URANIUM DISTRIBUTION IN THE CAVE CREEK-CAREFREE AREA, CENTRAL ARIZONA, AND IMPLICATIONS FOR INDOOR RADON

by

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INTRODUCTION

Radon is a colorless, odorless gas produced by the natural radioactive decay of uranium. The U.S. Environmental Protection Agency has determined that exposure to indoor radon may increase a person's risk of developing lung cancer. Indoor-radon levels generally correlate with uranium concentration in underlying rocks and soil, and some areas of Arizona are known to have elevated levels of uranium.

This study is part of an ongoing evaluation of potential radon hazards in Arizona by the Arizona Geological Survey and the Arizona Radiation Regulatory Agency. This report presents results of a study of the distribution of uranium in rocks and basin-fill sediments in the Cave Creek-Carefree area of central Arizona.

Uranium concentrations were measured using a portable gamma-ray spectrometer. The spectrometer survey followed the methods outlined in Duncan and Spencer (1993b) and the same equipment was used during both investigations. Indoor-radon data were supplied by the Arizona Radiation Regulatory Agency and well water-radon data were taken from Barnett (1990) and Duncan and Spencer (1993a).

LOCATION

This study focuses on the Cave Creek and Wildcat Hill 7.5' quadrangles (Figure 1), about 25 miles north of Phoenix. The study area includes the communities of Cave Creek, Carefree, and North Scottsdale.

GEOLOGY

Cave Creek-Carefree area

The geology in the Cave Creek and Wildcat Hill quadrangles is dominated by Precambrian granite and its weathered derivatives in the eastern and southern part and Precambrian meta-argillites in the western and northern part (Leighty and others, 1997; Skotnicki and Leighty, 1997). In the center of the study areas lies the Carefree Basin (Doorn, 1989; Doorn and Pewe, 1990), a structural trough formed by normal faulting in the middle Tertiary. Sediments derived from the surrounding mountains and consisting predominantly of Precambrian granite grus and meta-argillite fill the basin. Along the northern and southern margins of the basin are Tertiary andesite and basalt. Exposed intermittently along the northern edge of the basin is the White Eagle Mine Formation, a lacustrine sedimentary deposit consisting of tuffaceous and marly silt and clay.

Gravity modeling indicates that the depth to consolidated bedrock in the Carefree Basin is about 2000 feet (Oppenheimer, 1980; Doorn, 1989). Well logs indicate as much as 1300 feet of alluvial sediments below the surface in the southeast part of the basin (Doorn, 1989).

Previous Studies

Detailed mapping of bedrock in the Cave Creek and Wildcat Hill quadrangles was accomplished by Skotnicki and Leighty (1997) and Leighty and Skotnicki (1997). The geology and hydrology of the Carefree Basin were studied in great detail by Doorn (1989) and Doorn and Pewe 1991. Other geologic mapping includes Gomez (1978), Kenny (1986), and Gorey (1988). Wagner (1979) performed geophysical modeling of the area. Lacustrine sediments of the White Eagle Mine Formation were studied by Lewis (1920) and Duncan and others (1993a). Barnett (1990) measured

