# Distribution of indoor radon concentrations and uranium-bearing rocks in Texas

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**Abstract** The purpose of this study was to compare regional patterns of indoor radon concentration with uranium-bearing rock zones and county populations in Texas. Zones yielding radon concentrations that are relatively high for Texas include shale and sandstone in northwest Texas; red beds in north-central Texas; felsic volcanic rocks in west Texas; and sandstone, limestone, and igneous rocks in central Texas. Located in northwest Texas, only five of the 202 counties evaluated have mean indoor radon concentrations above 4.0 pCi $l^{-1}$. Two of those counties have populations above the state median of 20 115. The highest county mean concentration is 8.8 pCi $l^{-1}$. Results of this study suggest that (1) regional geology influences indoor radon concentrations in Texas, (2) statewide, the radon concentrations are relatively low, (3) highly populated counties do not coincide with regions of high indoor radon concentration, and (4) regions that may warrant further monitoring include northwest Texas and, to a lesser degree, west and central Texas.

**Key words** Radon · Texas · Uranium-bearing rock formations

## Introduction

While public awareness of the indoor radon problem has increased significantly over the past decade, many buildings still have not been tested. Most state's have limited resources to conduct radon tests. Efficient use of available resources requires focusing on regions that may be prone to elevated radon levels. As uranium is the ultimate source of radon gas, geology should be a primary consideration in delineating potentially hazardous regions within a state. The governing influence of geology can be evaluated by studying spatial associations between uranium-bearing rock formations and indoor radon concentrations. The purpose of this study was to examine associations between indoor radon concentrations and rock units with above-average uranium concentrations in Texas. A secondary goal was to compare regional patterns of indoor radon concentrations with county populations throughout the state.

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## Background

The average uranium concentration in the earth's crust is approximately 2.7 ppm (Brookins 1988). Rocks having higher than average concentrations of uranium include felsic igneous rocks such as granite and rhyolite, carbonaceous black shales, phosphatic sedimentary rocks, glauconite-bearing sandstones, and fluvial sandstones (Gundersen and others 1992; Otton 1992; Montgomery 1995). Metamorphic rocks derived from parents in the preceding list can also contain above-average uranium concentrations.

Several investigators have reported elevated indoor radon concentrations in buildings overlying granite and shale. The Pikes Peak granite in Colorado, USA (Burkhart and Huber 1993), and Sandia Mountains in New Mexico, USA (Brookins 1991), are both associated with high indoor radon concentrations. Shale formations that have contributed to elevated radon levels in the United States include the Martinsburg Formation in West Virginia (Schultz and others 1992), Marcellus shale in western New York (Hand and Banikowski 1988), Pierre Shale in Colorado (Burkhart and Huber 1993), and Ohio shale (Harrell and others 1991). Similarly, Brown and others (1992) found that shale was associated with high indoor radon concentrations in the Coastal Plain and Piedmont physiographic provinces of Virginia. Shale and granite are among the uranium-bearing rocks in the present study.

## Approach

The ArcView geographic information system (GIS) (ESRI 1994) was used to map, query, and analyze county mean indoor radon concentrations reported by the Texas Department of Health (TDH 1994). Data were obtained from a 1991 survey of residential indoor radon concentrations. Measurements were made with activated charcoal adsorption canisters under closed-house conditions, following US Environmental Protection Agency (US EPA) protocols. The survey was designed so that all houses within a specific county had an equal chance of being tested. A total of 2890 measurements were obtained. Mean concentrations are reported for 202 of 254 Texas counties.

From a map of energy resources compiled by St. Clair and others (1976), five regions in Texas with uranium-bearing surficial strata were defined (Fig. 1). The remainder of the state, underlain by Paleozoic through Cenozoic sedimentary rocks, was designated zone 1. The uranium-bearing zones are shale and sandstone of the Triassic Dockum Group in northwest Texas (zone 2); red beds of the Permian Wichita Group in north-central Texas (zone 3); felsic volcanic rocks in west Texas (zone 4); sandstone, limestone, and igneous rocks of the Llano uplift in central Texas (zone 5); and sandstones and shale of the Tertiary Catahoula Formation in southeast Texas (zone 6). Radioactive anomalies and uranium mineral occurrences are associated with each of the zones listed above (St. Clair and others 1976).

