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INDOOR RADON AND RADON SOURCES ALONG THE SOUTHWESTERN EDGE OF THE CANADIAN SHIELD

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Average indoor radon concentrations have been measured using track registration detectors in 55 residential buildings during the past two years. Working levels were sampled in the 26 homes included in last summer's survey. Waterborne radon concentrations were measured using a liquid scintillation technique at 79 sites. Soilborne radon concentrations were measured using liquid scintillation (64 sites), track registration (26 sites), and solid scintillation (11 sites) techniques. Most survey sites were monitored for at least one year and some for more than two years in intervals ranging from 3 to 7 months. These sites, primarily located in the northeastern quadrant of Minnesota, were selected to provide a sample of regional geology and housing. A survey is in progress that includes fifteen additional homes in Minnesota and the Upper Penninsula of Michigan. Average indoor airborne radon concentrations varied from less than 0.5 pCi/l to 29 pCi/l (2.6 pCi/l median). Waterborne radon concentrations were found to range from less than 30 pCi/l to 3000 pCi/l (170 pCi/l median). Average radon soil gas concentrations ranged between 20 pCi/l and 600 pCi/l (160 pCi/l median). Soilborne radon concentrations determined by 1.76 MeV gamma emissions were found to range from 0.6 to 1.4 pCi/g (0.9 pCi/g median). In situ, high energy gamma fluxes measured with a mobile scintillator ranged from 50 to over 500 counts per minute. Soil radon emanation concentrations, determined by a liquid scintillation procedure, varied from 0.05 to 0.19 pCi/g (0.11 pCi/g median). Significant seasonal and yearly variation has been observed in airborne radon. Compartmental radon concentration differences appear to be more pronounced in the summer than in the winter. Preliminary statistical analysis of this, as yet incomplete, data shows no simple correlation between source strengths and average basement radon concentrations. Further analysis of the data is planned.

Introduction

Recent progress in understanding the nature and extent of elevated indoor radon concentrations has been hampered by a lack of widespread, detailed regional data[1]. Previous research indicates that indoor radon concentrations are influenced by local geology, hydrology, meteorology, housing characteristics, and lifestyles[2]. Past radon measurements in the upper Midwest have been limited in scope and duration. Given the Precambriam origin of our bedrock, glacial history of our soil, and the trend towards energy-efficient housing, this region has the potential to contain homes with high radon concentrations.

The survey work reported here started in the summer of 1983 with a small number of sites in central Minnesota that were selected randomly to sample all housing types and surface geology. Subsequently, sites that are spread more widely over the region were added until the survey now includes approximately 70 residential buildings. These buildings are mainly located in central and northeastern Minnesota but there are also sites in Colorado, Wisconsin, and Michigan. Data obtained from these and other regional locations include average indoor radon concentrations, working levels, local high energy gamma fluxes, waterborne and soilborne radon concentrations.

Experimental Methods

Time-averaged airborne radon concentrations were measured by track registration material (CR39) enclosed in a 125 ml jar that was sealed with a microporous polycarbonate membrane[3,4]. The detectors were placed in the two lowest levels in each home, usually at a height of approximately 2 m. After exposure, the detectors were chemically etched and the tracks counted manually under magnification. Tests in a controlled radon atmosphere and in homes show that this method is reproducible to within approximately 30% at low exposures and better than 20% at higher exposures. Absolute concentrations are established by side-by-side calibration with Terradex type SF Track Etch[R] detectors. The calibration coefficients from different measurement intervals show a variation of approximately 40%. Working levels were measured sites using either a modified Kusnetz or modified Tsivoglou (lowest floor) technique with a Ludlum model 43-1 alpha scintillation probe coupled to a model 2200 scaler. Typical uncertainties were on the order of 20%.

Waterborne radon concentrations were measured using a small sample, liquid scintillation technique[5] with a Beckman model 100C scintillation spectrometer. Care was taken to obtain an unaerated sample directly from the home's principal water supply. Most sites have private wells. The sensitivity is approximately 20 pCi/l and the reproducibility is approximately 10%.

Four techniques, two laboratory-based and two _in situ_, were used to characterize the soil's radon concentration. The soil samples for laboratory analysis were collected within 1 m of each site from a depth of approximately 1 m. Soilborne radon concentration was determined from the 1.76 MeV gamma flux from small (7 ml) samples inserted into the well of a 3' x 3' NaI. Data from this method is labelled SG in the Figures and Tables. In addition, radon emanation concentrations were measured with a liquid scintillation technique (label LS)[6]. At 26 sites the radon soil gas concentration was surveyed with filtered track registration detectors (label CR39) capped with thoron filters[7]. Finally, in order to get a rapid overall relative measure of the radium and thorium concentrations at a site, the 1.6 to 2.6 MeV gamma flux was surveyed in several areas of the upper midwest with a sheiled, carborne 3" x 3" NaI scintillator.

