Final Report of

THE TEXAS INDOOR RADON SURVEY

Conducted by the Texas Department of Health
and Southwest Texas State University

and supported by a grant from the
U.S. Environmental Protection Agency

Prepared by

Gary Smith
Texas Department of Health

Charles Johnson, Terry Browning, and Sandy Ransom
Southwest Texas State University

June 1994

CONTENTS

Summary

Exposure to elevated levels of indoor radon in residential structures has been suggested by many researchers to pose a public health risk and be related to a potential increase in the incidence of lung cancer. To thoroughly examine this issue, the Texas Department of Health commissioned a statewide survey of indoor residential radon to determine the extent of the problem in Texas, and to identify potential "hot spots." It should be kept in mind that cigarette smoking is, by far, the greatest cause of lung cancer, but exposure to elevated levels of indoor radon may represent the second leading risk factor for lung cancer, especially for nonsmokers.

This final report contains a compilation of the Winter 1991 data and all the indoor radon data collected prior to and after the survey months of January, February, and March 1991. Texas homes, when viewed on a statewide basis, have a relatively low level of radon, averaging 1.0 pCi/l (pico curies per liter) of air. Such levels are not a major public health concern, as it would be extremely costly and difficult for homeowners to achieve lower average residential levels on a statewide basis. This Texas average is within the national norms, where U.S. homes have been reported to have average indoor radon levels between 1.0 and 2.0 pCi/l of air.

However, when examined on a regional basis, several areas of Texas are identified where local geology is suspected of contributing to the potential for elevated levels of indoor radon. The Panhandle area of Texas, especially those counties clustered in a band through its center, is shown to have the highest potential for indoor radon. This area of the state is the only area to report any sizable number of homes with radon over 20 pCi/l of air. Correspondingly, it's also the area of the state with the greatest number of homes measuring over 4 pCi/l of air. Four pCi/l is the threshold of concern according to EPA guidelines. Other areas of the state with a potential (based on geology) for elevated radon levels include the Big Bend area (also based on survey results), Llano Uplift, and the uranium mining areas in South Texas.

Since indoor radon in Texas is a localized problem, efforts to educate citizens about the potential dangers of radon can be focused most effectively in those counties with elevated radon potential. For the most part, the areas of Texas where radon levels are highest are also areas of lower population density, minimizing the public health risk and maximizing the chance of finding and correcting any threats to the public health.

1. Introduction to the Indoor Radon Survey

History of the Radon Question

For many years, radiation scientists and epidemiologists have noted a strong correlation between exposure to elevated concentrations of radon (including radon decay products) and increased risk for lung cancer among underground uranium miners (NRC, 1988; Harley, et al., 1990; Woodward, et al., 1991). More recently, studies by other scientists have found higher than expected radon concentrations in homes in various parts of the United States (Nero, 1986, Cohen, et al., 1991; Ganas, 1989; NRC, 1991; EPA, 1987a). This has led public health specialists to a concern that radon exposure within our homes may be a harmful health risk comparable to that experienced by many underground miners. The EPA has suggested that indoor radon is the most serious environmental carcinogen which the EPA must address for the general public (Puskin, 1989). While cigarette smoking is recognized as the principle agent responsible for lung cancer, accounting for about 85% of the lung cancer deaths in the United States; exposure to radon gas has been suggested as a major agent involved in the remaining fifteen percent (Council on Scientific Affairs, American Medical Association, 1991). Kreinbrock, et al (1992) have reported that the German Commission on Radiation Protection estimates that 4 to 12 percent of the total lung cancer cases in Germany are caused by exposure to indoor radon. In response to the public concern about the potential harmful effects of radon, the Environmental Protection Agency (EPA) began a campaign in 1986 to determine the average radon exposure for homes within the United States and to encourage all citizens to test their homes for indoor radon.

In 1986, the Texas Department of Health (TDH) began distribution of indoor radon information in response to requests from Texas citizens. At that time, even without specifically budgeted state money designated to address indoor radon concerns, TDH managed to support a modest effort in response to this nonregulatory issue. In June 1989, the Governor of the State of Texas designated the Texas Department of Health, Bureau of Radiation Control (BRC) the lead agency for evaluation and further analysis of the potential for indoor radon in Texas. Following that designation, the BRC applied for additional funding from the EPA to conduct further analysis and testing of indoor radon in Texas homes. An EPA grant was awarded to TDH in April, 1990, in part to fund a statewide survey of indoor radon. The results from that statewide survey of indoor radon are the subject of this report. The survey was designed to address two questions:

(1) What is the average radon concentration in Texas homes, and

(2) Are there any Texas regions of higher radon potential ("hot spots")?

The grant was also used to provide additional radon training and equipment for BRC personnel, and to further expand indoor radon education efforts.

A Strategy for Addressing the Radon Question

Over the past several years TDH/BRC has designed an organizational structure which allows it to address new radiation issues including that of indoor radon. Individuals in several different programs within BRC and the Public Health Regions spend part of their time working on questions surrounding indoor radon. The strategy used by TDH to address the indoor radon problem falls into four functional areas:

(1) Management of radon activities, which includes planning, organization, and oversight is performed by Bureau of Radiation Control staff. A staff member from the Division of Licensing, Registration and Standards functions as the radon contact for TDH, while a staff member from the Division of Compliance and Inspection serves as the contact between the Bureau and the Public Health Regions.

(2) Educational information is supplied by the Public Information and Training Program staff of the Bureau of Radiation Control. EPA documents continue to form the basis of all radon materials distributed to concerned individuals, but some radon information, like this report, may be developed internally.

(3) The need for assessment of regional radon potential is an important part of TDH's radon effort, involving the completion of this statewide indoor radon survey. The survey was conducted during the winter months of January, February, and March 1991, and was administered in accordance with EPA guidelines. Over 4000 radon detectors were distributed to randomly selected homes across the state. All participating home owners, who completed the survey, received a form letter which reported their survey result and advised them on related radon health risks. TDH contracted with health researchers at Southwest Texas State University (SWT) to conduct the survey.

(4) A last area of response to potential radon problems is qualified consultation in radon measurement, mitigation, and construction techniques which may reduce radon accumulations in new structures. Training programs on indoor radon will enable Bureau of Radiation Control personnel to better provide consultation to concerned Texas citizens about their radon exposure and corrective actions. Staff from the Public Health Regions and the Division of Compliance and Inspection will respond to requests for public assistance in cases where previous radon testing has shown potential problems and/or the radon concentration has been found to be greater than 20 pCi/l.

2. Background Information on Indoor Radon

Radon-222 is an odorless, colorless, naturally occurring radioactive gas. It's produced by the radioactive decay of radium-226, which arises from the radioactive decay of uranium-238. Radon-222 is a noble gas (chemically unreactive) that can readily migrate through permeable rocks and soils and eventually seep into buildings or be released into the atmosphere.

All isotopes of radon are radioactive. For radiation safety reasons, radon-222 is the most important isotope to consider.

Radon further decays into radioactive, chemically reactive particles, which can attach themselves to other airborne particles such as dust in a home environment. If inhaled, these now radioactive particles, may cause damage to lung tissues and increase the risk of lung cancer. It is these decay products which pose the real health threat from radon in our homes. When the trapped radon decay products in lung tissues undergo further radioactive decay, the surrounding lung tissue can be damaged.

EPA estimates that thousands of lung cancer deaths each year may be attributable to radon or radon decay products (Harley and Harley, 1990).

Radon-222 can be measured by several different techniques including continuous radon monitors, alpha-track devices, electret ion chambers, charcoal canisters, and others. There are also techniques for the direct measurement of radon decay products (EPA, 1989).

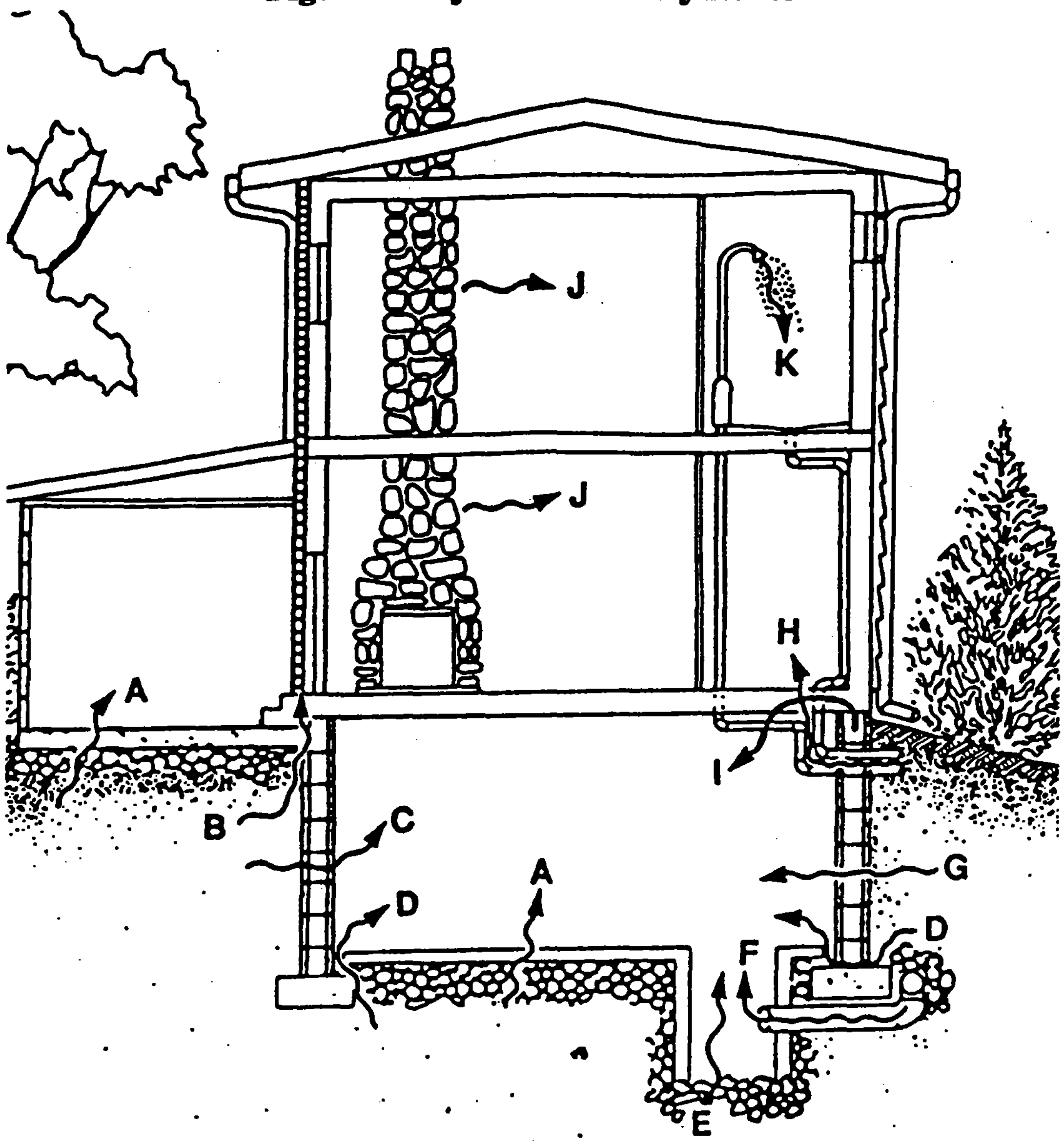
Radon-222 is measured in units of pCi/l (picocuries per liter of air) and the decay products are measured in WL (working levels, amount of alpha particle energy released into one liter of air).

High levels of naturally occurring radon-222 are most likely found where there are significant amounts of uranium in the soil or rocks. Sometimes these areas are clearly identifiable because of previous uranium or phosphate mining activity. Other areas of the state, although not commercially viable mining sites, may still experience a potential danger from radon sources in the soil or rock.

The movement of radon into houses is controlled largely by the soil permeability under a foundation and access to the interior of the house through openings in the foundation. Radon-222 gas can seep into a house through cracks in the foundation, openings around drainage pipes caused by shrinkage of concrete, sump pumps in basements, plumbing penetrations in slabs, or any other openings in foundations or walls (Figure 1).

Almost all houses in the United States have some indoor radon; most range around 1 to 2 pCi/l. The only way to be certain about radon levels is to test a house, and usually repeat the test over several seasons. There will be seasonal variation in measured household radon levels due to environmental differences of temperature and

Figure 1. Major Radon Entry Routes



Major Radon Entry Routes

A. Cracks in concrete slabs
B. Spaces behind brick veneer walls
C. Pores and cracks in concrete blocks
D. Floor-wall joints
E. Exposed soil, as in a sump
F. Weeping (drain) tile
G. Mortar joints
H. Loose fitting pipe penetrations
I. Open tops of block walls
J. Building materials such as rock
K. Water (from some wells)

Source: EPA, 1987b

humidity and the degree a house is open to the outside environment allowing radon to escape.