Zones 2, 3, and 6 were digitized off of an energy resources map compiled by Kier and others (1977). A geologic map of Texas compiled by Renfro and others (1973) was used to digitize zones 4 and 5. Maps of the uranium-bearing rock units (Fig. 1) and Texas counties were overlaid to determine which counties overlapped each zone. Indoor radon concentrations associated with the six different zones were compared statistically. The non-parametric Kruskal-Wallis test was used instead of a one-way

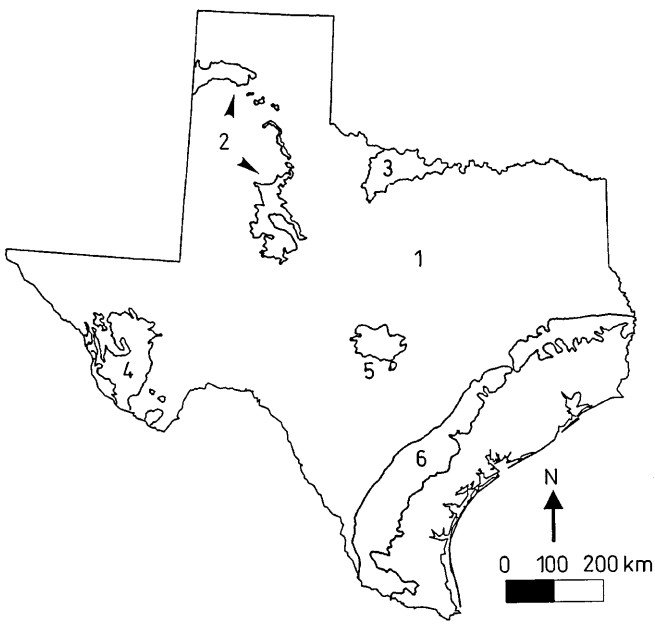


**Fig. 1**
Zones of uranium-bearing rocks

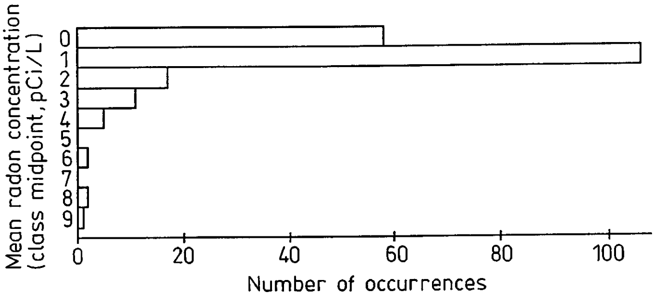


**Fig. 2**
Histogram of county mean indoor radon concentrations (picocuries per liter)

ANOVA because the dependent variable (county mean indoor radon concentration) is not normally distributed (Fig. 2). The Kruskal-Wallis statistic tests the equivalency of several samples (Davis 1986). Observations from $m$ samples, each corresponding to a different zone (Fig. 1), are pooled and then ranked from smallest to largest (smallest value = rank 1). For each sample $k$, the sum of the ranks are found:

$$R_k = \sum_{i=1}^{n_k} R(X_{ik}) \tag{1}$$

where $R(X_{ik})$ is the rank of the $i$th observation in the $k$th sample. The total number of observations is

$$N = \sum_{k=1}^{m} n_k \tag{2}$$

where $n_k$ is the number of observations in the $k$th sample. The null hypothesis is that the $m$ populations from which the samples are taken have identical distributions. Alternatively, at least one of the populations has a different central value. From the sum of ranks, the Kruskal-Wallis $H$ statistic is computed as (Davis 1986)

$$H = \frac{12}{N(N+1)} \sum_{k=1}^{m} \frac{R_k^2}{n_k} - 3(N+1) \tag{3}$$

Calculations were made with MINITAB (Minitab 1991). The software package also calculates a $z$ value for each sample. For sample $k$,

$$z_k = \frac{\overline{R}_k - (N+1)/2}{\sqrt{(N+1)(N/n_k - 1)/12}} \tag{4}$$

The value of $z_k$ indicates how the mean rank $\overline{R}_k$ for sample $k$ differs from the mean rank $\overline{R}$ for all $N$ observations. Prior to implementing the Kruskal-Wallis test, observed county mean indoor radon concentrations (OC) were adjusted to control for house construction (basement versus alternative construction). The US EPA (Cohen 1992) calculated that houses with basements have an average of 1.8 times the indoor radon concentration of houses with alternative construction. In the present study, county means were adjusted downward by employing the correction factor (CF) of 1.8, considering the fraction of houses sampled in a county with a basement (FB):

$$CV = \frac{OC}{1 - FB(1 - CF)} \quad (5)$$

where $CV$ is the corrected county mean concentration. The purpose of the computation is to remove the effect of basements. County sample sets with a high fraction of basements are adjusted furthest. No adjustment is made to county means that are calculated solely from nonbasement observations. (Less than 2% of the houses in Texas have basements.)

