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STATEWIDE RADON SURVEYS: SCREENING VS LONG-TERM MEASUREMENTS

by: D. J. Steck
Physics Department
St. John's University
Collegeville, MN 56321

ABSTRACT

Statewide indoor airborne radon distributions are being assessed using screening protocols. A comparison between EPA-assisted screening surveys in Minnesota and Wisconsin and a survey of the long-term, average indoor radon concentrations in those two states illustrates the limited ability of screening measurements to predict long-term radon concentrations. In both states, the median of the screening distribution was not significantly different from the median of the yearly average radon concentration in the living spaces. A comparison of both measurement protocols applied in 76 Minnesota houses shows that while the medians of the distributions are the same, the two measurement protocols can give quite different results in individual houses. Screening results failed to predict living space radon in excess of 4 pCi/l for 20% of the cases (false negative). In 30% of the cases, the screening measurement indicated a false positive. Concurrent measurements using a continuous radon monitor, charcoal canister, and track registration detectors show significant variance between short-term measurements and yearly average concentrations.

INTRODUCTION

During the last two years, the USEPA has been assisting states in conducting statewide radon surveys in order to assess the nationwide distribution of indoor radon concentrations. To conserve time and resources, these surveys have employed a measurement protocol (screening) that sampled the radon concentration in the lowest level of the house with a charcoal canister exposed under closed house conditions during the winter months for a two day period. Since radon-related health risks depend on long-term exposure, it is vital to know the relationship between these short-term measurements (Screen) and long-term radon concentrations in the living spaces (Living Space Rn). Previous studies showed significant variation between several types of short-term measurements and long-term concentrations.(1)(2) However, to date, no comparison has been published of the statewide EPA-designed screening surveys with long-term radon concentrations in the living spaces.

Since many factors can contribute to variation in radon entry and retention in houses, it is important that comparisons of measurement protocols include samples drawn from a broad range of radon sources, housing types, weather, and life-styles. The present work was designed to compare two statewide survey protocols in the subartic, subtropical upper midwest.

EXPERIMENTAL PROCEDURE

The important characteristics of the measurement protocols are summarized in Table 1.

Briefly, the statewide survey that I conducted between 1983-87 sampled the indoor airborne radon concentrations on the two lowest levels of each of 250 houses (This survey will be labelled Living Space Rn survey). Track registration-type detectors were left in place for 8-12 months. Houses monitored for less than 12 months were monitored during the heating season (October - June). (3)(4)(5) Some houses have been monitored for years. Nearly 100 houses were measured separately in winter and summer. Radon concentrations from houses measured only during the heating season were adjusted for seasonal variation by the seasonal behavior patterns of the average house. The yearly-average radon concentration in the living spaces (Living Space Rn) was calculated from the individual level measurements as either: (a) the average of all above grade level concentrations or, if the below-grade level was used as a living space, (b) 80% of the above grade concentrations and 20% of the below grade concentrations. Individual houses were clustered into town-sized areas (1-40 mi^2) that were selected to fully sample the variety of surface geologies and housing types. Approximately 215 houses were located in Minnesota, 25 in Northern Wisconsin and 10 in the Upper Peninsula of Michigan. (See Figure 1)

The Wisconsin Department of Health and Social Services surveyed 1191 houses (WDHScreen) during the 1986-87 heating season (December - April) following a protocol designed by the USEPA.(6) The 25 Wisconsin houses included in my survey were located in regions 5 and 10 of the Wisconsin survey (232 houses). The Minnesota Department of Health conducted an EPA designed survey (MDHScreen) of 1001 houses during the 1987-88 heating season (December - April).(7) In both screening surveys, indoor airborne radon concentrations were measured in the lowest level of the house by charcoal canisters left in place for 2 days (Screen). Houses were selected randomly within regions of each state. The number of houses sampled in each region was weighted by population and/or geological potential for elevated radon sources. In Minnesota, the sampling density ranges from 2 to 560 mi^2 per canister.

