Title

MAPPING SURFICIAL RADIUM CONTENT-CONTENT AS A PARTIAL INDICATOR OF RADON CONCENTRATIONS IN U.S. HOUSES

Permalink

https://escholarship.org/uc/item/8z90s07m

Authors

Revzan, K.L.
Nero, A.V.
Sextro, R.G.

Publication Date

1987-12-01

LBL-24344

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE
DIVISION

Presented at the Fourth International Symposium on the Natural Radiation Environment, Lisbon, Portugal, December 7–12, 1987, and to be published in Radiation Protection Dosimetry

Mapping Surficial Radium Content as a Partial Indicator of Radon Concentrations in U.S. Houses

K.L. Revzan, A.V. Nero, and R.G. Sextro

December 1987

APPLIED SCIENCE
DIVISION

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

Presented at the Fourth International
Symposium on the Natural Radiation
Environment, Lisbon, Portugal,
December 7-11, 1987; submitted to
Radiation Protection Dosimetry

LBL-24344

MAPPING SURFICIAL RADIUM CONTENT AS A PARTIAL INDICATOR OF RADON CONCENTRATIONS IN U.S. HOUSES

K.L. Revzan, A.V. Nero, R.G. Sextro
Indoor Environment Program
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

December, 1987

This work was supported by the Director, Office of Energy Research, Office of Health and Environmental Research, Human Health and Assessments Division and Pollutant Characterization and Safety Research Division, and by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Systems Division of the U.S. Department of Energy (DOE) under Contract No. DE-AC03-76SF00098. It was also supported by the Office of Radiation Programs, of the U.S. Environmental Protection Agency (EPA) through Interagency Agreement DW89932609-01-0 with DOE. This report has not been subjected to EPA review. Its contents do not necessarily reflect the views of EPA, nor does mention of firms, trade names, or commercial products constitute endorsement or recommendation for use.

MAPPING SURFICIAL RADIUM CONTENT AS A PARTIAL INDICATOR OF RADON CONCENTRATIONS IN U.S. HOUSES

K.L. Revzan, A.V. Nero, R.G. Sextro
Indoor Environment Program,
Lawrence Berkeley Laboratory, Berkeley, CA 94720, U.S.A.

Abstract

In connection with the problem of indoor radon, we discuss the use of a database developed from the National Aerial Radiometric Reconnaissance in the development of a map of radium in soil for the contiguous 48 states. We examine the relationship between the results of measurements of radon in houses and the indications of the U.S. map, noting that some, but by no means all, of the areas known to have elevated radon concentrations appear as areas of higher radium concentration than their surroundings and that there are other areas, in which measurements of high radon levels have not been made, which are suggested as deserving of interest. We discuss mapping techniques for smaller areas and possible methods of dealing with apparent discrepancies between adjacent areas. We show that, on a national basis, as much as half the variation in radon from region to region may be accounted for by the level of radium in the soil, but that there are regions for which the radium concentration does not account for the relatively high observed radon.

Although the distribution of indoor ^{222}Rn (radon) concentrations in the United States appears to be roughly lognormal(1), it is apparent that the occurrences of high concentrations are not uniformly distributed throughout the country, but are generally found in selected areas, some of which have been identified. While it is unclear what percentage of the houses with elevated levels are in areas with high average concentrations, it is useful to proceed on the assumption that the percentage is large, and to attempt to identify such areas.

A major, though not necessarily the most important, factor determining the concentration of radon in the air inside houses is the concentration in the pore spaces of the underlying soil(2). For that reason, a useful first step in the identification of areas of elevated radon is the development of a map of soil gas concentration or, what is roughly equivalent, a map of radium concentration in soil, for the U.S. Though such a map cannot *exclude* any area of the country from the possibility of having houses with high radon levels (since, for example, high permeability soil may allow transport of sufficient soil gas of low radon concentration to produce a high indoor concentration), it can suggest certain areas which are likely to have large numbers of those houses.

The NARR Database

The data for a radium map were obtained by the National Aerial Radiometric Reconnaissance (NARR), begun in 1974 as an element of a national program designed to discover uranium-bearing rock formations. As a part of that mission, the NARR measured the gamma radiation from the top 0.5 m of soil or rock of the U.S. For a full description of survey techniques and sources of error and a reference list, see reference 3.

