (P) 5%≤R<20%
Older Alluvial Fan Deposits (Qpoaf)[Pleistocene]	R = 14.3%? N = 7 N ≥ 4 pCi/L = 1 Maximum = 6.9	**Moderate** (P) 5%≤R<20%
Santa Cruz Mudstone (Tsc)[upper Miocene] (*Santa Cruz County R = 17.9 %)*	R =? N = 0 N ≥ 4 pCi/L =? Maximum =?	**Moderate** (P) Based on Santa Cruz County Data
Santa Margarita Sandstone (Tsm)[upper Miocene] (*Santa Cruz County R = 6.3 %)*	R =? N = 0 N ≥ 4 pCi/L =? Maximum =?	**Moderate** (P) Based on Santa Cruz County Data
Whiskey Hill Formation (Tw)[middle and lower Eocene]	R = 17.4 N = 23 N ≥ 4 pCi/L = 4 Maximum = 9.2 pCi/L	**Moderate** 5%≤R<20%

Table 4b. Moderate radon potential geologic units in San Mateo County based on 2007-2008 CDPH short-term indoor radon data
(P)=Unit radon potential is provisional (less certain) because unit has significantly less than 25 tests

Geologic/Map Unit	Indoor-Radon Data	Radon Potential
Artificial Fill (af)[Historic]	R = 0.0% N = 62 N ≥ 4 pCi/L = 0 Maximum = 2.9	Low R < 5%
Franciscan Complex: Greenstone (fg)[Cretaceous and Jurassic]	R = 0.0%? N = 12 N ≥ 4 pCi/L = 0 Maximum = 0.9	Low (P) R < 5%
Franciscan Complex: Sandstone (fs) [Cretaceous and Jurassic]	R = 0.0% N = 64 N ≥ 4 pCi/L = 0 Maximum = 3.8	Low R < 5%
Franciscan Complex: Sheared Rock (melange) (fsr) [Cretaceous and Jurassic]	R = 0.0% N = 64 N ≥ 4 pCi/L = 0 Maximum = 2.7	Low R < 5%
Colma Formation (Qc)[Pleistocene] (some occurrences)	R = 3.2% N = 31 N ≥ 4 pCi/L = 1 Maximum = 15.2 pCi/L	Low R < 5%
Marine terrace deposits (Qmt)[Pleistocene] (some occurrences)	R = 0%? N = 12 N ≥ 4 pCi/L = 0 Maximum = 1.5 pCi/L	Low (P) R < 5%
Alluvial fan and fluvial deposits-*Outside of San Francisquito Creek Watershed Alluvial Fan* (Qhaf)[Holocene]	R = 4.3% N = 23 N ≥ 4 pCi/L = 1 Maximum = 5.7 pCi/L	Low R < 5%
Alluvial fan and fluvial deposits-*Outside of San Francisquito Creek Watershed Alluvial Fan* (Qhb and Qhl)[Holocene]	R=33.3%? N=6 N ≥ 4 pCi/L = 2 Maximum = 6.3 pCi/L	Low (P) Few tests; two ≥ 4 pCi/L sites surrounded by low potential geologic units
Alluvial fan and fluvial deposits-*Outside of San Francisquito Creek Watershed Alluvial Fan* (Qpaf)[Pleistocene]	R = 0% N = 31 N ≥ 4 pCi/L = 0 Maximum = 2.6 pCi/L	Low R < 5%
Merced Formation (QTm)[lower Pleistocene and upper Pliocene]	R = 0% N = 29 N ≥ 4 pCi/L = 0 Maximum = 1.7 pCi/L	Low R < 5%
Younger (inner) alluvial fan deposits (Qyf)[Holocene] (some occurrences)	R = 0%? N = 10 N ≥ 4 pCi/L = 0 Maximum = 2.3 pCi/L	Low (P) R < 5%
Younger (outer) alluvial fan deposits (Qyof)[Holocene] (some occurrences)	R = 0%? N = 6 N ≥ 4 pCi/L = 0 Maximum = 3.8 pCi/L	Low (P) R < 5%
Serpentinite (sp)[Cretaceous and/or Jurassic]	R = 0%? N = 13 N ≥ 4 pCi/L = 0 Maximum = 1.4 pCi/L	Low (P) R < 5%

Table 4c. Low radon potential geologic units in San Mateo County based on 2007-2008 CDPH short-term indoor radon data
(P)=Unit radon potential is provisional (less certain) because unit has significantly less than 25 tests

Geologic Units with Provisional High and Moderate Radon Potentials

The Monterey Formation has been previously documented in CGS radon studies as having higher potential indoor-radon areas in California coastal counties from Santa Cruz to Los Angeles (Churchill, 2010; 2008; 2007; 2006; and 2005). Several occurrences of the Monterey Formation are present in San Mateo County. Unfortunately, only one CDPH radon survey measurement, 3.7 pCi/L, was obtained for the Monterey Formation in San Mateo County (Table 4a). Based on previous studies the Monterey Formation in San Mateo County is assumed to have high radon potential despite the lack of indoor-radon data and has been assigned provisional high radon potential status.

The Lambert Shale and San Lorenzo Formation have lithologic and chemical characteristics in common with the Monterey Formation. Six of the ten Lambert Shale related indoor-radon measurements equal or exceed 4 pCi/L; the highest measuring 94.8 pCi/L. The single indoor-radon measurement available for the San Lorenzo Formation measured 28.3 pCi/L. Based on available indoor-radon data, similarities in character to the Monterey Formation, and a high radon potential classification for the Lambert Shale in Santa Cruz County (Churchill, 2010) the Lambert Shale and San Lorenzo Formation have been assigned provisional high radon potentials (Table 4a).

Four out of 14 (29 percent) indoor-radon survey data are ≥ 4 pCi/L for a Franciscan chert occurrence in Belmont (within the area bounded by Belmont and Laurel Creeks, the El Camino Real and San Juan Blvd.). Consequently, the Franciscan chert at this location has been assigned a provisional high radon potential (Table 4a). Additional indoor-radon measurements are needed to confirm this radon potential category assignment. Chert in California has not been previously recognized as a rock type associated with elevated indoor-radon homes. However, chert with above-typical crustal uranium concentrations has been suggested as a possible source of radon for homes with elevated indoor-radon concentrations in Ohio (Harrell and others, 1993, page 13). Limited indoor-radon data are low for other San Mateo County chert areas and have resulted in their assignment to the unknown radon potential category.

The Whiskey Hill Formation has 4 of 23 (17 percent) indoor-radon survey measurements greater or equal to 4 pCi/L; the highest measuring 9.2 pCi/L. Consequently, this formation has been assigned a provisional moderate radon potential based on indoor-radon data (Table 4b). The Whiskey Hill Formation is not known to occur in Santa Cruz County.

High Radon Potential Assignment for the San Francisquito Creek Alluvial Fan

A review of radon survey data for alluvial (unconsolidated sedimentary) geologic units found 14 of the 35 ≥ 4 pCi/L CDPH radon survey measurements for San Mateo County (40 percent) occur in alluvial units in the Menlo Park-Atherton area. The same alluvial units elsewhere in San Mateo County have few or no associated ≥ 4 pCi/L radon survey measurements. Further investigation found the unconsolidated sedimentary units in the Menlo Park-Atherton area with the ≥ 4 pCi/L measurements belong to the San Francisquito Creek alluvial fan. Together, the San Francisquito Creek watershed (source of the fan sediments) and alluvial fan area contain almost half of the ≥ 4.0 pCi/L CDPH survey measurements for San Mateo County.

Sowers (2004) mapped the San Francisquito Creek watershed and fan boundaries. These boundaries are shown along with indoor-radon site locations and the San Mateo County Boundary in Figure 3. San Francisquito Creek is the largest stream on the western margin of San Francisco Bay and drains a watershed of 37 square miles (Sowers, 2004). During thousands of years the creek built up an alluvial fan radiating out to the northeast from where it exits the hills near the intersection of Alpine Road and Junipero Serra Boulevard. The fan comprises thick deposits of sand and gravel that have been divided into eight geologic units by Brabb and others (1998). Much of Menlo Park, Atherton, Palo Alto (Santa Clara County), East Palo Alto, and the Stanford campus (Santa Clara County) are located on this alluvial fan.

Note that the portion of the alluvial fan located in Santa Clara County is not part of this study. CDPH has not undertaken an indoor-radon survey of Santa Clara County as of the time of this report. However, the 94301 Zip Code area is almost entirely within the Santa Clara County portion of the San Francisquito Creek alluvial fan. The CDPH Zip Code database for radon lists 7 of 39 tests (18 percent) from Zip Code 94301 as equal or greater than 4 pCi/L, confirming elevated radon potential for this part of the San Francisquito Creek alluvial fan. The alluvial fan also underlies small to moderate sized portions of other Santa Clara County Zip Codes, 94303, 94304, 94305 and 94306. These areas, generally within one to two miles of San Francisquito Creek, may have increased potential for ≥ 4 pCi/L homes but available indoor-radon data are insufficient to confirm this possibility.

The San Francisquito Creek watershed contains occurrences of the Monterey Formation, Lambert Shale, San Lorenzo Formation and Whiskey Hill Formation, which are known or suspected to have high or moderate radon potential as previously discussed. High and moderate radon potential sediment derived from these four units and deposited in the San Francisquito Creek alluvial fan may explain the relatively high percentage of ≥ 4 pCi/L indoor measurements within the fan. Studies

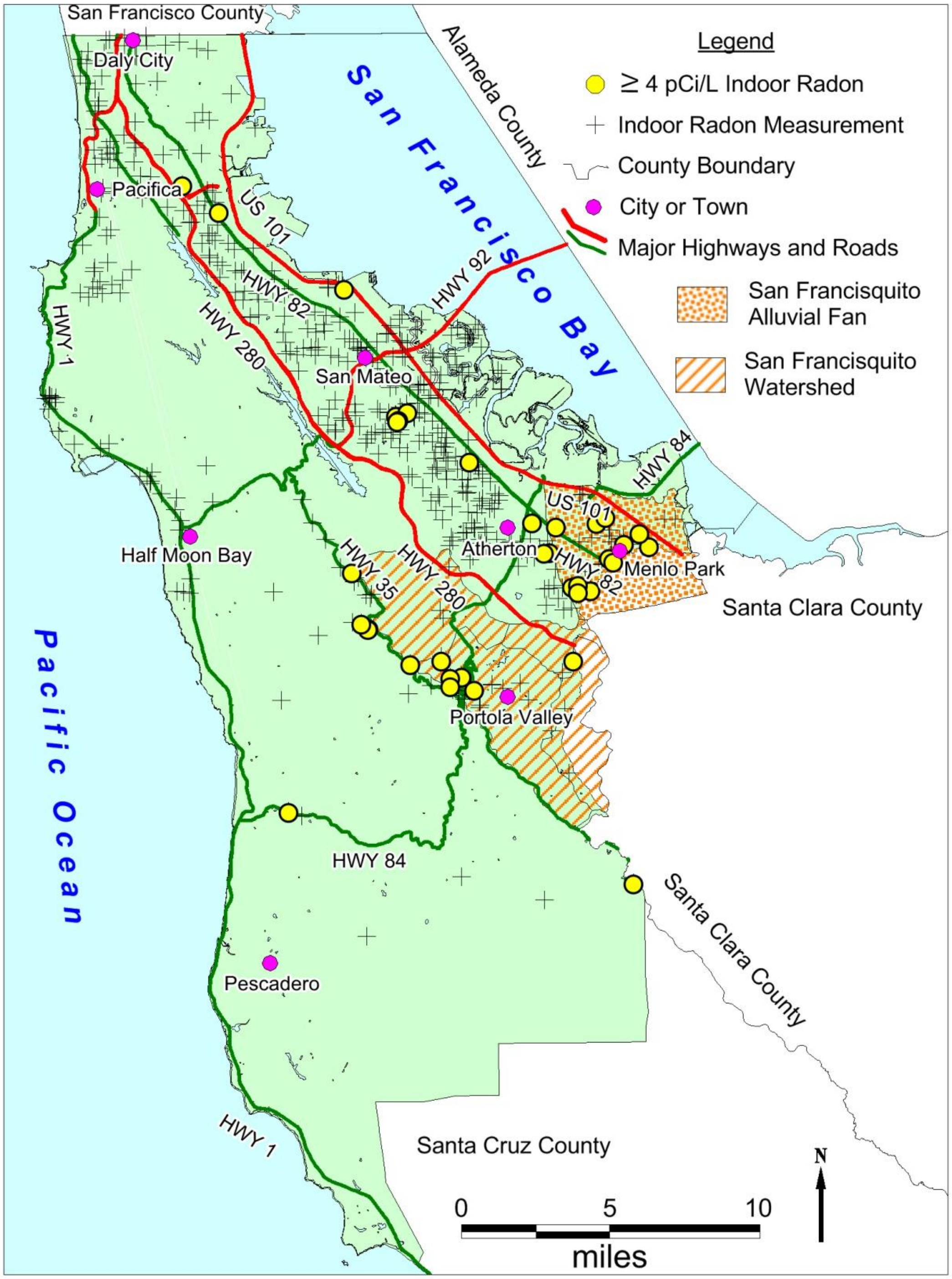

Figure 3. San Francisquito Creek alluvial fan and watershed and CDPH 2007-2008 County radon survey test locations.

involving measurements of radon in soil gas or appropriate surface gamma-ray spectral measurements of alluvial fan and watershed areas would help to evaluate the validity of this hypothesis.

Eight alluvial geologic map units are included within the San Mateo County portion of the San Francisquito alluvial fan. These units and their associated indoor-radon data within the fan are shown in Table 5a. Qhaf, Qhfp, Qhl, Qpaf, and Qpoaf unit occurrences within the San Francisquito Fan have associated indoor-radon data that either have multiple ≥ 4 pCi/L measurements or maximum single measurements significantly exceeding 4 pCi/L. Each unit likely contains some sediment derived from most or all of the higher radon potential bedrock geologic

Unit Symbol	Unit Name	N tests	N ≥ 4pCi/L data	Percent ≥ 4 pCi/L	Low pCi/L	High pCi/L
Qhaf	Alluvial fan and fluvial deposits (Holocene)	1	1	100		35.9
Qhfp	Floodplain deposits (Holocene)	13	5	38.5	0.5	25.9
Qhl	Natural levee deposits (Holocene)	3	3	100	4.6	12.1
Qhb	Basin deposits (Holocene)	5	0	0	0.7	3.1
Qhbm	Bay mud (Holocene)	0	0	--	--	--
Qhsc	Stream channel deposits (Holocene)	0	0	--	--	--
Qpaf	Alluvial fan and fluvial deposits (Pleistocene)	20	5	25.0	0.5	8
Qpoaf	Older Alluvial fan and fluvial deposits (Pleistocene)	4	1	25	0.5	6.9
Total for all eight alluvial units within the San Francisquito Fan (includes Qhb-Basin deposits)		46	15	32.6	0.5	35.9
Total for combined Qhaf, Qhfp, Qhl, Qpaf and Qpoaf unit areas within the San Francisquito Fan (excludes Qhb-Basin deposits)		41	15	36.6	0.5	35.9

Table 5a. Portions of San Mateo County alluvial fan and associated geologic units located within the San Francisquito Creek Alluvial Fan.

units in the San Francisquito watershed. Given the alluvial units source rock similarity, it was decided to treat the portion of the fan represented by these five alluvial units as a single entity in regard to radon potential. The combined radon data for this entity are shown in the last row of Table 5a. This part of the fan has been assigned high radon potential because 36.6 percent of the indoor-radon measurements exceed 4 pCi/L (Table 4a). No indoor-radon data are available for units Qhsc and Qhbm within the fan so they have been assigned unknown radon potential. Unit Qhb areas within the fan have been assigned a provisional low radon potential based on five indoor-radon measurements, all under ≥ 4 pCi/L.