Potential Health Risks from Radon

Radon risk estimates have been developed from epidemiologic studies of underground uranium miners, with several studies recording lung cancer incidence and radon exposure among underground miners (NRC, 1988). Some researchers argue that these studies suffer from many uncertainties (Cothern, 1990) including; (1) in some instances, the levels of radon or radon decay products to which the miners were exposed are unknown and dose estimates were made by the researchers; (2) a majority of miners smoked during their working lives (tobacco use confounds estimates of relationships between radon exposure and the incidence of lung cancer); (3) miners are exposed to many other toxic air pollutants in the conduct of their work; (4) there is uncertainty in how

Table 1. Radon Risk If You Smoke

pCi/l	If 1,000 people who smoked were exposed to this level over a lifetime, about this number would get lung cancer	The Risk of Cancer From Radon Compares to.....	What To Do: Stop Smoking and...
20	135	100 times risk of drowning	Fix your home
10	71	100 times the risk of dying in a home fire	Fix your home
8	57		Fix your home
4	29	100 times the risk of dying in an airplane crash	Fix your home
			Consider fixing your home between 2 and 4 pCi/l
2	15	2 times the risk of dying in a car crash	
			Reducing radon levels below 2 pCi/l is difficult
1.3	9	Average indoor radon level	
0.4	3	Average outdoor radon level	

Source: EPA, 1992

Table 2. Radon Risk If You've Never Smoked

pCi/l	If 1,000 people who never smoked were exposed to this level over a lifetime, about this number would get lung cancer	The Risk of Cancer From Radon Compares to.....	What To Do:
20	8	The risk of being killed in a violent crime	Fix your home
10	4		Fix your home
8	3	10 times the risk of dying in an airplane crash	Fix your home
4	2	The risk of drowning	Fix your home
2	1	The risk of dying in a home fire	Consider fixing your home between 2 and 4 pCi/l Reducing radon levels below 2 pCi/l is difficult
1.3	less than 1	Average indoor radon level	
0.4	less than 1	Average outdoor radon level	

Source: EPA, 1992

to relate radon risk factors derived from studies of the mining environment to the possible radon risks factors for the domestic environment; and (5) there is uncertainty in how to compare the homogeneous miner population to the heterogeneous domestic population. Because of these uncertainties and others, EPA expresses risk estimates as a range of numbers (see Tables 1 and 2). Recent work by the National Research Council of the National Academy of Sciences (NRC, 1991) indicated that domestic risk factors may be too high.

Accordingly, EPA modified its Radon Risk Evaluation Charts in a revised Citizen's Guide to Radon (EPA, 1992). EPA's Radon Risk Evaluation Charts (Table 1 & 2) list numerical values for health risks per 1000 people exposed at a constant radon concentration, a 70-year exposure period, and 75% house occupancy rate. Radon exposure and associated health risks are described as being a combination of average annual radon concentration and duration of exposure.

An increased risk of lung cancer is the

only known health effect currently associated with long term exposure to elevated radon levels, although collaborative studies are underway to examine the relationship of other cancers to radon exposure (Darby, 1992).

When a house is discovered with elevated indoor radon, and mitigation efforts are determined necessary, the following general methods are available; (1) sealing off entry routes into the home by covering exposed dirt in floors or basements with concrete or gas-proof liners, sealing cracks and holes in slabs, covering sumps and placing removable plugs in untrapped floor drains; (2) increasing the ventilation rate in a house by either passive or active means, or (3) soil ventilation by drawing away radon gas from the soil before it reaches the house, such as below-slab suction (EPA, 1988).

Technical guidance for building radon resistance into a new structure is available from the Environmental Protection Agency (see Appendix B and EPA, 1991).

3. Procedures for the Texas Survey of Indoor Radon

The overall objective of the Texas state survey of indoor radon was to respond to the public's questions and concerns about indoor radon exposure. The potential risk associated with long term exposure to elevated radon concentrations is an increased risk for lung cancer. A statewide screening survey was designed to define; (1) the statewide average indoor radon concentration in homes, and (2) the regional average indoor radon concentrations (to identify "hot spots") by county.

Survey Sample - To simplify survey procedures, only owner-occupied houses, selected at random, were surveyed in this study. Rental houses were excluded to simplify survey procedures and avoid the problems of gaining permission to conduct radon measurements from house owners. In addition, high-rise structures, apartments, and group quarters were excluded from the study to create a uniform sampling population. These exclusions did not materially affect the statistical basis of the survey, and had the advantage of making a complex undertaking feasible in a reasonable amount of time.

Survey Procedures - Indoor radon measurements were made through the use of activated charcoal adsorption (AC) canisters and alpha-track detection (ATD) devices, both supplied by the EPA. Measurements were made using the activated charcoal canisters under closed-house conditions following EPA survey protocols. Homeowners were instructed to place the canister in an interior room, exposed to the air for seven days. At the end of seven days, they were to seal the canister and quickly mail it directly to the EPA laboratory. The activated charcoal method measures radon levels by exposing an air-tight container of activated charcoal to air in an interior room for seven days. Radon decay products produced by radon adsorbed on the charcoal emit gamma rays which can be measured by scintillation detectors.

In addition, long term alpha track detectors (ATD) were used to measure twelve-month radon levels for a much smaller subset of the survey sample. Homeowners were instructed to place the detectors in interior rooms for each livable level of their home. They were to remain in these locations for a 12 month period. An activated charcoal canister was sent along with the ATD, with the homeowner instructed to place it next to the ATD on the first level of their home. They were asked to expose the charcoal canister for a one week period. Periodically, every three months, another activated charcoal canister was mailed to the homeowner, with similar instructions for a one week exposure. At the end of 12 months, a mailing envelope was sent to the homeowner suitable for returning the ATD to the researchers, who accumulated the ATDs and mailed them as a group to EPA.

Alpha track detectors (ATDs) measure radon by accumulating damage (tracks) caused by alpha particles as they penetrate a small piece of special plastic inside the device. Upon collection, the plastic is treated to enhance the size of the alpha tracks, and the resulting holes are counted under a microscope.

Measurements using activated charcoal canisters were designed to determine the peak values during closed home periods during winter months. The alpha-track detectors were used to measure radon levels over a longer period of 12 months.

Regional Sampling Plan - A regional sampling plan, based largely on geological potential for indoor radon, was produced to aid in the random allocation of radon detectors, and provide a basis for interpretation of survey results. Survey staff examined available geological and population data for the state of Texas and grouped all Texas counties with respect to their potential for indoor radon. Contiguous counties with a similar potential for radon were grouped into regions. Some regions defined for this study were identified because of their underlying geology and potential for elevated radon levels. Large metropolitan areas were designated as regions to control their dominance of the sample due to larger populations. If the large metropolitan areas had not been defined as separate regions, the equal random sampling used for this study would have allowed these large cities to have a much larger number of canister placements, leaving large parts of rural Texas unmeasured. Figure 2 shows the regional sampling areas developed in consultation between the EPA, Research Triangle Institute, and the Texas researchers. Thirteen regions were more than any other state surveyed under the EPA sponsored program, but were necessary to adequately survey the divergent regions of Texas.

Telephone lists were randomly generated, with all residents within a defined region having an equal chance of being chosen. With the total number of homes needed for the survey known, it then became a matter of choosing a proportional sampling plan to insure that the large metropolitan areas did not dominate the survey. Each group of fifty randomly generated names and addresses contained houses from throughout the state in proportion to the percentages for each region designated by the sampling plan. The large metropolitan areas were sampled at a lower percentage to insure that rural areas would have adequate numbers in the survey. Even with 13 sampling regions (more than any other state), some sparsely populated counties had to be included in a region with more populous counties; leading to the probability of some counties not being sampled. Financial constraints prevented more regions or homes from being used in the sampling plan.

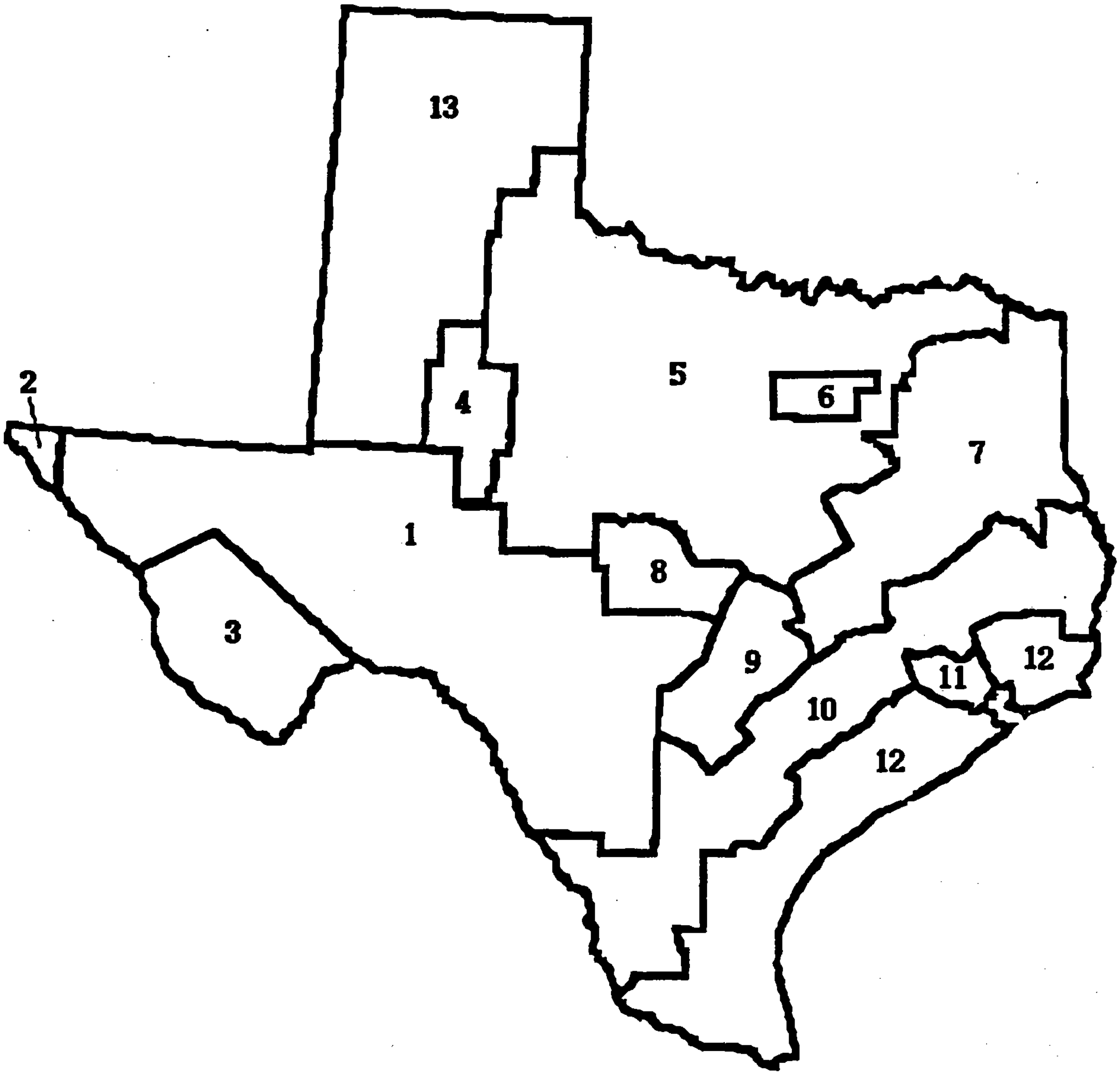
Home owners were contacted by telephone in each region on a random basis at a frequency determined by the county's radon potential and population density. The results of the indoor radon survey were analyzed and reported at the county level in order to better understand identified "hot spots."

Sample Size and Allocation of Detectors
Survey staff initially placed over 4000 charcoal canisters throughout the state for the measurement of indoor radon, and over 300 Alpha Track Detector's (ATD's) for the determination of radon levels for a twelve-month period. Those homes receiving the twelve-month ATD measurement devices also received a charcoal canister for each climatic season, or a total of four charcoal canisters for the year. The routine placement of charcoal canisters was accomplished through the use of "waves" or lists of 50 telephone numbers (with names and addresses) supplied by the Research Triangle Institute under contract to the EPA. In order to avoid introducing statistical bias, all telephone numbers in each opened wave were called in a search for working numbers and eligible participants. Initial refusals to take part in the study were called again, at different times in hopes of better explaining the importance of the study and gaining the homeowner's cooperation. Up to six tries were made to convince home owners of the importance of participation in the survey.

Counties with no valid placements through this first attempt at random sampling were re-sampled by calling a variety of public institutions within the county and talking to the first contact who answered the telephone. It was thought that it would be better to have canister placements in every Texas county through this random contact method than to leave some counties un-sampled. Thirty-one canister measurements were accomplished through this secondary attempt at sampling.