Results

A statistical summary of the average airborne, waterborne, and soilborne radon concentration is shown in Table 1. Table 2 summarizes the variations of the indoor airborne radon concentrations by season and compartment. The indoor radon and source distributions, shown in Figures 1 through 6, show a somewhat log-normal shape. Deviations from log normality are understandable in light of the nonuniformity of geological variation in site selection and the bias in measurement repitition. A summary of the radon and source data at each site (including working levels and gamma flux) is given in Table 3. Those soilborne radon concentrations missing in Table 3 are currently being measured.

Conclusions

Average indoor airborne radon concentrations observed in this study are significantly above the accepted national average but fall within previously observed regional extremes[1,2]. Specifically, approximately 70% of the measurements exceed 1 pCi/l, 40% exceed 3 pCi/l, 30% exceed 4 pCi/l, and 10% exceed 8 pCi/l. The airborne radon concentrations differ by floor, season, and year. A preliminary comparison of the central Minnesota concentrations with those from northeastern Minnesota indicate a regional variation as well.

While the airborne concentrations exceed the national average, external radon source strengths appear to be near or below the national averages. Waterborne radon concentrations are significantly higher in northeastern Minnesota than in central Minnesota. Simple regressional analysis failed to yield any significant correlation between the source strengths and the average basement concentration. A more detailed statistical analysis is planned for this spring when the data set is more complete. Any conclusion concerning the utility of various source measurements for predicting elevated indoor concentrations must await that analysis.

Acknowledgments

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Table I. Statistical summary.

Data Set	Number	Min,Max	Arithmetic Average	Median	Geometric Average	Stanerr	1Sigma	Range
**************************			INDOOR AIR		**********************************			
		pCi/l	pCi/l	pCi/l	Lin(Log)	pCi/l	pCi/l	pCi/l
All	135	0.5,29	3.7	2.6	2.7(.431)	1(0.002)	1.2	5.7
***	Seasonal							
Summer	39	1.0,29	4.3	1.4	2.5(0.398)	1(0.067)	0.9	6.5
Winter	96	0.5,18	3.4	2.7	2.8(0.447)	1(0.020)	1.4	5.4
***	Compartmental							
Below	70	0.7,29	4.9	3.1	3.3(0.519)	1(0.032)	1.4	7.8
First	65	0.5,7	2.5	2.1	2.1(0.322)	1(0.028)	1.2	3.8
***	Seasonal and Compartmental ***							
Sumbelow	22	1.0,29	6.4	2.2	3.6(0.556)	1(0.022)	1.2	10.8
Winbelow	47	0.7,18	4.2	3.1	3.2(0.505)	1(0.006)	1.6	6.6
Sumfirst	17	1.0,3.8	1.8	1.2	1.6(0.204)	1(0.012)	1	2.5
Winfirst	49	0.5,7	2.7	2.6	2.4(0.380)	1(0.005)	1.3	4.2
******************************				WATERBORNE	********************************			
All	79	20,3000	361	170	171(2.233)	1.1(.038)	52	564
CENT MN	56	20,2600	274	140	125(2.097)	1.1(.054)	39	399
NE MN	21	100,3000	664	220	403(2.605)	2 (0.299)	153	1058
******************************				SOILBORNE	******************************			
LS:pCi/g	64	0.05,0.19	0.11	0.11	.11(-.959)	1 (0.002)	0.08	0.15
SG:pCi/g	15	0.6,1.4	0.9	0.9	0.9(-.046)	1 (0.011)	0.6	1.3
CR:pCi/l	26	20,600	160	90	100(2.000)	1 (0.015)	38	220

Table II. Compartmental and seasonal ratios.

	Number	Average	Median	Range
A. First Floor/Below				
Summer	15	0.9	0.7	0.3 to 2.7
Winter	44	1.0	0.9	0.1 to 4.3
B. Summer/Winter				
First Floor	6	1.1	0.9	0.6 to 2.2
Below Grade	18	2.2	1.8	0.4 to 10.3

Table III. Summary by site.

