STUDY OF THE REPORTED INDOOR RADON MEASUREMENT RESULTS FOR RESIDENTIAL STRUCTURES AND LARGE BUILDINGS IN FLORIDA

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ABSTRACT

Indoor radon concentrations have been tested in thousands of residential housing units and large buildings during the past six a half years in the State of Florida. Beginning in 1989, testing has been conducted in compliance with the state radon regulations. These regulations mandate that periodic indoor radon testing be conducted in facilities that render services of public nature, and require certification for individuals providing radon measurement and mitigation services for a fee or remuneration in Florida. Reported indoor radon measurement results were developed into database resources, maintained by the Florida Department of Health and Rehabilitative Services (HRS). One resource generated from the mandatory testing results of facilities, and the other generated from the certified radon businesses reporting their measurement activities as a part of their license requirements. As of July 1996, HRS's databases contain indoor radon test results for 32,563 and 23,594 residential housing and non-residential units, respectively. The residential part of these data sets is approximately 10-fold larger than the previous major survey performed in Florida during 1986-1987 by Geomet Technologies, Inc., in which only residential housing units was surveyed. Correlation analysis between the total number of buildings and the population geographical distribution, as variables, of HRS's data sets resulted in 0.85 and 0.97 correlation coefficients for residential housing and non-residential units, respectively. These coefficients indicate that both variables were independent and a reasonable random distribution exist, which qualifies the data sets to be used for statewide representation. A statewide weighted average indoor radon concentration of 1.55 pCi/l is found to exist in Florida residential units with 11.8% of all housing units experiencing indoor radon levels exceeding 4 pCi/l. The statewide weighted average indoor radon concentration for non-residential units is 0.74 pCi/l with approximately 6% of buildings with levels greater than 4 pCi/l. Applying correction factors for the average household occupancy and population growth to the 1994 population data, a conservative estimate of at least one half-million residential housing units in Florida are exposed to indoor radon concentrations exceeding the national action level.

INTRODUCTION

There have been large scale radon surveys in Florida that can be divided into two categories based on the procedures and objectives of the survey. One survey was mandated by the Florida Legislature in 1986. Its purpose was to identify all significant land areas where buildings should be constructed to radon resistant standards. To identify these areas and assess the distribution of indoor radon the survey measured indoor radon concentrations in households across Florida as well as radon soil-gas concentrations and gamma radiation field measurements. A second nationwide survey which included Florida, was initiated by the United States Environmental Protection Agency (USEPA) in response to the Indoor Radon Abatement Act passed by Congress in 1988. This survey assessed the radon potential of the entire United States and emphasized the geologic assessment of soils and rocks in addition to data on indoor radon concentrations. The resulting radon potential maps were intended to assist state radon programs in targeting their radon resources and to identify areas where radon resistant construction should be used. The information from this USEPA survey was further used and expanded by the Florida Department of Community Affairs (DCA) to develop more detailed potential maps.

The survey directed by the USEPA enlisted the aid of the United States Geological Survey (USGS) through an interagency agreement. This survey assessed five indicators of radon potential; 1) indoor radon measurements, 2) geology, 3) aerial radiometric data, 4) soil parameters, and 5) foundation types. This combined effort resulted in the an *EPA Map of Radon Zones* for each state (USEPA 1993). Each county was designated as a Zone 1, 2 or 3 based on its radon potential. Zone 1 being the highest potential and Zone 3 the lowest. State and local governments could concentrate resources in Zones 1 and 2 to increase their efficiency. Because Florida had its own requirement to develop radon protection maps, DCA used additional data and sophisticated modeling techniques to further refine its maps. The resulting maps identify areas that should use Florida's radon resistant construction standards.

The survey mandated by the Florida Legislature in 1986 (House Bill 1380) was commissioned by the Florida Institute of Phosphate Research (FIPR) and performed by the primary contractor Geomet Technologies, Inc. Geomet was assisted by subcontractors that included the University of Florida and Florida State University. The study was completed and published in 1989 as the "Florida Statewide Radiation Study (FSRS)", (Najda et. al. 1989). The principal methodology of this survey was to measure indoor radon concentrations across the state. However, approximately half of the sites included radon in soil gas and gamma radiation measurements. Some of this data was subsequently used by the other radon potential mapping projects.