In an attempt to compare the results from two different radon measurement protocols applied in the same house, I supplied the Minnesota Department of Health with the telephone numbers of the Minnesota homes included in my Living Space Rn survey. Seventy of those houses along with 4 houses that I was monitoring monthly during 1988 were included for a combined survey (Combined). To investigate the effects of daily variation during the short-term sampling period (5), I monitored the airborne radon concentration with a continuous radon monitor (Pylon Model AB+PRD-1). These houses were sampled in late March through early April 1988.

RESULTS

A statistical summary of the data sets is given in Table 2. These survey results are best compared on the basis of their geometric averages since the Living Space Rn and Combined surveys are reasonably well represented by log-normal distributions. Histograms of WDHScreen and MDHScreen suggest log-normal behavior. On that basis of comparison, the Living Space Rn and Screen measures do not appear to be significantly different from each other for either the WDHScreen survey or the Combined survey. Unfortunately the MDHScreen data was not analyzed for log-normal behavior so no exact comparison can be made at present. I am trying to obtain the full data set to perform that analysis. However the ratio of the MDHScreen Survey median value to the Living Space Rn Survey geometric mean is approximately the same as that ratio in the combined survey. Therefore, I believe that when I complete the full log-normal analysis, the conclusion that the surveys are sampling the same distribution will hold.

A detailed analysis of the relationship between the Living Space Rn and the Screen measurements in the houses included in the Combined survey indicates that these measures are correlated with a high level of confidence (99.9%). (See Figure 2)

Concurrent measurements using a charcoal canister, continuous radon monitor, and track registration detectors are shown in Table 3. While the short-term measurements (2 day and 1 month) were in general agreement (factor of two), they vary significantly from the yearly-average radon concentration at each site. The difference between the hourly average radon concentration and the charcoal canister measurement appears to be systematic. It is unclear at present whether this is due to a calibration error in the radon monitor or a systematic error in correcting the charcoal canister count rate for environmental effects (such as temperature and humidity), or errors introduced by temporal variations in radon concentration..

DISCUSSION

A statistical analysis of the surveys' averages strongly suggests that the Screen distributions are drawn from the same sample population as the Living Space Rn. Thus, while the Screen distributions have a somewhat larger variation, the median values are not significantly different from the median values of the Living Space Rn distributions. In addition, it appears that the Combined survey is representative of both statewide Minnesota surveys. Thus, an analysis of the ratio of the

Living Space Rn to Screen from the Combined survey measurements should be representative of the behavior of this ratio in the larger surveys.

Figure 2 illustrates that the Living Space Rn and Screen measurements are strongly correlated ($p<.001$). Figure 3 indicates that the ratio is log-normally distributed with an arithmetic average of 0.99, a geometric average of 0.82, and a standard deviation of 1.74. Thus, in a survey of many houses, one could expect that the Screen average to give an adequate measure of the average value of the Living Space Rn, since the median value of the screen is only 20% higher than the Living space Rn and the average values are almost the same.

This result is at odds with the conventional wisdom that the screening measurement, i.e., the closed house, winter measurement in the lowest level in the house, is expected to be the "worst case". In my Minnesota survey, however, the average value of the ratio of the first floor radon concentration to the basement radon concentration was 0.7 in the winter and 0.5 in the summer (3 months).(4) The average basement radon concentration was essentially the same year-round. Based on these seasonal and compartmental variations, I would have predicted that an accurate screening measure of the winter basement concentrations would yield a Living Space Rn to Screen ratio of 0.75. Given the uncertainties in detection, sampling, seasonal variation, etc., the observed ratio, 0.82, seems quite reasonable.

The large geometric standard deviation of the Living Space Rn to Screen ratio means that an individual home's Living Space Rn is likely (95% chance) to be between 0.25 and 2.5 times the Screen measurement. Thus, a Screen measurement is not a particularly useful tool for predicting indoor radon in an individual house. As Figure 4 shows, the Combined survey Screen measurement, when interpreted as suggested by the EPA, failed to detect 20% of the houses with indoor radon concentrations in excess of 4 pCi/l (false negative). This same interpretation produced a false positive result for 30% of the houses whose concentration was below 4 pCi/l. One would have to lower the Screen threshold to 2 pCi/l before the interpretation would become 95% reliable for false negatives. This improvement in reliability would come at the expense of an increased number of false positives since approximately 70% of houses in Minnesota have Living Space Rn in excess of 2 pCi/l but only 30% exceed 4 pCi/l.