Low Radon Potential Eastern San Mateo County Alluvial Fan Areas North of the San Francisquito Alluvial Fan

A number of other alluvial fans are present in San Mateo County along the western margin of San Francisco Bay to the north of the San Francisquito Creek alluvial fan. These fans are smaller in area than the San Francisquito Creek alluvial fan. The watersheds feeding sediment to these alluvial fans contain few or no occurrences of known or suspected elevated radon potential rock units. Low radon potential for these fans is reflected in the radon data for Qhaf and Qpaf geologic units (the only units with substantial indoor-radon measurements). Table 5b shows only one of 54 indoor-radon measurements for these units exceeds 4 pCi/L.

Unit Symbol	Unit Name	N Tests	N ≥ 4 pCi/L data	Percent ≥ 4 pCi/L	Low pCi/L	High pCi/L
Qhaf	Alluvial fan and fluvial deposits (Holocene)	23	1	4.3	0.5	5.7
Qhfp	Floodplain deposits (Holocene)	1	0	0	--	0.5
Qhl	Natural levee deposits (Holocene)	2	1	50.0	0.5	8.5
Qhb	Basin deposits (Holocene)	4	1	25.0	1.0	6.3
Qhbm	Bay mud (Holocene)	1	0	0	--	0.5
Qhsc	Stream channel deposits (Holocene)	2	0	0	0.5	1.3
Qpaf	Alluvial fan and fluvial deposits (Pleistocene)	31	0	0	0.1	2.6
Qpoaf	Older Alluvial fan and fluvial deposits (Pleistocene)	3	0	0	2.0	3.1
Total for all geologic units in alluvial fans except those associated with the San Francisquito Creek alluvial fan		67	3	4.5	0.1	8.5

Table 5b. Radon data for San Mateo County alluvial fans and associated geologic units (excludes radon data from portions of geologic units associated with the San Francisquito Creek Alluvial Fan)

Consequently, both geologic units (outside of the San Francisquito Alluvial Fan) have been assigned low radon potential. Too few indoor-radon data are available for the remaining alluvial units associated with these alluvial fans and they have been assigned unknown radon potential.

Other Alluvial Geologic Unit Occurrences in Central and Western San Mateo County and Their Radon Potentials

Alluvial geologic map units are defined by a combination of physical properties of the sediment, geometry of the sedimentary deposit, and the geologic characteristics of the site of sediment deposition. Lithology and chemical characteristics of the sediments are not normally considered and may vary significantly from location to location within an alluvial unit if the sediment source rocks vary significantly for different parts of the alluvial unit. As a result, the radon potential will sometimes vary between occurrences of a alluvial unit or within an occurrence of an alluvial map unit. The difference in radon potentials for San Francisquito Creek alluvial fan units and the eastern San Mateo alluvial fan alluvial units is an example of this situation. Additionally, many alluvial unit occurrences are relatively small and may not have associated indoor-radon data. Given these facts, it was decided to assign alluvial unit occurrences with few or no indoor-radon data the radon potential of the surrounding/underlying bedrock unit or the potential of the bedrock unit immediately up slope. As a result, most San Mateo County geologic map alluvial units will have occurrences with different radon potentials, related to the potentials of the local bedrock geologic map units. Table 6 shows the radon potentials associated to each alluvial unit.

Alluvial unit symbol	Alluvial unit name	Radon potentials assigned to alluvial unit occurrences
Qcl	Colluvium (Holocene)	Moderate, low or unknown
Qhaf	Alluvial fan and fluvial deposits (Holocene)	High, moderate, low or unknown
Qhfp	Floodplain deposits (Holocene)	High, low or unknown
Qhsc	Stream channel deposits (Holocene)	High, moderate, low or unknown
Qmt	Marine terrace deposits (Pleistocene)	Low or unknown
Qof	Coarse-grained older alluvial fan and stream terrace deposits (Pleistocene)	Moderate, low or unknown
Qpaf	Alluvial fan and fluvial deposits (Pleistocene)	High, moderate, low or unknown
Qpoaf	Older alluvial fan deposits (Pleistocene)	High, moderate, low or unknown
Qs and Qhbd	Sand dune and beach deposits (Holocene); beach deposits	Low (typically low potential where radon tests are available elsewhere in California)
Qyf	Younger (inner) alluvial fan deposits (Holocene)	High, moderate, low or unknown
Qyfo	Younger (outer) alluvial fan deposits (Holocene)	High, moderate, low or unknown

Table 6. San Mateo County alluvial geologic map unit occurrences and possible radon potentials

Summary of San Mateo County Geologic Unit Lithology and Radon Potentials

In the following list, bullets identify common rock and sediment types assigned to each radon potential category in San Mateo County:

<u>High radon potential units:</u>

- Marine organic-rich siliceous (porcelaneous) shale with chert, mudstone (porcelaneous), impure diatomite and calcareous claystone (Monterey Formation-Tm)
- Mudstone, siltstone and claystone with sandstone, glauconitic sandstone and microcrystalline dolomite in places (Lambert Shale-Tla, San Lorenzo Formation-Tsl, and San Lorenzo Formation-Rices Mudstone Member-Tsr)
- San Francisquito Creek alluvial fan, flood-plain and natural levee deposits containing alluvium derived from marine organic-rich siliceous shale areas
- Franciscan Formation chert, locally interbedded with shale in San Mateo between Belmont Creek and Laurel Creek

Moderate radon potential units:

- Arkosic sandstone interbedded with of mudstone and shale (Butano Sandstone-Tb)
- Friable, very fine-to very coarse-grained arkosic sandstone with glauconite (Santa Margarita Sandstone-Tsm)
- Siliceous mudstone, mudstone and siltstone with minor sandstone (Santa Cruz Mudstone-Tsc)
- Mixed unit with arkosic sandstone, silty claystone, glauconitic sandstone and tuffaceous siltstone; tuffaceous and silty claystone are expansive (Whiskey Hill Formation-Tw)
- Older alluvial fan deposits containing alluvium derived from marine organic-rich siliceous shale areas (Older Alluvial Fan Deposits-Qpoaf, in part)

Low radon potential units:

- Greenstone, sandstone and sheared rock (mélange) (Franciscan complex geologic units)
- Serpentinite
- Friable arkosic sand with subordinate amounts of gravel, silt and clay (Colma Formation-Qc)
- Poorly consolidated sand and gravel (Marine terrace deposits-Qmt)
- Alluvial fan and fluvial deposits outside of the San Francisquito Creek watershed alluvial fan (Holocene alluvial fan deposits-Qhaf, Holocene basin deposits-Qhb, Holocene natural levee deposits-Qhl, Pleistocene alluvial fan deposits-Qpaf, in part)
- Younger Holocene alluvial fan deposits in central and western San Mateo County (Younger (inner) alluvial fan deposits-Qyf), Younger (outer) alluvial fan deposits-Qyof)
- Friable sandstone, siltstone, claystone with conglomerate lenses and a few beds of friable volcanic ash (Merced Formation-QTm)

NURE PROJECT URANIUM DATA

Background

Between 1975 and 1983, the United States government funded the National Uranium Resource Evaluation (NURE) project. The goal of NURE was to identify new domestic sources (ore deposits) of uranium for energy and national defense. NURE uranium exploration activities included airborne gamma-ray spectral surveys that estimated the uranium content of soils and rocks at points along a grid of flight-lines. Locations with unusually high uranium abundance were considered targets for additional work to determine whether or not economically recoverable uranium deposits were present. In some parts of California soil and stream sediment samples were collected for laboratory uranium determinations but such sampling did not take place in San Mateo County.

Airborne Radiometric Data

NURE airborne radiometric data used in this study were compiled from the original data files by Duval (2000). A total of 184.4 miles of flight-line data are available for San Mateo County from this survey. The flight-line grid pattern, shown in Figure 4, consists of east-west flight lines 2-4.3 miles apart and a single south-southeast to north-northwest flight line running up the western portion of the San Francisco peninsula. A specially equipped helicopter flew a few hundred feet above the ground at about 90 miles per hour along these flight lines and recorded 8,101 gamma-ray spectral measurements. The average distance between data measurements is about 120 feet.

One of the gamma-ray energies measured during the NURE airborne radiometric survey is generated during decay of the isotope bismuth-214. Bismuth-214 is one of the radioactive daughter isotopes of uranium-238. It forms soon after radon-222 decays and quickly decays to Polonium-214 (see Table 1). The NURE program used bismuth-214 gamma-ray data to calculate estimates of the soil-rock uranium content, in parts-per-million (ppm), at each of the flight line measurement locations. Under the NURE survey conditions, each airborne uranium measurement represents the average uranium content within the upper 18 inches of surficial material (rock or soil) over an area of approximately 48,000 square feet (approximately 1.1 acres; See High-Life Helicopters, 1980a and 1980b). Because the uranium values are calculated from bismuth-214 gamma-ray data, they are referred to as equivalent uranium (eU) data to distinguish them from uranium data determined by direct chemical methods (i.e., laboratory determinations for uranium in rock and soil samples by delayed neutron activation, fluorescence or other laboratory methods).

Soil moisture, atmospheric inversion and other conditions can negatively impact airborne eU data measurements (Grasty, 1997). Consequently, eU data are treated as qualitative to semi-quantitative indicators of areas with increased uranium in rock or soil in the San Mateo County radon potential study.

Figure 5 shows flight-line data locations where eU equal or exceed 5.0 ppm. The average uranium content of the earth’s crust is about 2.5 ppm, so 5.0 ppm or higher data, two or more times the crustal uranium average, is commonly considered anomalously high and is so considered in this study. San Mateo County geologic units with higher percentages of ≥ 5.0 ppm eU data are assumed more likely to have homes with radon levels exceeding 4.0 pCi/L than geologic units with low percentages of ≥ 5.0 ppm eU data.

Appendix F summarizes NURE airborne eU data for 67 geologic units in San Mateo County. These data suggest the following geologic units are more likely to have **high or moderate radon potentials**:

Alluvial deposits
Qyf-Younger (inner) alluvial fan deposits (Holocene)

Marine sedimentary rocks
Tss-Unnamed sandstone, shale and conglomerate (Paleocene)
Tsm-Santa Margarita Sandstone (upper Miocene)
Tsc-Santa Cruz Mudstone (upper Miocene)
Tm-Monterey Formation (middle Miocene)
Tla-Lambert Shale (Oligocene and lower Miocene)

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

Artificial Fill
af-Artificial fill (Historic)
alf-Artificial levee fill (Historic)
fg-Greenstone (Franciscan Formation)
fs-Sandstone (Franciscan Formation)
fsr-Sheared rock ((mélange) Franciscan Formation)
sp-serpentinite (Cretaceous and/or Jurassic)

Igneous rocks
Kgr-Granitic rocks of Montara Mountain
Tmb-Mindego Basalt and related volcanic rocks (Miocene and/or Oligocene)

Alluvial Deposits
Qhaf-Alluvial fan and fluvial deposits (Holocene)
Qhb-Basin deposits (Holocene)
Qmt-Marine terrace deposits (Pleistocene)
Qof-Coarse-grained older alluvial fan and stream terrace deposits (Pleistocene)
Qpaf-Alluvial fan and fluvial deposits (Pleistocene)

Non-marine sedimentary rocks
QTsc-Santa Clara Formation (lower Pleistocene and upper Pliocene)

Marine sedimentary rocks
Tb-Butano Sandstone (middle and lower Eocene)
Tpsg-San Gregorio Sandstone Member of the Purisima Formation? (Pliocene)

Tpt-Tahana Member of Purisima Formation? (Pliocene and upper Miocene)
Tptu-Tunitas Sandstone Member of Purisima Formation? (Pliocene)
Tst-Twobar Shale Member of San Lorenzo Formation (Oligocene and upper Eocene)
Tvq-Vaqueros Sandstone (lower Miocene and Oligocene)
Tw-Whiskey Hill Formation (middle and lower Eocene)
Kpp-Pigeon Point Formation (upper Cretaceous)

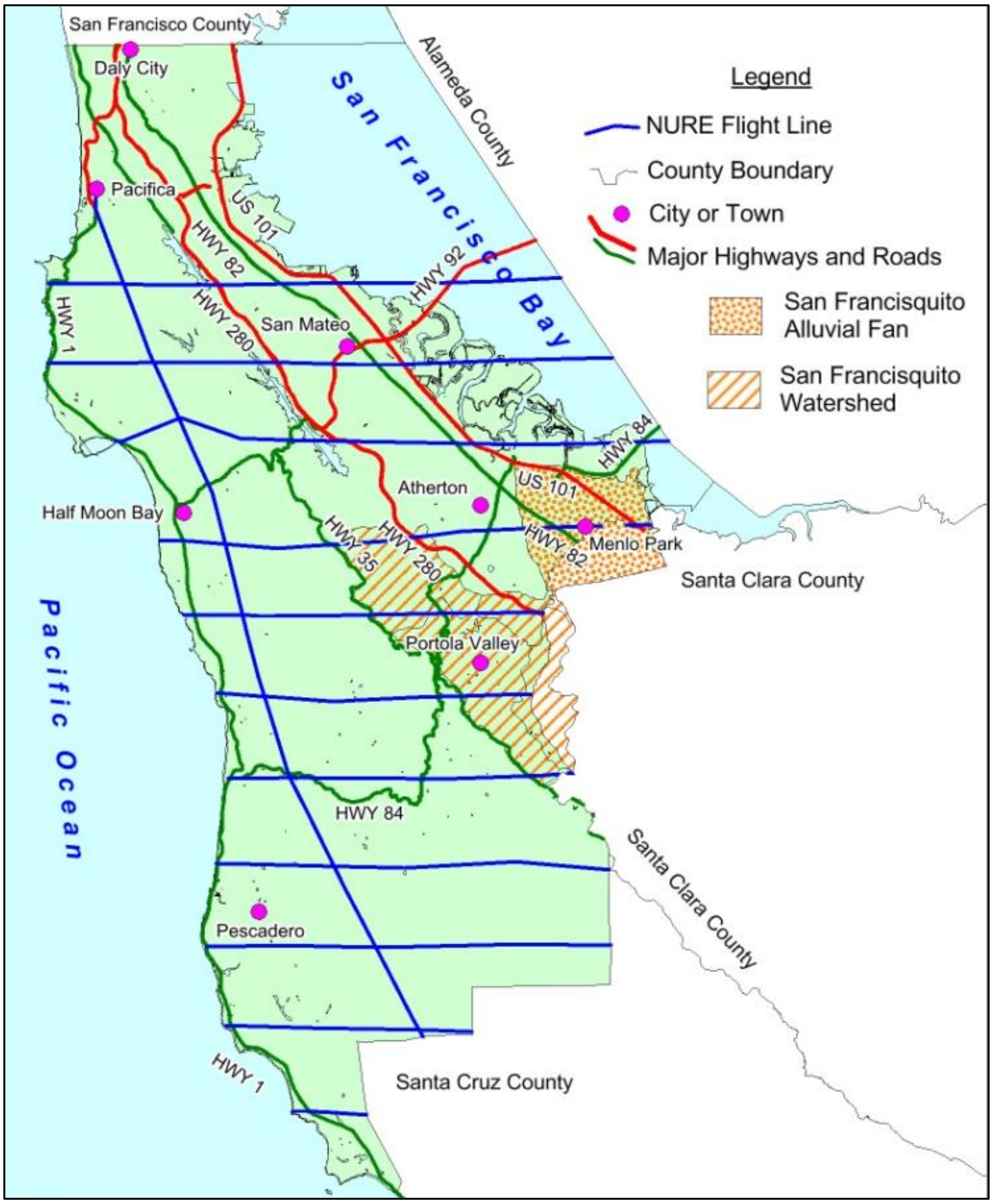

Figure 4. NURE project flight lines for San Mateo County

San Francisquito Watershed Alluvial Fan

NURE airborne eU survey data for the San Francisquito Creek Watershed alluvial fan do not exceed 5 ppm eU, which is often considered the threshold boundary between normal and anomalously elevated background uranium concentrations (twice average crustal uranium