To evaluate the statewide indoor radon hazard, county mean indoor radon concentrations were compared with corresponding county populations. ArcView was used to identify counties with above-median populations and mean indoor radon concentrations above the US EPA action level of 4.0 pCi $l^{-1}$.

## Results

County mean indoor radon concentrations range from 0.0 to 8.8, with a median of 0.75. The distribution of county means is positively skewed (Fig. 2). Most of the counties in the data set have mean concentrations below 2.0 pCi $l^{-1}$. Counties with mean indoor radon concentrations that exceed the US EPA standard are Carson, Hale, Randall, Sherman, and Swisher, all located in northwest Texas near zone 2 (Fig. 3).

Figure 3 exhibits a correlation among radon levels in neighboring counties. Regions of similar concentration

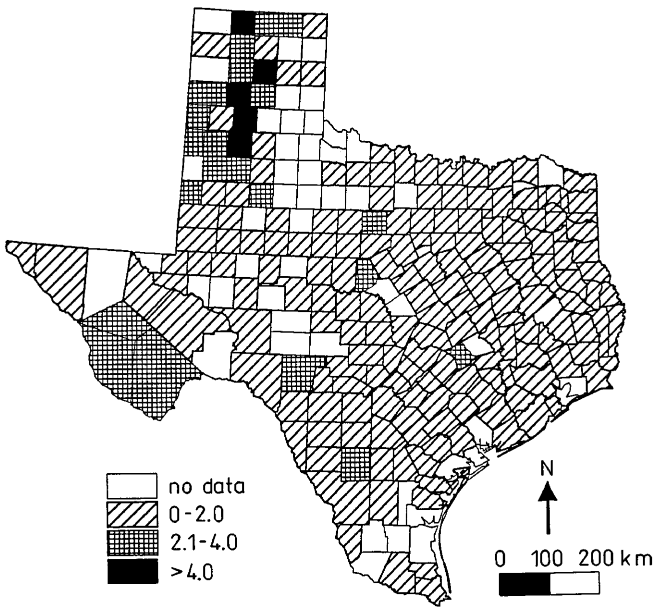


**Fig. 3**
Distribution of county mean indoor radon concentrations (picocuries per liter)

**Table 1**
Kruskal-Wallis test results for county mean indoor radon concentrations[a]

| Level | Observations | Median | Average rank | $Z$ value |
|---|---|---|---|---|
| 1 | 135 | 0.63 | 97.3 | −1.46 |
| 2 | 15 | 1.70 | 157.4 | 3.85 |
| 3 | 6 | 0.95 | 116.3 | 0.63 |
| 4 | 5 | 2.27 | 145.2 | 1.69 |
| 5 | 7 | 1.28 | 156.1 | 2.51 |
| 6 | 34 | 0.50 | 73.4 | −3.08 |
| Overall | 202 | | 101.5 | |

[a] $H = 31.59$, $P = 0.000$; $H = 32.36$, $P = 0.000$ (adjusted for ties).

generally extend over multiple counties, suggesting the possible influence of regional geology. A geological influence is also supported by the Kruskal-Wallis test. Based on the computed $H$ statistic, the null hypothesis that zones 1–6 yield equivalent indoor radon concentrations is rejected (Table 1). Zones 2–5 are associated with higher county-mean indoor radon concentrations than zone 1. The highest radon concentrations are associated with zone 2, the Dockum Formation.

Anomalously low radon concentrations for counties associated with zone 6 may be due to a lack of observations above local zones of uranium mineralization. St. Clair and others (1976) note that uranium concentrations are localized and discontinuous, and compose only a small part of shale or sandstone sequences in which they occur. Localized roll-front uranium deposits are common in fluvial sands (Gundersen and others 1992), which occur in the Catahoula Formation. Zone 6 contains several abandoned uranium mines that are in reclamation (Texas Railroad Commission, personal communication). The mined deposits occur at depth, often below the water table, and the influence of such deposits on near-surface soil-gas radon levels (and hence indoor radon concentrations) may be subdued (US EPA 1993).

The 1993 Texas county populations (Goldman 1994) range from 834 to 2 965 765, with a median of 20 115 (Fig. 4). In general, counties with high populations do not occupy regions of high indoor radon concentrations (Fig. 3). Only 2 of the 202 counties in the data set have above-median populations and mean indoor radon concentrations above 4.0 pCi $l^{-1}$ (Fig. 5). Those counties, Carson and Hale, are both located in northwest Texas. Figure 3 can also be used to identify counties where data are lacking and indoor radon concentrations may be high. Such counties occur in northwest Texas and, to a lesser degree, in west and central Texas.