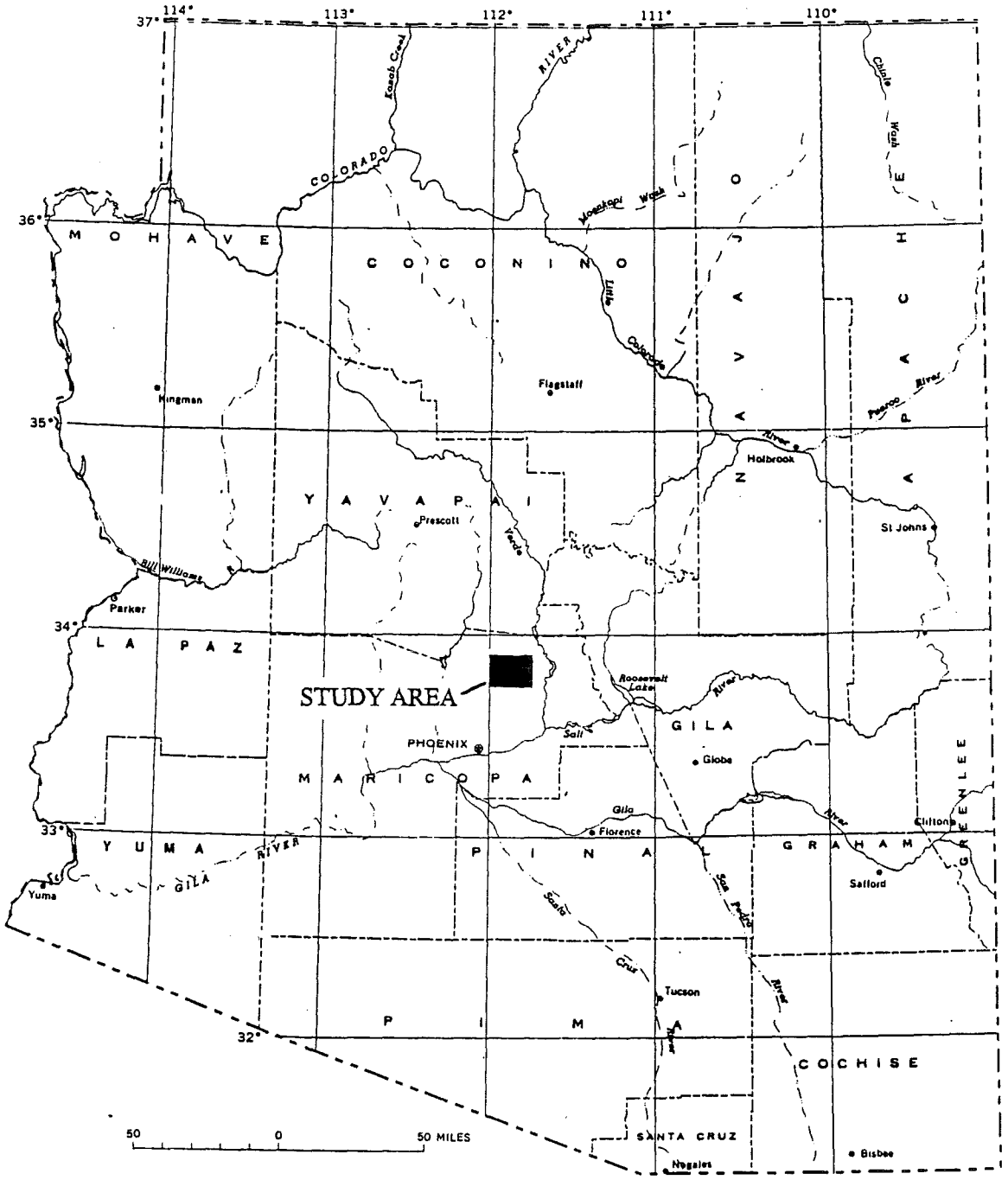

Figure 1. Location of study area.

radon in well water in the Carefree Basin, and Luning and others (1982) and Emer and others (1988) did reconnaissance measurements of uranium and radon in the area.

GAMMA-RAY SPECTROMETER SURVEY

Methods

The Arizona Geological Survey conducted a survey of the Cave Creek-Carefree area using an EG&G geoMetrics model GR-310 portable gamma-ray spectrometer. The machine employs an external detector containing a 347-cm^3, thallium-doped, sodium iodide crystal and a high-gain photomultiplier tube. Four independent channels provide measurements of the diagnostic gamma radiation for uranium (via bismuth-214, 1.76 million electron volts [MeV]), thorium (via thallium-208, 2.62 MeV), needed for uranium assay corrections, as well as total gamma radiation (0.4 to 4.0 MeV) and potassium.