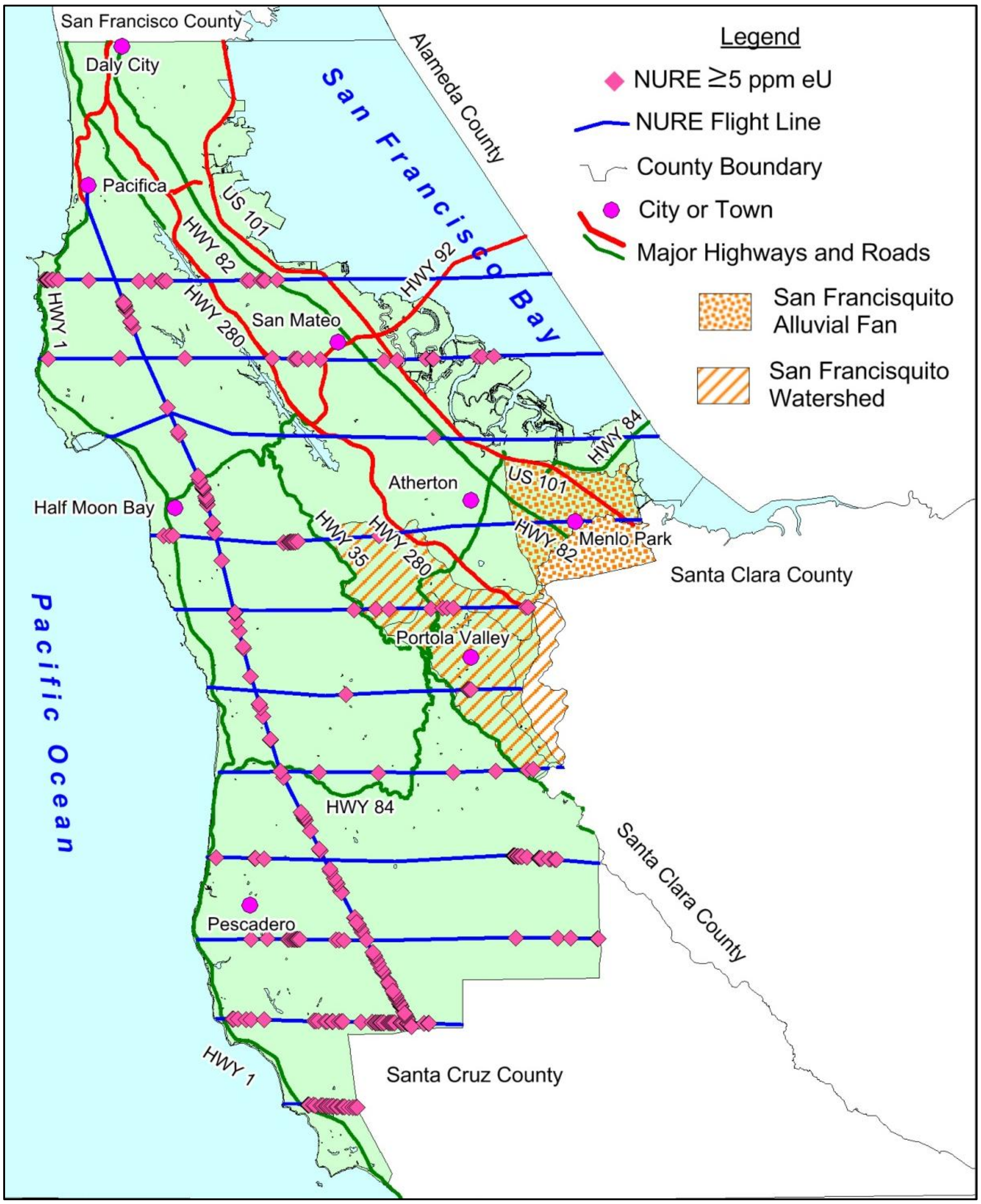

Figure 5. NURE project flight lines and equivalent uranium (eU) anomalies

concentration). This is inconsistent with indoor-radon survey measurements which suggest increased radon potential for the San Francisquito Creek Alluvial Fan. A possibility for this inconsistency is discussed in the *San Francisquito Creek Alluvial Fan Soils and NURE Data* section, page 32.

SAN MATEO COUNTY SOIL DATA

Soil Properties and Indoor-Radon

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. However, radon is more readily released from its point of origin and may migrate further in dry soils than wet soils because it is captured (dissolved) and held in the water (Brookins, 1990, Appleton, 2005). Appendix G provides information on the relationship between different soil types and San Mateo County geologic units.

Most soils in San Mateo County have moderate permeability and low shrink-swell character, or moderately–slow or slow permeability and moderate to high shrink-swell character (see Kashiwagi and Hokholt, 1991; and Lindsey, 1969). These soil permeability and shrink-swell characteristics readily permit radon movement from the subsurface to buildings foundations.

Unfortunately, about two-thirds of indoor-radon measurements in the CDPH-Radon Program survey are in San Mateo County urban areas and located on cut and fill and modified soil areas having highly variable soil properties. Radon survey results show about 3.5 percent of houses located on these soils with indoor-radon concentrations ≥ 4 pCi/L.

Appendix H lists representative permeability, shrink-swell and depth to bedrock information for San Mateo County soils associated with at least one indoor-radon measurement. The information is compiled from the Natural Resource Conservation Service (NRCS) soil surveys and maps for San Mateo County (Kashiwagi and Hokholt, 1991; Lindsey, 1969; and Wagner and Nelson, 1961, and digital maps CA 637 and CA689, available

for downloading at:
http://soildatamart.nrcs.usda.gov/Survey.aspx?County=CA081).

Soil property and radon data summarized in Tables 7a and 7b suggest soils with moderate to moderately slow permeability, moderate shrink-swell character or soils with a low shrink-swell horizon underlain by moderate or high shrink-swell horizons may have elevated potential for association with ≥ 4 pCi/L homes.

Soil Permeability	**% all soil permeability groups**	**N**	**N ≥ 4 pCi/L**	**% ≥ 4 pCi/L**	**Maximum pCi/L**
Rapid	0.6	3	0	?	0.7
Rapid to moderately slow	0.2	1	0	?	1.0
Moderate	3.2	15	4	27?	15.3
Moderate to moderately rapid	2.1	10	1	10?	4.4
Moderate to moderately slow	1.3	6	1	?	4.1
Moderate to moderately rapid to very slow to moderately slow	0.2	1	0	?	0.8
Moderate to moderately slow to slow to moderately slow	0.2	1	0	?	0.6
Moderate to slow	4.1	19	6	32?	83.8
Moderately slow	8.1	38	8	21.1	35.9
Moderately slow to moderate	0.6	3	0	?	1.7
Moderately slow to slow	3.0	14	0	0?	1.5
Moderately slow to moderately rapid to very slow to moderately slow	0.9	4	0	?	0.6
Slow	0.9	4	1	?	4.8
Highly Variable	67.0	313	11	3.5	25.9
Urbanland-smoothed	6.9	32	1	3.1	15.2
Urbandland >85% asphalt, concrete and building covered	0.6	3	3	?	12.1
total	99.9	467	36		

Table 7a. Soil permeability and home indoor-radon data

Soil Shrink-Swell Character	% all soil permeability groups	N	N ≥ 4 pCi/L	% ≥ 4 pCi/L	Maximum pCi/L
High	9.8	10	1	10.0?	4.8
Moderate	43.1	44	11	25.0	35.9
Low	5.9	6	0	?	2.1
Low soil above moderate soil	16.7	17	2	11.8?	4.4
Low soil above moderate soil above low soil	2.9	3	0	?	1.7
Low soil; or Low soil above moderate soil above high soil	18.6	19	6	31.6?	94.8
Moderate soil; or Moderate soil above high soil	2.0	2	0	?	1.7
Low soil over moderate soil over high soil over low soil	1.0	1	0	?	0.6
	100.0	102	20		

Table 7b. Soil shrink-swell character and home indoor-radon data.

San Francisquito Creek Alluvial Fan Soils and NURE Data

Soils along the eU survey flight-line are about 50 percent urban land, and 50 percent Botella (moderately slow permeability; moderate shrink-swell) + urban land. The urban land soil map unit consists of areas where more than 85 percent of the surface is covered by asphalt, concrete, buildings and other structures. Possibly these surface covers and buildings are attenuating some of the eU (Bismuth-214) gamma-ray signal along the flight-line, preventing anomalous eU measurements. Confirming this possibility would require a special study beyond the scope of this report.

RADON POTENTIAL ZONES

Final San Mateo County Geologic Unit Radon Potentials

San Mateo County radon potential zones are based on the locations of geologic units classified as having high, moderate, low or unknown radon potential. The final rankings of San Mateo County geologic units for this report and the associated radon potential map are based upon: 1) indoor-radon data; 2) NURE airborne eU data; and 3) NRCS soil data for permeability and shrink-swell character. For some San Mateo County geologic units with little or no data available, radon potentials were assigned based on radon potentials previously determined for those geologic units in Santa Cruz County and other California coastal counties where data were available for those units. Geologic units with insufficient data from within San Mateo County and from previous studies were assigned “unknown” radon potential. Tables 8a and 8b list San Mateo geologic units with assigned high and moderate radon potentials respectively. These tables provide information about which data support the assigned radon potential for individual geologic units. Appendix I-1 is a similar table for low radon potential units. Appendix I-2 is a list of geologic units with unknown radon potential due to limited or no data.

Geologic Unit (symbol and name)	**Indoor Radon Data**	**NURE Airborne eU Data**	**NRCS Soil Perm. and Shrink-Swell Data**	**Assigned Radon Potential** (additional reason)
Bedrock units				
fc-Franciscan Chert	X	ND	X?	**High (P)** R > 20%?
Tla-Lambert Shale	x	X	X	**High (P)** (Santa Cruz Co. data)
Tls-Lambert Shale and San Lorenzo Formation undivided	ID	--	X	**High (P)** (Santa Cruz Co. Lambert Shale data)
Tm-Monterey Formation	ID (n=1)	X	X	**High (P)** (Santa Cruz Co. and other counties data)
Tsl-San Lorenzo Formation	ID (n=1)	ND	X	**High (P)** (Monterey Fm. and Lambert Shale similarity)
Tsr-San Lorenzo Formation: Rices Mudstone Member	ND	ID	X	**High (P)** (Santa Cruz Co. data)
Combined portions of alluvial units within the San Francisquito alluvial fan				
Qhaf, Qhfp, Qhl, Qpaf and Qpoaf (parts)	XX	--	X?	**High** R > 20%

Table 8a. San Mateo County geologic units and strength of supporting data for high radon potential designation

XX = more than 25 indoor radon measurements support assigned potential
X = 10 to 24 indoor radon measurements support assigned potential; or NURE eU data or soils data support assigned potential
x = < 10 indoor radon measurements support assigned potential
-- does not support assigned potential
ID = Insufficient data to evaluate support or non-support of assigned potential
ND = no data
(P) = Provisional, radon potential confidence slightly uncertain (additional data needed)

Geologic Unit (symbol and name)	**Indoor Radon Survey Data**	**NURE Airborne eU Data**	**NRCS Soil Perm. And Shrink-Swell Data**	**Assigned Radon Potential** (additional reason for assignment)
Bedrock Units				
Tb-Butano Sandstone	x	--	X	**Moderate(P)** (Santa Cruz County data)
Tsc-Santa Cruz Mudstone	ND	X	X	**Moderate(P)** (Santa Cruz Co. data)
Tsm-Santa Margarita Sandstone	ND	X	X	**Moderate (P)** (Santa Cruz Co. data)
Tvq-Vaqueros Sandstone	ID	--	X	**Moderate (P)** (Santa Cruz Co. data)
Tw-Whiskey Hill Formation	x	--	X	**Moderate (P)**
Alluvial units assigned moderate potential because they are on or adjacent to moderate potential bedrock units				
Qcl-Colluvium (part)	ND	x	X	**Moderate (P)**
Qhaf-Alluvial fan and fluvial deposits (part)	ND	--?	X	**Moderate (P)**
Qhb-Basin deposits (part)	ND	ND	ND	**Moderate (P)**
Qhl-Natural levee deposits (part)	ND	ND	ND	**Moderate (P)**
Qhsc-Stream channel deposits (part)	ND	--?	ND	**Moderate (P)**
Qof-Coarse-grained older alluvial fan and terrace deposits (part)	ND	x	X	**Moderate (P)**
Qpaf-Alluvial fan and fluvial deposits (part)	ID	--?	X	**Moderate (P)**
Qpoaf-Older alluvial fan deposits (part)	x	X?	X	**Moderate (P)**
Qyf-Younger alluvial fan deposits (part)	ID	X?	X	**Moderate (P)**

Table 8b. San Mateo County geologic units and strength of supporting data for moderate radon potential designation
(See Table 8a footnotes)

Figure 6 shows the San Mateo radon zone locations and Figure 7 shows the San Mateo radon zones in relationship to ≥ 4 pCi/L measurements and anomalously high NURE airborne eU data. Tables 9a and 9b contain information about the radon data population characteristics for each radon potential zone. Tables 10a and 10b provide information about ≥ 4 pCi/L indoor measurements incidence rates for each radon potential zone and the density of indoor-radon survey measurements per zone.