		Source: / Technique:	Water LS	Soil LS	SG	CR39	Gamma	AIR: Year	83 Summer		83 Winter 84		84 Summer		84 Winter 85		85 Summer		85 Winter 86		Daughters mWL	
ID #	State	Town Units:→	pCi/l	pCi/g	pCi/g	pCi/l	Counts	pCi/l	Below	First	Below	First	Below	First	Below	First	Below	First	Below	First	Below	First
		Err.→	(5%,50)	(0.07)	(0.2)	(30%,50	(50)	(30%, 5)													(20%)	
SB31	MN	Avon	100	0.14	1.1	110	200		2	2	2	2	6	5	3	3			U	U	11	14
FB31	MN	Avon	90	0.10	0.6	65					7	5	9		5	3						
FB32	MN	Avon	100	0.15	0.4	60					3	3			8	4						
FB33	MN	Cold Spring	270	0.16		55					4	3			4	2						
FB34	MN	St.Joesph	90	0.15		600					5	7			5	4						
FB35	MN	St.Joesph	140	0.08	0.9	20					5	1	6		18	2						
FB36	MN	St.Joesph	190	0.15	1.2	80					1	1										
FB37	MN	St.Joesph	390	0.15	1.3	80					1	1										
FB38	MN	Avon	120	0.05	0.6	130					3	1										
FB39	MN	St.Joesph	170	0.14	1.1	125					2	4										
FB310	MN	St.Joesph	1500	0.16	1.0	150					4	4			3	3						
FB311	MN	St.Cloud	2600			300					3	3	7		3	2						
FB312	MN	St.Cloud	20	0.11		180	150					2										
FB313	MN	St.Joesph	250	0.17							6											
FB314	MN	Richmond	300	0.12	1.4	20					4	4	5		6	2						
FB315	MN	Richmond	680			450						2										
FB316	MN	St.Cloud	1100	0.08	0.6	200					7	4										
FB317	MN	St.Joesph	80	0.12		120					8	4	29		18	4						
FB318	MN	Collegeville	50								1	2										
FB319	MN	Collegeville	50								2	7										
FB320	MN	Collegeville	50								2	3										
FB321	MN	Collegeville	50								1	2										
FB322	MN	Collegeville	50									2										
FB323	MN	Collegeville	50									1										
FB324	MN	Collegeville	50								1	1										
FB325	MN	St. Joseph	30								3	1										
FB326	MN	Collegeville	50	0.14		80	200				1	1			2	2		1	U			
FB327	CO	Old Snowmass													9				U	U		
FB328	MN	St.Joesph	1150	0.06		500					5		5		3	3						
SB41	MN	Avon											25		2	5						
SB42	MN	Sauk Rapids	90	0.10		25							3		2	3						
FB41	MN	St.Cloud	20	0.08		70									4	3						
FB42	MN	Duluth	20			25									4	2						
FB43	WI	Menomonie	200			50									6	4						
FB44	MN	New Prague	150			70									3	4						
FB45	MN	St.Cloud	110	0.05											3	2						
FB46	MN	St.Cloud	20			75									2	1						
FB47	MN	St.Cloud	20	0.12		250									3	2						
FB48	MN	St.Cloud	20												2	1						
SB51	MN	Pequot Lakes	170	0.10													1			U		2
SB52	MN	Cloquet	350	0.10													1	3	U	U	28	6
SB53	MN	Cloquet	520	0.14													1	1	U	U	3	1
SB54	MN	Cloquet	330	0.13													1	1	U	U	22	8
SB55	MN	Cloquet	450	0.12													1	1	U	U	10	8
SB56	MN	Moose Lake	170	0.12													13	4	U	U	150	83
SB57	MN	Moose Lake	2700	0.10														1		U	2	4
SB58	MN	Moose Lake	930	0.12			200										1	1	U	U	10	2
SB59	MN	Moose Lake	350	0.10			100										2	2	U	U	10	9
SB510	MN	Moose Lake	280	0.12			100										2	1	U	U	11	1
SB511	MN	Moose Lake	180	0.14			100										10	3	U	U	23	14
SB512	MN	Sturgeon Lake	140	0.11			250										2	1	U	U	24	2
SB513	MN	Kerrick	1250	0.10			300											1	U	U	18	2
SB514	MN	Sandstone	1120	0.09			200										1	1	U	U	9	1
SB515	MN	Mora	150	0.09			100										1	1	U	U	12	1
SB516	MN	Mora	850	0.19			250												U	U	19	5
SB517	MN	Hinckley	220	0.11			100												U	U	2	1
SB518	MN	Hinckley	100	0.10			200												U	U	5	2
SB519	MN	Finlayson	450	0.10			100												U	U	16	1
SB520	MN	Sawyer	160	0.11			150													U		2
SB521	MN	Carlton	210	0.09			150												U	U	8	4
SB522	MN	Kettle River	3030	0.13			400												U	U	24	7
FB51	MN	Sauk Center	150	0.11			200												U	U	8	2
FB52	MN	Kensington	230	0.18			150												U		2	
FB53	MI	Eagle River					150												U	U		5
FB54	MI	Eagle River																	U			
FB55	MI	Eagle River																	U			
FB56	MI	Ahmeek																	U			
FB57	MN	Moose Lake																	U	U		
FB58	MN	Kettle River																	U	U		