The survey was carried out by seven subcontractors, each of which was responsible for a number of National Topographic Map Series quadrangles of 2° longitude by 1° latitude or 140-200 by 112 km. Data were collected along primary flightlines, separated by intervals of 5 km or less in regions of interest and 10 km in others, and along tie lines, running perpendicular to the primary lines and separated by intervals of 20-30 km. Counting rates for gamma rays of interest, among them that of ^{214}Bi, a decay product of radon, were recorded at intervals of 1 second, so that each datum represents the radiation from an area whose diameter is on the order of 50-100 m. The flightline itself is covered completely, with considerable overlap between adjacent points, but there is obviously considerable missing information for the territory between flightlines. The spectrometers were calibrated using concrete pads containing known concentrations of the nuclides of interest. The data given as ppm equivalent uranium, which we express as Bq kg^{-1} or pCi g^{-1} radium, are actually a better indicators of pore space radon than it is of uranium or radium in soil granules.

Although the complete NARR data are available on magnetic tapes, the variety of formats used and the large storage requirements make use of the data inconvenient at best. To create a database which could be retained on a single storage device, we divide the east-west flightlines into 125 intervals, each covering 0.016° of longitude, and the north-south flightlines into 80 intervals, each covering 0.025° of latitude; each interval represents roughly 1.6 km (1 mi). Although the complete data can only support a resolution of 10 km, since that is the usual flightline spacing, the higher resolution of the database may prove useful if a technique of using the tie lines as a basis for interpolation is developed.

The reduced data are stored by quadrangle in ASCII files. For each interval, we have stored the central longitude and latitude, the flightline number and direction, the Federal Information Processing System code for the state and county in which the point lies, and the arithmetic mean and standard deviation of Ra (pCi g^{-1}), Th (ppm), K (percent), atmospheric ^{214}Bi (equivalent pCi g^{-1} Ra) and gross gamma (counts). The subcontractor's code for the rock or soil type is also stored; codes used by different subcontractors are not identical, so that the usefulness of the geological information is limited. For each quadrangle, a separate file contains information on the subcontractor, calibration of detectors, and aircraft type, averages of the nuclide concentrations, temperature, and atmospheric pressure for each flightline, and a list of the states and counties covered by the main data file, with the number of data points lying in each. The entire database requires approximately 350 megabytes of storage.

The U.S. Map

Figure 1 is a map of the contiguous 48 states on which each dot represents the average of the stored (1.6 km) radium concentrations for the surrounding 20 × 20 km area. Data from primary and tie lines are treated identically. The radius of the dot indicates the magnitude of the concentration (see caption). Blank areas occur where data were not available; the map will be revised in the near future. Areas of the map with higher radium concentration appear darker than those of low concentration.

The map reveals that certain areas appear sufficiently different in character from their surroundings to lead to suspicion that there might be problems involved in attempting to compare data from subcontractors using different detection systems, despite their use of the same calibration pads. The problem is perhaps most clearly exhibited in two quadrangles of central south Wyoming and central north Colorado which appear lighter in shading than adjacent quads. In both, all of the 20 × 20 km averages are in the lowest range; the surroundings are at least one range higher. The means of Ra for the two anomalous quadrangles are 6.3 and 8.1 Bq kg^{-1} , while the mean Ra of the six surrounding quadrangles is 33.3 Bq kg^{-1} ; the mean values of Th and K for all 8 quadrangles are similar to one another, so that the problem appears to be with the uranium calibration alone. However, the subcontractor used a detection system with identical calibration factors, presumably the same system, in a number of other quadrangles, none of which stands out from its surroundings. The cause of the Wyoming-Colorado anomaly remains unclear.

Other possible calibration anomalies appear in southwestern South Dakota (a single quad surveyed by a different subcontractor from the surrounding quads), eastern Washington and western Idaho (two quads, each flown by a different subcontractor), and San Jose, California, which will be discussed below. The average radium concentration of the territories surveyed by individual subcontractors ranges from 20 to 32 Bq kg^{-1}, but the variation may be explained, at least in part, by the different areas of the country flown by each; the question of the importance of subcontractor performance remains open.