Although the placement of detectors was accomplished by using a random telephone list, the actual number of canisters placed in any given geographical region depended on the regional potential for radon and the population density. To insure the placement of samples in rural areas of the state and identify potential rural "hot spots," it was necessary to sample at a higher density in rural regions which may have a higher geological potential for radon, but a lower population density; and at a lower frequency in densely populated metropolitan areas. Because of this objective to identify rural "hot spots," the statewide sample cannot be considered a true proportional sample of the state, nor truly representative of the state as a whole. Therefore, since

Figure 2. Regional Sampling Plan



1 - Southwest Texas
2 - El Paso
3 - Big Bend
4 - West Texas Shales
5 - North Texas
6 - Dallas/ Fort Worth
7 - East Texas
8 - Llano Uplift
9 - Central Texas (Austin - San Antonio)
10 - Tertiary Sands Crescent
11 - Harris County (Houston)
12 - Gulf Coast
13 - Texas Panhandle

the rural areas of the state were sampled in greater numbers disproportionately to the metropolitan areas, the statewide percentages cannot simply be multiplied to determine the number of homes in the state with elevated indoor radon. Percentages measured within individual counties, however, can be used as determinants of the potential radon problem for that county, since all residents within a specific county had an equal chance of being chosen for the survey. Readers should be cautioned, however, that counties with fewer than five measurements are still tentative at best.

Quality Assurance/Quality Control - Precision for radon analysis was established by placement and analysis of duplicate samples in survey staff member's homes. Accuracy estimates were provided by the EPA's Montgomery, Alabama laboratory as part of their routine QA/QC program. Blank samples were submitted for radon spiking and analysis at the rate of 2 percent of the total canisters placed, and were selected from throughout all canister shipments.

Data entry was monitored by using double entry file building (the returned data disk from the EPA contractor was compared to the on-site data file to identify errors). Manual data entry at TDH also served as an additional quality control check for the data stream.

Staffing for the Survey - The Texas Department of Health contracted with health researchers in the Department of Health Administration at Southwest Texas State University. Working from a central location on the SWT campus near Austin (the location of the Department of Health headquarters), part-time graduate and undergraduate students operated the telephone banks, which were the heart of the survey. On-site supervision was provided by SWT faculty; and project oversight was the responsibility of TDH.

SWT health researchers presented a proposal based on the placement of up to a maximum of 4500 activated charcoal canisters and 450 alpha track detectors. TDH staff evaluated the proposal and negotiated an interagency contract with SWT. Personnel from both SWT and TDH received appropriate radon survey training from the EPA and Research Triangle Institute. EPA guidelines for a random statewide survey were followed. Potential survey participants were first contacted by mail, which was followed by telephone interviews to confirm eligibility. SWT staff mailed out radon detectors to eligible participants and confirmed their use. Under TDH agreement, SWT received copies of all analytical reports from EPA (TDH received duplicates), encoded them in a computer database, and mailed results to all survey participants.

Standard Forms - Standard form letters were used to announce the house survey to potential participants and to return radon analytical results to participating home owners (see appendix A for samples of both letters). EPA-supplied questionnaires were used to gather demographic and other relevant information from eligible participants. These data were entered into machine readable form by the staff of the Research Triangle Institute, under contract to the EPA.

Data Management and Analysis - The Texas Department of Health worked with SWT and the EPA to develop an information storage and management system for all radon related data. Specifically, relevant questionnaire responses and radon analytical results were stored in a computer database. Radon analyses were done by EPA's National Air and Radiation Environmental Laboratory in Alabama and finished data sets were returned to TDH and SWT.

4. Results and Discussion of the Texas Survey

Activated Charcoal Canister Results

Charcoal canisters were mailed to over 4000 homeowners throughout Texas. Of these canisters, 2859 valid winter measurements were returned from the initial random sample including canisters from the canister only survey and winter canisters from the ATD survey discussed later. The attrition was due to a variety of reasons, including some homeowners who delayed conducting the tests until past the winter season, home owners deciding to not take part after first agreeing to the test, or canisters being lost in the mail.

An additional 31 canisters were placed in volunteer homes from initially un-sampled counties obtained through random contacts reached by calling a variety of public institutions in counties not sampled in the initial attempts. Further results in this report will combine the initial random cases with this second group of volunteer cases for a total sample of 2890 cases.

Statewide Results - When examined statewide, Texas has a low level of indoor radon in homes, with an arithmetic mean of 1.0 pCi/l. The percent of Texas homes tested during this survey with a radon level above 4.0 pCi/l (the threshold of concern by EPA definition) is 3.6 percent (Table 3). Furthermore, 0.3 percent of the Texas homes tested in this survey have a radon level above 20 pCi/l. These results should not be extrapolated to the state level due to the use of a sampling design that was not random statewide.

A disproportionate sampling design was used, instead, to insure that less densely populated areas of the state (such as West Texas) were over sampled; to improve chances of not

Table 3. Texas Statewide Results

Arith. Mean pCi/l	Geo. Mean pCi/l	Median pCi/l	75 th Percentile pCi/l	90 th Percentile pCi/l	% Houses >4 pCi/l	%Houses >20 pCi/l
1.0	0.5	0.6	1.2	2.2	3.6	0.3

missing potential hot spots. Many potential hot spots were in rural areas of the state and disproportionate sampling was necessary because of the low population density and wide separation between towns or homes. Thus, because of the sampling strategy used, the overall findings, as reported in this report, cannot be generalized to make a statement about all homes in Texas. These findings are useful, however, to help identify which geographical regions in the state have a higher potential and concern for indoor radon.

County Results - When statewide data are analyzed on a county basis, the geological potential for radon is more evident. The sampling plan used in this survey was a balance between geological potential for radon and population density factors. In many cases, counties in Texas were grouped into larger regions identified by their pre-survey geological potential for radon, and weighted disproportionately according to their population density. Within these defined groups of counties or regions, all homes had an equal chance of participating in the survey. In some cases, more heavily populated counties within these regions overshadowed the less populated counties, causing some counties to have low numbers or no homes in the survey. Due to the large number of Texas counties, it was necessary to group them into regions for cost considerations.

In general, the Texas counties which have higher potential for residential radon are found in the West Texas Panhandle region; the Big Bend area; and the Llano Uplift area. All the counties where higher levels of radon were found have geology which supports their higher potential. Valid radon measurements were collected from 237 out of the 254 Texas counties. Table 4 lists the results by county where two or more measurements were recorded. Counties with only one radon measurement have had that measurement deleted from the table to avoid drawing unnecessary attention to a single reading. High values from single canister measurements may have been the result of laboratory error or poor canister procedures on the part of the home owner, and are less reliable. Data from counties with fewer than five measurements are reported, but should be considered inconclusive at best. When reviewing Table 4, it should be remembered that a large amount of variation can be found in the residential radon levels of homes in areas of increased radon potential. The variation may be due to many factors including family life-style and house construction. A high mean radon level for a county may be caused by a single high, but legitimate, measurement. Also, a low mean radon level does not mean all houses in that county will have low radon measurements. Unique construction techniques, such as underground or berm surrounded homes, as well as energy efficient or tightly sealed homes, may show higher indoor radon levels.

Counties where a calculated average level of radon exceeds the Environmental Protection Agency threshold level of concern of 4.0 pCi/l include Carson (1 of 4 measurements above 4.0 pCi/l), Hale (9 of 18 measurements above 4.0 pCi/l), Randall (7 of 20 measurements above 4.0 pCi/l), Sherman (5 of 5 measurements above 4.0 pCi/l), and Swisher (2 of 5

Table 4. Residential Radon Measurements by County

County	Mean	Number	Percent >4 pCi/l	Percent >20 pCi/l	Minimum Value	Maximum Value
ANDERSON	<.5	8	.0	.0	<.5	1.4
ANDREWS	1.0	2	.0	.0	.8	1.1
ANGELINA	<.5	13	.0	.0	<.5	1.3
ARANSAS	<.5	2	.0	.0	<.5	<.5
ARCHER	.7	2	.0	.0	<.5	1.2
ARMSTRONG	2.9	3	33.3	.0	1.5	5.8
ATASCOSA	.5	11	.0	.0	<.5	1.7
AUSTIN	.6	7	.0	.0	<.5	2.2
BAILEY	3.6	3	33.3	.0	.6	8.6
BANDERA	.5	5	.0	.0	<.5	1.0
BASTROP	1.4	10	10.0	.0	<.5	9.8
BAYLOR	1.0	2	.0	.0	.6	1.4
BEE	<.5	5	.0	.0	<.5	.9
BELL	1.2	17	.0	.0	<.5	3.9
BEXAR	1.1	61	3.3	.0	<.5	6.7
BLANCO	1.9	3	.0	.0	1.1	2.7
BORDEN	*	1				
BOSQUE	1.0	5	.0	.0	<.5	1.5
BOWIE	.5	24	.0	.0	<.5	1.8
BRAZORIA	<.5	29	.0	.0	<.5	3.3
BRAZOS	.9	17	5.8	.0	<.5	4.2
BREWSTER	2.4	63	15.9	.0	<.5	8.4
BRISCOE	*	1				
BROOKS	**					
BROWN	2.6	6	33.3	.0	<.5	7.8
BURLESON	*	1				
BURNET	1.3	96	4.2	.0	<.5	13.9
CALDWELL	<.5	7	.0	.0	<.5	2.2
CALHOUN	*	1				
CALLAHAN	.6	5	.0	.0	<.5	1.4
CAMERON	<.5	11	.0	.0	<.5	1.4
CAMP	.8	2	.0	.0	.5	1.0
CARSON	8.8	4	25.0	25.0	1.2	30.1
CASS	.6	9	.0	.0	<.5	1.1
CASTRO	1.6	3	.0	.0	.8	2.7
CHAMBERS	**					
CHEROKEE	1.0	6	.0	.0	.5	1.6
CHILDRESS	**					
CLAY	1.0	5	.0	.0	<.5	1.8
COCHRAN	*	1				
COKE	**					
COLEMAN	.6	2	.0	.0	<.5	.9
COLLIN	1.0	37	2.7	.0	<.5	5.2
COLLINGSWORTH	**					
COLORADO	<.5	6	.0	.0	<.5	<.5

Table 4. Residential Radon Measurements by County (continued)

County	Mean	Number	Percent >4 pCi/l	Percent >20 pCi/l	Minimum Value	Maximum Value
COMAL	1.2	20	.0	.0	<.5	3.7
COMANCHE	.6	4	.0	.0	.5	1.0
CONCHO	<.5	2	.0	.0	<.5	<.5
COOKE	1.0	8	.0	.0	.7	1.9
CORYELL	.9	6	.0	.0	<.5	2.2
COTTLE	**					
CRANE	*	1				
CROCKETT	.8	4	.0	.0	<.5	1.2
CROSBY	1.2	3	.0	.0	.7	1.8
CULBERSON	**					
DALLAM	*	1				
DALLAS	1.2	95	3.2	.0	<.5	6.8
DAWSON	1.8	3	.0	.0	1.1	2.7
DE WITT	<.5	4	.0	.0	<.5	.7
DEAF SMITH	3.0	8	12.5	.0	.6	7.7
DELTA	*	1				
DENTON	1.0	33	.0	.0	<.5	3.0
DICKENS	*	1				
DIMMIT	.5	2	.0	.0	.5	.5
DONLEY	*	1				
DUVAL	.8	3	.0	.0	<.5	2.1
EASTLAND	.6	5	.0	.0	<.5	1.2
ECTOR	1.0	40	2.5	.0	<.5	7.3
EDWARDS	2.5	2	.0	.0	<.5	<.5
EL PASO	1.0	106	1.9	.9	<.5	21.6
ELLIS	.8	13	.0	.0	<.5	2.3
ERATH	<.5	6	.0	.0	<.5	.7
FALLS	<.5	2	.0	.0	<.5	.7
FANNIN	1.0	2	.0	.0	<.5	1.8
FAYETTE	1.1	16	.0	.0	<.5	3.2
FISHER	*	1				
FLOYD	<.5	2	.0	.0	<.5	.5
FOARD	**					
FORT BEND	<.5	23	.0	.0	<.5	1.5
FRANKLIN	<.5	2	.0	.0	<.5	.5
FREESTONE	<.5	3	.0	.0	<.5	<.5
FRIO	<.5	3	.0	.0	<.5	1.0
GAINES	.8	3	.0	.0	.6	1.0
GALVESTON	<.5	33	.0	.0	<.5	.9
GARZA	2.1	18	5.6	.0	<.5	6.9
GILLESPIE	1.3	13	7.6	.0	<.5	4.7
GLASSCOCK	*	1				
GOLIAD	<.5	4	.0	.0	<.5	.7
GONZALES	1.3	5	.0	.0	<.5	3.4
GRAY	1.8	9	.0	.0	1.0	2.6

Table 4. Residential Radon Measurements by County (continued)