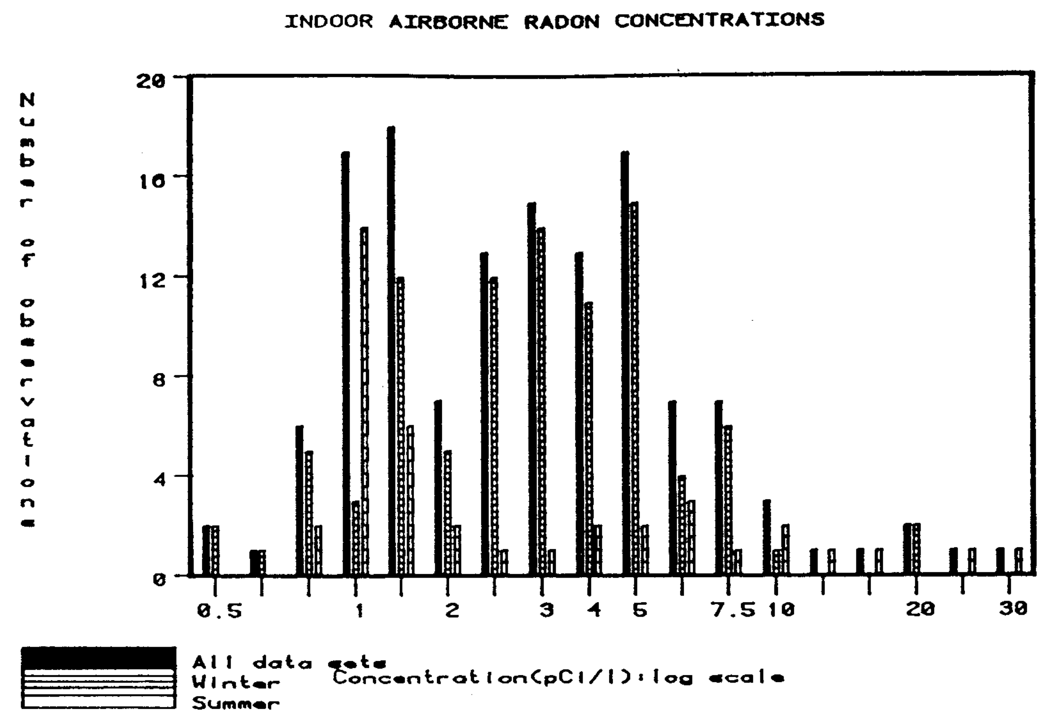


Figure 1: Seasonal distributions.

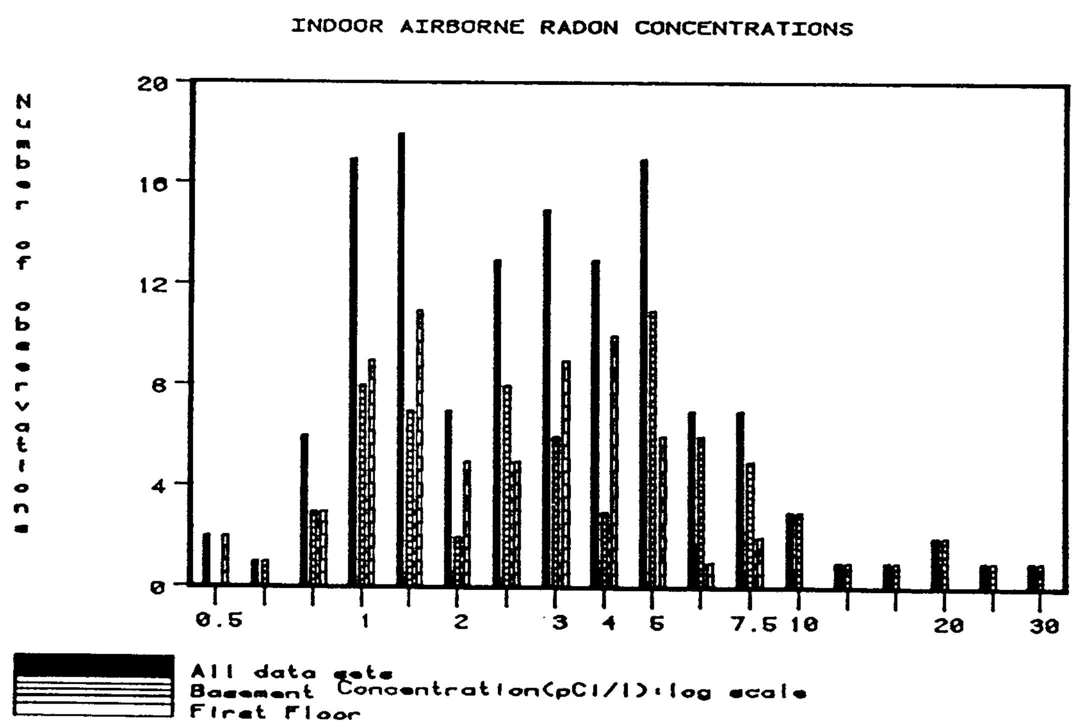


Figure 2: Compartmental distributions.