The following areas, which the map reveals as having noticeably high radium concentrations compared to their surroundings, have also been found to have high radon concentrations in homes(1): eastern Pennsylvania-northern New Jersey (Reading Prong), eastern Tennessee-western North Carolina, eastern Washington-western Idaho (Spokane-Cour d'Alene), and western Florida (phosphate-bearing land). Apart from Florida, where the situation is well understood, and Tennessee, the mean levels of radium in these areas are not particularly high, and the nature of the relationship between the means of radium in soil and radon in houses remains to be established.

For the sake of completeness, we may mention the regions which are known to have high radon concentrations but do not appear, according to our data reduction, to have high radium levels and those which, conversely, have high radium concentrations but in which high radon levels have not, at least as yet, been found. In the former category there is just one region: the Red River valley of North Dakota. While the map shows the valley to be somewhat higher in radium than the territory to the east and west, the level is the same as that of the territory to the south, so that it is difficult to infer that this might be a region of interest. In the latter category, there are a number of obvious examples: central California, southern Arizona-New Mexico, a number of regions in the Rocky Mountain states, central New Hampshire-southern Maine, and, most conspicuously, southwestern South Dakota. Some of these are known to be areas in which uranium deposits occur; some, as we have suggested, may stand out because of calibration problems; some may be worthy of investigation. We are presently examining these questions.

Mapping of Quadrangles

The quadrangle is the most natural mapping scale between the U.S. as a whole and the very detailed studies which will be necessary for regions of particular interest. Maps of soil radium for individual quadrangles can be useful in analyzing discontinuities which appear on the U.S. map, in pointing out discontinuities not apparent on the larger scale map, and in identifying smaller regions of high concentration. Since there are fewer than 500 quadrangles, the number of maps is large but not unmanageable. We present here a treatment of one quadrangle of particular interest.

The San Jose quadrangle, located entirely in California between longitudes 120° and 122° W and between latitudes 37° and 38° N, appears on the U.S. map as a region having radium concentrations generally in the third or fourth range, i.e., between 40 and 80 Bq kg^{-1} . The elevated radon concentrations which are suggested by these figures have not been reported, although it is not clear that sufficient measurements have been made to have discovered them. A radium map of the primary flightline data for this quadrangle at the scale of 10 × 10 km, using the same technique used in the creation of the U.S. map, is provided as Figure 2, whose caption provides details. The map reveals three regions of elevated concentrations with the possibility of a fourth beginning at the right bottom. The regions of high concentrations are surrounded by areas of much lower levels. A similar map of the tie line data differs markedly in character.

The occurrence of temperature inversions in the area suggests that examining the relationship between the corrected radium level and the temperature during data collection might be productive. We find that the San Jose quadrangle exhibits a fairly high positive statistical correlation between the average temperature for the period of data collection for a primary (east-west) flightline and the average radium concentration reported for that flightline (Pearson correlation 0.78; probability of the absence of correlation 0.000). The positive correlation does not appear for the tie lines, nor does it appear for the other nuclides for either the primary or tie lines; neither does it appear for any of the surrounding quadrangles.

The appearance of quadrangles whose radium concentrations are discontinuous with their surroundings or are, in some other way, anomalous, suggests that corrective measures be taken when the data are actually used. The simplest of these measures, which might be used where a calibration problem is suspected, is to apply a correction factor so that the transition to the surrounding quadrangles is smooth. A somewhat more sophisticated approach is to use the data from the tie lines, weighted to adjust for the smaller number of points if desired, together with the primary flightline data, to create a new set of values for the quadrangle; mathematical techniques to carry out this procedure, which involve interpolation and smoothing, are readily available. Finally, it is possible to create contour maps from the individual data points. Such maps can be compared with similar maps for adjoining quadrangles, and the data for one or more of the quadrangles can be adjusted to produce a smooth transition. A contour map of the San Jose quadrangle, in which both primary and tie line data have been used, is provided as Figure 3.