## Summary and conclusions

The primary objective was to evaluate associations between uranium-bearing rock formations and indoor rad-

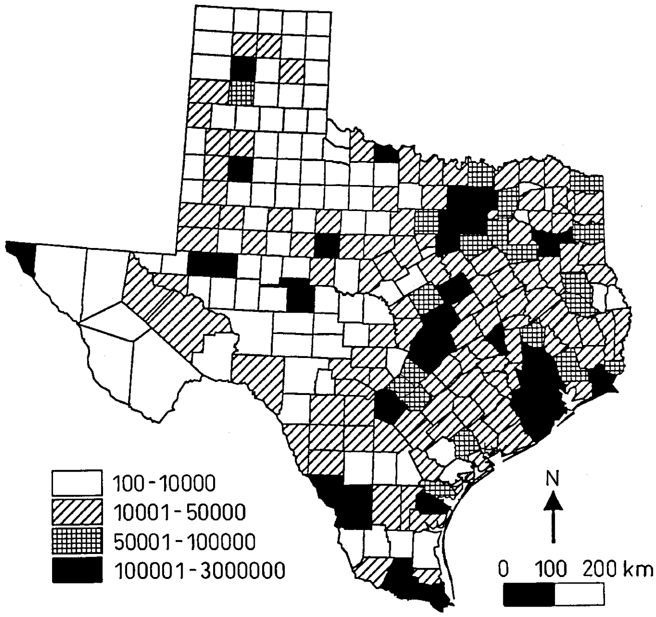


**Fig. 4**
County populations

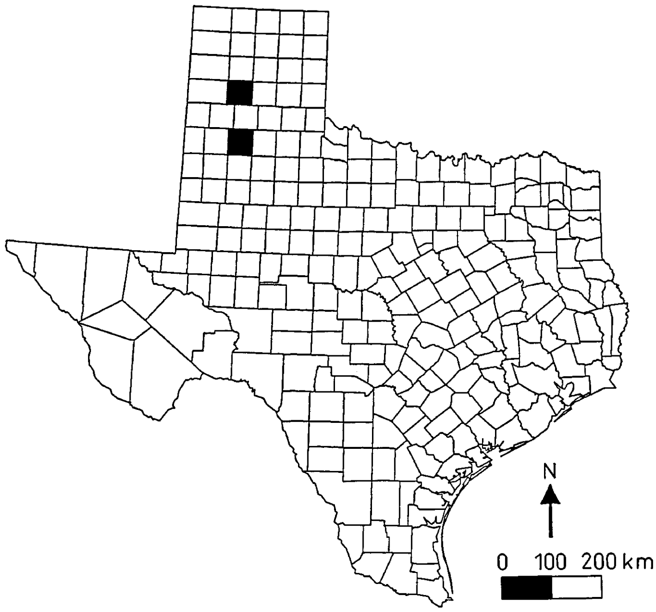


**Fig. 5**
Counties with above-median populations and mean indoor radon concentrations above 4.0 pCi $l^{-1}$

on concentrations in Texas. Regional variations in county mean indoor radon concentrations were evaluated with computer mapping. A geographic information system and statistical software were used to study associations between county mean indoor radon concentrations and regional geology. Five zones of radioactive anomalies and uranium mineral occurrences were identified.

Results of this study suggest that geology exerts an important influence on the distribution of indoor radon concentrations in Texas. Regions of similar indoor radon concentrations extend across multiple counties, suggesting the influence of underlying geology. A geological influence is also supported by the Kruskal-Wallis test statistic, which indicates that the six zones are not associated with the same population of indoor radon concentrations. Four of the five uranium-bearing rock zones are associated with county mean indoor radon concentrations that are above those for the rest of the state.

Overall, indoor radon concentrations in Texas are low relative to the EPA action level. The majority of counties in the data set have mean concentrations below 2 pCi $l^{-1}$. Five counties located in northwest Texas have mean indoor radon concentrations above 4 pCi $l^{-1}$.

The most populated counties in Texas do not have high indoor radon concentrations. However, there are two counties, Carson and Hale, having above-median populations and mean indoor radon concentrations that exceed the EPA standard. Both are located near zone 2 in northwest Texas. Counties in the vicinity of zone 2 in northwest Texas that lack measurements warrant additional monitoring.

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