Count times of 1, 10, 100, or 1000 seconds may be selected, and due to the random nature of radioactive decay, longer count times generate less statistical error and greater precision. Periodic comparisons of 100- versus 1000-second count times confirmed that the shorter count time was sufficiently accurate for the purposes of this study and so was used for data acquisition. Uranium concentrations in parts per million (ppm) were calculated from the field data using correction factors and assay equations developed by Duncan and Spencer (1993b).

Results

Figure 2 is a histogram of uranium concentrations determined by spectrometer measurements. The mean for 93 assays in the Cave Creek area is 3.61 ppm. (Ignoring the two highest measurements lowers the average to 3.03 ppm.) For comparison, the average uranium in the Safford and lower San Pedro Valleys is 3.6 and 3.65 ppm, respectively (Harris, 1994; 1996). Uranium concentrations of 7 ppm or greater are considered anomalous (Duncan and Spencer, 1993b). Anomalous concentrations of uranium were measured in lacustrine sediments of the White Eagle Mine Formation and in a few exposures of Precambrian granite. Locations of spectrometer measurements and uranium concentrations are shown on Plate 1.

Analyses of eight samples were performed by a commercial lab to check the quality of the spectrometer data. Figure 3 shows the results of laboratory analyses versus spectrometer measurements. Some of the laboratory analyses have uranium concentrations different from those of the spectrometer, and the results show less correlation than those of previous studies. Several factors may be responsible for the difference between the chemical versus spectrometer results. First, the spectrometer measures radiation from a much large area, typically about 25 m^2, which may contain zones of normal as well as anomalous levels of uranium. Samples collected for chemical analyses, on the other hand, typically represent a much smaller area or a single layer that may have lower or higher uranium levels than the average of the larger surrounding area. Also, chemical analyses measure uranium in samples directly, whereas spectrometers measure gamma rays emitted from near the surface by bismuth-214, a daughter of radon. If radon, a gas, is lost from the surface, as could happen in the case of unconsolidated sediments, the full amount of uranium in the sediment may not be accounted for in measurements of bismuth-214.