The Statistics of Radium in Soil

On the basis of the 22,172 averages used for the 20 × 20 km map, the geometric mean (GM) radium is 25 Bq kg^{-1}, the geometric standard deviation (GSD) is 1.6, the arithmetic mean (AM) is 27 Bq kg^{-1}, and the arithmetic standard deviation (ASD) is 12 Bq kg^{-1}. These parameters are useful for making comparisons among regions, but they are misleading in that each datum is treated as if it were itself an observation rather than as an average of data which are themselves averages of original observations. Since we have retained the number of observations, the AM, and the ASD for each 1.6 km flightline datum, it is a simple matter to calculate an ASD for each 20 × 20 km region and then, to calculate an ASD for the contiguous U.S. On the basis of the original 24,591,855 measurements, this number is 21 Bq kg^{-1}. Calculation of the GM and GSD on the same basis involves approximations, since we have not retained the GM and GSD of the observations in our database and we do not wish to return to the data tapes. If we assume the data to be lognormally distributed, we may use the AM and ASD to calculate a GM and GSD: 21 Bq kg^{-1} and 2.0, respectively. As a check on this result, we may calculate a GM and GSD for *each* 1.6 km datum and then calculate overall parameters from these numbers: the GM on this basis is 22 Bq kg^{-1} and the GSD is again 2.0.

If we now consider that each original observation itself represents an integration of several hundred square feet and that large areas of the country remain unobserved due to the relatively large distances between flightlines, it is apparent that the actual GM of observations of radium in soil made at ground level, each representing an area the size of a house, is likely to be somewhat greater than 2.0. The GM of measurements of radon concentration in houses in the U.S. is approximately 2.8(1). Suppose that the indoor radon concentration is the product of the soil gas radon concentration, represented by the radium concentration, and some other lognormally distributed factor or combination of factors. Given the fact that the logarithms of GSDs add in quadrature, two factors contributing equally to the variation in radon would each have a GSD of 2.1, which is very close to the calculated GSD for radium. The observed variation in radium in soil may thus account for roughly half the observed variation in indoor radon.

It is clear, however, that in certain regions of high radon concentrations we must look to factors other than radium in soil. In part of eastern Pennsylvania, for example, we find a GM radon concentration of 120 Bq m^{-3} with a GSD of 3.4(1), which is a factor of 3.6 higher than the national GM. (The parameters for the Reading Prong area are considerably larger.) The GM radium for this area is generally 20-40 Bq kg^{-1} , with a high of 56 Bq kg^{-1} ; the GSD is generally 1.5-2.5. If the relationship between radium and the other factor or factors affecting radon in houses were to be the same in eastern Pennsylvania as in the contiguous 48 states as a whole, the GM radium should be on the order of 75 Bq kg^{-1} and the GSD should be 2.4. We are in the process of investigating a detailed NARR survey of the Reading Prong to determine if there are variations in radium which are obscured by the relatively low spatial resolution of the general survey.

We are not yet in a position to determine the usefulness of the NARR data in predicting indoor radon concentrations. Only after we develop maps of the other factors influencing radon entry, resolve the questions surrounding the reliability of the NARR data, and determine whether local occurrences of high radium in rock or soil have been obscured by the averaging process involved in data collection will a final judgment be possible.

Acknowledgements

This work was supported by the Director, Office of Energy Research, Office of Health and Environmental Research, Human Health and Assessments Division and Pollutant Characterization and Safety Research Division, and by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Systems Division of the U.S. Department of Energy (DOE) under Contract No. DE-AC03-76SF00098. It was also supported by the Office of Radiation Programs, of the U.S. Environmental Protection Agency (EPA) through Interagency Agreement DW89932609-01-0 with DOE. This report has not been subjected to EPA review. Its contents do not necessarily reflect the views of EPA, nor does mention of firms, trade names, or commercial products constitute endorsement or recommendation for use.

References

1. Nero, A.V., Schwehr, M.B., Nazaroff, W.W., and Revzan, K.L., *Distribution of Airborne Radon-222 Concentrations in U.S. Homes.* Science 234 992-997 (1986).
2. Sextro, R.G., Moed, B.A., Nazaroff, W.W., Revzan, K.L., and Nero, A.V., *Investigations of Soil as a Source of Indoor Radon.* Ch. 2 of Hopke, P.K., ed., *Radon and Its Decay Products*, American Chemical Society (1987).
3. Moed, B.A., Nazaroff, W.W., Nero, A.V., Schwehr, M.B., and Van Heuvelen, A., *Identifying Areas with Potential for High Radon Levels: Analysis of the National Airborne Radiometric Reconnaissance Data for California and the Pacific Northwest.* Bonneville Power Administration (U.S. Department of Energy), DOE/BP-00098-5 (1985).