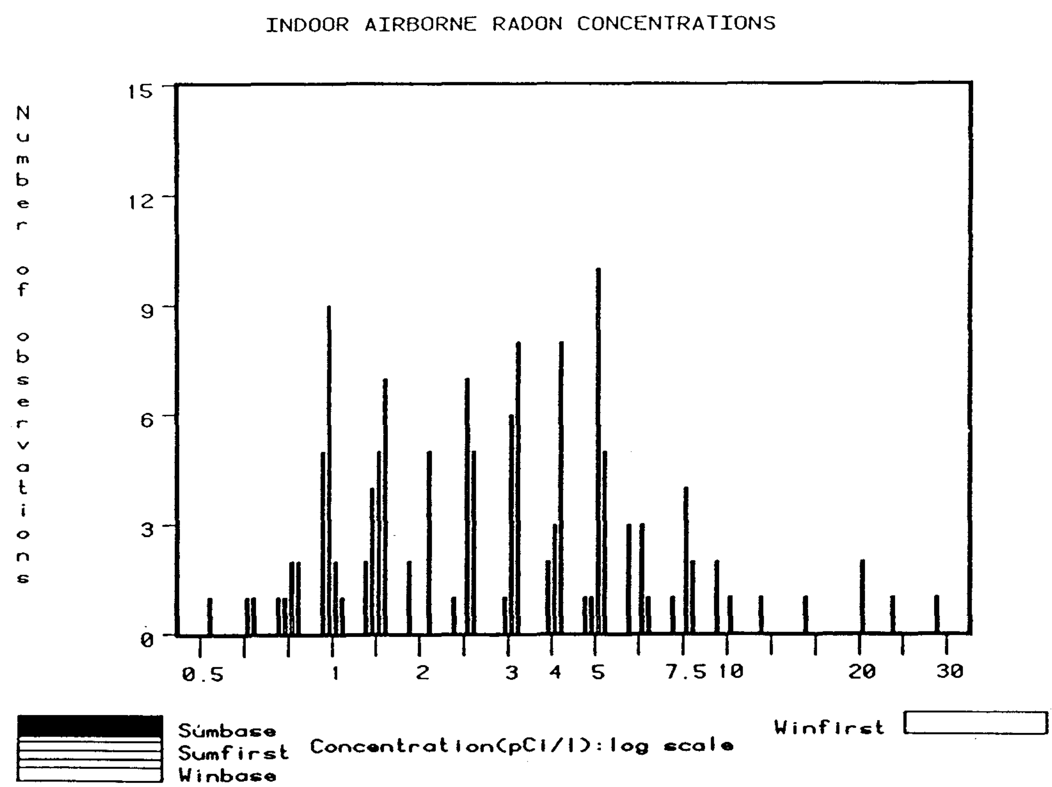
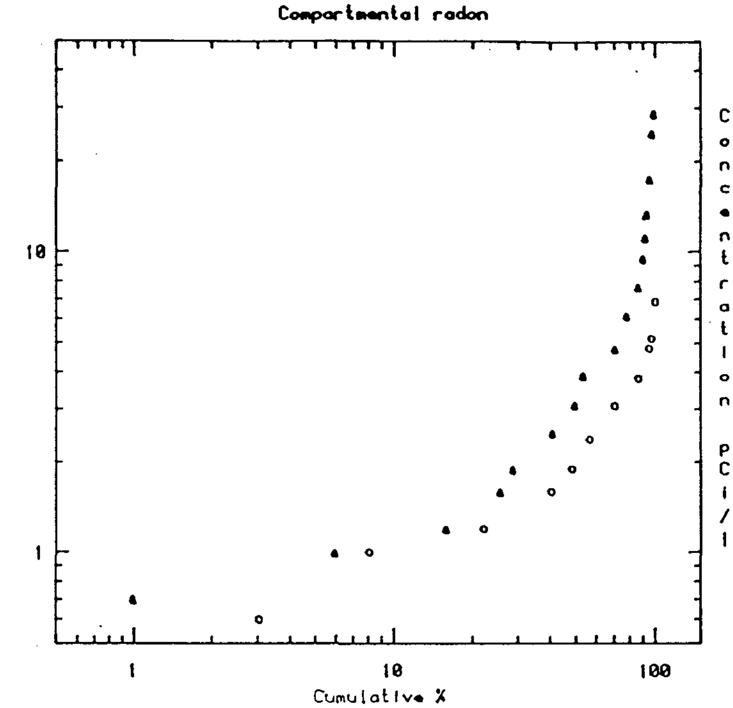
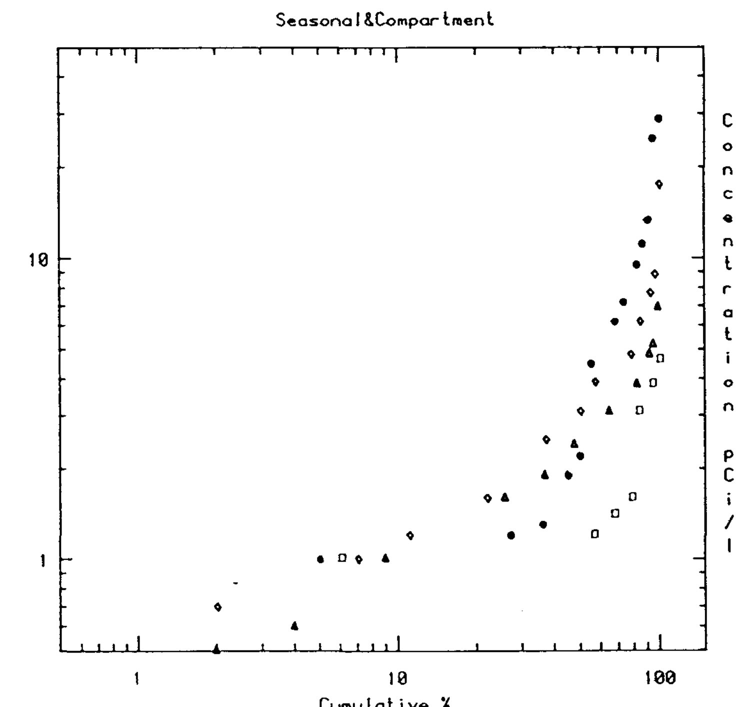