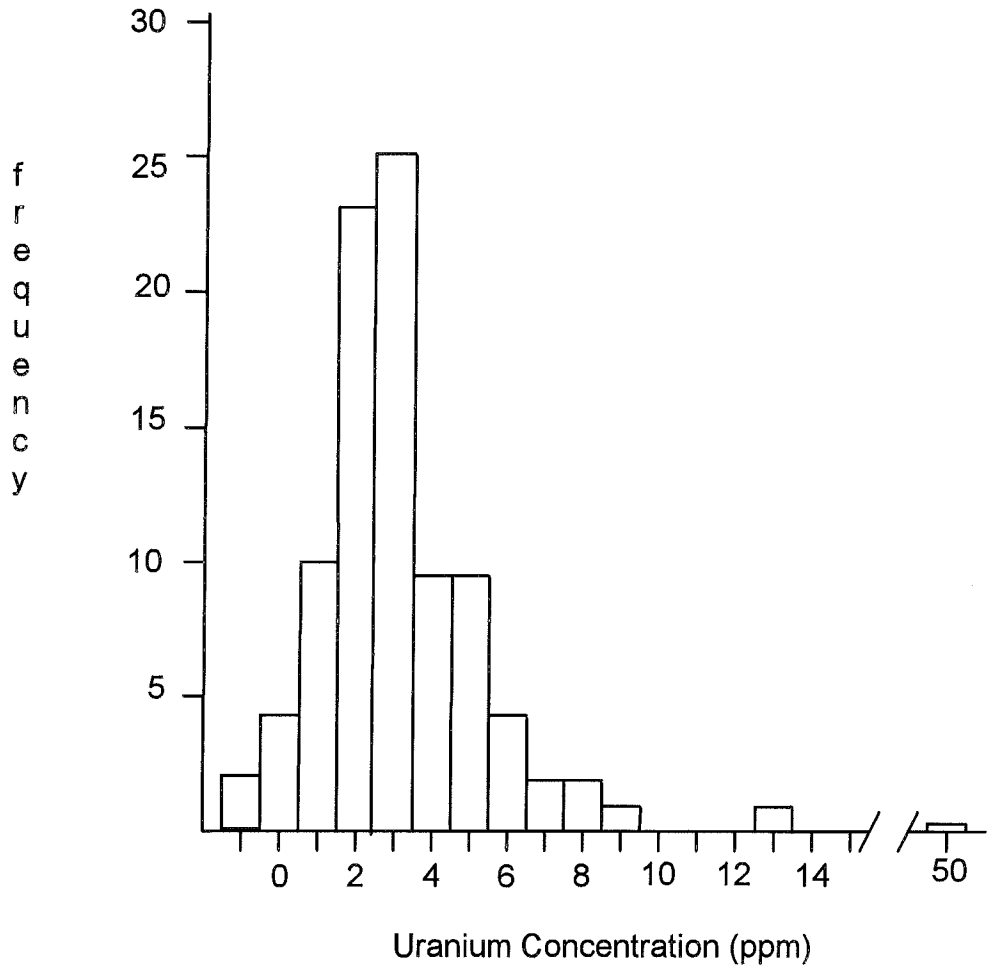

Figure 2. Histogram of uranium concentrations in the Cave Creek area. Concentrations greater than 6 ppm are considered anomalous. Values less than zero reflect error introduced during measurement and calculation of concentration (Duncan and Spencer, 1993b), and reveal an accuracy of measurement of approximately ± 2-3 ppm.