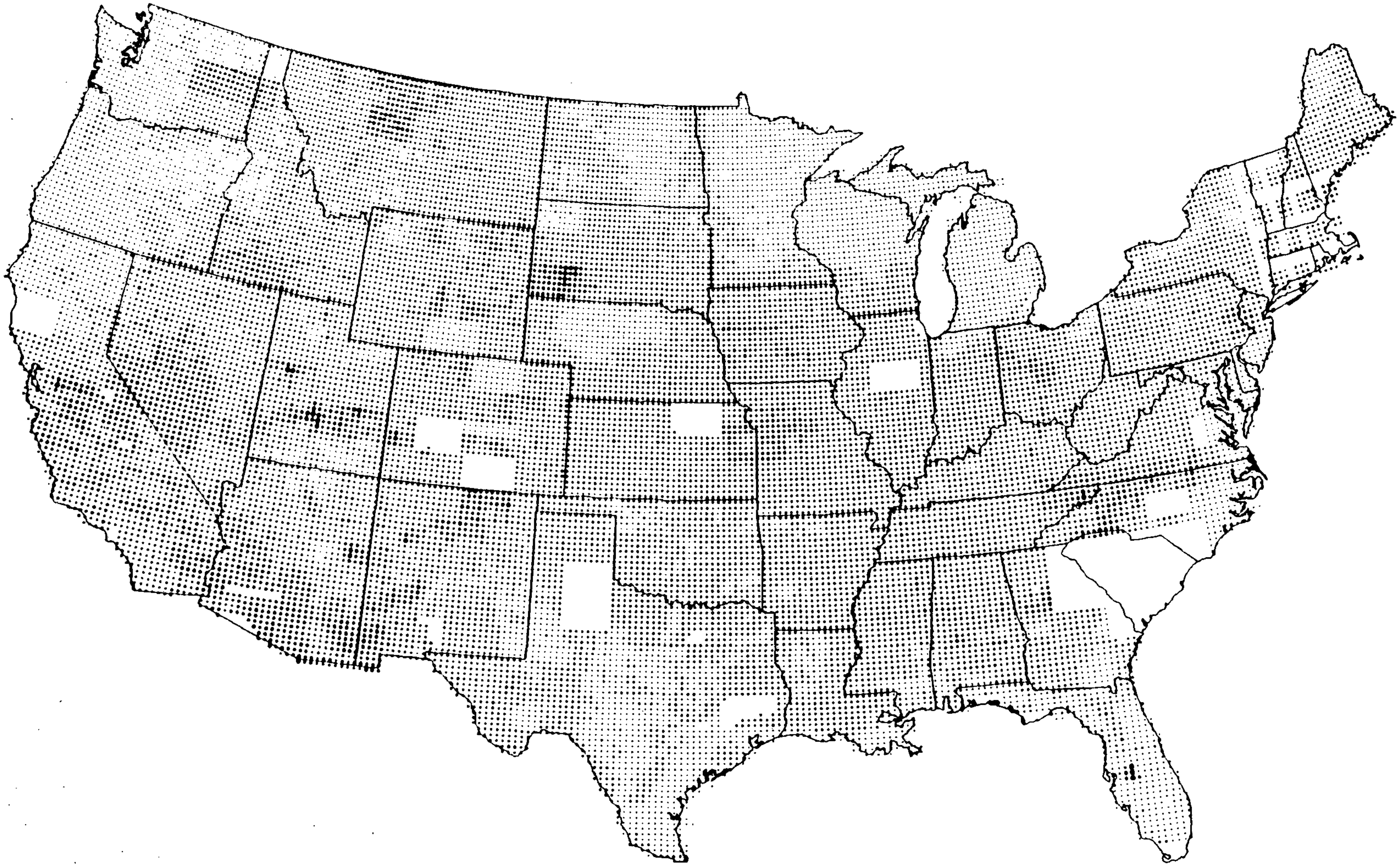

Figure 1.
Mean radium in soil for 20 X 20 km areas of the contiguous 48 states. From the smallest to the largest, the 6 circle radii represent concentrations of 0–20, 20–40, 40–60, 60–80, 80–100, and > 100 Bq kg^{-1} soil.