Figure 3: Seasonal and compartmental distributions.



Δ = Basement, O =First Floor

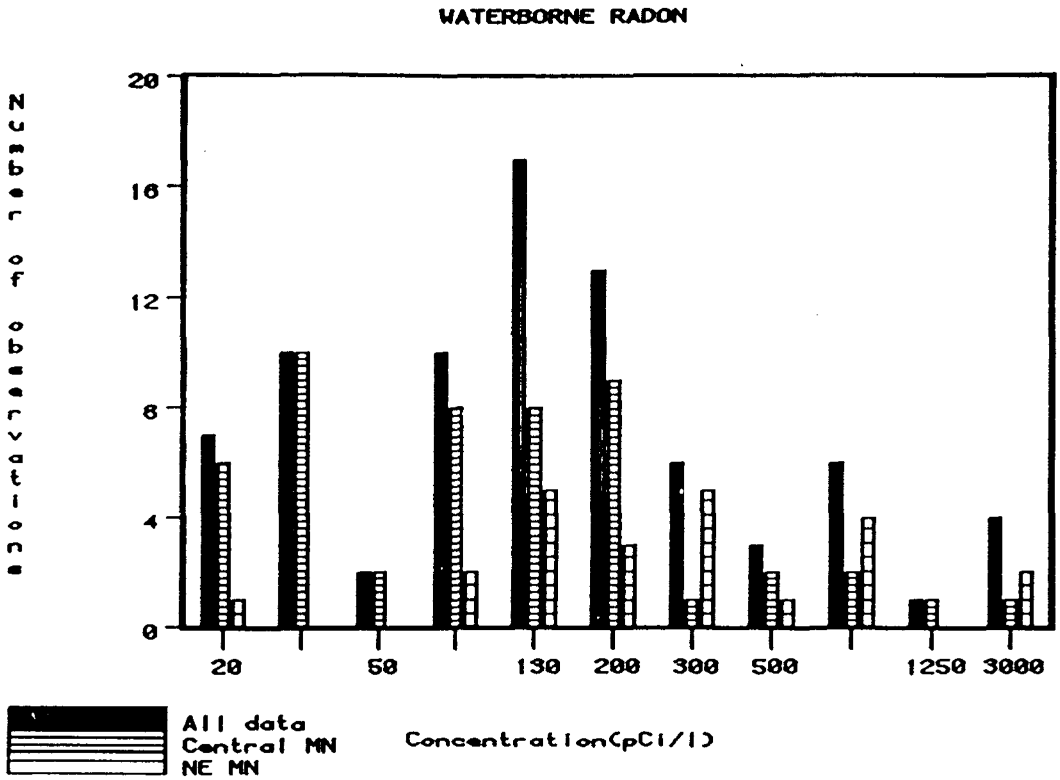


Δ =Winter First Floor

O =Summer Basement

□ =Summer First Floor

Figure 4: Indoor radon cumulative % distributions.