In the FSRS, two survey approaches were employed, land and population -based, to cover the state. The USGS's 1:24,000 quadrangle maps, developed from aerial photography around the 1970s, were used in the land-based survey to select residential structures for testing. Results generated from charcoal canisters deployed for 72-hour, and qualified under the land-based selection criteria were successfully collected from 3,050 households. Based upon these results a statewide average indoor radon concentrations of 1.0 pCi/l with 3.8% of the tested homes equal or exceeding 4 pCi/l. The maximum indoor radon concentration detected in this survey (34.2 pCi/l) was observed in Marion County.

In the population-based survey, random selection of households was employed based on the 1980 Census database. Unlike the land-based survey, which was performed by trained field technicians, the population-based survey was performed by household occupants who received instructions and communications by the mail. This arrangement allowed for simultaneous covering of the state's counties in a short period of time compared to the segmented nature of covering in the land-based survey. The population-based survey measured only indoor radon concentrations while the land-based survey measured indoor radon and progeny, soil-gas radon, and indoor/outdoor gamma radiation fields. A total of 3,106 household results, from charcoal canisters deployed for 72-hour, qualified under the population-based housing unit selection criteria. These measurements were completed in a period of approximately six months. A statewide average indoor radon concentration of 0.7 pCi/l was obtained with 2.6% of the homes equal to or exceeding 4 pCi/l. The maximum indoor radon concentration was observed in Lee County at 28.2 pCi/l.

APPROACH

As a part of establishing radiation standards in the State of Florida, the State Department of Health and Rehabilitative Services developed Chapter 10D-91, Part XIII, of the Florida Administrative Code (FAC) to implement the provisions of Section 404.056 of the Florida Statutes. Upon the legislation passing of this rule in 1986, the state became the first in the nation to establish radiation standards in buildings for the protection of its citizens from excessive radiation exposure from naturally occurring radioactive materials.

In 1989, Chapter 10D-91 of the FAC (administered by HRS) mandates that all individuals performing radon measurement and mitigation services in Florida for a fee or other remuneration be certified by the state. Furthermore, the Chapter established a mandatory periodic (5-year cycle) indoor radon testing program for buildings where services of public nature are rendered. These buildings include K-12 grade private and public schools, 24-hour care facilities (hospitals, nursing homes, adult congregate living facilities, mental and correctional institutions, ..., etc.), and all state-licensed day care centers for children or minors. This provides for a major source of indoor radon concentration measurement results. All indoor radon results of the mandatory testing program are collected by HRS as a part of facilities compliance with the state regulations. Indoor radon measurement results, performed by certified individuals in the state, are also collected by HRS on a monthly basis as a part of the licensee certification requirements. All collected data have been organized and electronically entered into the respective databases, thus forming a major indoor radon concentration data resources for the State of Florida.

As of July 1996, the HRS databases have indoor radon test results for 32,563 and 23,594 residential housing units and non-residential units, respectively. Each indoor radon concentration unit result is generated from one or more indoor radon measurement devices. Testing procedures for residential housing units have been performed according to the USEPA short-term testing protocols. Testing for non-residential units have been conducted according to the mandatory measurement procedures outlined in Chapter 10D-91 of the FAC. The latter incorporates requirements for several building aspects of significant influence on indoor radon during testing such heating, ventilating, and air conditioning systems. Significant numbers of these unit results, particularly the non-residential results consist of the average reading of many devices employed in the testing of that building. Thus, each unit result represents the spacial average indoor radon concentration of the tested space and the temporal average indoor radon concentration for a minimum 48-hour period in that space. All indoor radon measurement devices used in conducting the tests meet proficiency requirements of the USEPA or an alternate proficiency program determined to be substantially equivalent to the USEPA measurement proficiency program (FHRS 1994).

The above indoor radon concentration data resources have been organized into three databases. Certified-reported housing units database contains residential indoor radon concentration results performed by certified radon individuals. Mandatory-reported residential housing units database contains results from facilities that were initially constructed as residences, and mandatory-reported non-residential units database contains results from primarily large buildings. Considering the method of acquiring indoor radon results, the certified-reported database is similar to the FSRS's land-based survey where testing was performed by trained technicians. The mandatory-reported residential housing units database is similar to the population-based survey, where testing was performed under the responsibility of the household owner. In comparison, the certified-reported database has 30,543 residential housing unit results, approximately 10-fold the size of data used in the FSRS land-based survey. The mandatory-reported residential database has approximately 65% the household units used in the FSRS population-based survey. Since the FSRS study covered only residential housing units, the HRS mandatory-reported non-residential units database represents a unique source, and the only major one, for indoor radon testing results performed in large and commercial buildings in Florida.