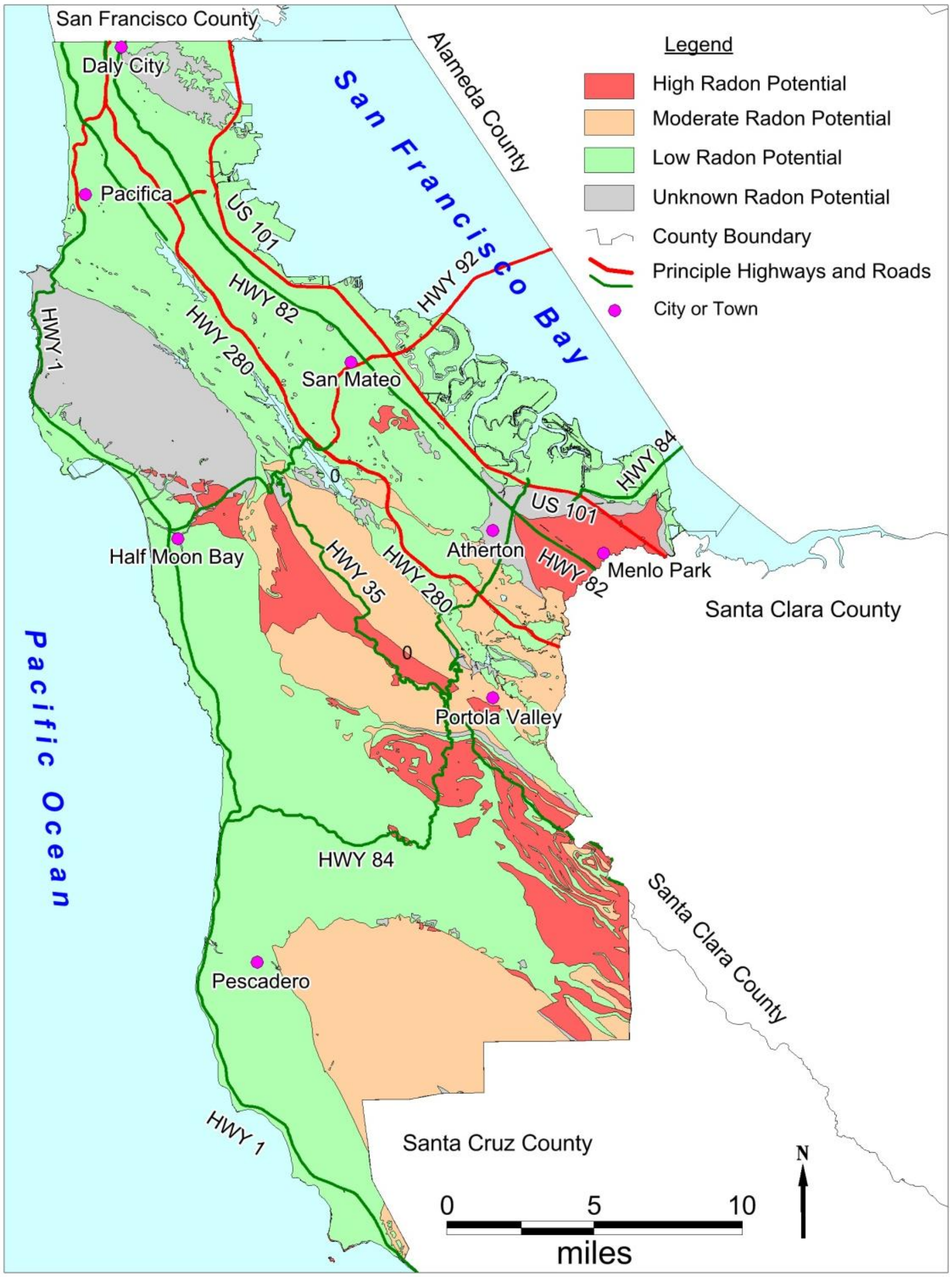

Figure 6. San Mateo County radon potential zones

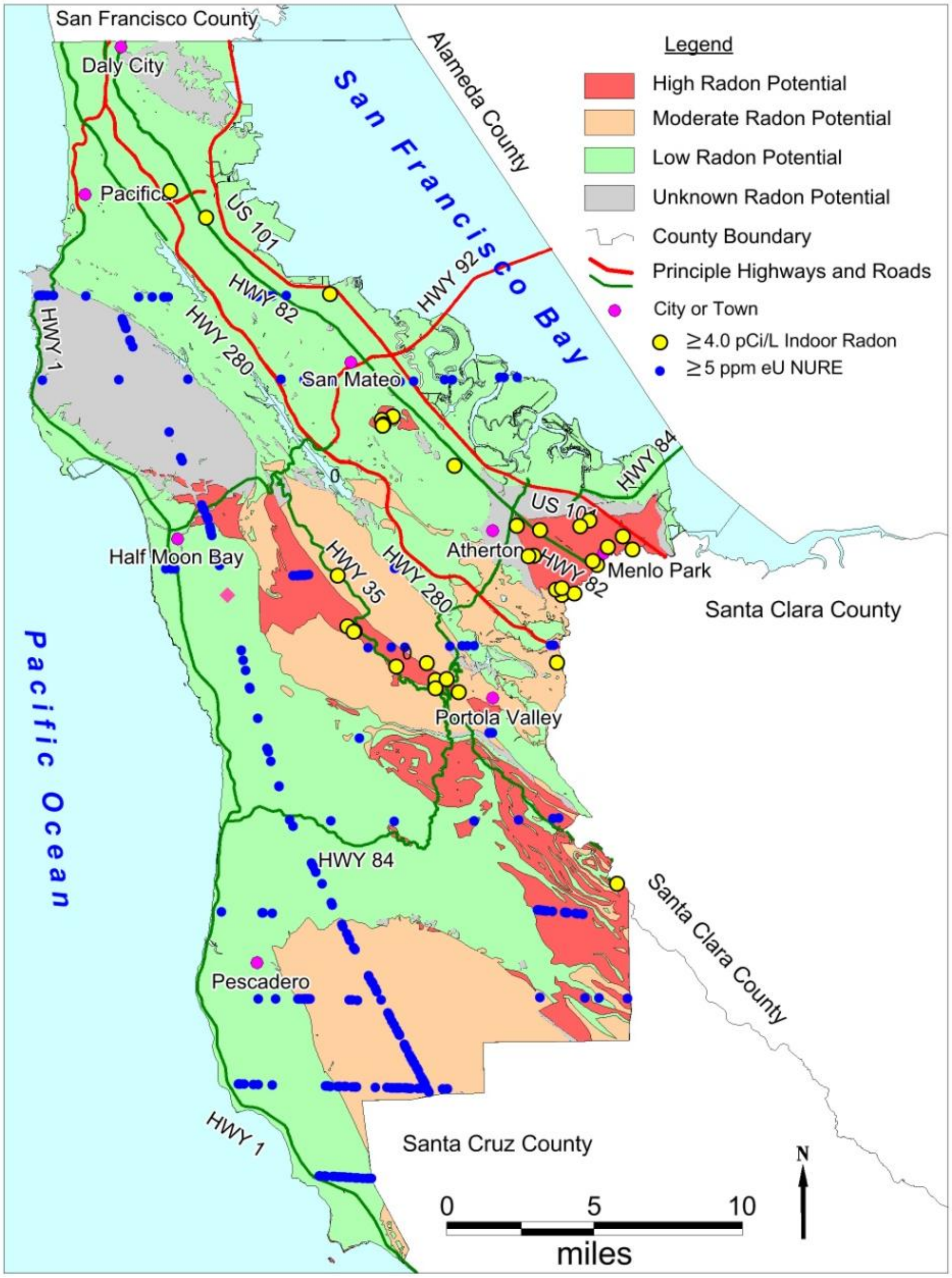

Figure 7. San Mateo County radon potential zones with supporting anomalous indoor-radon survey data and NURE project airborne

Potential Zone	n	Median pCi/L	pCi/L at 25%	pCi/L at 75%	Min pCi/L	Max pCi/L
High	60	3.55	1.50	5.45	0.5	94.8
Moderate	40	1.40	0.90	2.9	0.2	14.1
Low	342	0.50	0.50	0.9	0.1	15.2
Unknown	36	0.75	0.50	1.4	0.5	3.1
All	478	0.60	0.50	1.5	0.1	94.8

Table 9a. Radon zone data characteristics

Potential Zone	n	n ≥ 4.0 pCi/L	% data ≥ 4.0 pCi/L	n ≥ 10.0 pCi/L	% ≥ 10.0 pCi/L	n ≥ 20.0 pCi/L	% ≥ 20.0 pCi/L	Area-land only (sq-mi)
High	60	25	41.7	7	11.7	4	6.7	46.0
Moderate	40	6	15.0	1	2.5	0.0	0.0	88.9
Low	342	4	1.2	1	0.3	0.0	0.0	267.6
Unknown	36	0	0.0	0	0.0	0.0	0.0	47.5
All	478	35	7.3	9	1.9	4	0.8	450.0

Table 9b. n ≥ 4.0 pCi/L incidence per radon potential zone

Zone	% of all ≥ 4.0 pCi/L data	% of all ≥ 10.0 pCi/L data	% of all ≥ 20.0 pCi/L data	% Area	Cumulative % of all ≥ 4.0 pCi/L	Cumulative % of Santa Cruz County Area
High	71.4	77.7	100.0	10.2	71.4	10.2
Moderate	17.1	11.1	0.0	19.8	88.5	30.0
Low	11.4	11.1	0.0	59.5	99.9	89.5
Unknown	0.0	0.0	0.0	10.6	0.0	100.0
All	99.9	99.9	100.0	100.1	99.9	

Table 10a. ≥ 4.0 pCi/L incidence rates for San Mateo County by radon potential zone

Zone	Average Rate: ≥ 4.0 pCi/L Measurements per square mile	Average Rate: All measurements per square mile
High	0.5435	1.3043
Moderate	0.0675	0.4499
Low	0.0149	1.2780
Unknown	0.0000	0.7579
All	0.0778	1.0622

Table 10b. Radon data distribution by radon potential zone

RADON POTENTIAL ZONE STATISTICS

Indoor-Radon Measurement Data Characteristics

Indoor-radon survey data population descriptive statistics for each radon potential zone (for non-transformed, log_{10}- transformed and ln-transformed data) are provided in Appendix J, Appendix K and Appendix L.

Indoor-Radon Measurement Frequency Distributions

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

Data non-normality has important implications for certain statistical operations. For example, t-test comparisons should not be used for comparing non-normal (non-parametric) populations. For this reason, the Mann-Whitney rank sum test is used for comparisons of sub-populations of the indoor-radon test data by radon zone in the 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

Mann-Whitney rank sum test statistical comparisons of High, Moderate and Low radon potential zone indoor-radon data populations are listed in

Appendix N. Results of these comparisons show the indoor-radon data population for each radon potential zone is statistically distinct. This result, along with the medians for each radon zone indoor-radon data population decreasing in rank order (high>moderate>low), is statistical evidence supporting the validity of San Mateo County radon potential zone definitions.

Estimated San Mateo County Population Exposed to 4.0 pCi/L or Higher Radon Concentrations in Indoor Air

Population estimates for each radon potential zone were obtained using GIS methods to overlay San Mateo radon potential zones with 2010 census tract data (U.S. Department of Commerce, 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 11 lists the resulting population estimates and estimated number of homes for the different radon potential zones. Table 12 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 percentages for each zone. Table 12 also contains an estimate for individuals exposed to ≥ 4.0 pCi/L based upon radon zone ≥ 4.0 pCi/L percentages and populations (weighted), an estimate based on the overall radon survey ≥ 4.0 pCi/L percentage and county population (unweighted), and an estimate based on the CDPH Zip Code data for San Mateo County and county population (unweighted). Note that the unweighted estimated populations are higher than the weighted estimated population. This situation likely results from sample bias with more measurements from higher radon potential areas than lower potential areas. In fact, the CDPH survey was designed to target suspected higher radon potential geologic unit occurrences over lower potential geologic unit occurrences. Consequently, the weighted population estimate is expected to be more representative of the actual situation in San Mateo County than the unweighted estimates.

Radon Potential Zone	Estimated Total Population within Zone—2010 Census Statistics	Estimated Total Homes within Zone—2010 Census Statistics	
		Average Household Population*	Estimated Number of Homes
High	60,441	2.74	22,058
Moderate	20,936	2.74	7,640
Low	542,394	2.74	197,954
Unknown	94,678	2.74	34,554
Total	718,449	2.74	262,206

Table 11. Population and home estimated by radon potential zone

*Persons per household, 2007-2011, San Mateo County Quick Facts from the US Census Bureau http://quickfacts.census.gov/qfd/states/06/06081.html

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	60,441	25,204 41.3%	7,072 11.7%	4,050 6.7%	10.2	46.0
Moderate	20,936	3,140 15.0%	523 2.5%	0 0.0%	19.8	88.9
Low	542,394	6,509 1.2%	1,627 0.3%	0 0.0%	59.5	267.6
Unknown	94,678	0 0.0%	0 0.0%	0 0.0%	10.6	47.5
Population Estimate Weighted by Radon Zone and Population Distribution						
Totals (weighted, i.e., sum of zone population estimates	718,449	34,853 (4.9%)	9,222 (1.3%)	4,050 (0.6%)	100.0	450.0
Population Estimate by Radon Survey Results Without Regard to Radon Zone or Population Distribution						
Totals for San Mateo County	718,449	52,447* (7.3%) 51,728** (7.2%)	13,651* (1.9%)	5,748* (0.8%)	100.0	450.0

Table 12. Estimates of San Mateo County population exposed to 4.0 pCi/L or greater indoor radon levels in residences (based on 2010 U.S. Census Data)
*Estimated using 2007-2008 CDPH indoor-radon survey data
**Estimated using CDPH Zip Code data for San Mateo County Zip Codes (as of 5/4/2010)

SAN MATEO COUNTY RADON MAPPING PROJECT SUMMARY

Procedures and Results

Short-term radon test data from CDPH, NURE project airborne radiometric data, and NRCS soil data were used to evaluate geologic units in San Mateo County for their potential to be associated with homes at or above the U.S. EPA recommended radon action level of 4.0 pCi/L. 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, the presence of anomalous airborne radiometric data for uranium, and associated soil permeability and shrink-swell characteristics facilitating or hindering radon movement.

The final radon potential zones have the following characteristics:

High Radon Potential Zone: comprises 10.2 percent (46.0 square miles) of San Mateo County and contains 71.4 percent of the ≥ 4.0 pCi/L measurements and 100 percent of the ≥ 20 pCi/L measurements in the San Mateo CDPH indoor-radon survey. The maximum survey measurement for a home in this zone is 94.8 pCi/L (for an unknown floor and room in a slab-on-grade foundation house). Follow-up tests of a first-floor play room and bedroom were 83.7 pCi/L and 60.0 pCi/L, respectively.

Moderate Radon Potential Zone: comprises 19.8 percent (88.9 square miles) of San Mateo County and contains17.1 percent of the ≥ 4.0 pCi/L measurements and no ≥ 20 pCi/L measurements in the San Mateo CDPH indoor-radon survey. The maximum CDPH radon survey measurement for a home in this zone was 14.1 pCi/L (for a room in a slab-on-grade foundation home, floor unknown).

Low Radon Potential Zone: this zone comprises 59.5 percent (267.6 square miles) of San Mateo County and contains 11.4 percent of the ≥ 4.0 pCi/L measurements and no ≥ 20 pCi/L measurements in the San Mateo CDPH indoor-radon survey. The maximum CDPH radon survey measurement for a home in this zone was 15.2 pCi/L (for a room in crawl-space foundation home, floor unknown).

Unknown Radon Potential Zone: this zone comprises 10.6 percent (47.5 square miles) of San Mateo County and contains no ≥ 4.0 pCi/L measurements and no ≥ 20 pCi/L measurements in the San Mateo CDPH indoor-radon survey. The maximum radon survey measurement for a home in this zone was 3.1 pCi/L.

Note that both indoor-radon concentrations exceeding the U.S. EPA recommended action level of 4 pCi/L and indoor-radon concentrations below this action level were identified in the high, moderate and low radon potential zone areas. The only way to know the indoor-radon concentration in a particular home or building is by testing the indoor-air for radon, regardless of the zone in which the building is located.

Statistical 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 the P values for these tests (the probability of being wrong in concluding that there is a true difference between the groups) listed in Appendix O are less than 0.001. This is strong statistical support for the different San Mateo radon potential zones representing distinct groups of indoor- radon potentials.

RECOMMENDATIONS

Indoor-radon testing should be encouraged in San Mateo County, particularly in the high and moderate radon potential zone areas which represent 30 percent of the county. Additional indoor-radon measurements within unknown potential areas should also be encouraged because there are insufficient data currently available in these areas to estimate their radon potential.

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 possible, if necessary, but will be more expensive than the cost of adding radon reducing features during house construction.

In recent years some south Bay Area homes have been remodeled to add basements. Homes with basements tend to have increased incidence of indoor-radon concentrations exceeding the U.S. EPA action level. Indoor-radon testing should be encouraged in homes that have added basements and radon-resistant new construction practices should be considered for basement additions to homes.