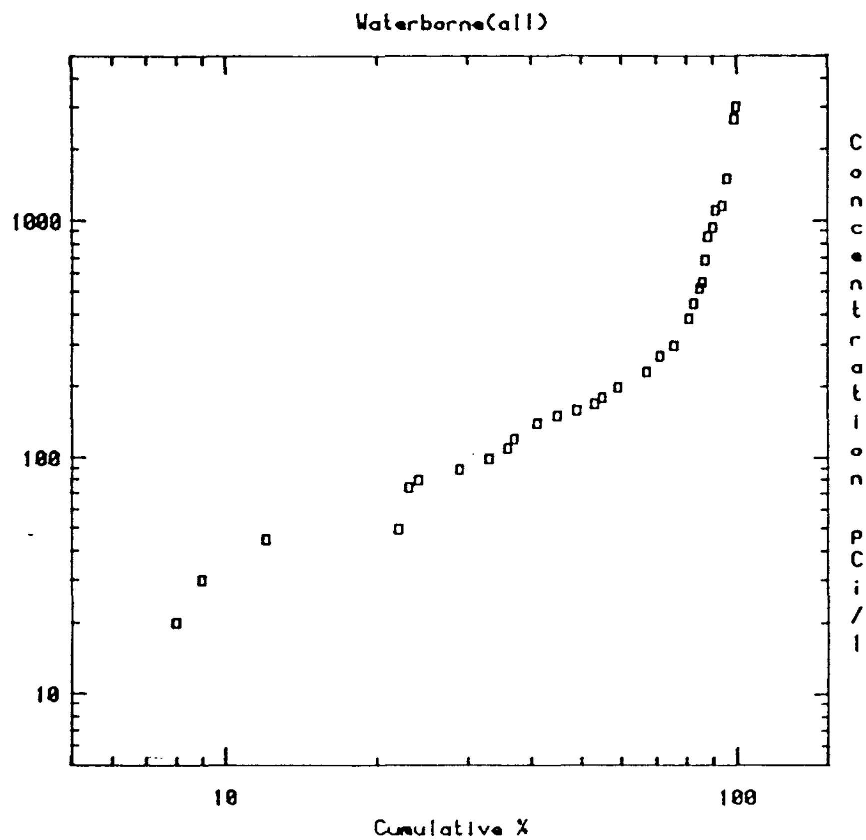


Figure 5: Waterborne radon distributions.