The reliability failure in individual houses is aggravated when the Screen threshold is raised above 4 pCi/l (discounting). The effects of the kind of discounting suggested in the Wisconsin Health Department report are shown in Figure 5.(6) That discounting was based on "According to unofficial EPA estimates, those winter screening measurements may vary from 2 to 6 times greater than the actual annual average radon value."(6) The report suggested there was little likelihood that annual average radon concentrations would exceed 4 pCi/l not only for screening measures below 4 pCi/l, but also for measures up to 10 pCi/l, and possibly up to 20 pCi/l. In the Combined survey group, this would cause the percentage of false negatives to rise from 20% to 70% and 90% respectively.

The lack of reliability of the Screen measurement for small sample populations limits the use of the current statewide screening surveys to locate "hot-spots". My survey suggests that the important geographic variation of radon is town-sized (10 mi^2) or smaller.(8) Thus, a methodology for finding "hot-spots" that includes an unreliable detector and a sampling density of 2-560 mi^2 per detector is unlikely to locate "hot-spots".

An analysis of the concurrent measurements at six sites (see Table 3) re-emphasizes the failure of either two day average (Screen or Continuous Monitor) or the monthly average radon measurements to reliably predict the annual average radon concentration for small sample populations. Both two day averages are strongly correlated with the monthly average.

Since the Combined survey and concurrent measurements were made in March 88, it is natural to ask whether this month was representative of the winter of 88 or the winters of 83-87. Table 4 suggests that there was nothing highly unusual about this month for the winter of 88. In addition, the radon concentration in March were reasonably representative of the radon concentrations in previous years at sites that have been monitored for several years.

CONCLUSIONS

In the upper midwest, statewide radon screening surveys based on EPA protocols can adequately characterize the average radon concentration in the living spaces. However, such surveys do not provide individual homeowners with a reliable assessment of the long-term radon concentrations in their home nor are they useful in locating "hot-spots". Current EPA interpretation of the radon screening results produce a significant failure rate for houses in our region. The conventional wisdom for our region should be that the screening measurements will usually be about 20% too high but could easily be anywhere from 400% too high to 40% too low. At present, the only reliable way to assess the long-term radon exposure in the living spaces is to take a long-term measurement of the radon concentration in those spaces.

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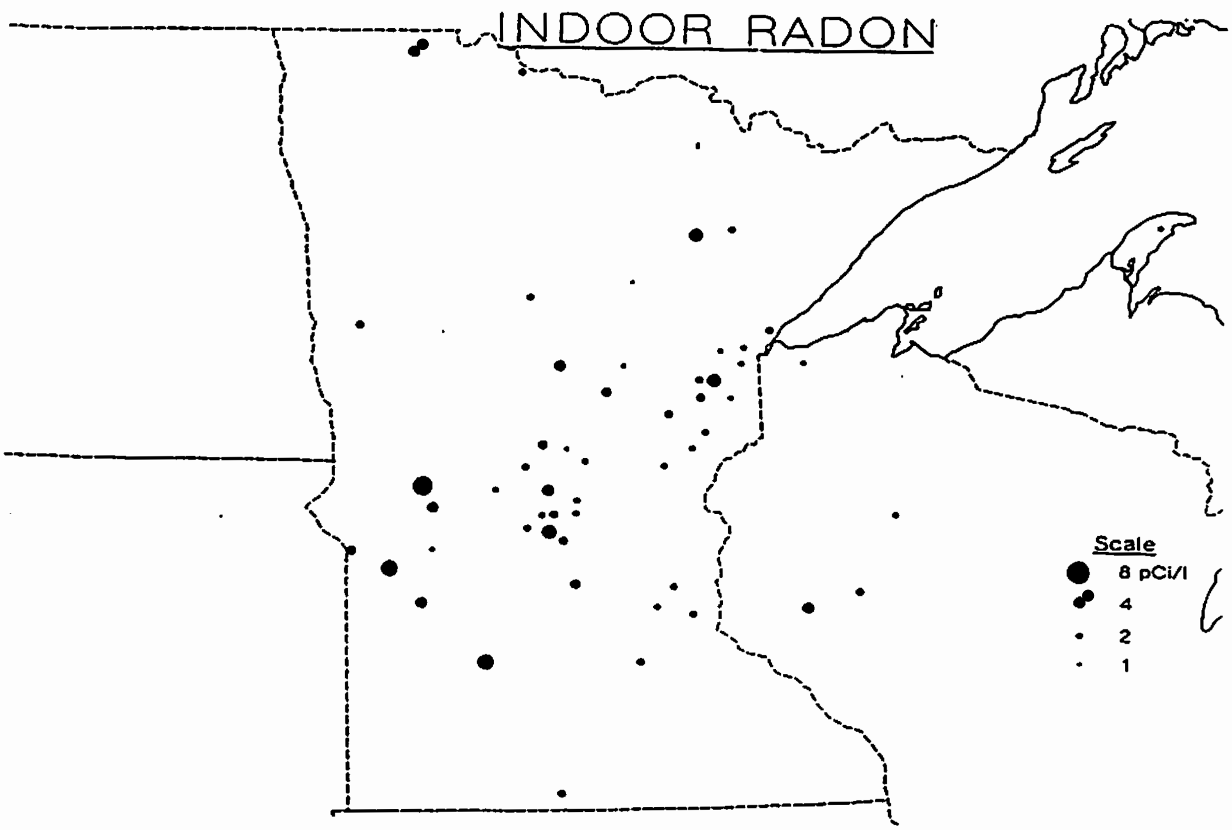