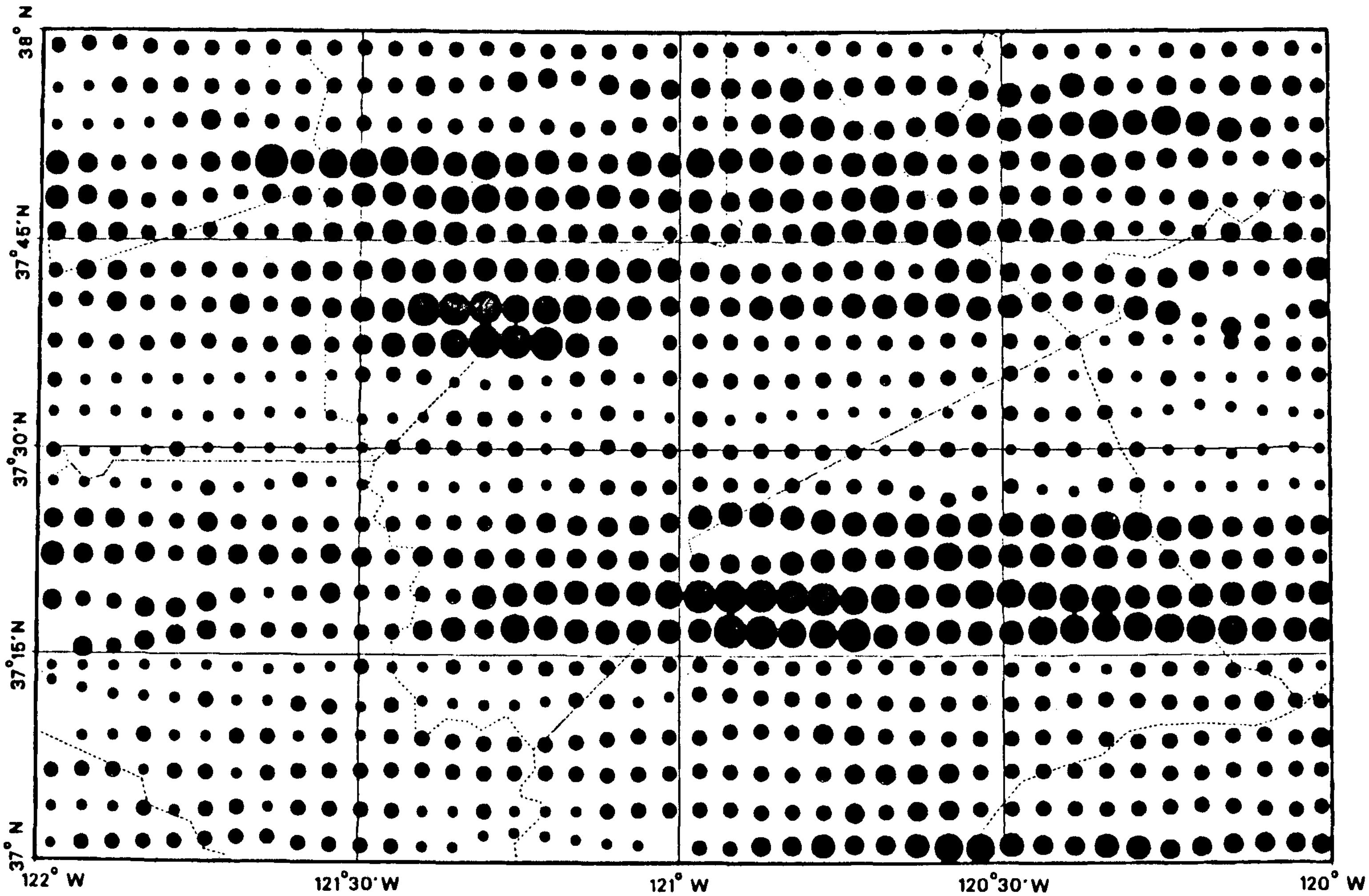

Figure 2.
Mean radium in soil for 5 km distances along primary flightlines of the San Jose quadrangle. From the smallest to the largest, the 6 circle radii represent concentrations of 0–30, 30–60, 60–90, 90–120 120–150, and > 150 Bq kg^{-1} soil. Dotted lines are county boundaries.