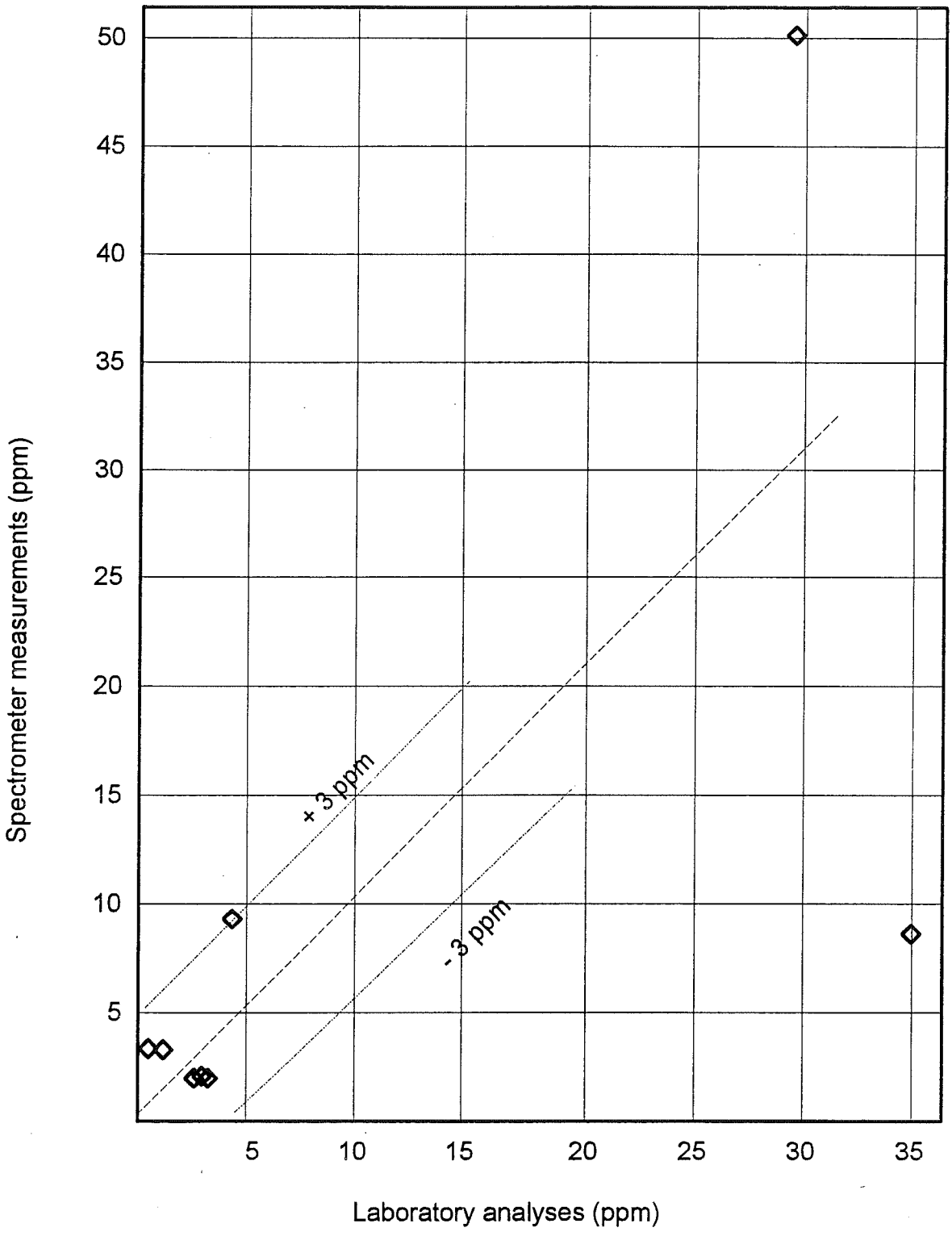

Figure 3. Plot of spectrometer measurements versus commercial laboratory analyses of rocks and sediments in the Cave Creek area.

URANIUM GEOLOGY

Rock-type Associations

Precambrian granites in the Cave Creek area measured in this study have uranium concentrations of <1 to 13 ppm, well within the range of other Precambrian granites in Arizona. In fact, Precambrian granites can have much higher uranium contents. The Dells Granite near Prescott was found to have up to 39 ppm uranium by Silver and others (1980) and has a mean uranium content of 8.3 ppm (Proctor and others, 1993). The Lawler Peak Granite, near Bagdad has uranium concentrations as high as 551 ppm, with an average of 14.6 ppm (May and others, 1982). Weathered Precambrian granite and granitic grus, which forms an extensive pediment in the eastern half of the study area, has low levels of uranium, indicating possible leaching and removal of much of the original uranium content.

Basin-fill alluvium of the Carefree Basin generally contains low concentrations of uranium, regardless of the parent rock. Anomalous uranium concentrations were encountered in the mid-Tertiary White Eagle Mine Formation, a lacustrine deposit containing tuffaceous marl. The sediments are exposed north of Cave Creek along the margins of the Carefree Basin and their uranium contents have been measured previously by Scarborough (1979), Luning and others (1982), Doorn (1989), Doorn and Pewe (1991), and Duncan and Spencer (1993a).

Origin of Uranium Anomalies

Granitic rocks. On the basis of the lack of miarolitic cavities, sparse sodic feldspars, lack of sodic amphiboles and pyroxenes, and insufficient primary hematite to serve as a reductant, Luning and others (1982) considered the Precambrian granites of Cave Creek to be unfavorable for uranium deposits. Their interpretation of the difference between the chemically determined uranium concentration versus a usually higher apparent uranium content based on spectrometer measurements is that uranium has been leached, but not its radioactive daughter products. Spectrometers, which actually measure bismuth-214 as a surrogate for uranium content, may "detect" uranium that is no longer there. The uranium that is present in background concentrations is mostly contained in zircon (Silver and others, 1980).