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APPENDIX A

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

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

High (pCi/L)	Low (pCi/L)	Difference (pCi/L)	Percent Difference*
83.8	60.0	23.8	28.4
15.2	0.7	14.5	95.4
6	4.0	2.0	33.3
5.6	4.7	0.9	16.1
4	3.9	0.1	2.5
4	3.9	0.1	2.5
4	3.4	0.6	15
3.9	3.9	0.0	0.0
3.9	3.4	0.5	12.8
3.9	3.4	0.5	12.8
3.7	3.2	0.5	13.5
2.9	2.6	0.3	10.3
2.3	1.6	0.7	30.4
2.3	2.1	0.2	8.7
2.2	2.2	0.0	0.0
2.2	2.0	0.2	9.1
2.2	1.8	0.4	18.2
2.2	2.0	0.2	9.1
2.2	1.8	0.4	18.2
2	1.1	0.9	45.0
2	1.8	0.2	10.0
2	1.8	0.2	10.0
2	1.8	0.2	10.0
2	1.8	0.2	10.0
1.9	1.5	0.4	21.1
1.8	1.8	0.0	0.0
1.7	1.6	0.1	5.9
1.6	0.5	1.1	68.8
1.5	1.0	0.5	33.3
1.5	0.9	0.6	40.0
1.5	0.7	0.8	53.3
1.4	0.5	0.9	64.3
1.3	0.9	0.4	30.8
1.1	0.9	0.2	18.2
1.1	1.0	0.1	9.1
1.1	0.8	0.3	27.3
1	0.9	0.1	10.0
1	0.7	0.3	30.0
1	0.5	0.5	50.0
0.9	0.5	0.4	44.4
0.9	0.7	0.2	22.2

APPENDIX A continued

High (pCi/L)	Low (pCi/L)	Difference (pCi/L)	Percent Difference*
0.9	0.5	0.4	44.4
0.7	0.5	0.2	28.6
0.7	0.5	0.2	28.6
0.6	0.5	0.1	16.7
0.5	0.5	0.0	0.0
0.5	0.5	0.0	0.0
0.5	0.5	0.0	0.0
0.5	0.5	0.0	0.0

*Percent Difference = (Difference ÷ High) X100

APPENDIX B

Charcoal Detector Field Blanks

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

APPENDIX C

Laboratory Spikes of Charcoal Detectors

Date	Mean Chamber Radon Conc. pCi/L	Test Result pCi/L	Difference from Mean Chamber Conc. pCi/L	Minimum Chamber Conc. pCi/L	Maximum Chamber Conc. pCi/L	Test Result within 10% of the Maximum and Minimum Radon Concentrations for the Chamber?
1/24/08	14.4	17.3	2.9	12.7	16.1	Yes
1/24/08	14.4	19.8	5.4	12.7	16.1	No
1/24/08	14.4	12.8	1.6	12.7	16.1	Yes
1/24/08	14.4	16	1.6	12.7	16.1	Yes
1/24/08	14.4	18.1	3.7	12.7	16.1	No
1/24/08	14.4	16	1.6	12.7	16.1	Yes
1/24/08	14.4	18.4	4.0	12.7	16.1	No
1/24/08	14.4	15	0.6	12.7	16.1	Yes

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
94.8**	83.8	11.0	11.6	23	12/30/07	01/21/08
94.8**	60.0	34.8	36.7	23	12/30/07	01/21/08
28.3***	18.1	10.2	36.0	50	12/11/07	01/30/08
28.3***	23.2	5.2	18.0	70	12/11/07	02/19/08
18.1***	23.2	5.1	22.0	22	01/28/08	02/19/08
7.5+	1.9	5.6	74.6	34	01/10/08	02/13/08
6.0****	4.0	2.0	33.3	66	12/22/07	02/26/08
6.0****	3.9	2.1	35.0	66	12/22/07	02/26/08
6.0****	3.9	2.1	35.0	66	12/22/07	02/26/08
6.0****	3.4	1.6	26.7	66	12/22/07	02/26/08
3.7	3.2	0.5	13.5	42	11/26/07	01/07/08
1.4*****	1.1	0.3	21.4	26	12/22/07	01/17/08
1.4*****	0.8	0.6	42.9	26	12/22/07	01/17/08
0.5	1.0	0.5	50.0	27	12/11/07	01/07/08
0.5	0.9	0.4	44.4	34	11/26/07	12/30/07

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

APPENDIX E
Geologic Map units and Indoor Radon Data for San Mateo County

Unit Symbol	Unit Name	N Rn Tests	N Rn Tests GE 4 pCi/L	R%*	High pCi/L	Cities with Occurrences of Unit	Zip Codes with Occurrences of Unit
af	Artificial fill (Historic)	62	0	0	2.9	Burlingame, Daly City, Millbrae, Pacifica, Redwood City, San Bruno, San Mateo, South San Francisco	94010, 94014, 94015, 94030, 94044, 94065, 94066, 94080, 94401, 94402, 94403, 94404
alf	Artificial levee fill (Historic)	1	0	?	0.5	Redwood City	94065
fc	Franciscan Complex: Chert (Cretaceous and Jurassic)	19	4	21.1?	12.3	Belmont, Portola Valley, San Carlos, San Mateo	94002, 94028, 94070, 94403
fg	Franciscan Complex: Greenstone (Cretaceous and Jurassic)	12	0	?	0.9	Loma Mar, Pacifica, Redwood City, San Bruno, San Mateo	94021, 94044, 94062, 94066, 94403
fs	Franciscan Complex: Sandstone (Cretaceous and Jurassic)	64	0	0	3.8	Belmont, Burlingame, Pacifica, Redwood City, San Bruno, San Carlos, San Mateo, South San Francisco	94002, 94010, 94044, 94061, 94062, 94066, 94070, 94080, 94402, 94403
fsr	Franciscan Complex: Sheared rock (melange) (Cretaceous and Jurassic)	34	0	0	2.7	Belmont, Burlingame, Millbrae, Redwood City, San Mateo, South San Francisco	94002, 94010, 94030, 94062, 94080, 94402, 94403,
Kgr	Granitic rocks of Montara Mountain	4	0	?	1.1	El Granada, Moss Beach	94018, 94038

Unit Symbol	Unit Name	N Rn Tests	N Rn Tests GE 4 pCi/L	R%*	High pCi/L	Cities with Occurrences of Unit	Zip Codes with Occurrences of Unit
KJs	Unnamed sandstone (Cretaceous or Jurassic)	4	0	?	3.0	Brisbane, Daly City	94005, 94014
Qal	Alluvium (Holocene)	1	0	?	0.7	Half Moon Bay	94019
Qc	Colma Formation (Pleistocene)	31	1	3.3	15.2	Burlingame, Daly City, Millbrae, San Bruno, San Mateo, South San Francisco	94010, 94014, 94015, 94030, 94066, 94080, 94402
Qcl	Colluvium (Holocene)	11	0	?	2.3	Daly City, Pacifica, Redwood City	94014, 94044, 94062,
Qhaf	Alluvial fan and fluvial deposits (Holocene)	24	2	8.3	35.9	Burlingame, Menlo Park, Portola Valley, San Carlos, San Mateo, South San Francisco	94010, 94025, 94028, 94070, 94080, 94401, 94402, 94403
Qhb	Basin deposits (Holocene)	9	1	11.1?	6.3	Burlingame, Menlo Park, Redwood City	94010, 94025, 94063
Qhbm	Bay mud (Holocene)	1	0	?	0.5	Redwood City	94065
Qhfp	Floodplain deposits (Holocene)	14	5	35.7?	25.9	Atherton, Menlo Park, Palo Alto, Redwood City, South San Francisco	94027, 94025, 94061, 94080, 94303
Qhl	Natural levee deposits (Holocene)	5	4	80?	12.1	Menlo Park, Millbrae, San Bruno	94025, 94030, 94066
Qhsc	Stream channel deposits (Holocene)	2	0	?	1.3	Belmont, Redwood City	94002, 94062
Qmt	Marine terrace deposits (Pleistocene)	12	0	?	1.5	Half Moon Bay, Moss Beach	94019, 94038

Unit Symbol	Unit Name	N Rn Tests	N Rn Tests GE 4 pCi/L	R%*	High pCi/L	Cities with Occurrences of Unit	Zip Codes with Occurrences of Unit
Qof	Coarse-grained older alluvial fan and stream terrace deposits (Pleistocene)	2	0	?	0.8	Half Moon Bay, Moss Beach	94019, 94038
Qpaf	Alluvial fan and fluvial deposits (Pleistocene)	51	5	9.2	8.0	Atherton, Burlingame, Menlo Park, Redwood City, San Carlos, San Mateo	94010, 94025, 94027, 94061, 94062, 94070, 94401, 94402, 94403
Qpoaf	Older alluvial fan deposits (Pleistocene)	7	1	14.3?	6.9	Menlo Park, Redwood City, Portola Valley	94025, 94028, 94062
QTm	Merced Formation (lower Pleistocene and upper Pliocene)	29	0	0	1.7	Burlingame, Daly City, Millbrae, Pacifica, San Bruno, South San Francisco	94010, 94015, 94030, 94044, 94066, 94080
QTsc	Santa Clara Formation (lower Pleistocene and upper Pliocene)	2	0	?	1.2	Portola Valley, Redwood City	94028, 94061
Qyf	Younger (inner) alluvial fan deposits (Holocene)	10	0	?	2.3	Half Moon Bay, Pacifica, South San Francisco	94019, 94044, 94080
Qyfo	Younger (outer) alluvial fan deposits (Holocene)	6	0	?	3.8	Half Moon Bay, Pacifica	94019, 94044
sp	Serpentinite (Cretaceous and/or Jurassic)	13	0	?	1.4	Burlingame, Redwood City	94010, 94061, 94062
Tb	Butano Sandstone (middle and lower Eocene)	8	1	12.5?	14.1	Redwood City	94062

Unit Symbol	Unit Name	N Rn Tests	N Rn Tests GE 4 pCi/L	R%*	High pCi/L	Cities with Occurrences of Unit	Zip Codes with Occurrences of Unit
Tl	Ladera Sandstone (upper(?) and middle Miocene)	1	0	?	0.5	Menlo Park	94025
Tla	Lambert Shale (Oligocene and lower Miocene)	10	6	60.0?	94.8	Half Moon Bay, Redwood City	94019, 94062
Tm	Monterey Formation (middle Miocene)	1	0	0	3.7	La Honda	94020
Tp	Purisima Formation (Pliocene and upper Miocene)	1	0	?	0.6	Half Moon Bay	94019
Tpp	Purisima Formation: Pomponio Mudstone Member (Pliocene)	1	0	?	0.5	San Gregorio	94074
Tpt	Purisima Formation: Tahana Member (Pliocene and upper Miocene)	1	0	?	0.9	La Honda	94020
Tsl	San Lorenzo Formation (Oligocene and upper and middle Eocene)	1	1	?	28.3	La Honda	94020
Tvq	Vaqueros Sandstone (lower Miocene and Oligocene)	1	0	?	0.5	Half Moon Bay	94019
Tw	Whiskey Hill Formation (middle and lower Eocene)	23	4	17.4?	9.2	Menlo Park, Portola Valley, Redwood City, San Carlos	94025, 94028, 94061, 94062, 94070

*R% = [(N Rn Tests GE 4 pCi/L) ÷ (N Rn Tests)] X 100
? = reliability of the geologic unit R value is uncertain because of the small number of indoor-radon tests

APPENDIX F

San Francisco 1X2 Degree Quadrangle NURE Airborne Radiometric Survey Equivalent Uranium (eU) Data for San Mateo County

NURE Airborne eU data measurements ≤ 0 ppm were dropped; Shaded rows indicate data by geologic unit within and outside of the San Francisquito alluvial fan)

Unit Symbol	Unit Name	N eU data	N eU data ≥ 5 ppm	% eU ≥ 5 ppm	Low eU ppm	High eU ppm	Median eU ppm
af	Artificial fill (Historic)	198	3	1.5	0.2	5.1	2.1
alf	Artificial levee fill (Historic)	69	1	1.4	0.1	5.2	1.6
fc	Chert (*Franciscan Formation*)	0	--	--			
fcg	Conglomerate (*Franciscan Formation*)	0	--	--			
fg	Greenstone (*Franciscan Formation*)	198	2	1.0	0.1	6.1	1.5
fl	Limestone (*Franciscan Formation*)	11	0	0.0	0.7	3.7	1.9
fm	Metamorphic Rocks (*Franciscan Formation*)	0	--	--			
fs	Sandstone (*Franciscan Formation*)	385	6	1.6	0.1	6.3	1.6
fsr	Sheared rock ((melange) *Franciscan Formation*)	155	4	2.6	0.3	6.1	2.1
Jgb	Gabbro (Jurassic?)	19	0	0.0	0.1	3.1	1.4
Jsv	Siliceous volcanic rocks and keratophyre (Jurassic?)	0	--	--			
Ka	Anchor Bay Conglomerate (Cretaceous)	0	--	--			
Kgr	Granitic rocks of Montara Mountain	553	5	0.9	0.1	5.9	1.5
KJf	Franciscan Complex, undivided (Cretaceous and Jurassic)	27	0	0.0	0.1	4.9	2.8

Unit Symbol	Unit Name	N eU data	N eU data ≥ 5 ppm	% eU ≥ 5 ppm	Low eU ppm*	High eU ppm*	Median eU ppm*
KJs	Unnamed sandstone (Cretaceous or Jurassic)	0	--	--			
KJv	Unnamed volcanic rocks (Cretaceous or older)	0	--	--			
Kpp	Pigeon Point Formation (Upper Cretaceous)	88	3	3.4	0.4	6.4	2.6
Ks	Unnamed sandstone and shale (Cretaceous?)	0	--	--			
Ksh	Unnamed shale (Upper Cretaceous)	0	--	--			
m	Marble and hornfels (Paleozoic?)	0	--	--			
Qal	Alluvium (Holocene)	33	1	3.0	0.5	6.0	2.2
Qc	Colma Formation (Pleistocene)	22	3	13.6	0.7	6.3	2.85
Qcl	Colluvium (Holocene)	160	6	3.8	0.1	7.5	2.1
Qhaf (all)	Alluvial fan and fluvial deposits (Holocene)	91	2	2.2	0.1	6.0	2.7
Qhaf (in SF Fan)	*Alluvial fan and fluvial deposits (Holocene)*	15	0	0.0	0.7	3.3	1.7
Qhaf (outside SF Fan)	*Alluvial fan and fluvial deposits (Holocene)*	76	2	2.6	0.1	6.0	2.8
Qhasc	Artificial stream channels (Historic)	1	0	0.0	1.3	1.3	1.3
Qhb (all)	Basin Deposits (Holocene)	72	0	0.0	0.2	4.3	2.35
Qhb (in SF Fan)	*Basin Deposits (Holocene)*	0	--	--			
Qhb (outside SF Fan)	*See Qhb above*						
Qhbd	Beach deposits (Holocene)	0	--	--			
Qhbm	Bay mud (Holocene)	186	1	0.1	0.1	5.3	1.5