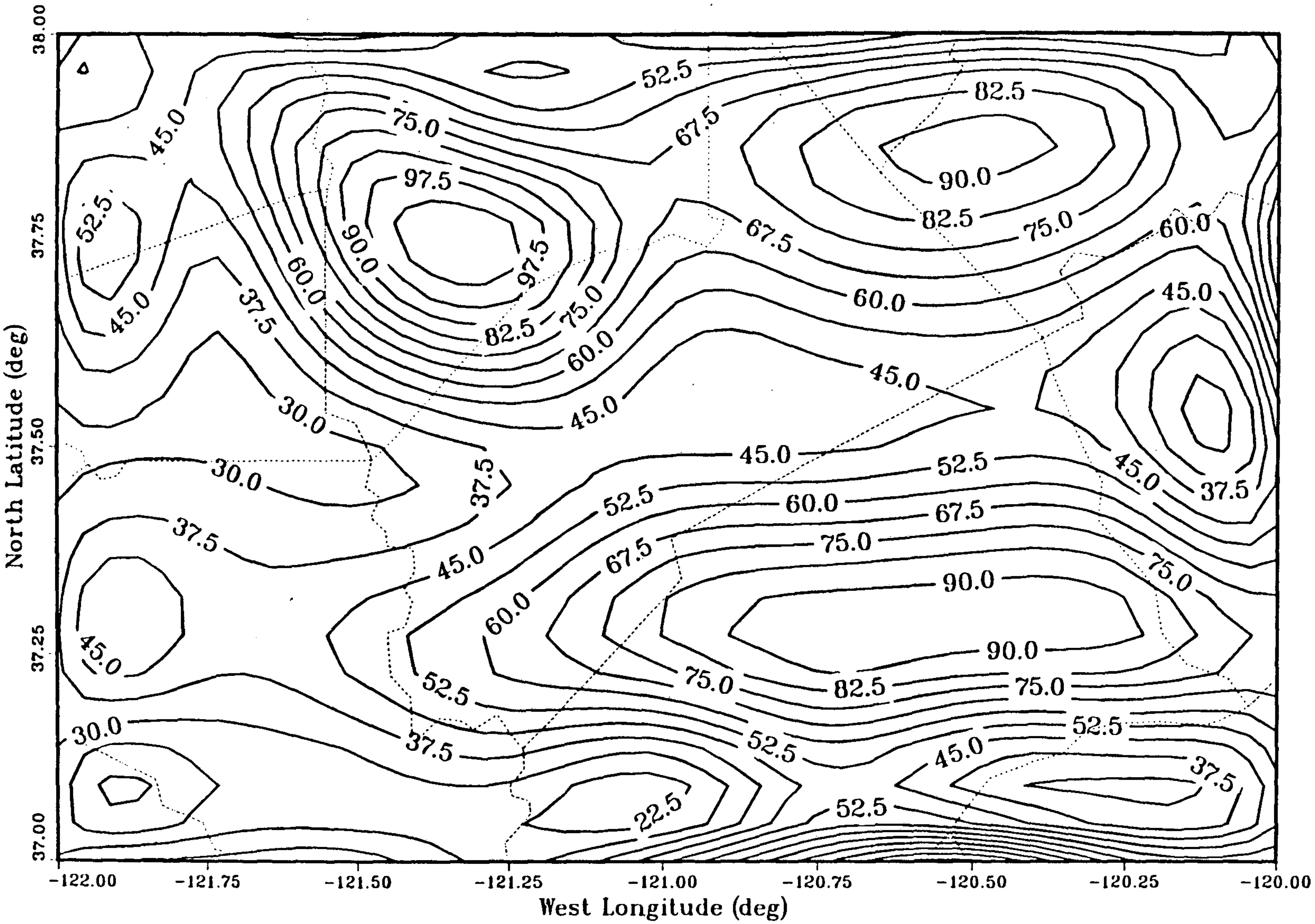

Figure 3.
Contour map of radium in soil for the San Jose quadrangle.
The interval between contours is 7.5 Bq kg^{-1} soil.
Dotted lines are county boundaries.