County	Mean	Number	Percent >4 pCi/l	Percent >20 pCi/l	Minimum Value	Maximum Value
GRAYSON	1.2	14	7.1	.0	<.5	5.3
GREGG	1.0	22	4.5	.0	<.5	7.1
GRIMES	.5	3	.0	.0	<.5	1.4
GUADALUPE	1.3	17	5.9	.0	<.5	5.4
HALE	7.9	18	38.9	11.1	<.5	41.3
HALL	*	1				
HAMILTON	<.5	3	.0	.0	<.5	<.5
HANSFORD	3.7	3	33.3	.0	.6	6.8
HARDEMAN	**					
HARDIN	.6	7	.0	.0	<.5	1.2
HARRIS	<.5	131	.0	.0	<.5	3.8
HARRISON	.5	22	.0	.0	<.5	1.2
HARTLEY	<.5	2	.0	.0	<.5	.6
HASKELL	*	1				
HAYS	1.2	18	.0	.0	<.5	2.6
HEMPHILL	*	1				
HENDERSON	.7	14	7.1	.0	<.5	5.1
HIDALGO	.5	22	.0	.0	<.5	1.9
HILL	.5	2	.0	.0	<.5	.7
HOCKLEY	2.8	9	11.1	.0	<.5	13.5
HOOD	1.2	7	.0	.0	<.5	3.0
HOPKINS	<.5	7	.0	.0	<.5	.6
HOUSTON	.5	9	.0	.0	<.5	1.3
HOWARD	1.1	120	2.5	.0	<.5	8.0
HUDSPETH	<.5	2	.0	.0	<.5	.8
HUNT	.9	9	.0	.0	<.5	2.6
HUTCHINSON	1.5	14	7.1	.0	<.5	6.3
IRION	*	1				
JACK	*	1				
JACKSON	*	1				
JASPER	.5	11	.0	.0	<.5	3.1
JEFF DAVIS	3.7	16	18.8	.0	<.5	13.6
JEFFERSON	<.5	28	.0	.0	<.5	.9
JIM HOGG	*	1				
JIM WELLS	*	1				
JOHNSON	.6	10	.0	.0	<.5	2.1
JONES	1.0	5	.0	.0	<.5	2.8
KARNES	1.7	3	33.3	.0	<.5	4.4
KAUFMAN	.8	6	.0	.0	<.5	1.6
KENDALL	.9	6	.0	.0	<.5	1.9
KENEDY	**					
KENT	**					
KERR	1.5	19	5.3	.0	<.5	6.0
KIMBLE	*	1				
KING	**					

Table 4. Residential Radon Measurements by County (continued)

County	Mean	Number	Percent >4 pCi/l	Percent >20 pCi/l	Minimum Value	Maximum Value
KINNEY	<.5	3	.0	.0	<.5	<.5
KLEBERG	*	1				
KNOX	<.5	2	.0	.0	<.5	.9
LA SALLE	3.8	2	50.0	.0	<.5	7.6
LAMAR	<.5	7	.0	.0	<.5	.5
LAMB	2.9	10	30.0	.0	.8	6.9
LAMPASAS	*	1				
LAVACA	1.1	10	10.0	.0	<.5	7.5
LEE	3.4	4	25.0	.0	<.5	9.8
LEON	<.5	3	.0	.0	<.5	<.5
LIBERTY	<.5	3	.0	.0	<.5	.5
LIMESTONE	<.5	7	.0	.0	<.5	<.5
LIPSCOMB	1.6	2	.0	.0	1.2	1.9
LIVE OAK	.9	5	.0	.0	<.5	2.5
LLANO	1.6	52	13.5	.0	<.5	5.4
LOVING	**					
LUBBOCK	2.4	73	13.7	1.4	<.5	23.9
LYNN	1.4	2	.0	.0	1.2	1.5
MADISON	<.5	3	.0	.0	<.5	.7
MARION	1.2	2	.0	.0	1.0	1.3
MARTIN	.8	2	.0	.0	.5	1.2
MASON	1.2	20	10.0	.0	<.5	7.0
MATAGORDA	.7	9	.0	.0	<.5	2.9
MAVERICK	1.4	4	.0	.0	.8	2.2
MCCULLOCH	1.2	26	3.8	.0	<.5	12.5
MCLENNAN	1.1	32	3.1	.0	<.5	5.9
MCMULLEN	<.5	3	.0	.0	<.5	.7
MEDINA	.5	9	.0	.0	<.5	1.1
MENARD	1.0	3	.0	.0	.6	1.4
MIDLAND	1.1	47	.0	.0	<.5	3.4
MILLS	**					
MILAM	.7	7	.0	.0	<.5	1.7
MITCHELL	1.4	35	5.7	.0	<.5	14.0
MONTAGUE	.5	4	.0	.0	<.5	1.3
MONTGOMERY	<.5	31	.0	.0	<.5	2.1
MOORE	2.9	7	28.5	.0	<.5	5.2
MORRIS	.7	7	.0	.0	<.5	1.1
MOTLEY	**					
NACOGDOCHES	.5	8	.0	.0	<.5	1.4
NAVARRO	<.5	3	.0	.0	<.5	.5
NEWTON	<.5	2	.0	.0	<.5	<.5
NOLAN	.9	5	.0	.0	<.5	1.8
NUECES	.6	19	.0	.0	<.5	2.1
OCHILTREE	3.6	5	40.0	.0	2.1	5.5
OLDHAM	**					

Table 4. Residential Radon Measurements by County (continued)

County	Mean	Number	Percent >4 pCi/l	Percent >20 pCi/l	Minimum Value	Maximum Value
ORANGE	.4	14	.0	.0	<.5	1.2
PALO PINTO	.9	7	.0	.0	<.5	2.2
PANOLA	<.5	10	.0	.0	<.5	.7
PARKER	<.5	8	.0	.0	<.5	1.3
PARMER	2.5	5	20.0	.0	<.5	6.2
PECOS	<.5	6	.0	.0	<.5	.8
POLK	.5	7	.0	.0	<.5	1.3
POTTER	2.8	32	28.1	.0	<.5	6.6
PRESIDIO	2.4	46	17.4	.0	<.5	7.2
RAINS	<.5	4	.0	.0	<.5	<.5
RANDALL	5.7	20	35.0	5.0	.5	33.1
REAGAN	<.5	2	.0	.0	<.5	<.5
REAL	<.5	3	.0	.0	<.5	<.5
RED RIVER	*	1				
REEVES	1.1	10	.0	.0	<.5	2.8
REFUGIO	*	1				
ROBERTS	**					
ROBERTSON	.6	5	.0	.0	<.5	1.1
ROCKWALL	<.5	2	.0	.0	<.5	.5
RUNNELS	.6	4	.0	.0	.6	1.1
RUSK	<.5	13	.0	.0	<.5	.9
SABINE	.5	3	.0	.0	<.5	.8
SAN AUGUSTINE	.7	5	.0	.0	<.5	1.5
SAN JACINTO	<.5	5	.0	.0	<.5	.5
SAN PATRICIO	.6	7	.0	.0	<.5	3.1
SAN SABA	1.2	30	3.3	.0	<.5	9.6
SCHLEICHER	*	1				
SCURRY	1.3	78	2.5	.0	<.5	7.6
SHACKELFORD	<.5	2	.0	.0	<.5	.7
SHELBY	<.5	4	.0	.0	<.5	<.5
SHERMAN	8.2	5	80.0	.0	<.5	15.6
SMITH	.5	52	.0	.0	<.5	3.7
SOMERVELL	*	1				
STARR	*	1				
STEPHENS	2.3	3	.0	.0	1.4	3.4
STERLING	1.7	3	.0	.0	<.5	3.6
STONEWALL	*	1				
SUTTON	*	1				
SWISHER	6.3	5	40.0	.0	<.5	15.4
TARRANT	1.1	86	3.8	.0	<.5	7.4
TAYLOR	1.3	27	11.1	.0	<.5	5.7
TERRELL	*	1				
TERRY	1.6	5	.0	.0	<.5	3.3
THROCKMORTON	*	1				
TITUS	<.5	7	.0	.0	<.5	1.0

Table 4. Residential Radon Measurements by County (continued)

County	Mean	Number	Percent >4 pCi/l	Percent >20 pCi/l	Minimum Value	Maximum Value
TOM GREEN	1.0	15	.0	.0	<.5	3.3
TRAVIS	1.3	57	7.3	.0	<.5	7.0
TRINITY	*	1				
TYLER	.5	4	.0	.0	<.5	1.0
UPSHUR	.5	9	.0	.0	<.5	1.1
UPTON	*	1				
UVALDE	.7	7	.0	.0	<.5	1.9
VAL VERDE	<.5	9	.0	.0	<.5	1.0
VAN ZANDT	<.5	8	.0	.0	<.5	.7
VICTORIA	1.4	9	11.1	.0	<.5	9.5
WALKER	.7	14	.0	.0	<.5	2.8
WALLER	<.5	6	.0	.0	<.5	.6
WARD	.6	5	.0	.0	<.5	1.0
WASHINGTON	<.5	5	.0	.0	<.5	1.1
WEBB	<.5	22	.0	.0	<.5	1.9
WHARTON	<.5	4	.0	.0	<.5	1.9
WHEELER	1.8	4	.0	.0	<.5	3.2
WICHITA	1.4	14	7.7	.0	<.5	4.3
WILBARGER	*	1				
WILLACY	.5	2	.0	.0	<.5	.6
WILLIAMSON	1.3	41	2.4	.0	<.5	6.4
WILSON	<.5	6	.0	.0	<.5	1.0
WINKLER	.6	3	.0	.0	<.5	1.0
WISE	.7	3	.0	.0	<.5	1.5
WOOD	<.5	16	.0	.0	<.5	.8
YOAKUM	2.6	5	20.0	.0	<.5	7.3
YOUNG	.9	2	.0	.0	.7	1.1
ZAPATA	<.5	3	.0	.0	<.5	<.5
ZAVALA	.6	4	.0	.0	<.5	1.1

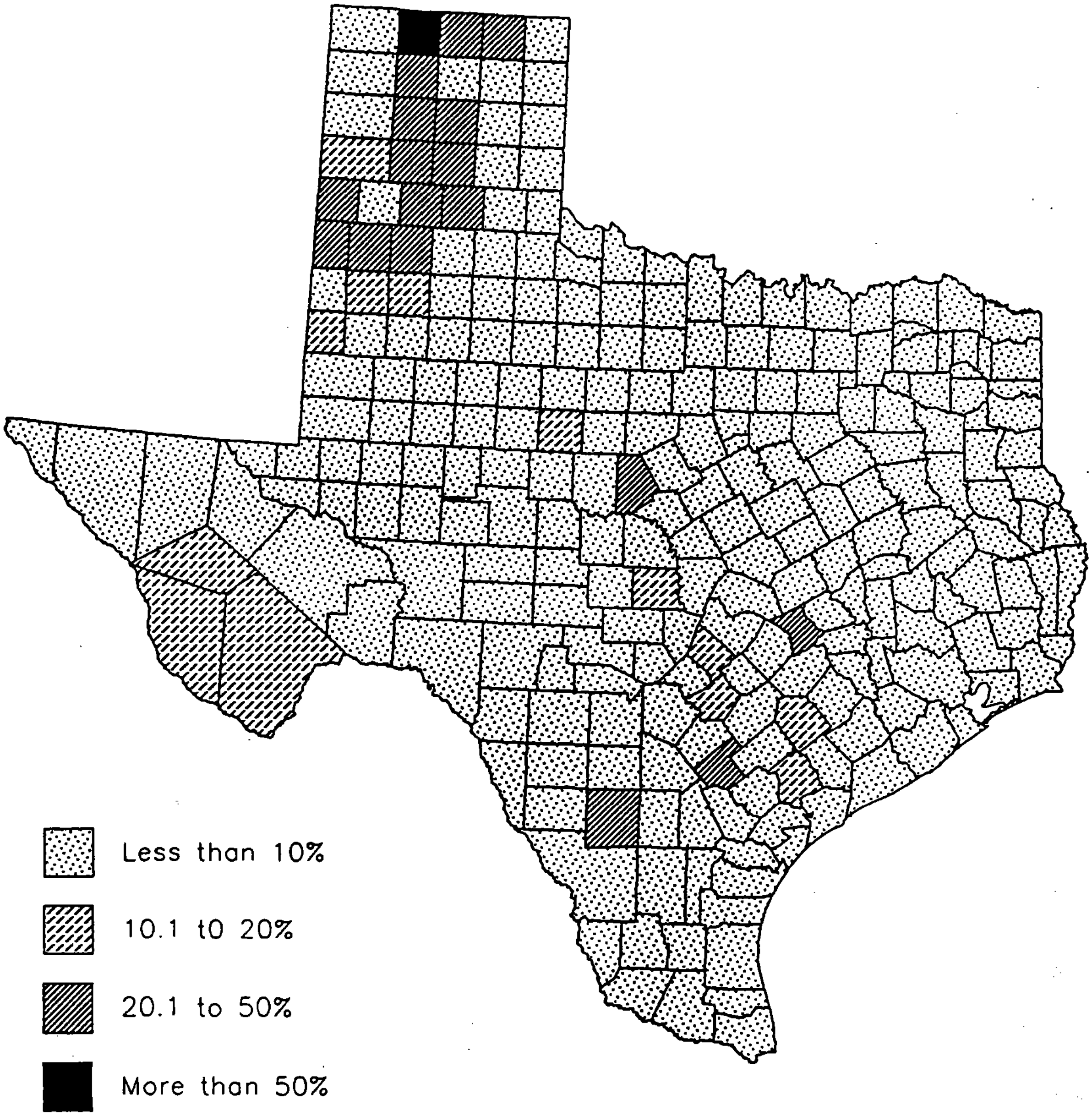
* County has only one valid measurement
** County has no valid measurements

measurements above 4.0 pCi/l). All of these counties are found in the Central Panhandle region of Texas.