Figure 1. Geographic Distribution of Indoor Radon Concentrations. The concentration shown for each town is the median value of the yearly-average radon concentrations in the living spaces.

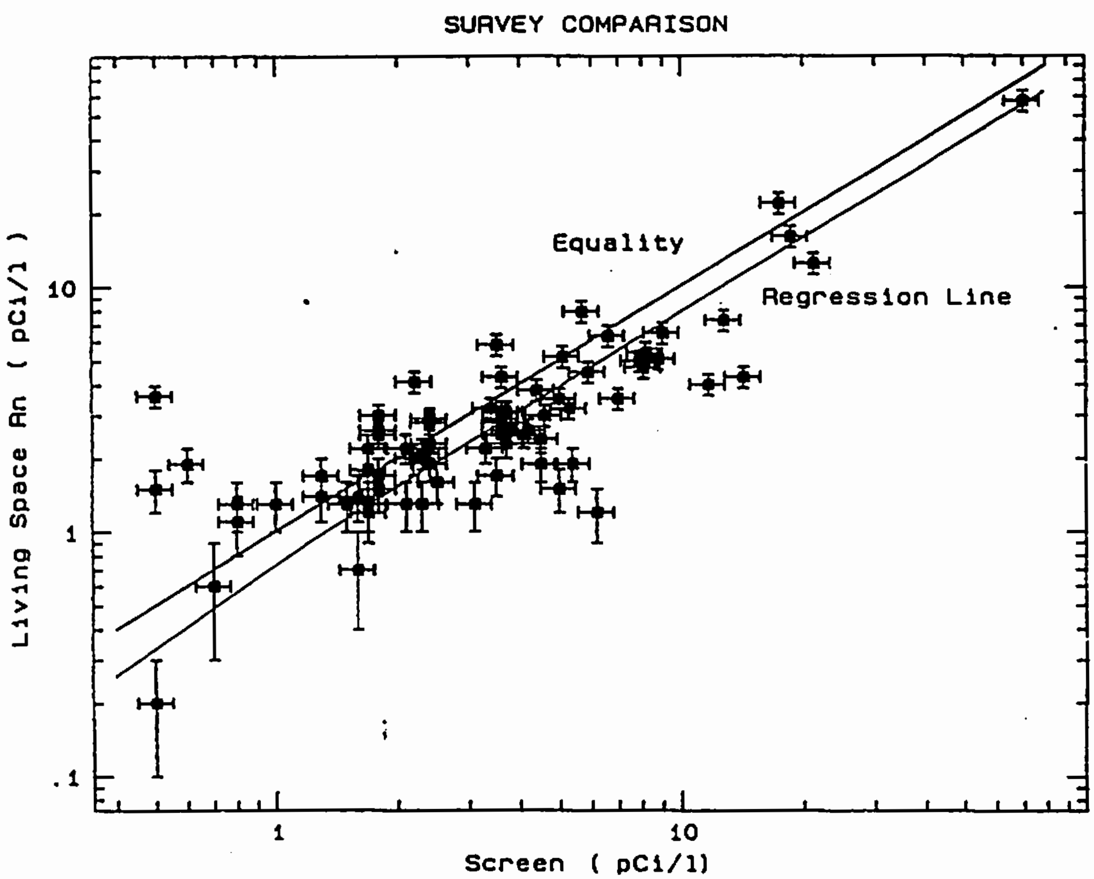

Figure 2. A comparison of the Living Space Rn results and Screen results for 76 houses in the combined survey. Equal values would lie along the upper line (labelled equality). The lower line represents a regression fit (99.9% confidence of correlation).