Unit Symbol	Unit Name	N eU data	N eU data ≥ 5 ppm	% eU ≥ 5 ppm	Low eU ppm*	High eU ppm*	Median eU ppm*
Qhfp (all)	Floodplain deposits (Holocene)	24	0	0.0	0.4	4.0	1.7
Qhfp (in SF Fan)	*Floodplain deposits (Holocene)*	14	0	0.0	0.4	4.0	1.6
Qhfp (outside SF Fan)	*Floodplain deposits (Holocene)*	10	0	0.0	1.1	2.3	1.7
Qhl (all)	Natural levee deposits (Holocene)	21	0	0.0	0.4	4.7	2.1
Qhl in SF Fan	*Natural levee deposits (Holocene)*	15	0	0.0	0.4	4.7	2.1
Qhl (outside SF Fan)	*Natural levee deposits (Holocene)*	6	0	0.0	0.7	3.4	2.3
Qhsc (all)	Stream channel deposits (Holocene)	16	1	6.3	0.3	5.6	2.0
Qhsc (in SF Fan)	*Stream channel deposits (Holocene)*	1	0	--	--	1.1	1.1
Qhsc (outside SF Fan)	*Stream channel deposits (Holocene)*	15	1	6.7	0.3	5.6	2.1
Qmt	Marine terrace deposits (Pleistocene)	212	8	3.8	0.2	5.7	2.2
Qof	Coarse-grained older alluvial fan and stream terrace deposits (Pleistocene)	118	3	2.5	0.2	5.9	2.0
Qpaf (all)	Alluvial fan and fluvial deposits (Pleistocene)	148	0	0.0	0.3	4.3	1.9
Qpaf in SF Fan)	*Alluvial fan and fluvial deposits (Pleistocene)*	68	0	0.0	0.3	4.3	1.8
Qpaf (outside SF Fan)	*Alluvial fan and fluvial deposits (Pleistocene)*	80	0	0.0	0.6	4.3	2.2
Qpaf1	Alluvial terrace deposits (Pleistocene)	0	--	--			

Unit Symbol	**Unit Name**	**N eU data**	**N eU data ≥ 5 ppm**	**% eU ≥ 5 ppm**	**Low eU ppm***	**High eU ppm***	**Median eU ppm***
Qpoaf (all)	Older alluvial fan deposits (Pleistocene)	32	2	6.3	0.7	5.5	2.7
Qpoad (in SF Fan)	*Older alluvial fan deposits (Pleistocene)*	0	--	--			
Qpoaf (outside SF Fan)	*See Qpoaf above*						
Qs	Sand dune and beach deposits (Holocene)	24	0	0.0	0.1	3.1	1.8
QTm	Merced Formation (lower Pleistocene and upper Pliocene)	33	2	6.1	1.1	6.3	2.7
QTsc	Santa Clara Formation (lower Pleistocene and upper Pliocene)	124	3	2.4	0.1	6.4	1.9
Qyf	Younger (inner) alluvial fan deposits (Holocene)	191	18	9.4	0.1	8.7	2.6
Qyfo	Younger (outer) alluvial fan deposits (Holocene)	48	3	6.3	0.6	8.3	2.95
sp	Serpentinite (Cretaceous and/or Jurassic)	47	1	2.1	0.5	5.5	2.1
Tb	Butano Sandstone (middle and lower Eocene)	402	11	2.7	0.1	7.8	1.7
Tbs	Shale *in Butano Sandstone* (lower Eocene)	0	--	--			
Tl	Ladera Sandstone (upper(?) and middle Miocene)	28	0	0.0	0.2	3.9	2.2
Tla	Lambert Shale (Oligocene and lower Miocene)	328	26	7.9	0.1	7.3	2.6
Tlo	Lompico Sandstone (middle Miocene)	6	0	0.0	1.7	3.1	2.85

Unit Symbol	Unit Name	N eU data	N eU data ≥ 5 ppm	% eU ≥ 5 ppm	Low eU ppm*	High eU ppm*	Median eU ppm*
Tls	Lambert Shale and San Lorenzo Formation, Undivided (lower Miocene, Oligocene, middle and upper Eocene)	28	0	0.0	0.4	4.3	1.95
Tm	Monterey Formation (middle Miocene)	119	14	11.8	0.1	7.1	3.0
Tmb	Mindego Basalt and related volcanic rocks (Miocene and/or Oligocene)	230	2	0.9	0.1	5.5	1.9
Tp	Purisima Formation (Pliocene and upper Miocene)	298	32	5.4	0.1	8.8	2.5
Tpl	Lobitos Mudstone Member (Pliocene) of Purisima Fm	138	6	4.3	0.2	6.0	2.2
Tpm	Page Mill Basalt (middle Miocene)	0	--	--			
Tpp	Pomponio Mudstone Member (Pliocene) of Purisima Fm	154	6	3.9	0.1	6.0	2.6
Tpsg	San Gregorio Sandstone Member (Pliocene) of Purisima Fm?	70	0	0.0	0.3	4.8	2.250
Tpt	Tahana Member (Pliocene and upper Miocene) of Purisima Formation?	629	3	0.5	0.1	6.4	1.9
Tptu	Tunitas Sandstone Member (Pliocene) of Purisima Fm?	42	0	0.0	0.1	3.8	1.45
Tsc	Santa Cruz Mudstone (upper Miocene)	383	65	17.0	0.2	8.8	3.4

Unit Symbol	Unit Name	N eU data	N eU data ≥ 5 ppm	% eU ≥ 5 ppm	Low eU ppm*	High eU ppm*	Median eU ppm*
Tsl	San Lorenzo Formation (Oligocene and upper and middle Eocene)	0	--	--			
Tsm	Santa Margarita Sandstone (upper Miocene)	133	23	17.3	0.3	6.9	3.5
Tsr	Rices Mudstone Member (Oligocene and upper Eocene) *of San Lorenzo Formation*	13	0	0.0	0.6	3.4	1.9
Tss	Unnamed sandstone, shale and conglomerate (Paleocene)	93	17	18.3	0.2	9.0	2.7
Tst	Twobar Shale Member (middle and upper Eocene) *of San Lorenzo Formation*	70	0	0.0	0.3	4.7	2.5
Tuv	Unnamed Sedimentary and Volcanic Rocks (Miocene and Oligocene)	0	--	--			
Tvq	Vaqueros Sandstone (lower Miocene and Oligocene)	134	3	2.2	0.1	5.7	1.9
Tw	Whiskey Hill Formation (middle and lower Eocene)	302	2	0.7	0.1	5.8	1.8
Tws	Shale in Whiskey Hill Formation	6	1	16.7	1.6	5.3	2.2

Geology Map Reference: Brabb, E.E., Graymer, R.W., and Jones, D.L., 1998, Geology of the onshore part of San Mateo County, California: A digital database; U.S. Geological Survey Open-File Report 98-137.
http://pubs.usgs.gov/of/1998/of98-137/

OFR 98-137 Sheet 2 of 2, Correlation of Map Units and Description of Map Units.
http://pubs.usgs.gov/of/1998/of98-137/smexpl.pdf

APPENDIX G

Geologic Units, NRCS Soil Units and Indoor Radon Data

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
af	Artificial fill (Historic)	110	Candlestick-Kron-Burlburl complex, 30-75 percent slopes	1	0	0		0.5
af	Artificial fill (Historic)	123	Orthents, cut and fill-Urban land complex, 0-5 percent slopes	1	0	0		0.6
af	Artificial fill (Historic)	124	Orthents, cut and fill-Urban land complex, 5-75 percent slopes	2	0	0		0.5
af	Artificial fill (Historic)	133	Urban land-Orthents, cut and fill complex, 5-75 percent slopes	3	0	0	0.5	0.7
af	Artificial fill (Historic)	134	Urban land-Orthents, reclaimed complex, 0-2 percent slopes	50	0	0	0.2	2.1
af	Artificial fill (Historic)	135	Urban land-Orthents, smoothed complex, 5-50 percent slopes	5	0	0	0.5	2.9
alf	Artificial levee fill (Historic)	134	Urban land-Orthents, reclaimed complex, 0-2 percent slopes	1	0	0		0.5
fc	Chert (Franciscan Formation)	115	Los Gatos Loam, 30-50 percent slopes	1	0	0		2.3
fc	Chert (Franciscan Formation)	121	Orthents, cut and fill, 0-15 percent slopes	1	0	0		0.5

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
fc	Chert (Franciscan Formation)	124	Orthents, cut and fill-Urban land complex, 5-75 percent slopes	17	4	23.5	0.5	12.3
fg	Greenstone (Franciscan Formation)	113	Fagan loam, 15 to 30 percent slopes	1	0	0		0.5
fg	Greenstone (Franciscan Formation)	121	Orthents, cut and fill, 0-15 percent slopes	1	0	0		0.5
fg	Greenstone (Franciscan Formation)	124	Orthents, cut and fill-Urban land complex, 5-75 percent slopes	5	0	0	0.5	0.6
fg	Greenstone (Franciscan Formation)	133	Urban land-Orthents, cut and fill complex, 5-75 percent slopes	5	0	0	0.5	0.9
fs	Sandstone (Franciscan Formation)	113	Fagan loam, 15 to 30 percent slopes	1	0	0		1.7
fs	Sandstone (Franciscan Formation)	116	Maymen gravelly loam, 30-50 percent slopes	1	0	0		0.5
fs	Sandstone (Franciscan Formation)	122	Orthents, cut and fill, 15-75 percent slopes	2	0	0	0.5	0.7
fs	Sandstone (Franciscan Formation)	124	Orthents, cut and fill-Urban land complex, 5-75 percent slopes	37	0	0	0.3	3.8
fs	Sandstone (Franciscan Formation)	131	Urban land	1	0	0		0.5
fs	Sandstone (Franciscan Formation)	132	Urban land-Orthents, cut and fill complex, 0-5 percent slopes	4	0	0	0.5	0.9
fs	Sandstone (Franciscan Formation)	133	Urban land-Orthents, cut and fill complex, 5-75 percent slopes	17	0	0	0.5	2.9

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
fsr	Sheared rock ((melange) Franciscan Formation	111	Candlestick Variant loam, 2-15 percent slopes	1	0	0		0.5
fsr	Sheared rock ((melange) Franciscan Formation	115	Los Gatos Loam, 30-50 percent slopes	2	0	0	2.0	2.3
fsr	Sheared rock ((melange) Franciscan Formation	124	Orthents, cut and fill-Urban land complex, 5-75 percent slopes	21	0	0	0.5	2.7
fsr	Sheared rock ((melange) Franciscan Formation	132	Urban land-Orthents, cut and fill complex, 0-5 percent slopes	3	0	0	0.7	1.5
fsr	Sheared rock ((melange) Franciscan Formation	133	Urban land-Orthents, cut and fill complex, 5-75 percent slopes	7	0	0	0.5	1.3
Kgr	Granitic rocks of Montara Mountain	MmF2	Miramar coarse sandy loam, very steep, eroded	1	0	0	0	1.0
Kgr	Granitic rocks of Montara Mountain	130	Typic Arglustollos, loamy-Urban land association, 5-15 percent slopes	3	0	0	0.6	1.1
KJs	Unnamed sandstone (Cretaceous or Jurassic)	124	Orthents, cut and fill-Urban land complex, 5-75 percent slopes	2	0	0	0.8	3
KJs	Unnamed sandstone (Cretaceous or Jurassic)	130	Typic Arglustollos, loamy-Urban land association, 5-15 percent slopes	1	0	0		0.5
KJs	Unnamed sandstone (Cretaceous or Jurassic)	133	Urban land-Orthents, cut and fill complex, 5-75 percent slopes	1	0	0		0.5
Qal	Alluvium (Holocene)	FcA	Farallone coarse sandy loam, nearly level	1	0	0		0.7

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qc	Colma Formation (Pleistocene)	123	Orthents, cut and fill-Urban land complex, 0-5 percent slopes	3	0	0	0.5	0.5
Qc	Colma Formation (Pleistocene)	131	Urban land	1	0	0		0.5
Qc	Colma Formation (Pleistocene)	132	Urban land-Orthents, cut and fill complex, 0-5 percent slopes	4	0	0	0.5	1.2
Qc	Colma Formation (Pleistocene)	133	Urban land-Orthents, cut and fill complex, 5-75 percent slopes	9	0	0	0.5	1.8
Qc	Colma Formation (Pleistocene)	134	Urban land-Orthents, reclaimed complex, 0-2 percent slopes	1	0	0		0.8
Qc	Colma Formation (Pleistocene)	135	Urban land-Orthents, smoothed complex, 5-50 percent slopes	13	1	7.7	0.3	15.2
Qcl	Colluvium (Holocene)	TuC2	Tunitas clay loam, sloping, eroded	1	1	--		4.8
Qcl	Colluvium (Holocene)	109	Candlestick-Barnabe complex, 30- 50 percent slopes	1	0	0		1.7
Qcl	Colluvium (Holocene)	123	Orthents, cut and fill-Urban land complex, 0-5 percent slopes	1	0	0		0.5
Qcl	Colluvium (Holocene)	124	Orthents, cut and fill-Urban land complex, 5-75 percent slopes	3	0	0	0.5	1.2
Qcl	Colluvium (Holocene)	132	Urban land-Orthents, cut and fill complex, 0-5 percent slopes	1	0	0		0.7

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qcl	Colluvium (Holocene)	133	Urban land-Orthents, cut and fill complex, 5-75 percent slopes	4	0	0	0.5	2.3
Qcl	Colluvium (Holocene)	134	Urban land-Orthents, reclaimed complex, 0-2 percent slopes	1	0	0		0.8
Qhaf	Alluvial fan and fluvial deposits (Holocene)	108	Botella-Urban land complex, 0-5 percent slopes	1	1	--		35.9
Qhaf	Alluvial fan and fluvial deposits (Holocene)	114	Francisquito-Urban land complex, 5-15 percent slopes	1	0	0		0.6
Qhaf	Alluvial fan and fluvial deposits (Holocene)	123	Orthents, cut and fill-Urban land complex, 0-5 percent slopes	2	0	0	0.5	2.2
Qhaf	Alluvial fan and fluvial deposits (Holocene)	124	Orthents, cut and fill-Urban land complex, 5-75 percent slopes	1	0	0		0.5
Qhaf	Alluvial fan and fluvial deposits (Holocene)	132	Urban land-Orthents, cut and fill complex, 0-5 percent slopes	17	1	5.9	0.5	5.7
Qhaf	Alluvial fan and fluvial deposits (Holocene)	133	Urban land-Orthents, cut and fill complex, 5-75 percent slopes	1	0	0		0.5
Qhaf	Alluvial fan and fluvial deposits (Holocene)	134	Urban land-Orthents, reclaimed complex, 0-2 percent slopes	1	0	0		0.7
Qhb	Basin Deposits (Holocene)	132	Urban land-Orthents, cut and fill complex, 0-5 percent slopes	9	1	11.1	0.7	6.3

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qhbm	Bay mud (Holocene)	134	Urban land-Orthents, reclaimed complex, 0-2 percent slopes	1	0	0		0.5
Qhfp	Floodplain deposits (Holocene)	107	Botella loam, 0-5 percent slopes	1	0	0		1.2
Qhfp	Floodplain deposits (Holocene)	108	Botella-Urban land complex, 0-5 percent slopes	6	2	33.3	0.5	5.1
Qhfp	Floodplain deposits (Holocene)	132	Urban land-Orthents, cut and fill complex, 0-5 percent slopes	6	3	50.0	0.5	25.9
Qhfp	Floodplain deposits (Holocene)	135	Urban land-Orthents, smoothed complex, 5-50 percent slopes	1	0	0		0.5
Qhl	Natural levee deposits (Holocene)	131scl (sandy clay loam)	Urban land	2	3	--	4.6	12.1
Qhl	Natural levee deposits (Holocene)	132	Urban land-Orthents, cut and fill complex, 0-5 percent slopes	2	1	--	0.5	8.5
Qhsc	Stream channel deposits (Holocene)	116	Maymen gravelly loam, 30-50 percent slopes	1	0	0		1.3
Qhsc	Stream channel deposits (Holocene)	132	Urban land-Orthents, cut and fill complex, 0-5 percent slopes	1	0	0		0.5
Qmt	Marine terrace deposits (Pleistocene)	WmA	Watsonville loam, nearly level	3	0	0	0.5	0.6
Qmt	Marine terrace deposits (Pleistocene)	WmB	Watsonville loam, gently sloping	1	0	0		0.5