RESULTS AND DISCUSSION

The number of occupied housing units in Florida was (3,744,254), according to the 1980 Census used in the FSRS's land and population -based surveys. Using the numbers of tested households units in the land and population -based surveys, the statewide sampling coverage representations are approximately 0.081% and 0.082%, respectively. The combined figure for both surveys therefore is approximately 0.163%. To compare this figure with the residential housing units results in the HRS databases, an estimate of 2.7 persons per household can be used. Florida population estimate was reported in 1994 as 13,878,905 (FDOC 1996). With the consideration of population growth of 4% per year, the compound increase of population in 1996 can be estimated as (15,011,423), which results in approximately 5,559,786 residential housing units. The statewide sampling coverage is then 0.586%, approximately 3.5 times the FSRS figure.

Unlike the sampling representation in the FSRS, in which a design measure was employed to ensure proportional statistical representation statewide, the general structure of the collected indoor radon concentrations for both residential housing and non-residential unit sets in the HRS databases was not initially designed to ensure random distribution of sample representation with respect to the state geographical population. A one concern is that socio-economical factors associated with region(s) in the state might had influenced collected results and therefore resulted in a biased representation statewide with respect to specific geographical regions. Nevertheless, the resulted data collection was rather expected than designed to provide reasonable random representation proportional to the population geographical dependence statewide since no area-specific requirements were implemented in the state regulations for the purpose of indoor radon testing.

Figure 1 shows the total number of buildings tested in each county for both residential and non-residential units databases and the distribution of statewide county populations. In both databases positive correlation are observed. Correlation analysis of county population and number of tested buildings variables results in correlation coefficients (r) of 0.85 and 0.97 for residential housing units and non-residential units databases, respectively. As evidence from the figure, a strong random distribution, particularly for the non-residential set, exist between the county population variable and the total number of tested buildings variable in that county, in which neither of them can be controlled. Therefore, qualification of both data-sets based on reasonable random sampling representation statewide can be safely assumed.