Examination of the Texas counties map (Figure 3) for percentage of homes with radon measurements above 4.0 pCi/l clearly shows a greater potential for elevated indoor radon in the Texas Panhandle region.

The counties of Jeff Davis (3 of 16 measurements above 4.0 pCi/l), Presidio (8 of 46 measurements above 4.0 pCi/l), and Brewster (10 of 63 measurements above 4.0 pCi/l) are all found in the Texas Big Bend region, and have subsurface geology which support a higher potential for indoor radon. The counties of Mason (2 of 20 measurements above 4.0 pCi/l) and Llano (7 of 52 measurements above 4.0 pCi/l) are both in the Llano Uplift region, and also have local geology

Figure 3. Texas Counties - Percent of Homes > 4.0 pCi/l

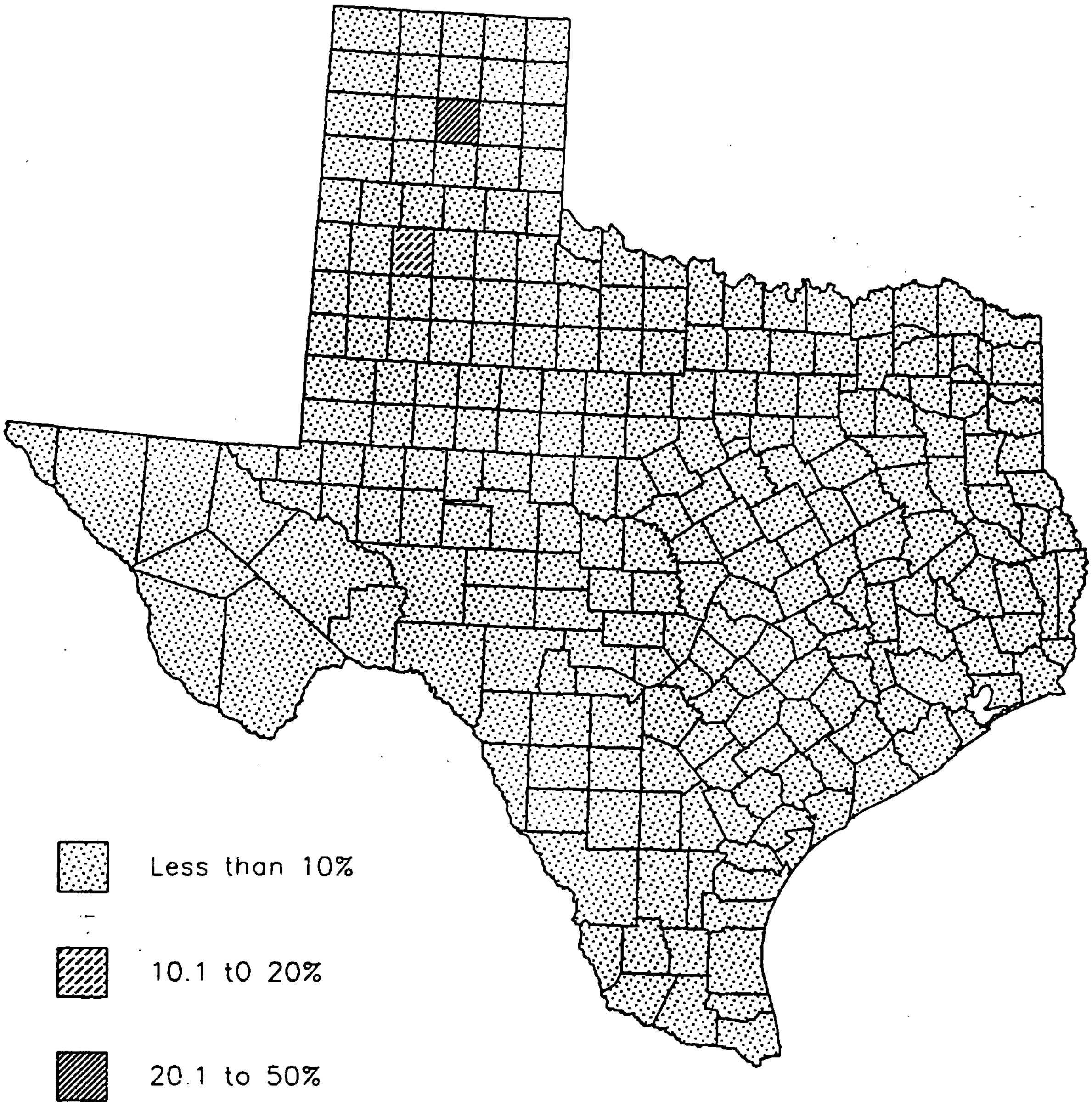


* The Panhandle county of Briscoe is shaded as "20.1 to 50 %" similar to neighboring counties.

supportive of radon production.

Other counties showing elevated potential for indoor radon have only a few measurements, but are reported here since they have surface and subsurface geology which could provide a source for radon, and there is the likelihood that some homes in these counties have elevated radon levels. Because of these geological sources and the likelihood that some homes in these counties have elevated radon levels, the counties are shown on the map.

Figure 4. Texas Counties - Percent of Homes > 20 pCi/l



However, because of the small number of measurements, they should be taken as inconclusive without further and more numerous measurements. These counties include the Coastal Bend and South Texas counties of La Salle (1 of 2) measurements above 4.0 pCi/l), Karnes (1 of 3 measurements above 4.0 pCi/l), Victoria (1 of 9 measurements above 4.0 pCi/l), and Lavaca (1 of 10 measurements above 4.0 pCi/l). In each of these counties, only one measurement was found above 4.0 pCi/l.

Three additional Texas counties of Bastrop (1 of 10 measurements above 4.0 pCi/l), Brown (2 of 6 measurements above 4.0 pCi/l), and Taylor (3 of 27 measurements above 4.0 pCi/l) had at least 10 percent of their measurements above 4.0 pCi/l.

Examination of the Texas county map for the percentage of homes over 20 pCi/l (Figure 4) shows only two counties with potentially more than 10 percent of the homes at this level. Hale (2 of 18 measurements above 20 pCi/l) and Carson (1 of 4 measurements above 20 pCi/l) are both in the previously identified Texas Panhandle region of higher radon potential.

Regional Differences in Charcoal Canister Results

Table 5 lists the 13 sampling regions and their mean values for charcoal canister results. When examining this table, remember that these regions were defined because of either their potential for radon producing subsurface geology or to minimize the effects of large metropolitan areas. Of the homes measured, the Texas Panhandle has more homes above the criterion EPA concern level of 4 pCi/l, having 21.7 percent of the homes above this point. The Panhandle region also had the highest percentage of homes above 20 pCi/l, reporting 1.9 percent.

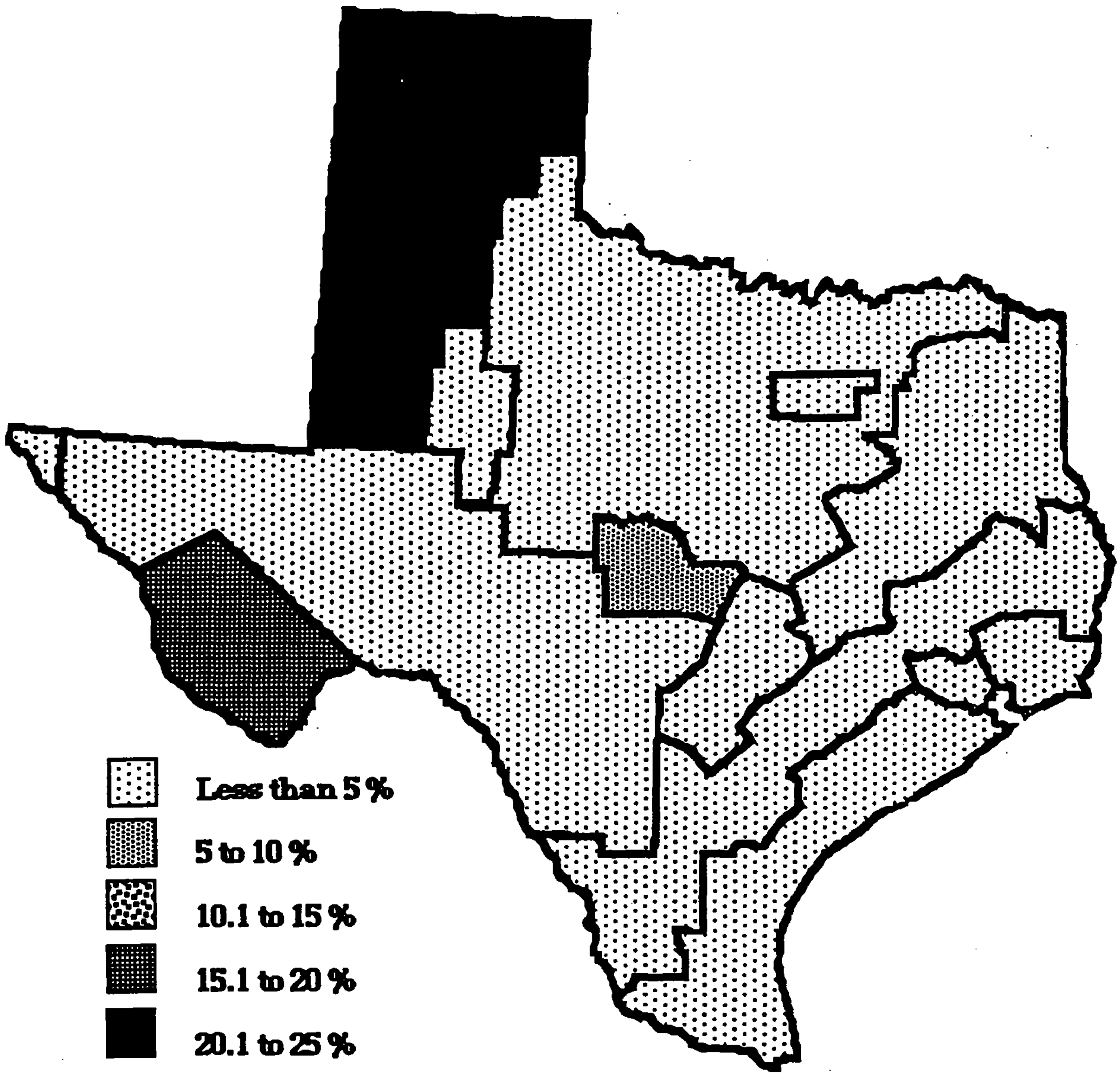
Other regions of concern include the Big Bend region with 17.2 percent, and the Llano uplift with 7.0 percent of the homes above 4 pCi/l.

These results are seen graphically in Figures 5 and 6, which map the regional percentage of homes over 4 pCi/l and 20 pCi/l, respectively.