Sedimintary rocks. Uranium anomalies in the sediments of late-Cenozoic basins in Arizona are generally restricted to marly, diatomaceous, and cherty lacustrine sediments. These types of uranium-bearing sediments have been described in the Verde Valley (Duncan and Spencer, 1993c) and in the Safford and San Pedro valleys (Harris, 1994, 1996). The basin fill of the Cave Creek-Carefree area contains small, scattered exposures of marly, diatomaceous lacustrine sediments that were deposited in lacustrine or playa environments. These conditions promote the deposition of fine-grained sediments and evaporites, including diatomite, gypsum, marl, and organic matter.

Although most carbonate rocks contain very little uranium, especially those deposited in oxidizing environments, some impure carbonates can contain considerably more uranium. Impurities such as clay, organic matter, and silica gel can absorb uranium (Jones, 1978; Schmidt-Collerus, 1979). Tuffaceous sediments may be altered to clay and release silica shortly after deposition, providing sites for uranium adsorption (Zielinski, 1980).

Organic matter in the basin sediments would also contribute to an increased uranium content by reducing the soluble, oxidized form of uranium U(+6) to the insoluble U(+4) state. The presence of organic matter may increase the uranium content by a factor of 10,000 or more over that of the surface runoff or groundwater supplying uranium to the basin (Schmidt-Collerus, 1979).

Conditions during or after deposition of the White Eagle Mine Formation were apparently favorable for the accumulation and preservation of uranium in the diatomaceous and marly

sediments. Oxidizing conditions at the time of deposition would have kept uranium in its soluble state and would have prevented the preservation of organic matter which facilitates the precipitation of uranium (Mickle and Mathews, 1978). Oxidizing conditions at the present may increase the mobility of uranium, flushing it out of surficial sediments, resulting in the low concentrations found in most sediments in southeast Arizona basins.

The concentration of uranium in basin fill is probably more strongly controlled by the nature of the sediments and depositional environment than the amount of influx of uranium. A U.S. Department of Energy survey (Luning and others, 1982) concluded that the lacustrine rocks of the Cave Creek area were the only sediments favorable for the accumulation of anomalous uranium. The alluvial sediments that make up most of the basin-fill in the study area contain low concentrations of uranium.

Correlation with indoor-radon levels

A residential indoor-radon testing program was performed by the Arizona Radiation Regulatory Agency from 1987 to 1989. The U.S. Environmental Protection Agency has set a guideline indoor radon limit of 4 picocuries per liter (pCi/l), above which mitigation is recommended. Charcoal canister results from 35 homes in the Cave Creek-Carefree area show a mean indoor radon level of 3.03 pCi/l, higher than the average of about 1 pCi/l for all of Arizona. Five homes (14%) registered at or below 1.0 pCi/l; Eight homes (23%) had radon levels higher than 4.0 pCi/l, compared with 5.4% of homes statewide. The highest reading from the area was 13.9 pCi/l. Tested homes are identified by zip code only, so their precise location relative to the various rocks types or high-radon wells in the area is unknown. Also, the small sampling size of 35 homes may not give an accurate representation of the average and range of indoor radon levels.

Correlation with radon in water

A study of well water in the Cave Creek-Carefree area found radon levels of 260 to 8,150 pCi/l (Table 1), with an average of 1,740 pCi/l (Barnett, 1990); a mean of 1148 pCi/l was reported for 32 wells sampled statewide (Duncan and others, 1993). Radon levels in water do not correlate with uranium content of the aquifer sediments present in the screened intervals of wells. Barnett (1990) found that the highest radon in water was from wells in Precambrian granite and meta-argillite, but the meta-argillite typically has the lowest uranium content of any rocks in the study area.

Studies by the U.S. Department of Energy have shown that water may be a significant source of radon in the home, with up to one third of indoor radon coming from water usage, particularly showers (U.S. Department of Energy, 1993). On average, water contributes one pCi/l to indoor-air radon levels for each 10,000 pCi/l radon in the water (Cross and others, 1985). The contribution to indoor radon from residential water use in the Cave Creek-Carefree area is undefined, but could be important. The U.S. Environmental Protection Agency has recently proposed a limit of 300 pCi/l for radon in water.