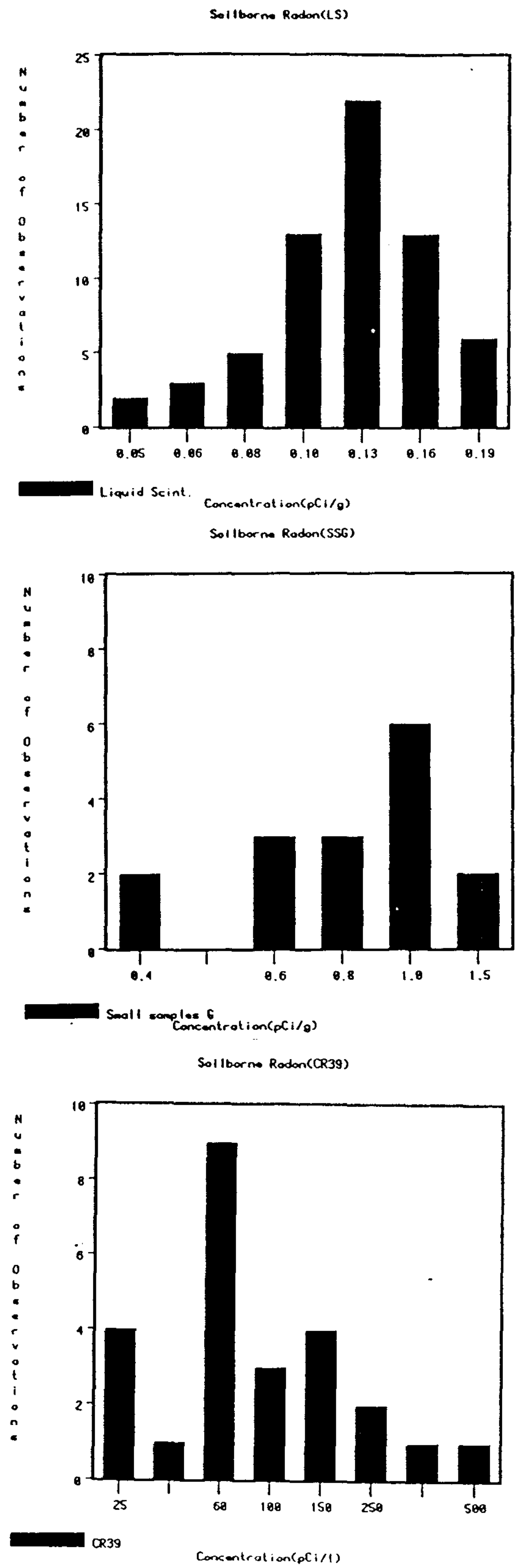
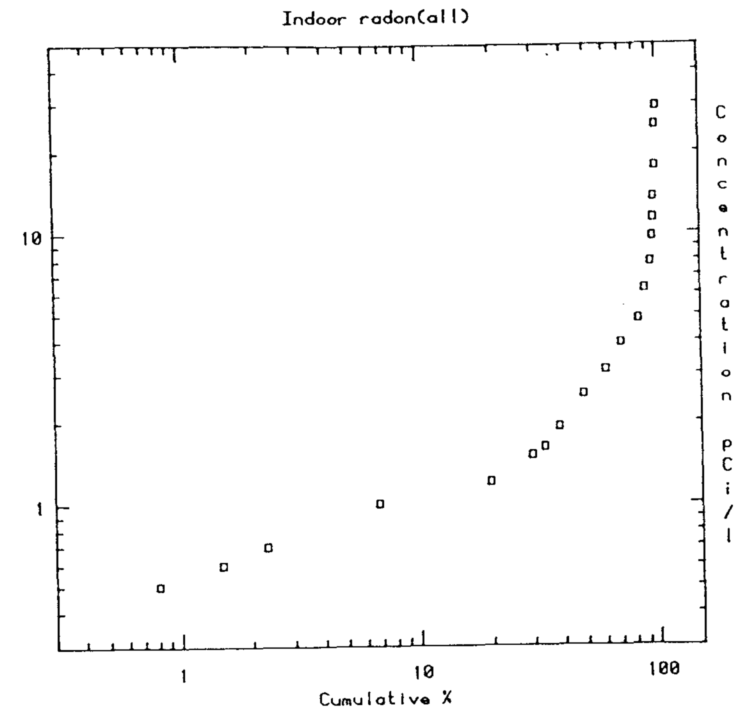
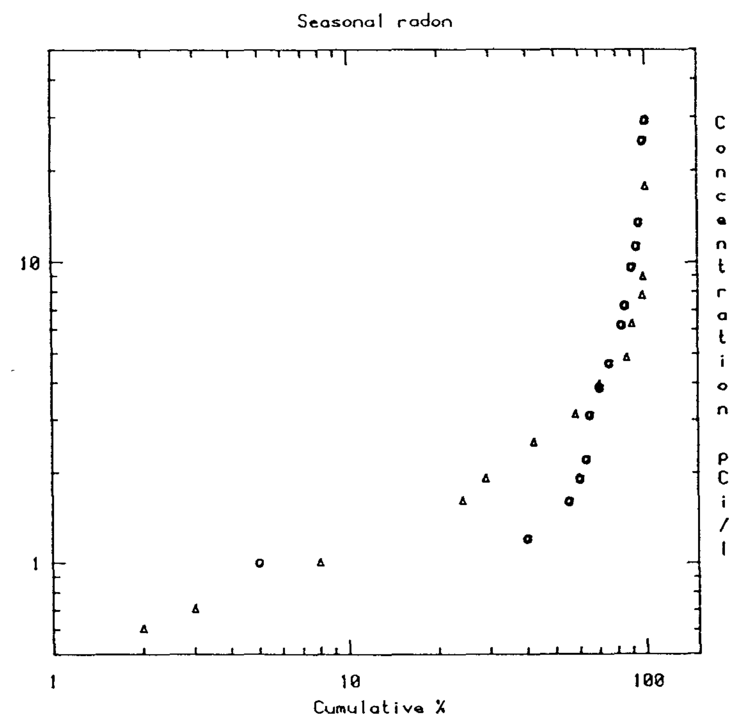


Figure 6: Soilborne radon distributions.





(c) Δ= Winter, O= Summer

Figure 4: Indoor radon cumulative % distributions.