Table 5. Regional Differences in Charcoal Canister Results

Region	Mean	Number	Percent >4	pCi/l >20	Minimum Value	Maximum Value
Southwest Texas	1.0	208	1.9	0.0	<.5	7.6
El Paso	1.2	97	2.1	1.0	<.5	21.6
Big Bend	2.6	122	17.2	0.0	<.5	13.6
West Texas Shales ...	1.3	241	3.3	0.4	<.5	14.0
North Texas	1.0	348	2.6	0.0	<.5	7.8
Dallas/Ft Worth	1.1	172	3.5	0.0	<.5	7.4
East Texas	0.7	296	1.0	0.0	<.5	7.1
Llano Uplift	1.4	213	7.0	0.0	<.5	13.9
Central Texas	1.2	237	3.8	0.0	<.5	9.8
Tertiary Sands	0.6	204	1.0	0.0	<.5	7.5
Harris County	<.5	122	0.0	0.0	<.5	3.8
Gulf Coast	0.5	215	0.5	0.0	<.5	9.5
Texas Panhandle	3.3	258	21.7	1.9	<.5	41.3

Figure 5. Survey Regions - Percent of Homes > 4 pCi/l

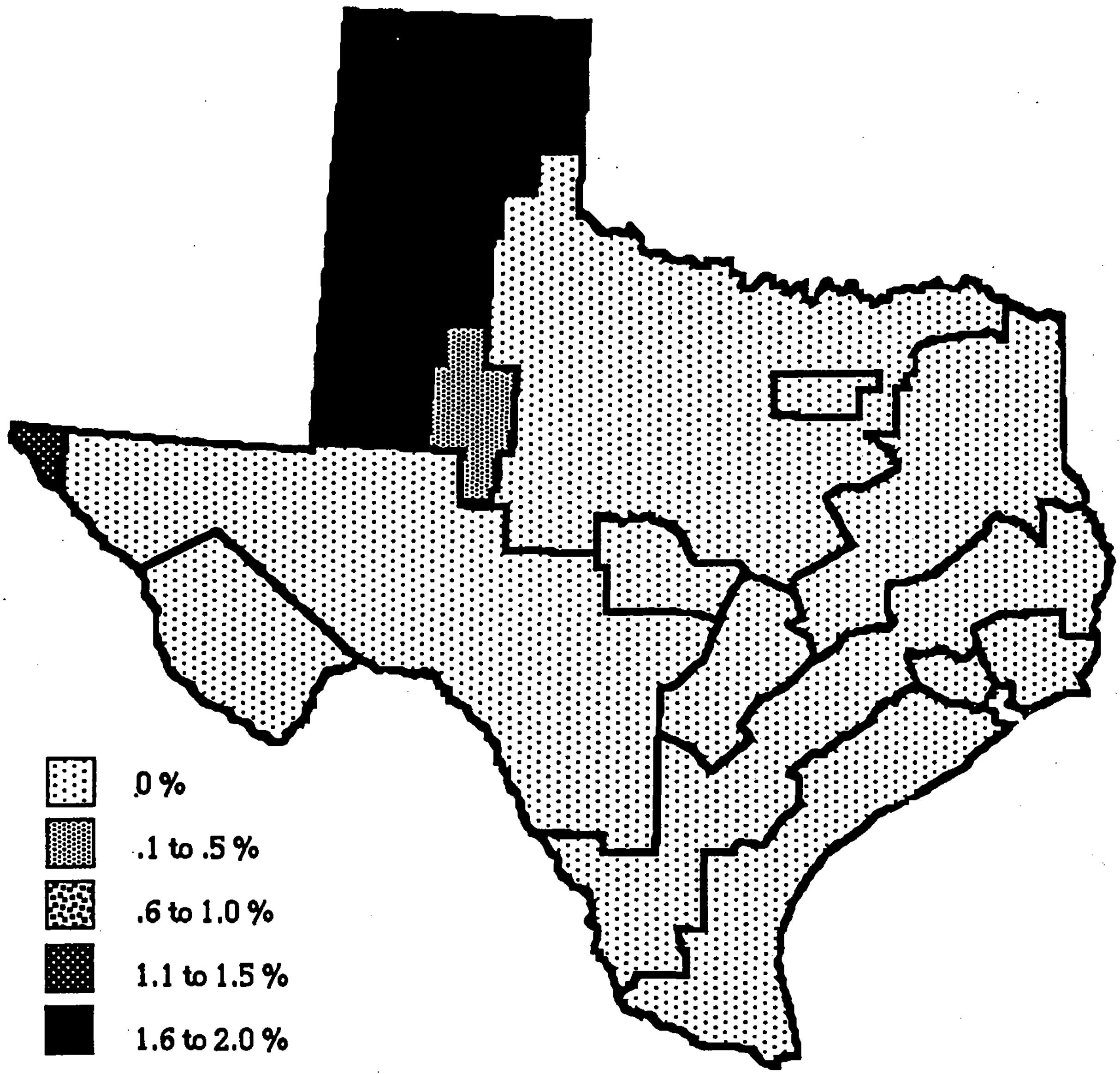


Alpha-Track Detector Results

Alpha-track detectors (ATDs) were mailed to a sample of slightly more than 300 Texas homes - much smaller than the charcoal canister sample.

The acceptance rate by homeowners for the 12-month commitment required for ATD placement was expectedly lower than the shorter term activated charcoal canister acceptance rate.

Figure 6. Survey Regions - Percent of Homes > 20 pCi/l



Alpha-track detectors measured typical Texas radon levels over a 12-month period, and helped determine the relationship between radon measurements using one-week charcoal canisters and the 12 month ATDs. Alpha-track detectors measure long-term average concentrations of radon over a 12 month exposure - the optimum measurement period for health risk estimations. While the short-term activated charcoal canister winter measurements show peak values, their limitations should be recognized knowing that, usually, the average exposure for a whole year will be lower. Long-term ATD measurements are usually lower due to homes being open to the outside during milder seasons. All measurements for this study could not be made using ATDs because of increased analytical expense and greater chance of nonparticipation or lost detectors. Of the more than 300 home owners who agreed to participate in the 12-month ATD study, only 115 returned their detectors. And of those 115 homes, not all detectors placed on multiple floors found their way back to EPA labs for analysis. Reasons for non-return ranged from being accidentally thrown out during the 12-month period to residents moving. Some detectors were clearly lost in transit to EPA labs, given the number of homeowners who wrote asking for detector results when they were never received by the researchers or EPA.

With only 115 homes returning ATDs,and some of those being incomplete, ATD coverage for the state is sparse. Some interesting results, however, were obtained. Fifty-nine of the 254 Texas counties had at least one ATD measurement. Ninety-four ATDs were returned that were placed on the first livable level of the home. And another 95 ATDs were returned that were placed on the second livable level. Only two ATDs were returned from placements on third livable house levels.

Higher ATD results were easily explained by subsurface geology. Areas of the state where higher radon levels were expected, typically, had at least one high ATD reading. The Llano uplift area was revealed by high ATD readings from Burnet and Llano counties. The Big Bend area was revealed by readings from Jeff Davis county. The Panhandle area was seen by ATD in Deaf Smith and Randall counties. The West Texas shales were noted by a high reading from Sterling county. The few other moderate ATD readings were similarly linked to subsurface geology.

The highest ATD level reported for Texas was from Jeff Davis county in the Big Bend region with a measurement of 21.9 pCi/l. Upon inquiry, it was found that this was a basement reading, and that the ATD for the second livable level of the house was 5.0 pCi/l. This was one of the few homes where at least three canisters plus an ATD were returned. The average canister level for the winter, spring, and summer canisters was 2.1 pCi/l, one-tenth the level reported by the higher ATD. No explanation could be provided by the homeowner for the differences. The other home measured in Jeff Davis county with ATDs reported two ATD values less than 2.0 pCi/l, with all canister readings also less than 2.0 pCi/l.

The only other ATD reported at the 20 pCi/l level was one from Burnet county in the Llano Uplift region measuring exactly 20.0 pCi/l. This was also taken from a basement ATD, with the second level ATD reporting only 1.8 pCi/l. Unfortunately, the winter canister was the only one of four returned from this home, but it measured only 1.2 pCi/l. Other ATD measurements from Burnet county averaged only 1.4 pCi/l for the first livable level, and 1.7 pCi/l for the second level.

The third highest ATD measurement

Table 6. Results of Alpha Track Detectors and Quarterly Canisters

County	ATD1	ATD2	ATD3	Can1	Can2	Can3	Can4
ANGELINA							
Count	1	1	0	1	0	0	0
Minimum	1.0	1.4		<.5			
Maximum	1.0	1.4		<.5			
Average	1.0	1.4		<.5			
BANDERA							
Count	1	1	0	0	1	0	1
Minimum	.6	<.5			<.5		<.5
Maximum	.6	<.5			<.5		<.5
Average	.6	<.5			<.5		<.5
BELL							
Count	0	1	0	2	0	1	1
Minimum		1.6		.9		2.3	1.4
Maximum		1.6		1.2		2.3	1.4
Average		1.6		1.1		2.3	1.4
BEXAR							
Count	2	5	0	5	3	3	3
Minimum	.6	<.5		<.5	<.5	<.5	.7
Maximum	1.4	1.0		1.0	.7	.8	2.0
Average	1.0	.6		.6	<.5	<.5	1.4
BOWIE							
Count	1	1	0	2	0	1	0
Minimum	<.5	<.5		<.5		.8	
Maximum	<.5	<.5		.8		.8	
Average	<.5	<.5		.5		.8	
BRAZORIA							
Count	3	3	0	4	2	2	2
Minimum	<.5	<.5		<.5	<.5	.7	<.5
Maximum	1.0	.9		.9	.7	1.4	.7
Average	.7	.5		<.5	<.5	.7	<.5
BRAZOS							
Count	1	1	0	1	1	1	1
Minimum	<.5	.9		<.5	<.5	.7	<.5
Maximum	<.5	.9		<.5	<.5	.7	<.5
Average	<.5	.9		<.5	<.5	.7	<.5

Table 6. Results of Alpha Track Detectors and Quarterly Canisters (continued)

County	ATD1	ATD2	ATD3	Can1	Can2	Can3	Can4
BREWSTER							
Count	3	3	0	3	3	2	2
Minimum	.6	.7		.6	<.5	1.4	1.7
Maximum	2.8	3.2		3.3	1.1	2.0	7.0
Average	1.6	1.8		2.3	<.5	1.7	4.4
BROWN							
Count	1	1	0	1	0	1	1
Minimum	.8	1.0		.8		.9	.8
Maximum	.8	1.0		.8		.9	.8
Average	.8	1.0		.8		.9	.8
BURLESON							
Count	1	1	0	0	0	1	0
Minimum	<.5	<.5				<.5	
Maximum	<.5	<.5				<.5	
Average	<.5	<.5				<.5	
BURNET							
Count	8	9	0	11	6	7	7
Minimum	.5	<.5		<.5	<.5	<.5	<.5
Maximum	20	3.4		1.7	3.0	2.0	3.3
Average	3.8	1.5		1.1	1.1	1.2	1.5
CASS							
Count	1	1	0	2	0	1	1
Minimum	1.4	1.3		<.5		.8	<.5
Maximum	1.4	1.3		.9		.8	<.5
Average	1.4	1.3		.6		.8	<.5
CHILDRESS							
Count	1	1	0	0	1	0	1
Minimum	.6	.7			1.5		1.7
Maximum	.6	.7			1.5		1.7
Average	.6	.7			1.5		1.7
COLLIN							
Count	1	1	0	2	2	2	1
Minimum	<.5	1.4		.7	<.5	.6	<.5
Maximum	<.5	1.4		1.4	<.5	.9	<.5
Average	<.5	1.4		1.1	<.5	.8	<.5

Table 6. Results of Alpha Track Detectors and Quarterly Canisters (continued)

County	ATD1	ATD2	ATD3	Can1	Can2	Can3	Can4
COMAL							
Count	0	1	0	1	0	1	1
Minimum		1.4		.7		.7	1.4
Maximum		1.4		.7		.7	1.4
Average		1.4		.7		.7	1.4
DALLAS							
Count	5	4	0	6	1	7	2
Minimum	<.5	.6		<.5	<.5	<.5	<.5
Maximum	4.4	4.0		3.2	<.5	3.0	6.6
Average	1.5	1.6		.9	<.5	1.3	3.5
DEAF SMITH							
Count	2	2	0	1	1	2	2
Minimum	.6	1.2		.8	<.5	1.2	1.7
Maximum	3.0	2.9		.8	<.5	3.2	3.5
Average	1.8	2.1		.8	<.5	2.2	2.6
EL PASO							
Count	2	2	0	6	5	7	6
Minimum	<.5	<.5		<.5	<.5	<.5	<.5
Maximum	.6	.5		1.9	.8	1.2	2.7
Average	.5	<.5		1.0	<.5	.6	.9
ELLIS							
Count	0	1	0	1	1	1	1
Minimum		1.1		<.5	<.5	1.2	1.1
Maximum		1.1		<.5	<.5	1.2	1.1
Average		1.1		<.5	<.5	1.2	1.1
FAYETTE							
Count	1	1	0	2	1	1	1
Minimum	1.2	1.3		.9	1.7	1.3	.7
Maximum	1.2	1.3		.9	1.7	1.3	.7
Average	1.2	1.3		.9	1.7	1.3	.7
GREGG							
Count	1	1	0	1	0	0	0
Minimum	.6	.8		1.2			
Maximum	.6	.8		1.2			
Average	.6	.8		1.2			

Table 6. Results of Alpha Track Detectors and Quarterly Canisters (continued)