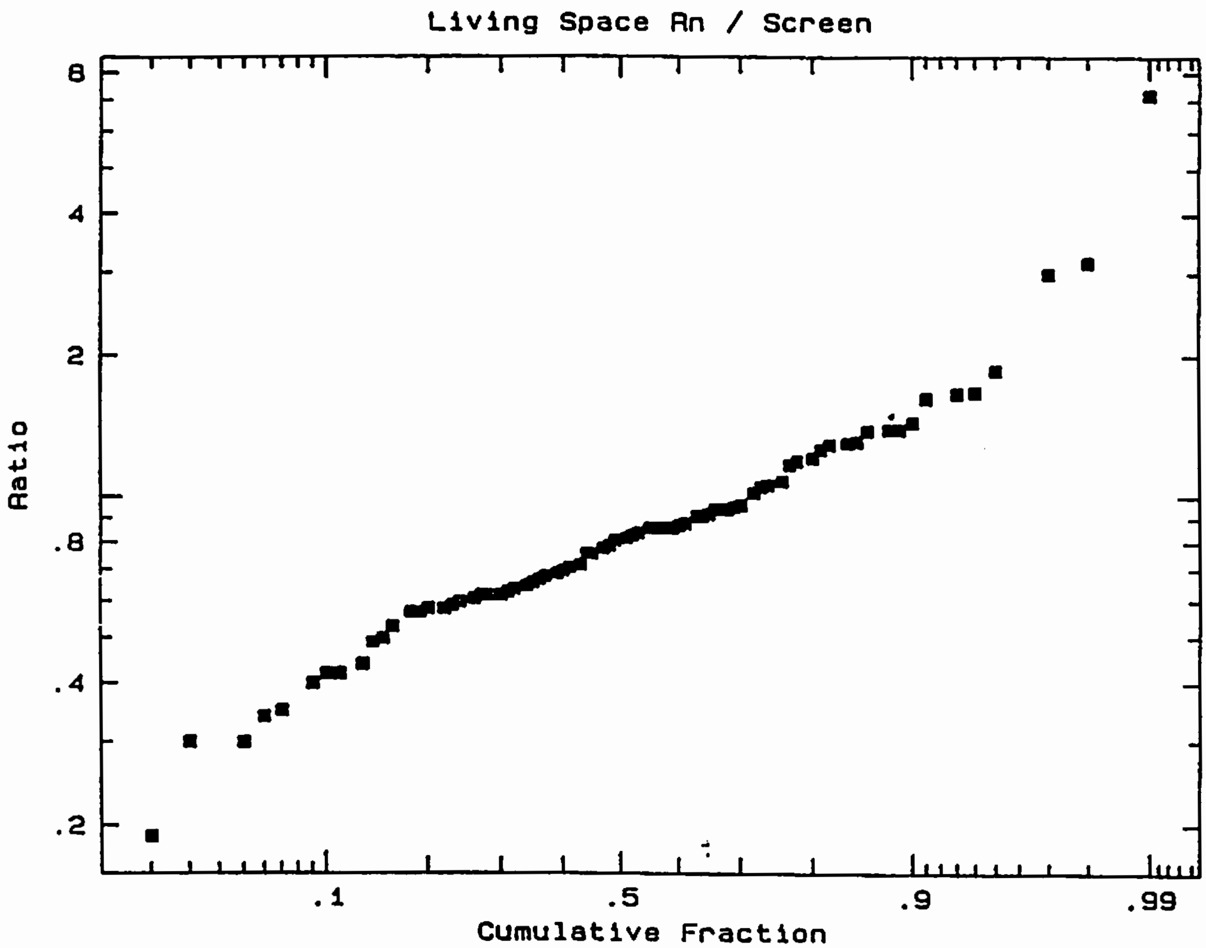

Figure 3. The Living Space Rn to Screen ratio probability distribution. A log-normal distribution would appear as a straight line on such a plot.