CONCLUSION

The Cave Creek-Carefree area contains a few areas of elevated uranium concentrations in sediments, but few residences are located in these areas. Levels of uranium average 3.61 ppm for the study area, compared to an average level of 1.6 ppm determined in a statewide survey (Duncan and Spencer, 1993). Deleting the two highest samples from the set yields an average of 3.02 ppm,

Table 1. Well locations, producing capacities, primary producing aquifers, and concentrations of radon in water for wells analyzed by Barnett (1990). Radon concentrations are mean values for wells sampled more than once. Producing capacity and aquifer formation are mostly from Doorn and Péwé (1991). Capacity numbers marked with an asterisk (*) are midpoints of ranges given by Doorn and Péwé (1991); those marked "est." are J.T. Duncan's estimates based on comparisons to nearby wells producing from the same aquifer. Formation symbols marked with question marks (?) are J.T. Duncan's tentative determinations based on producing aquifers in surrounding wells.

Well #	Location	Capacity (gpm)	Producing Fm.	^{222}Rn
1	A(6-5) 33aaa	87	Tcgr	1,660
2	A(5-5) 6daa	33	Tcgr	690
3	A(6-5) 31cdd	165	Tcgr	1,080
4	A(6-5) 31bda	1,450*	Tcgr	1,290
5	A(6-5) 30cca	160	Tcgr	1,900
6	A(6-5) 31ccc	1,278	Tcgr	770
7	A(6-5) 31bcc	750	Tcgr	1,400
8	A(6-4) 36bda	515	Tcgr	1,830
9	A(6-4) 35aad	220	Tcgr	940
10	A(6-4) 23dbd	25	Tcs	980
11	A(6-4) 26dcc	210	Tcgr	2,100
12	A(6-4) 11cdc	10 (est.)	pCap	2,990
13	A(6-4) 22dac	0	Tcnc	980
14	A(6-4) 27dbd	600*	pCcg	4,590
15	A(6-4) 15dcb	10	Twl	280
16	A(6-4) 22bbc	10	Tcn	430
17	A(6-4) 21dda	135*	Tcn/Tv	1,070
18	A(6-4) 28dda	100	Tcc/pCap	3,930
19	A(6-4) 28dac	80	Tcc/pCap	5,110
20	A(6-4) 28dca	30	Tcc/pCap	2,840
21	A(6-4) 21bdc	15 (est.)	Tcn (?)	1,530
22	A(6-4) 9bab	25	pCap	2,970
23	A(6-4) 28bdc	10 (est.)	Tcg/Tv/pCap (?)	260
24	A(6-4) 29aac	NA	Tcg/Tv (?)	390
25	A(6-4) 29ddb	15 (est.)	Qs/pCap (?)	260
26	A(6-4) 8dcb	100*	Tcn (?)	527
27	A(6-4) 32caa	500	Qs	380
28	A(6-5) 10bbb	NA	pCap	8,150

Table from Duncan and Spencer (1993a)

slightly lower than the average for the Safford and lower San Pedro Valleys (Harris, 1994, 1996), and much lower than the 4.6 and 11.5 ppm uranium in limestones and mudstones of the Verde Formation (Duncan and Spencer, 1993c). By contrast, Peake and Schumann (1991) estimate a concentration of 3 ppm uranium as being a reasonable average background level for the entire U.S.

Homes tested for indoor radon in the Cave Creek-Carefree area have levels above the average for homes statewide (but are still below the EPA action level). However, considering the widespread distribution high-radon water wells in the basin, water may be a significant source of indoor radon.

The possibility exists that other small or low-level uranium anomalies are present that were not found during this survey. Furthermore, the distribution of uranium in the subsurface basin-fill sediments has not been determined.

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