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qmt	Marine terrace deposits (Pleistocene)	NOTCOM	(not completed)	1	0	0		0.5
Qmt	Marine terrace deposits (Pleistocene)	130	Typic Arglustollos, loamy-Urban land association, 5-15 percent slopes	7	0	0	0.5	1.5
Qof	Coarse-grained older alluvial fan and stream terrace deposits (Pleistocene)	DcA	Denison clay loam, nearly level	1	0	0		0.5
Qof	Coarse-grained older alluvial fan and stream terrace deposits (Pleistocene)	DmA	Denison loam, nearly level	1	0	0		0.8
Qpaf	Alluvial fan and fluvial deposits (Pleistocene)	107	Botella loam, 0-5 percent slopes	1	0	0		0.8
Qpaf	Alluvial fan and fluvial deposits (Pleistocene)	108	Botella-Urban land complex, 0-5 percent slopes	18	4	22.2	0.5	6.3
Qpaf	Alluvial fan and fluvial deposits (Pleistocene)	123	Orthents, cut and fill-Urban land complex, 0-5 percent slopes	5	0	0	0.5	1.5
Qpaf	Alluvial fan and fluvial deposits (Pleistocene)	124	Orthents, cut and fill-Urban land complex, 5-75 percent slopes	2	0	0	0.5	0.5
Qpaf	Alluvial fan and fluvial deposits (Pleistocene)	131	Urban land	1	0	0		0.5
Qpaf	Alluvial fan and fluvial deposits (Pleistocene)	132	Urban land-Orthents, cut and fill complex, 0-5 percent slopes	24	1	4.2	0.5	8

Geologic Unit	**Geologic Unit Name**	**Soil Unit**	**Soil Unit Name**	**N**	**N ≥ 4 pCi/L**	**R%**	**Low pCi/L**	**High pCi/L**
Qpoaf	Older alluvial fan deposits (Pleistocene)	104	Alambique-McGarvey complex, 30-50 percent slopes	1	0	0		2.2
Qpoaf	Older alluvial fan deposits (Pleistocene)	108	Botella-Urban land complex, 0-5 percent slopes	6	1	16.7	0.5	6.9
QTm	Merced Formation (lower Pleistocene and upper Pliocene)	122	Orthents, cut and fill, 15-75 percent slopes	2	0	0	0.5	0.6
QTm	Merced Formation (lower Pleistocene and upper Pliocene)	124	Orthents, cut and fill-Urban land complex, 5-75 percent slopes	4	0	0	0.5	0.6
QTm	Merced Formation (lower Pleistocene and upper Pliocene)	132	Urban land-Orthents, cut and fill complex, 0-5 percent slopes	2	0	0	0.5	0.6
QTm	Merced Formation (lower Pleistocene and upper Pliocene)	133	Urban land-Orthents, cut and fill complex, 5-75 percent slopes	8	0	0	0.5	1.1
QTm	Merced Formation (lower Pleistocene and upper Pliocene)	135	Urban land-Orthents, smoothed complex, 5-50 percent slopes	13	0	0	0.5	1.7
QTsc	Santa Clara Formation (loser Pleistocene and upper Pliocene)	104	Alambique-McGarvey complex, 30-50 percent slopes	1	0	0		1.2
QTsc	Santa Clara Formation (loser Pleistocene and upper Pliocene)	132	Urban land-Orthents, cut and fill complex, 0-5 percent slopes	1	0	0		0.6
Qyf	Younger (inner) alluvial fan deposits (Holocene)	NOTCOM	(not completed)	3	0	0	0.5	1.0

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Qyf	Younger (inner) alluvial fan deposits (Holocene)	Dma	Denison loam, nearly level	1	0	0		0.5
Qyf	Younger (inner) alluvial fan deposits (Holocene)	Fca	Farallone coarse sandy loam, nearly level	2	0	0	0.5	0.5
Qyf	Younger (inner) alluvial fan deposits (Holocene)	SkB	Soquel loam, nearly level	1	0	0		2.3
Qyfo	Younger (outer) alluvial fan deposits (Holocene)	NOTCOM	(not completed)	4	0	0	0.5	3.8
Qyfo	Younger (outer) alluvial fan deposits (Holocene)	TeE2	Tierra loam, steep, eroded	1	0	0		0.8
Qyfo	Younger (outer) alluvial fan deposits (Holocene)	133	Urban land-Orthents, cut and fill complex, 5-75 percent slopes	1	0	0		0.9
sp	Serpentinite (Cretaceous and/or Jurassic)	124	Orthents, cut and fill-Urban land complex, 5-75 percent slopes	6	0	0	0.5	1.4
sp	Serpentinite (Cretaceous and/or Jurassic)	133	Urban land-Orthents, cut and fill complex, 5-75 percent slopes	7	0	0	0.5	0.5
Tb	Butano Sandstone (middle and lower Eocene)	HyF	Hugo and Josephine sandy loams, very steep	1	0	0		1.1
Tb	Butano Sandstone (middle and lower Eocene)	HyE2	Hugo and Josephine sandy loams, steep, eroded	1	0	0		1.3
Tb	Butano Sandstone (middle and lower Eocene)	104	Alambique-McGarvey complex, 30-50 percent slopes	6	1	16.7	0.6	14.1
Tl	Ladera Sandstone (upper(?) and middle Miocene)	108	Botella-Urban land complex, 0-5 percent slopes	1	0	0		0.5

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Tla	Lambert Shale (Oligocene and lower Miocene)	Buf	Butano loam, very steep	3	2	--	1.9	15.3
Tla	Lambert Shale (Oligocene and lower Miocene)	GaE2	Gazos fine sandy loam, steep, eroded	1	1	--		5.1
Tla	Lambert Shale (Oligocene and lower Miocene)	HyF	Hugo and Josephine sandy loams, very steep	1	0	0		2.5
Tla	Lambert Shale (Oligocene and lower Miocene)	HyD2	Hugo and Josephine sandy loams, moderately steep, eroded	1	1	--		4.4
Tla	Lambert Shale (Oligocene and lower Miocene)	LlF2	Lobitos loam, very steep, eroded	1	0	0		1.0
Tla	Lambert Shale (Oligocene and lower Miocene)	104	Alambique-McGarvey complex, 30-50 percent slopes	3	2	--	0.6	94.8
Tm	Monterey Formation (middle Miocene)	SaF2	Santa Lucia loam, very steep, eroded	1	0	0		3.7
Tp	Purisima Formation (Pliocene and upper Miocene)	LlF2	Lobitos loam, very steep, eroded	1	0	0		0.6
Tpp	Pomponio Mudstone Member (Pliocene) of Purisima Formation	CcD2	Cayucos clay loam, moderately steep, eroded	1	0	0		2.5
Tpt	Tahana Member (Pliocene and upper Miocene) of Purisima Formation?	HuC	Hugo and Josephine loams, sloping	1	0	0		0.9
Tsl	San Lorenzo Formation (Oligocene and upper and middle Eocene)	530scl (sandy clay loam)	Aptos loam, 15-30 percent slopes	1	1	--		28.3
Tvq	Vaqueros Sandstone (lower Miocene and Oligocene)	HyF	Hugo and Josephine sandy loams, very steep	1	0	0		0.5

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R%	Low pCi/L	High pCi/L
Tw	Whiskey Hill Formation (middle and lower Eocene)	GbC2	Gazos loam, sloping, eroded	1	0	0		0.5
Tw	Whiskey Hill Formation (middle and lower Eocene)	GbD2	Gazos loam, moderately steep, eroded	2	0	0	0.2	0.5
Tw	Whiskey Hill Formation (middle and lower Eocene)	GlD2	Gazos-Lobitos silt loams, moderately steep, eroded	1	0	0		0.9
Tw	Whiskey Hill Formation (middle and lower Eocene)	HyC2	Hugo and Josephine sandy loams, sloping, eroded	1	0	0		3.3
Tw	Whiskey Hill Formation (middle and lower Eocene)	HyD2	Hugo and Josephine sandy loams, moderately steep, eroded	3	0	0	1.0	1.6
Tw	Whiskey Hill Formation (middle and lower Eocene)	LlD2	Lobitos loam, moderately steep, eroded	1	0	0		0.5
Tw	Whiskey Hill Formation (middle and lower Eocene)	102	Accelerator-Fagan-Urban land complex, 5-15 percent slopes	3	1	--	0.8	4.1
Tw	Whiskey Hill Formation (middle and lower Eocene)	104	Alambique-McGarvey complex, 30-50 percent slopes	8	3	37.5	0.5	9.2
Tw	Whiskey Hill Formation (middle and lower Eocene)	109	Candlestick-Barnabe complex, 30- 50 percent slopes	1	0	0		0.9
Tw	Whiskey Hill Formation (middle and lower Eocene)	116	Maymen gravelly loam, 30-50 percent slopes	1	0	0		2.1
Tw	Whiskey Hill Formation (middle and lower Eocene)	132	Urban land-Orthents, cut and fill complex, 0-5 percent slopes	1	0	0		1.3
Tw	Whiskey Hill Formation (middle and lower Eocene)	133	Urban land-Orthents, cut and fill complex, 5-75 percent slopes	1	0	0		0.5

APPENDIX H

NRCS Soil Units and Indoor-radon Measurements

Soil Unit Symbol(s)	Soil Unit Name	Permeability by Soil Sub-unit	Substratum (based on 100K USGS Mapping)	Shrink - Swell	Depth to Bed Rock inches	N	N ≥ 4 pCi/L	R (%)	Min pCi/L	Max pCi/L
102	Accelerator-Fagan-Urban land complex, 5-15 percent slopes	Moderate 0-23”, moderately slow 23”-41”	Tw	Low, moderate	40-60	3	1	--	0.8	4.1
104	Alambique-McGarvey complex, 30-50 percent slopes	Moderate 0-30”; or moderate 0-7”, Moderately slow 7”-14” and slow 14”-37”	Qpoaf, QTsc, Tb, Tla, Tw	Low; Low, moderate, high	20-40	19	6	31.6	0.5	94.8
107	Botella loam, 0-5 percent slopes	Moderate 0-36”, moderately slow 36”-60”	Qhfp, Qpaf	Moderate	>60	2	0	0	0.8	1.2
108	Botella-Urban land complex, 0-5 percent slopes	Moderately slow 0-60”	Qhaf, Qpaf, Qhfp, Qpoaf, Tl	Moderate	>60	32	8	25.0	0.5	35.9
109	Candlestick-Barnabe complex, 30- 50 percent slopes	Moderate 0-20”, moderately slow, 20”-20-24”; Moderately rapid 0-7”, moderate 7”-12”	Qcl, Tw	Low, moderate; Low	20-40, 8-20	2	0	0	0.9	1.7
110	Candlestick-Kron-Burlburl complex, 30-75 percent slopes	Moderate 0-20”, moderately slow, 20”-20-24”; Moderately rapid 0-3”, moderate 3”-14”; Moderate 0-30”	af	Low, moderate; Low; Low	20-40, 10-20, 20-40	1	0	0		0.5

Soil Unit Symbol(s)	Soil Unit Name	Permeability by Soil Sub-unit	Substratum (based on 100K USGS Mapping)	Shrink - Swell	Depth to Bed Rock inches	N	N ≥ 4 pCi/L	R (%)	Min pCi/L	Max pCi/L
111	Candlestick Variant loam, 2-15 percent slopes	Moderate 0-21”, moderately slow 21” - 65”	fsr	Low, moderate	>60	1	0	0		0.5
113	Fagan loam, 15 to 30 percent slopes	Moderate 0-5”, moderately slow 5”-26”, slow 26”-43”	fg, fs	Moderate, moderate, high	40-60	2	0	0	0.5	1.7
114	Francisquito-Urban land complex, 5-15 percent slopes	Moderate 0-16”, moderately slow 16”-26”, slow 26”-50”, moderately slow 50”-60”	Qhaf	Low, moderate, high, moderate	>60	1	0	0		0.6
115	Los Gatos Loam, 30-50 percent slopes	Moderate 0-22”, moderately slow 22”-36”	fc, fsr	Low, moderate	20-40	3	0	0	2.0	2.3
116	Maymen gravelly loam, 30-50 percent slopes	Moderate 0-12”	fs, Qhsc, Tw	Low	10-20	3	0	0	0.5	2.1
121,122	Orthents, cut and fill, 0-15 percent slopes, 15-75 percent slopes	--	fc, fg, fs, QTm	--	--	6	0	0	0.5	0.7
123, 124	Orthents, cut and fill-Urban land complex, 0-5 percent slopes, 5-75 percent slopes	--	af(2), Qc, Qcl (2), Qhaf (2), Qpaf (2), QTm, sp, fc, fg, fs, fsr, KJs	--	--	112	4	3.6	0.5	12.3

Soil Unit Symbol(s)	Soil Unit Name	Permeability by Soil Sub-unit	Substratum (based on 100K USGS Mapping)	Shrink - Swell	Depth to Bed Rock inches	N	N ≥ 4 pCi/L	R (%)	Min pCi/L	Max pCi/L
130	Typic Arglustollos, loamy-Urban land association, 5-15 percent slopes	--	Kgr, KJs, Qmt	--	--	11	0	0	0.5	1.5
131	Urban land	--	fs, Qc, Qpaf	--	--	3	0	0	0.5	0.5
131scl	Urban land (sandy clay loam)	--	Qhl	--		3	2	--	4.6	12.1
132, 133	Urban land-Orthents, cut and fill complex, 0-5 percent slopes, 5-75 percent slopes	--	af, sp, fg, fs (2), fsr (2), KJs, Qc (2), Qcl (2), Qhaf (2), Qhb, Qhfp, Qhl, Qhsc, Qpaf, QTm (2), QTsc, Qyfo, Tw (2)	--	--	138	7	5.1	0.5	25.9
134, 135	Urban land-Orthents, reclaimed complex, 0-5 percent slopes, 5-50 percent slopes	--	af (2), alf, Qc (2), Qcl, Qhaf, Qhbm, Qhfp, QTm	--	--	87	1	1.2	0.3	15.2
530scl	Aptos loam, 15-30 percent slopes (sandy clay loam)		Tsl			1	1	--		28.3
Buf	Butano loam, very steep	Moderate	Tla	Moderate	36-60	3	2	--	1.9	15.3
CcD2	Cayucos clay loam, moderately steep, eroded	Slow	Tpp	High	24-60	1	0	0		2.5
DcA	Denison clay loam, nearly level	Moderately slow, slow	Qof	High	>60	1	0	0	--	0.5

Soil Unit Symbol(s)	**Soil Unit Name**	**Permeability by Soil Sub-unit**	**Substratum (based on 100K USGS Mapping)**	**Shrink - Swell**	**Depth to Bed Rock inches**	**N**	**N ≥ 4 pCi/L**	**R (%)**	**Min pCi/L**	**Max pCi/L**
DmA	Denison loam, nearly level	Moderate, moderately slow to slow	Qof, Qyf	High	>60	2	0	0	0.5	0.8
FcA	Farallone coarse sandy loam, nearly level	Rapid, rapid	Qal, Qyf	Low	>60	3	0	0	0.5	0.7
GaE2	Gazos fine sandy loam, steep, eroded	Moderately rapid, moderate	Tw	Moderate	12-36	1	1	--		5.1
GbC2, GbD2	Gazos loam, sloping, eroded; moderately steep, eroded	Moderate, moderate	Tw(2)	Moderate	12-36	3	0	0	0.2	0.5
GlD2	Gazos-Lobitos silt loams, moderately steep, eroded	Moderate, moderate and moderately slow	Tw	Moderate	12-36	1	0	0		0.9
HuC	Hugo and Josephine loams, sloping	Moderate, moderate; Moderate, moderately slow	Tpt	Low, Moderate	24-60	1	0	0		0.9
HyC2, HyD2, HyE2 HyF	Hugo and Josephine sandy loams, sloping, eroded; moderately steep, eroded; steep eroded; very steep	Moderately rapid, moderately rapid; Moderately rapid, moderately slow	Tw (2), Tla(2), Tb(2), Tvq	Low, Moderate	24-60	9	1	11.1	0.5	4.4
LlD2, LlF2	Lobitos loam, moderately steep, eroded; very steep, eroded	Moderate, moderately slow	Tla, Tp, Tw	Moderate	24-36	3	0	0	0.5	1.0

Soil Unit Symbol(s)	**Soil Unit Name**	**Permeability by Soil Sub-unit**	**Substratum (based on 100K USGS Mapping)**	**Shrink - Swell**	**Depth to Bed Rock inches**	**N**	**N ≥ 4 pCi/L**	**R (%)**	**Min pCi/L**	**Max pCi/L**
MmF2	Miramar coarse sandy loam, very steep, eroded	Rapid, moderately slow	Kgr	Moderate	36-60	1	0	0		1.0
TeE2	Tierra loam, steep, eroded	Moderate to moderately slow, very slow	Qyfo	High	60	1	0	0		0.8
TuC2	Tunitas clay loam, sloping, eroded	Moderately slow, slow	Qcl	High	60	1	1	--		4.8
WmA, WmB	Watsonville loam, nearly level; gently sloping	Moderate, very slow	Qmt (2)	High	60	4	0	0	0.5	0.6

APPENDIX I-1

Criteria for Low Radon Potential Ranking of 41 San Mateo Geologic Units and Groups of Units. Units are from the Geologic Map of San Mateo County by Brabb and others (1989). Symbols are defined at the end of the table.