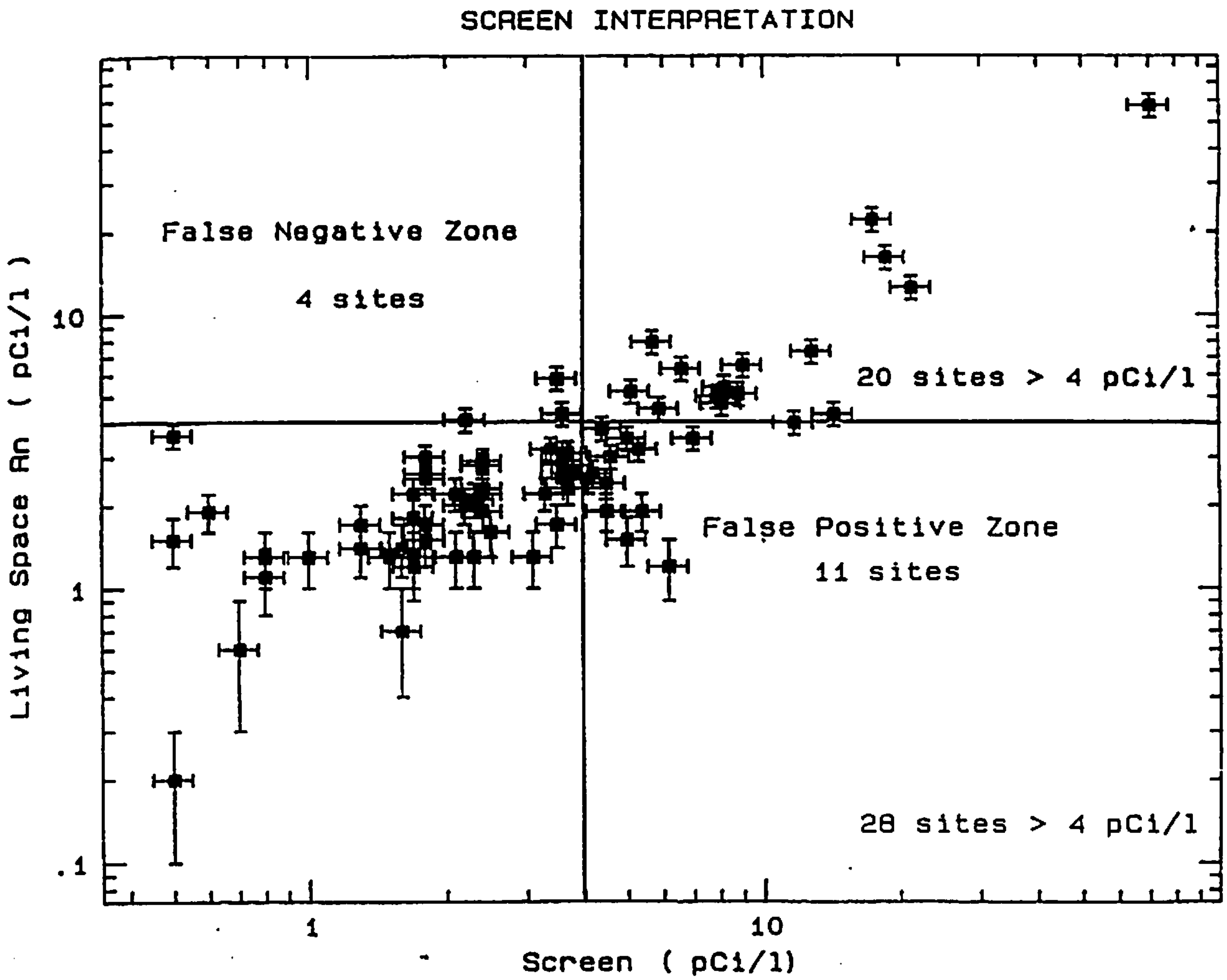

Figure 4. The reliability effects of applying a 4 pCi/l threshold to interpret the Screen measurement.