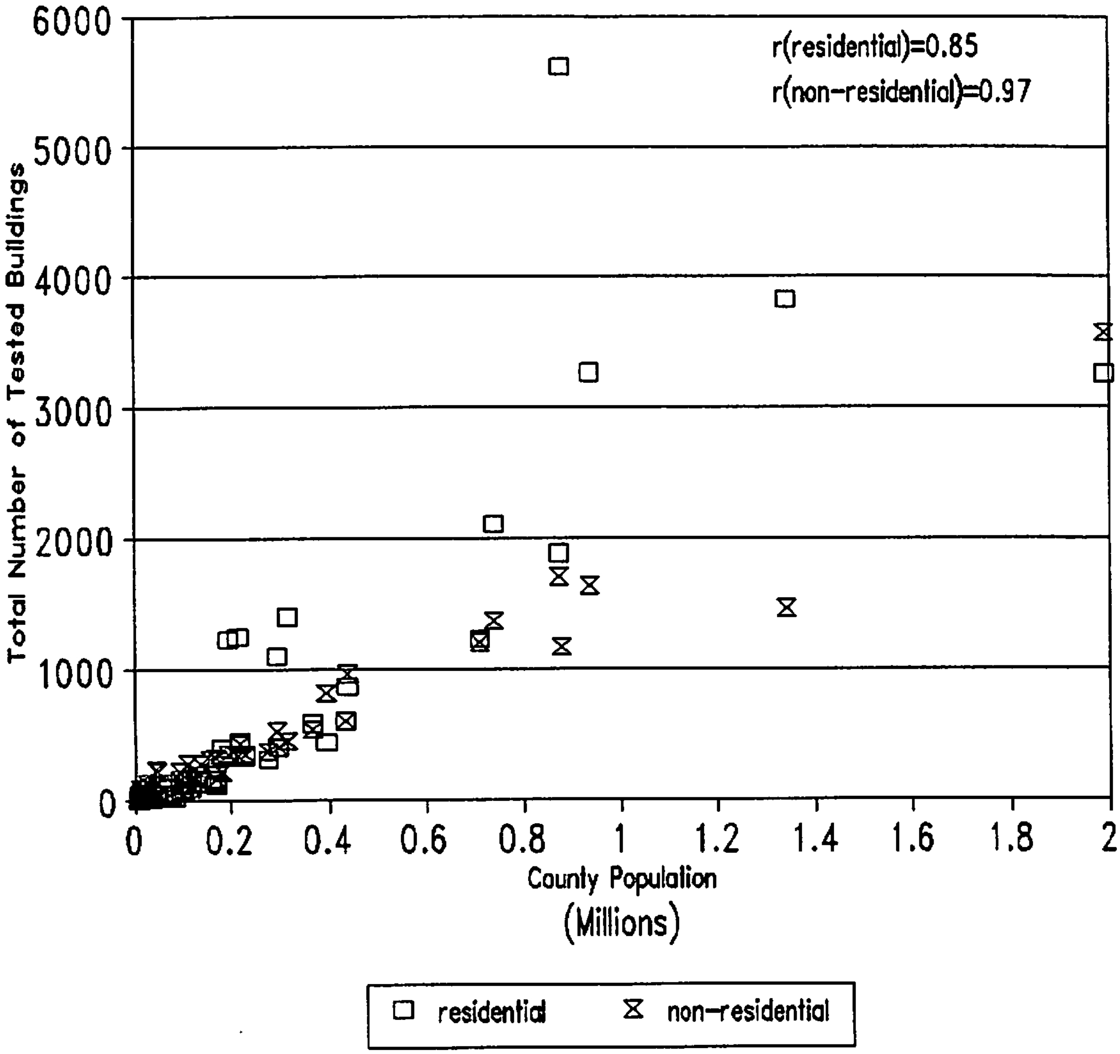

Figure 1: The total number of buildings tested and reported as corresponded to the estimated 1996 county population in Florida counties for HRS residential housing and non-residential data sets.

Indoor radon measurement results in HRS residential housing units databases have been collected over the period of nearly 6.5 years versus the one year collection period of the FSRS providing improvement for averaging the seasonal dependency of indoor radon. The statewide sampling coverage figure associated with the averaging of seasonal dependency of indoor radon concentrations in HRS residential housing units databases, provide significant improvement in representing indoor radon concentrations in Florida. Table 1 shows the summary of statewide average and maximum indoor radon concentrations obtained from each of the HRS and FSRS databases for residential housing and non-residential units. The weighted means of residential housing units calculated based on combining of residential data sets for both HRS and FSRS, are also shown. Table 2 listed the average and maximum indoor radon concentrations, along with other data, for the Florida 67 counties obtained from HRS residential housing and non-residential units data sets. The population of each county is reported in the third column according to the 1994 Florida population. The number of estimated housing units in 1996 for each county can therefore be calculated based on the factors of annual population growth and residential housing occupancy used earlier in this section. Each county in Table 2 is assigned an identification number (I.D., 1 to 67) starting alphabetically from Alachua County (I.D. 1) to Washington County (I.D. 67). These identification numbers may be used to refer information pertained to a specific county presenting in later figures.

Table 1: Summary of statewide weighted and maximum indoor radon concentrations for residential housing and non-residential units in HRS's databases and residential housing units in FSRS study.

Data Source	Average Indoor Radon Concentration (pCi/l)	Maximum Indoor Radon Concentration (pCi/l)
HRS Certified-Reported Database	1.6	270
HRS Mandatory-Reported Residential Database	0.81	97
HRS Mandatory-Reported Non-Residential Database	0.74	86.1
HRS Combined Residential Databases (weighted average)	1.55	----
FSRS Land-Based Residential Database	1.0	32.4
FSRS Population-Based Residential Database	0.7	28.2
FSRS Combined Residential Databases (weighted average)	0.85	----

Statewide average residential housing indoor radon concentrations of 0.81 pCi/l and 1.6 pCi/l are obtained from mandatory-reported and certified reported residential databases, respectively. The overall simple residential average indoor radon concentration of the resulted range (0.81-1.6) is then 1.2 pCi/l. Since the number of units tested in the certified-reported databases is 15 times greater than reported units in the mandatory-reported residential databases (30,543 vs. 2020) and the certified-reported testing were performed by trained individuals, the actual residential average indoor radon concentration is statistically closer to the 1.6 pCi/l end.