County	ATD1	ATD2	ATD3	Can1	Can2	Can3	Can4
HARRIS							
Count	3	8	1	8	4	5	5
Minimum	<.5	<.5	1.3	<.5	<.5	<.5	<.5
Maximum	<.5	1.1	1.3	.8	1.2	<.5	.8
Average	<.5	<.5	1.3	<.5	.5	<.5	<.5
HARRISON							
Count	1	0	0	1	1	1	1
Minimum	1.5			1.1	1.5	1.1	1.2
Maximum	1.5			1.1	1.5	1.1	1.2
Average	1.5			1.1	1.5	1.1	1.2
HAYS							
Count	2	2	0	1	1	1	1
Minimum	<.5	<.5		.6	0	.6	.8
Maximum	1.0	<.5		.6		.6	.8
Average	.7	<.5		.6		.6	.8
HENDERSON							
Count	1	1	0	1	0	0	2
Minimum	<.5	<.5		<.5			<.5
Maximum	<.5	<.5		<.5			<.5
Average	<.5	<.5		<.5			<.5
HOWARD							
Count	4	3	0	4	2	2	1
Minimum	<.5	<.5		<.5	<.5	<.5	1.8
Maximum	1.6	1.4		2.5	1.6	1.7	1.8
Average	.9	.8		1.7	1.0	1.0	1.8
HUNT							
Count	2	2	0	2	1	0	1
Minimum	<.5	<.5		<.5	<.5		<.5
Maximum	<.5	<.5		2.6	<.5		<.5
Average	<.5	<.5		1.7	1.0		<.5
JEFF DAVIS							
Count	2	2	0	2	2	2	1
Minimum	1.5	1.8		1.9	.6	1.4	1.9
Maximum	21.9	5.0		2.2	1.9	2.3	1.9
Average	11.7	3.4		2.1	1.3	1.9	1.9

Table 6. Results of Alpha Track Detectors and Quarterly Canisters (continued)

County	ATD1	ATD2	ATD3	Can1	Can2	Can3	Can4
JOHNSON							
Count	1	1	0	2	1	2	2
Minimum	1.4	.7		.7	.5	.8	<.5
Maximum	1.4	.7		.9	.5	3.8	.5
Average	1.4	.7		.8	.5	2.3	<.5
KENDALL							
Count	2	2	0	2	2	2	1
Minimum	.6	.5		.5	.6	1.4	1.2
Maximum	.7	.6		1.0	1.1	1.8	1.2
Average	.7	.6		.8	.9	1.6	1.2
LLANO							
Count	1	1	2	4	3	2	4
Minimum	10	3.4	1.0	<.5	<.5	.6	.8
Maximum	10	3.4	2.3	5.4	2.5	.7	4.9
Average	10	3.4	1.7	.7	2.5	.7	2.2
LUBBOCK							
Count	3	3	0	4	3	3	1
Minimum	.6	.6		<.5	<.5	.8	2.9
Maximum	2.2	2.1		3.7	1.8	2.5	2.9
Average	1.3	1.3		1.8	.9	1.6	2.9
LYNN							
Count	1	0	0	1	0	1	1
Minimum	1.0			1.5		1.2	1.3
Maximum	1.0			1.5		1.2	1.3
Average	1.0			1.5		1.2	1.3
MASON							
Count	1	1	0	2	2	1	0
Minimum	.8	.7		<.5	<.5	1.0	
Maximum	.8	.7		.6	<.5	1.0	
Average	.8	.7		.5	<.5	1.0	
MATAGORDA							
Count	1	1	0	1	1	1	1
Minimum	<.5	<.5		<.5	<.5	<.5	<.5
Maximum	<.5	<.5		<.5	<.5	<.5	<.5
Average	<.5	<.5		<.5	<.5	<.5	<.5

Table 6. Results of Alpha Track Detectors and Quarterly Canisters (continued)

County	ATD1	ATD2	ATD3	Can1	Can2	Can3	Can4
MCCULLOCH							
Count	1	1	0	0	1	1	1
Minimum	<.5	<.5			<.5	<.5	<.5
Maximum	<.5	<.5			<.5	<.5	<.5
Average	<.5	<.5			<.5	<.5	<.5
MCLENNAN							
Count	2	2	0	1	1	0	1
Minimum	<.5	<.5		<.5	.8		<.5
Maximum	.7	.6		<.5	.8		<.5
Average	<.5	.5		<.5	.8		<.5
MEDINA							
Count	2	2	0	1	1	1	2
Minimum	<.5	<.5		<.5	.5	.7	<.5
Maximum	7.6	<.5		<.5	.5	.7	.5
Average	4.0	<.5		<.5	.5	.7	<.5
MIDLAND							
Count	2	1	0	5	2	3	2
Minimum	2.8	3.4		.5	<.5	.7	<.5
Maximum	2.9	3.4		2.5	2.1	1.8	<.5
Average	2.9	3.4		1.1	1.2	1.2	<.5
MITCHELL							
Count	1	1	0	2	1	1	0
Minimum	.8	<.5		.9	<.5	1.1	
Maximum	.8	<.5		1.1	<.5	1.1	
Average	.8	<.5		1.0	<.5	1.1	
MORRIS							
Count	2	2	0	2	1	1	2
Minimum	<.5	.8		<.5	1.1	2.0	<.5
Maximum	1.2	1.2		.9	1.1	2.0	1.4
Average	.7	1.0		.7	1.1	2.0	.7
NUECES							
Count	2	1	0	3	1	1	1
Minimum	.7	.7		.7	.9	.5	<.5
Maximum	.8	.7		.8	.9	.5	<.5
Average	.8	.7		.8	.9	.5	<.5

Table 6. Results of Alpha Track Detectors and Quarterly Canisters (continued)

County	ATD1	ATD2	ATD3	Can1	Can2	Can3	Can4
PALO PINTO							
Count	1	1	0	1	1	0	1
Minimum	<.5	<.5		<.5	.5		1.2
Maximum	<.5	<.5		<.5	.5		1.2
Average	<.5	<.5		<.5	.5		1.2
PARKER							
Count	1	1	0	1	1	1	0
Minimum	.5	.6		<.5	<.5	.5	
Maximum	.5	.6		<.5	<.5	.5	
Average	.5	.6		<.5	<.5	.5	
PRESIDIO							
Count	2	0	0	4	2	2	2
Minimum	1.3			.7	<.5	<.5	3.9
Maximum	1.5			5.8	.9	7.3	6.0
Average	1.4			2.7	.5	3.7	5.0
RAINS							
Count	1	0	0	1	0	0	0
Minimum	<.5			<.5			
Maximum	<.5		<.5	<.5			
Average	<.5		<.5	<.5			
RANDALL							
Count	1	1	0	1	1	1	0
Minimum	6.4	6.5		8.4	3.3	5.1	
Maximum	6.4	6.5		8.4	3.3	5.1	
Average	6.4	6.5		8.4	3.3	5.1	
REEVES							
Count	1	1	0	1	0	0	0
Minimum	.8	.5		<.5			
Maximum	.8	.5		<.5			
Average	.8	.5		<.5			
RUNNELS							
Count	1	1	0	1	0	0	1
Minimum	1.0	.6		.7			.9
Maximum	1.0	.6		.7			.9
Average	1.0	.6		.7			.9

Table 6. Results of Alpha Track Detectors and Quarterly Canisters (continued)

County	ATD1	ATD2	ATD3	Can1	Can2	Can3	Can4
SAN AUGUSTINE							
Count	1	1	0	1	0	1	1
Minimum	1.2	1.2		1.2		1.4	.7
Maximum	1.2	1.2		1.2		1.4	.7
Average	1.2	1.2		1.2		1.4	.7
SAN SABA							
Count	2	2	0	1	2	1	1
Minimum	.6	.7		.7	<.5	<.5	1.1
Maximum	.9	1.2		.7	<.5	<.5	1.1
Average	.8	1.0		.7	<.5	<.5	1.1
SCURRY							
Count	2	2	0	3	2	1	1
Minimum	.5	.5		<.5	<.5	2.3	1.3
Maximum	.9	.7		1.7	<.5	2.3	1.3
Average	.7	.6		.8	<.5	2.3	1.3
SMITH							
Count	1	0	0	1	1	1	0
Minimum	<.5			1.0	<.5	<.5	
Maximum	<.5			1.0	<.5	<.5	
Average	<.5			1.0	<.5	<.5	
STERLING							
Count	1	1	0	1	0	1	1
Minimum	4.3	5.0		3.6		3.9	3.0
Maximum	4.3	5.0		3.6		3.9	3.0
Average	4.3	5.0		3.6		3.9	3.0
SUTTON							
Count	1	1	0	1	1	1	1
Minimum	<.5	<.5		<.5	.5	<.5	<.5
Maximum	<.5	<.5		<.5	.5	<.5	<.5
Average	<.5	<.5		<.5	.5	<.5	<.5
TARRANT							
Count	2	3	0	6	4	3	4
Minimum	.6	.8		<.5	<.5	<.5	<.5
Maximum	2.1	2.3		2.6	6.3	2.1	1.3
Average	1.4	1.3		1.4	2.6	1.0	.7

Table 6. Results of Alpha Track Detectors and Quarterly Canisters (continued)

County	ATD1	ATD2	ATD3	Can1	Can2	Can3	Can4
TAYLOR							
Count	1	1	0	1	1	1	0
Minimum	1.5	1.3		1.2	<.5	1.6	
Maximum	1.5	1.3		1.2	<.5	1.6	
Average	1.5	1.3		1.2	<.5	1.6	
UPSHUR							
Count	1	1	0	0	1	1	1
Minimum	<.5	.7		<.5	.5	<.5	
Maximum	<.5	.7		<.5	.5	<.5	
Average	<.5	.7		<.5	.5	<.5	
VICTORIA							
Count	1	1	0	0	1	0	1
Minimum	<.5	<.5			<.5		<.5
Maximum	<.5	<.5			<.5		<.5
Average	<.5	<.5			<.5		<.5
WALKER							
Count	1	1	0	1	1	1	1
Minimum	1.4	1.5		1.9	<.5	<.5	<.5
Maximum	1.4	1.5		1.9	<.5	<.5	<.5
Average	1.4	1.5		1.9	<.5	<.5	<.5
WASHINGTON							
Count	1	0	0	0	1	1	1
Minimum	<.5				<.5	.8	<.5
Maximum	<.5				<.5	.8	<.5
Average	<.5				<.5	.8	<.5
WHEELER							
Count	2	1	0	3	1	1	1
Minimum	<.5	.5		<.5	1.3	1.7	1.3
Maximum	2.0	.5		2.6	1.3	1.7	1.3
Average	1.1	.5		1.4	1.3	1.7	1.3
WILLIAMSON							
Count	2	1	0	1	3	2	0
Minimum	<.5	1.1		<.5	<.5	.5	
Maximum	.9	1.1		<.5	1.0	4.1	
Average	.6	1.1		<.5	<.5	2.3	

was reported from the Llano uplift area, in Llano County, from a basement reading of 10.0 pCi/l. the second livable level of the home reported 3.4 pCi/l, and the third livable level reported 2.3 pCi/l. No seasonal canister readings are available from this home. And no other ATD measurements were returned from other homeowners in Llano County who agreed to participate in the study. Canister readings from two of these homes did show measurements of 4.9 and 5.4 pCi/l. The average for all Llano canister readings from all seasons was 1.67 pCi/l.

Medina County, southwest of San Antonio, had one ATD report for a basement reading of 7.6 pCi/l. The second livable level of the same home reported only 0.4 pCi/l. The average of the spring, summer, and fall canisters was 0.5 pCi/l. The other ATD placements in Medina county reported only 0.3 pCi/l, with similar results for the canister readings.

The only ATD placement in Randall County shows a basement level of 6.4 pCi/l, and a second livable level of 6.5 pCi/l. The average of the winter, spring, and summer canister readings was 5.6 pCi/l. Dallas County had one home reporting a basement ATD reporting of 4.4 pCi/l, and a second livable level reporting of 4.0 pCi/l. The results of the winter, summer, and fall canisters averaged 4.26 pCi/l. Overall, the average for Dallas County for all ATDs was 1.5 pCi/l.

Sterling County had only one home participating in the ATD study, and it reported 4.3 pCi/l for the first livable level, and 5.0 pCi/l for the second. The average of winter, summer, and fall canister readings was 3.5 pCi/l. No other Sterling County ATD measurements are available.

Table 6 shows the aggregate results for all ATDs and canisters placed in this part of the study. Counties from which at least one ATD result is available are listed, whereas counties with only their charcoal canisters being reported were dropped. Unlike the charcoal canister tables, counties with only one ATD placement are reported, since so few placements are available for the state. Readers are cautioned that single measurements are subject to error, and are not good indicators for the county as a whole. Sizable variation is seen in those counties where more than one reading is available.

Relationship Between ATD and Canister Measurements

Alpha-track detectors are long-term (12-month) measurement devices which many people prefer for radon measurements. They are integrative devices, or show the average radon levels for a full year. Charcoal canisters, it is argued, provide only a snapshot view of the radon level, thus possibly misleading homeowners as to the potential health risk, especially if the measurements are taken in a closed house during the winter. Most screening programs such as this study use the charcoal canisters for a winter closed house study, primarily due to their inexpensive analysis, and the convenience of quick measurements. Specialists involved in radon studies are interested in the relationship between the 12-month measurements taken by ATDs and average reading of charcoal canisters. Both methods have their own sources of error, and neither can be said to be fool-proof. The ideal situation would be for the two methods to have a strong relationship, thereby allowing one to substitute for the other.