DISCOUNTING EFFECTS

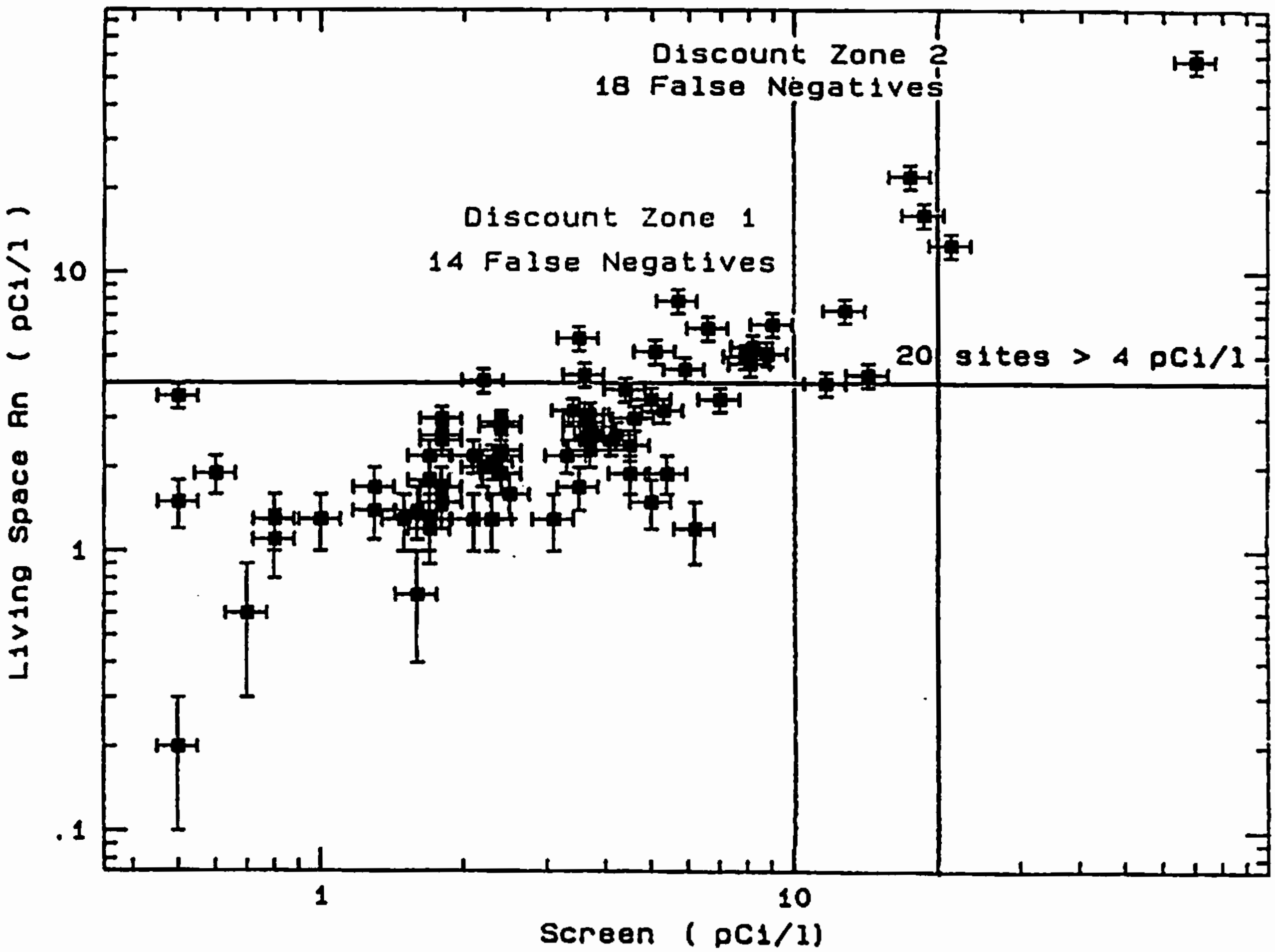

Figure 5. The effects of raising the interpretation threshold to 10 pCi/l and 20 pCi/l.