Geologic Unit	Indoor Radon Survey Data	NURE Airborne eU Data	NRCS Soil Perm. And Shrink-Swell Data	Assigned Radon Potential
af-artificial fill	XX	X	unk	Low
alf-artificial levee fill	ID	X	unk	Low
fcg-Franciscan complex conglomerate	ND	ND	unk	Low
fg-Franciscan complex greenstone	x	X	--	Low
fm-Franciscan complex metamorphic rocks	ND	ND	unk	Low
fs-Franciscan Complex sandstone	XX	X	--	Low
fsr Franciscan Complex sheared rock (mélange)	XX	X	--	Low
Jgb-Gabbro	ND	ND	unk	Low
KJf-Franciscan Complex--undivided	ND	X	unk	Low
KJv-Unnamed volcanic rocks—Cretaceous or older	ND	ND	unk	Low
Kpp-Pigeon Point Formation	ND	X	unk	Low
Qal-Alluvium	ND	X	X	Low (part of unit)
Qc-Colma Formation	XX	ID	unk	Low
Qcl- Colluvium	--	ND	X	Low (part of unit)
Qhaf-Alluvial fan and fluvial deposits-- *<u>Outside San Francisquito Creek Alluvial Fan</u>*	X	X	--	Low
Qhasc-Artificial stream channels	ND	ND	unk	Low (P)
Qhb-Basin Deposits-- *<u>Outside San Francisquito Creek Alluvial Fan</u>*	ID	X	--	Low (part of unit)
Qhbd-Beach Deposits	ND	ND	X	Low (P) (data in other counties support potential)
Qhbm-Bay Mud	ID	X	unk	Low
Qhfp-Floodplain deposits-- *<u>Outside San Francisquito Creek Alluvial Fan</u>*	ID	X	unk	Low (part of unit)
Qhl-Natural Levee deposits-- *<u>Outside San Francisquito Creek Alluvial Fan</u>*	ID	X	unk	Low (part of unit)

APPENDIX I-1 continued				
Geologic Unit	**Indoor Radon Survey Data**	**NURE Airborne eU Data**	**NRCS Soil Perm. And Shrink-Swell Data**	**Assigned Radon Potential**
Qhsc-Stream channel deposits	ID	X	--	Low (part of unit)
Qmt-Marine terrace deposits	X	X	unk	Low (part of unit)
Qof-Marine terrace deposits	ID	X	--	Low (part of unit)
Qpaf-Alluvial fan and fluvial deposits-- *Outside San Francisquito Creek Alluvial Fan*	XX	X	unk	Low
Qpaf-1—Alluvial terrace deposits	ND	ND	--	Low (P)
Qs-sand dune and beach deposits	ND	X	X	Low
QTm-Merced Formation	XX	--	unk	Low
QTsc-Santa Clara Formation	ND	X	--	Low
Qyf-Younger (inner) alluvial fan deposits	X	--	X or --	Low (part of unit)
Qyfo-Younger (outer) alluvial fan deposits	X	--	X or --	Low (part of unit)
sp-Serpentinite	x	X	unk	Low
Tl-Ladera Sandstone	ID	X	--	Low
Tmb-Mindego Basalt and related volcanic rocks	ND	X	--	Low
Tp Purisima Formation	ID	X	X	Low Santa Cruz Co. = Low
Tpl-Lobitos Mudstone Member of Purisima Formation	ND	X	--	Low
Tpm-Page Mill Basalt	ND	ND	unk	Low (P)
Tpp-Pomponio Mudstone Member of Purisima Formation	ID	X	--	Low
Tpsg-San Gregorio Sandstone Member of Purisima Formation	ND	X	--	Low
Tpt-Tahana Member of Purisima Formation?	ID	X	--	Low
Tptu-Tunitas Sandstone Member of Purisima Formation?	ND	X	X or --	Low

XX = more than 25 indoor radon measurements support assigned potential
X = 10 to 24 indoor radon measurements support assigned potential; or NURE eU data or soils data support assigned potential
x = < 10 indoor radon measurements support assigned potential
-- does not support assigned potential
ID = Insufficient data to evaluate support or non-support of assigned potential
ND = no data
(P) = provisional, confidence slightly to moderately uncertain (additional data needed)

APPENDIX I-2

San Mateo County Geologic Units with Unknown Radon Potential due to limited or no data

Unit Symbol	Unit Name
fc—part	Franciscan Formation Chert—not between Bellmont Creek and Laurel Creek in San Mateo (see Table 4a)
fl	Franciscan Complex-limestone
Jsv	Siliceous volcanic rocks and keratophyre
Ka	Anchor Bay conglomerate
Kgr	Granitic rocks of Montara Mountain
KJs	Unnamed sandstone
Ks	Unnamed sandstone and shale
Ksh	Unnamed shale
m	Marble and hornfels
Qal	Alluvium (Holocene)
Qcl	Colluvium (Holocene)
Qhaf	Alluvial fan and fluvial deposits (Holocene) –outside of SF Fan
Qhasc	Artificial stream channels (Historic)
Qhb—part	Basin deposits (Holocene)-- Outside of SF Fan
Qhfp—part	Floodplain deposits (Holocene) –outside of SF Fan
Qhsc—part	Stream channel deposits (Holocene) –outside of SF Fan
Qof--part	Coarse-grained older alluvial fan and stream terrace deposits (Pleistocene)
Qpaf—part	Alluvial fan and fluvial deposits (Pleistocene) –outside of SF Fan
Qpoaf—part	Older alluvial fan deposits (Pleistocene)
Qyf--part	Younger (inner) alluvial fan deposits (Holocene)
Qyfo--part	Younger (outer) alluvial fan deposits (Holocene)
Tbs	Shale in Butano Sandstone
Tlo	Lompico Sandstone
Tss	Unnamed sandstone and shale (Paleocene)
Tst	San Lorenzo Formation—Twobar Shale Member
Tuv	Unnamed sedimentary and volcanic rocks (Miocene and Oligocene)
Tw?	Whiskey Hill Formation-unit identification uncertain
Tws	Shale in Whiskey Hill Fm
Tws?	Shale in Whiskey Hill Formation-unit identification uncertain

APPENDIX J

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

	All Indoor Radon Data	High Zone Radon Data	Moderate Zone Radon Data	Low Zone Radon Data	Unknown Zone Radon Data
Size	478	60	40	342	36
Mean	1.773	6.637	2.458	0.915	1.047
Std. Dev.[1]	5.204	13.306	2.837	1.124	0.728
Std. Error[2]	0.238	1.718	0.449	0.0608	0.121
C.I. of Mean[3]	0.468	3.437	0.907	0.120	0.246
Range	94.7	94.3	13.9	15.1	2.6
Maximum	94.8	94.8	14.1	15.2	3.1
Minimum	0.1	0.5	0.2	0.1	0.5
Median	0.60	3.55	1.40	0.50	0.75
25%	0.50	1.50	0.90	0.50	0.50
75%	1.50	5.45	2.90	0.90	1.40
Skewness	13.281	5.392	2.545	7.770	1.613
Kurtosis	220.492	33.673	7.158	84.217	1.861
K-S Dist.[4]	0.389	0.343	0.272	0.338	0.244
K-S Prob.[5]	<0.001	<0.001	<0.001	<0.001	<0.001
SWilk W[6]	0.209	0.403	0.680	0.387	0.760
SWilk Prob[7]	<0.001	<0.001	<0.001	<0.001	<0.001
Sum	847.300	398.200	98.300	313.100	37.700
Sum of Squares	14419.850	13089.260	555.370	717.170	58.050

[1]Standard Deviation
[2]Standard Error of the Mean
[3]Confidence Interval for the Mean
[4]K-S Distance (The Kolmogorov-Smirnov distance)
[5]K-S Probability (The Kolmogorov-Smirnov probability)
[6]Shapiro-Wilk W (The Shapiro-Wilk W-statistic)
[7]Shapiro-Wilk Probability

APPENDIX K

Descriptive Statistics and Statistical Comparison of Indoor Measurements (Log(10)-transformed) by San Mateo County Radon Potential Zone

	All Indoor Radon Data	High Zone Radon Data	Moderate Zone Radon Data	Low Zone Radon Data	Unknown Zone Radon Data
Size	478	60	40	342	36
Mean	-0.0269	0.513	0.198	-0.145	-0.0591
Std. Dev.*	0.378	0.475	0.399	0.255	0.251
Std. Error*	0.0173	0.0613	0.0631	0.0138	0.0419
C.I. of Mean*	0.0340	0.123	0.128	0.0272	0.0850
Range	2.977	2.278	1.848	2.182	0.792
Maximum	1.977	1.977	1.149	1.182	0.491
Minimum	-1.000	-0.301	-0.699	-1.000	-0.301
Median	-0.222	0.550	0.145	-0.301	-0.126
25%	-0.301	0.173	-0.0458	-0.301	-0.301
75%	0.176	0.736	0.459	-0.0458	0.146
Skewness	1.548	0.462	0.362	1.531	0.818
Kurtosis	3.010	0.738	0.0910	3.542	-0.467
K-S Dist.*	0.220	0.107	0.0906	0.283	0.171
K-S Prob.*	<0.001	0.086	0.522	<0.001	0.009
SWilk W*	0.810	0.963	0.976	0.767	0.862
SWlk Prob*	<0.001	0.063	0.533	<0.001	<0.001
Sum	<12.864	30.783	7.909	-49.428	-2.127
Sum of Squares	68.603	29.110	7.778	29.384	2.333

*See footnotes for Appendix J

APPENDIX L

Descriptive Statistics and Statistical Comparison of Indoor Measurements (Ln-transformed) by San Mateo County Radon Potential Zone

	All Indoor Radon Data	High Zone Radon Data	Moderate Zone Radon Data	Low Zone Radon Data	Unknown Zone Radon Data
Size	478	60	40	342	36
Mean	-0.062	1.181	0.455	-0.333	-0.136
Std. Dev.*	0.871	1.094	0.919	0.588	0.578
Std. Error*	0.0398	0.141	0.145	0.0318	0.0964
C.I. of Mean*	0.0783	0.283	0.294	0.0625	0.196
Range	6.854	5.245	4.256	5.024	1.825
Maximum	4.552	4.552	2.646	2.721	1.131
Minimum	-2.303	-0.693	-1.609	-2.303	-0.693
Median	-0.511	1.267	0.334	-0.693	-0.290
25%	-0.693	0.399	-0.105	-0.693	-0.693
75%	0.405	1.695	1.057	-0.105	0.336
Skewness	1.548	0.462	0.362	1.531	0.818
Kurtosis	3.010	0.738	0.091	3.542	-0.467
K-S Dist.*	0.220	0.107	0.0906	0.283	0.171
K-S Prob.*	<0.001	0.086	0.522	<0.001	0.009
SWilk W*	0.810	0.863	0.976	0.767	0.862
SWilk Prob*	<0.001	0.063	0.533	<0.001	<0.001
Sum	-29.621	70.880	18.210	-113.812	-4.899
Sum of Squares	363.728	154.336	41.236	155.789	12.367

*See footnotes for Appendix J.

APPENDIX M

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

Data	N	W-Statistic*	P	Result
All-Untransformed	478	0.209	<0.001	Failed
All Data-Ln Transformed	478	0.810	<0.001	Failed
High Zone-Untransformed	60	0.403	<0.001	Failed
High Zone-Ln Transformed	60	0.963	=0.063	Passed
Moderate Zone-Untransformed	40	0.680	<0.001	Failed
Moderate Zone-Ln Transformed	40	0.976	=0.533	Passed
Low Zone-Untransformed	342	0.387	<0.001	Failed
Low Zone-Ln Transformed	342	0.767	<0.001	Failed
Unknown Zone-Untransformed	36	0.760	<0.001	Failed
Unknown Zone-Ln Transformed	36	0.862	<0.001	Failed

*Shapiro-Wilk Statistic (W)—tests the null hypothesis that the data was sampled from a normal distribution. Small values of W indicate a departure from normality (SigmaPlot®12 Statistics User's Guide part 2, Systat Software, Inc., p.23)

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

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

APPENDIX N

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

Mann-Whitney Rank Sum Test					
Group	*N*	*Missing*	*Median*	*25%*	*75%*
High Zone	60	0	3.550	1.500	5.450
Moderate Zone	40	0	1.400	0.900	2.900
Result	Mann-Whitney U Statistic = 724.5 T = 1544.500 n(small) = 40 n(big) = 60 (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	60	0	3.550	1.500	5.450
Low Zone	342	0	0.500	0.500	0.900
Result	Mann-Whitney U Statistic = 2233.000 T = 20117.000 n(small) = 60 n(big) = 343 (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	60	0	3.550	1.500	5.450
Unknown Zone	36	0	0.750	0.500	1.400
Result	Mann-Whitney U Statistic = 308.000 T = 974.000 n(small) = 36 n(big) = 60 (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	40	0	1.400	0.900	2.900
Low Zone	342	0	0.500	0.500	0.900
Result	Mann-Whitney U Statistic = 3026.500 T = 11473.5 n(small) = 40 n(big) = 343 (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)				
	APPENDIX N continued on next page				

Group	*N*	*Missing*	*Median*	*25%*	*75%*
Moderate Zone	40	0	1.400	0.900	2.900
Unknown Zone	36	0	0.750	0.500	1.400
Result	Mann-Whitney U Statistic = 417.000 T = 1083.000 n(small) = 36 n(big) = 40 (P=0.002) 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=0.002)				
Low Zone	342	0	0.500	0.500	0.900
Unknown Zone	36	0	0.750	0.500	1.400
Result	Mann-Whitney U Statistic = 4714.000 T = 8264.000 n(small) = 36 n(big) = 342 (P=0.013) 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=0.013)				