Of the 115 home owners returning their ATDs, only 112 also returned at least one charcoal canister. Table 7 shows the correlation between both the ATD from the lowest livable level and the ATD average and a charcoal canister reading from each of the four seasons. The ATD readings have Pearson product moment correlations with the seasonal canisters ranging from a low of .31 for the Spring canisters to a high of .66 for the Fall canisters. This may be explained by the houses being opened more in the Spring where the canisters had a mean of .73 pCi/l, the lowest of all four seasons and a standard deviation of .94, the lowest variability of all seasons. The highest correlation coefficient (r=.66) between ATDs and seasonal canister readings was for the Fall charcoal canisters and the average of all ATDs in the house.

Looking at the relationship between the ATD measurement taken from the first livable level and the measurement average of charcoal canisters (Table 8) when at least three canisters were returned, there is a Pearson product moment correlation coefficient of .39, that is significant at the .05 level. Although this coefficient was statistically significant, it is not a strong relationship. Only 31 homes met the requirement of having an ATD from the first livable level and three canisters.

Even lower relationships exist between ATDs and canisters from homes were only one canister was returned.

Examining the measurement provided by the first livable level ATD and the average of all four charcoal canisters shows a higher relationship between charcoal canisters and alpha-track detectors. Only 16 homes from this study, however, met this condition. For these homes, the Pearson product moment correlation coefficient was equal to .91, and was significant at the .01 level. This is the strong relationship between ATDs and canisters that would be preferred by radon measurement specialists, but these results are limited by the small sample and loss of homes from the original study.

Table 7. Correlations Between ATDs and Seasonal Canisters

	Winter	Spring	Summer	Fall
ADT1	.33**	.31*	.43**	.51**
N	70	55	57	55
ATD Average	.50**	.44**	.58**	.66**
N	82	62	67	65

* p < .05, ** p<.01

The high correlation coefficient reported between ATDs and canister measurements for houses with only two returned canisters can be explained as a statistical anomaly. Houses where only two canisters returned were more likely to have returned the Winter and Spring canisters creating an average between a high and low reading, that was by chance also closest to the long term reading from the ATD. So, although the correlation coefficient was significant, reason would explain the results as an anomaly.

Table 8. Correlations Between ATDs and an Average of Multiple Canisters

Number of cansisters	1	2	3	4
ATD1	.28	.82**	.39*	.91**
Number of homes	20	30	31	16
ATD Average	.31	.86**	.58**	.80**
Number of homes	23	34	35	20

* p < .05, ** p<.01

5. Conclusions and Recommendations

The activated charcoal canister measurements taken in this survey followed EPA guidelines for closed home testing during winter months, thus leading to a higher than normal accumulation of indoor radon. More realistically, the true annual radon levels and occupant exposures for these Texas homes would be lower than measured. The numbers reported represent the higher radon potential for these homes, not necessarily the radon levels experienced by the home owners on an annual basis. It should be remembered that the EPA guidelines for health risk are based on a 70-year lifetime exposure to an average radon concentration, and a 75 percent house occupancy rate for exposure time. Less exposure (as most people have) would result in a lower estimate of lung cancer risk. Given that the survey protocol for the data reported in this report required that the charcoal canisters be placed during the winter months (in closed-house conditions), and that in all likelihood average indoor radon levels on an annual basis would be up to 25 percent less, as reported by Rood, et al (1991), the annual risk levels for the homes measured in this survey are less than the initial data would suggest.

For this report, geology is the only factor examined in relation to indoor radon levels. The Panhandle High Plains area of Texas has the highest potential for indoor radon, with some counties such as Hale, Swisher, Randall, Carson, and Sherman reporting at least 25 percent (or higher) of the homes with indoor radon levels above 4.0 pCi/l. These findings are consistent with surface and subsurface Permian and Tertiary deposits with higher potential for uranium.

The Big Bend region is another area of the state with increased potential for elevated indoor radon. The three counties of Brewster, Jeff Davis, and Presidio all had at least 15 percent of the homes measured with radon levels above 4.0 pCi/l. Radon in these counties most likely results from uranium in Tertiary igneous intrusions and shales from Paleozoic periods. The Davis Mountains are noted for their Tertiary basaltic lavas and volcanic mud flows. Numerous faults and fractures are present in this region, having contributed to the upward movement of molten rock and volcanic vents. These faults and fractures act as conduits for upward migration of deeper sources of radon.

Other parts of the state with higher potential for indoor radon include counties above a crescent of Tertiary sands which parallels the Texas Gulf coast. This crescent extends from deep in South Texas up and toward the Texas-Louisiana border. Fortunately, most of the counties in this region did not exhibit elevated measurements for indoor radon. Counties above these sands, which reported some elevated potential, include La Salle and Karnes. Karnes County has been the site of commercial uranium mines for years. For a very limited number of measurements, other counties in this region show a small potential for elevated indoor radon. Lavaca and Victoria, both, report one out of eight canisters above 4.0 pCi/l.

Overall, Texas does not have as great a problem with elevated indoor radon as other states in the Midwest and Northeast United States. The fact that some areas of Texas report indoor radon levels higher than other areas is justification for further study and analysis. The goals of this survey were to establish a statewide radon average and to identify areas of the state which may have potential "hot spots." Those goals have been accomplished. Further research and surveys should now concentrate in the areas of the state where elevated indoor radon was reported.

6. References

Cohen, B. L., and R. S. Shaw, "Mean radon levels in US homes by states and counties," Health Physics, 1991, 60, 243-259.

Cothern, C. R., "Indoor air radon," *Review of Environmental Contaminants and Toxicology*, 1990, 111, 1-60.

Council on Scientific Affairs, American Medical Association, "Health Effects of Radon Exposure," *Archives of Internal Medicine*, 1991, 151, 4, 674-677.

Darby, Sarah C., "Does Radon Cause Cancers Other than Lung Cancer?," *Proceedings for The 1992 International Symposium on Radon and Radon Reduction Technology - Assessing the Risk,* September 22-25, 1992, Minneapolis, Minnesota.

Ganas, Michael J., "Radon Contamination in Dwellings." In *International Journal of Environmental Studies,* 1989, Vol. 32, pp. 247-260.

Harley, N. H., and J. H. Harley, "Potential lung cancer risk from indoor radon exposure," *CA*, 1990, 40, 5, 265-275.

Kreinbrock, L., Kreuzer, M., Wichmann, H. E., Gerken, M., Heinrich, J., Wolke, G., Goetze, H. J., Dingerkus, G., Keller, G., " The German Indoor Radon Study - An Intermediate Report after Two Years of Field Work," *Proceedings for The 1992 International Symposium on Radon and Radon Reduction Technology - Assessing the Risk,* September 22-25, 1992, Minneapolis, Minnesota.

National Research Council. 1988. *Health Risks of Radon and Other Internally Deposited Alpha-Emitters, BEIR IV.* National Academy Press, Washington, D. C.

National Research Council. 1991. *Comparative Dosimetry of Radon In Mines and Homes*, National Academy Press, Washington, D. C.

Nero, A. V., M. B. Schwehr, W. W. Nazaroff, and K. L. Revzan. "Distribution of Airborn Radon-222 Concentrations in U.S. Homes," *Science*, 1986, 234, 992-997.

Puskin, Jerome S., and Christopher B. Nelson. "EPA's Perspective on Risks from Residential Radon Exposure," *JAPCA*, 1989, 39, 7, 915-920.

Rood, A. S., J. L. George, M. D. Pearson, and G. H. Langner, Jr., "Year-to-year variations in annual average indoor 222Rn concentrations," *Health Physics*, 1991, 61, 3, 409-413.

U.S. Environmental Protection Agency. 1987a. *Radon Reference Manual.* EPA Office of Radiation Programs, Washington, D.C., EPA 520/1-87-20. September, 1987.

U.S. Environmental Protection Agency. 1987b. *radon Reduction in New Construction.* Office of Air and Radiation Research and Development, Washington, D.C., EPA OPA-87-009, August 1987.

U.S. Environmental Protection Agency. 1988. *Radon Reduction Techniques for Detached Houses*.. EPA Office of Research and Development, Washington, D.C., EPA/625/5-87/019, January 1988.

U.S. Environmental Protection Agency. 1989. *Indoor Radon and Radon Decay Product Measurement Protocols*. EPA Office of Radiation Programs, Washington, D.C., EPA 520-1/89-009, March 1989.

U.S. Environmental Protection Agency. 1991. *Radon-resistent Construction Techniques for New Residential Construction.* EPA Office of Research and Development, Washington, D.C., EPA/625/2-91/032, February 1991.

U.S. Environmental Protection Agency. 1992. *A Citizen's Guide to Radon. Second Edition.* EPA Office of Air and Radiation Programs, Washington, D.C., 402-K92-001, May 1992.

Woodward, A., D. Roder, A. J. McMichael, P. Crough, and A. Mylvaganam, "Radon daughter exposures at the Radium Hill uranium mine and lung cancer rates among former workers, 1952-87," *Cancer Causes Control*, 1991, 2, 4, 213-220.

7. Appendix A - Sample Lead and Report Letters

Texas Department of Health

Robert Bernstein, M.D., F.A.C.P.
Commissioner

1100 West 49th Street
Austin, Texas 78756-3189
(512) 458-7111

Robert A. MacLean, M.D.
Deputy Commissioner

Radiation Control
(512) 835-7000

November 30, 1990

Dear Resident:

You may have recently read about radon gas in newspapers or seen stories about this potential health threat on TV. Radon is a radioactive gas that occurs naturally in soil, rocks, and some building materials. Texas is concerned about radon and we want to know more about where in Texas radon may be a problem. The Texas Department of Health (TDH) has obtained assistance from the U.S. Environmental Protection Agency (EPA) to conduct a state-wide indoor radon survey designed to determine whether high radon concentrations exist in homes in Texas. Your home, along with several thousand other homes throughout Texas, has been randomly selected for the survey.

During January, February, or March 1991, a telephone interviewer from TDH will contact you to discuss your participation in the survey. If you decide to participate, you will be helping us determine whether Texas residents have high levels of radon in their homes and if so, where. You will be provided a copy of the sample results for your home which will become a permanent part of TDH's records.

As a participant in the survey, you may want to know if other people will see the results of the radon test made in your home. All names and addresses of participants in the survey will be confidential, and only the zip codes or telephone exchanges associated with the sample results will be made available. The enclosed Survey Information Sheet and excerpt from "A Citizen's Guide to Radon" provide information about the survey and radon gas. Please read them closely. If you have any other questions about the study, please call Dr. Gary Smith or Ms. Vonya Boykin at the Bureau of Radiation Control (part of TDH) at (512) 835-7000.

Your participation is voluntary but vitally important to the success of the study. Thank you for your consideration.

Yours truly,

David K. Lacker

David K. Lacker, Chief
Bureau of Radiation Control

Dear Resident

Thank you for your cooperation in our survey of Texas homes for Radon gas. This survey was a joint effort by the Texas Department of Health, the U. S. Environmental Protection Agency, and Southwest Texas State University. Through this survey, we will have a better understanding of where we may have elevated levels of naturally occurring Radon gas in Texas. Your voluntary participation was important to accurately report the situation for Texas.

The Radon measurement for your house was ___ pico Curie per liter (pCi/l) of air.

It is important to understand that all homes have some Radon gas accumulation. Even outdoors, the average Radon level is around 0.2 pCi/l. Radon is a naturally occurring gas that comes from the decay of radioactive elements within the earth. Radon gas is a colorless and tasteless radioactive gas that has been shown to be related to lung cancer. If you were exposed to 4 pCi/l of Radon on a regular basis during your life, it would increase your risk of lung cancer similar to smoking half a pack of cigarettes each day. Exposure on a regular basis to a Radon level of 20 pCi/l would be equivalent to smoking one pack of cigarettes each day. If you already are a smoker, then radon exposure will increase your risk of lung cancer.

The Environmental Protection Agency has recommended that remedial action be taken within one year, to help reduce Radon gas levels in homes with more than 4 pCi/l. Levels lower than 4 pCi/l do not require any further action. For homes with levels above 4 pCi/l of Radon, you should consider a repeat analysis and corrective action for your house. Charcoal canisters to repeat your own analysis can be purchased in some grocery and department stores.

Of your home measured above 20 pCi/l, then we strongly urge you to repeat the analysis and consider actions to remove the Radon from your house within the next several months. There are many simple methods for reducing Radon in homes to acceptable levels discussed in the literature you can get by calling the phone numbers below.

Again, thank you for your time and cooperation in this important public health project. If you have further questions about Radon or its removal, please call the Environmental Protection Agency Radon Office at 1-800-SOS-RADON for general literature, or the Texas radon Office at 1-512-835-7000 for specific information about this survey.

Sincerely

Charles Johnson, Director
Texas Residential Radon Survey

8. Appendix B - Contacts at Texas Department of Health and Environmental Protection Agency

Federal Contacts:

Environmental Protection Agency Radon Office
1-800-SOS-RADON

Environmental Protection Agency Region 6
1445 Ross Avenue
Dallas, Texas 75202-2733
(214) 655-7550

Texas Contacts:

Bureau of Radiation Control
Texas Department of Health
1100 West 49th Street
Austin, Texas 78756-3189
(512)834-6688