TABLES

TABLE 1. COMPARISON OF MEASUREMENT PROTOCOLS

Survey:	Screen	Living Space Rn	Combined
Sampling Time:	2 days (winter)	8-12 months 11 month average (heating season)	hourly, 2 day, and monthly for 1 year
Location:	Lowest level	Lowest two levels	Lowest level
Detector:	Charcoal Cannister	Track registration	Continuous Rn monitor, charcoal, track registration
Density: (mi^2 /detector)	2-560 County based	1 Town based	NA

TABLE 2 COMPARISON OF SURVEY RESULTS

Survey:	Sample Size	Arithmetic Average (pCi/l)	Geometric Average (pCi/l)
WDHScreen	232	2.9*	2.0† *÷ 1.1
Living Space Rn			
WI	25	2.8	2.2 *÷ 1.1
	(24)‡	(4.2)	(3.4 *÷ 1.2)
Living Space Rn			
MN	210	3.8	2.8 *÷ 1.1
	(185)	(5.5)	(3.9 *÷ 1.1)
MDHScreen	1001	4.8	3.5#
Combined			
Screen	76	5.2	3.2 *÷ 1.1
Living Space	76	4.0	2.6 *÷ 1.1
	(72)	(5.5)	(3.7 *÷ 1.1)

* population weighted averages
† numbers in parenthesis are below grade radon concentration statistics
‡ Median value
# the Living Space Rn Screen ration has an arithmetic average of 0.99, geometric average of 0.82 and a geometric standard deviation of 1.74

TABLE 3 CONCURRENT, AVERAGE RADON CONCENTRATION MEASUREMENTS

Measurement: (pCi/l)	Continuous Monitor Hourly	Screen 2 day	Track 1 month	Track 1 year
Site				
111A	1.9 ± 0.2	4.5 ± 0.5	2.4 ± 0.7	4.2 ± 0.6
111B	2.3 ± 0.2	4.7 ± 0.5	2.9 ± 0.8	4.2 ± 0.6
113	0.5 ± 0.1	0.6 ± 0.1	0.3 ± 0.2	2.0 ± 0.3
113S	0.3 ± 0.1	0.5 ± 0.1	0.1 ± 0.2	2.0 ± 0.3
1110	4.4 ± 0.4	5.9 ± 0.6	4.6 ± 0.1	4.8 ± 0.6
344		70 ± 17	160 ± 20	100 ± 15

TABLE 4 MONTHLY RADON CONCENTRATIONS AT 7 SITES

Site:	111A	111B	113A	113B	344A	344B	1110B
Oct 87	2.3*	3.4	2.5	8.3	36.	52.	
Nov 87	4.8	14.	3.5	2.4	50.	81.	
Dec 87	6.3	2.3	0.5	0.9	36.	60.	
Jan 88	4.7	0.5	0.0	4.5	31.	58.	
Feb 88	2.8	1.1	0.0	0.6	26.	52.	
Mar 88	2.4	2.9	0.7	0.1	91.	161	
Apr 88	6.2	5.8	0.3	0.3	66.	55.6	4.6
May 88	8.2	2.3	0.1	2.3	9.8	62.	3
Jun 88	3.6	3.0	0.5	1.5	11	20.	
Jul 88	3.3	3.6	0.0	0.0	1.4	2.5	
Aug 88	1.8	7.5	0.0	1.0	2.4	7.4	
Sep 88	5.1	9.4	2.2	5.1	10	6.5	

* typical uncertainty in monthly measurements is ± 30% with a minimum of 0..2 pCi/l