Giving an equal weight to the validity of each average result in the 32,563 reported residential units, the weighted mean of the average residential indoor radon concentrations is then equal to 1.55 pCi/l in Florida. The corresponding figures obtained from the FSRS study are 0.7 pCi/l and 1.0 pCi/l for the population and land -based survey, respectively. The same trend of obtaining higher levels when testing is performed by trained individuals is also evident. However, the sample number of residential units in the FSRS was in a similar order (3,106 vs. 3,050) for the population and land-based surveys bringing the weighted mean, considering equal weight of validity, of the average residential indoor radon concentration, practically equal to the simple average of 0.85 pCi/l. The latter figure is approximately half the current estimate based on the 10-fold size larger residential databases. This difference is believed to be attributed to two factors related to the condition and the volume of testing. It has been observed that when testing is performed with better control in employing the USEPA short-term testing protocols, through trained individuals, the testing result is likely to be higher than when testing performed by household owners. This phenomenon is true for both set of data collected by the FSRS and the HRS.

Table 2: Weighted average and maximum indoor radon concentrations in residential housing and non-residential units in Florida. The state is divided into eleven regions covering its 67 counties. The percentage columns show the percentage of reported units with indoor radon concentration greater than 4 Pci/l per the specific county.

NORTHWEST			RES.			NON- RES.		
I.D	County	Pop. (1994)	Avg. Pci/l	Max. (pCi/l)	>4pCi/l (%)	Avg. (pCi/l)	Max. (pCi/l)	>4pCi/l (%)
3	Bay	136,289	0.7	2.2	0.0	0.4	3.9	0.36
17	Escambia	277,067	1.0	48.3	0.65	0.7	24.0	1.89
30	Holmes	16,926	0.9	1.4	0.0	0.4	3.6	0.0
46	Okaloosa	158,318	0.6	2.9	0.0	0.5	62.6	0.65
55	Santa Rosa	93,813	2.7	2.9	0.0	0.6	14.5	6.88
66	Walton	31,860	0.6	1.0	0.0	0.4	3.1	0.0
67	Washington	18,115	0.6	1.3	0.0	0.4	3.8	0.0
APALACHEE								
7	Calhoun	11,565	1.8	2.5	0.0	0.3	3.7	0.0
19	Franklin	9,995	0.9	2.5	0.0	0.4	2.8	0.0
20	Gadsden	44,853	1.6	5.8	16.67	0.8	13.9	3.98
23	Gulf	13,265	0.5	0.7	0.0	0.7	8.6	6.25
32	Jackson	45,421	1.2	4.9	1.92	0.6	4.6	0.45
33	Jefferson	13,085	1.1	2.2	0.0	0.5	11.2	1.72
37	Leon	212,107	2.5	59.2	17.19	1.2	27.9	5.28
39	Liberty	6,538	0.3	0.3	0.0	0.5	20	5.0
65	Wakulla	16,441	2.3	2.4	0.0	1.0	4.0	0.0
SUWANNEE								
1	Alachua	193,879	4.5	270	32.89	2.2	82.7	22.25
4	Bradford	24,210	0.6	3.7	0.0	0.4	10	2.31
12	Columbia	48,897	4.1	117	12.5	1.2	13.3	9.22

15	Dixie	12,150	1.3	1.6	0.0	0.5	4.5	2.86
21	Gilchrist	11,526	1.1	2.2	0.0	1.5	37.1	3.57
24	Hamilton	11,918	0.3	0.6	0.0	0.7	3.9	0.0
34	Lafayette	5,826	0.3	0.3	0.0	0.5	2	0.0
40	Madison	17,768	10.3	11	50	0.7	8.6	5.26
61	Suwannee	29,299	1.2	5.1	4.35	0.7	3.7	0.0
62	Taylor	17,461	2.0	4.3	10	0.8	4	0.0
63	Union	12,534	1.2	1.3	0.0	0.5	10	1.27
	NORTHEAST							
2	Baker	19,700	0.9	2.3	0.0	0.6	2.8	0.0
10	Clay	117,779	0.8	4.9	1.48	0.7	49.6	1.21
16	Duval	710,592	0.8	5.9	0.41	0.5	8	0.83
18	Flagler	35,292	0.7	1.5	0.0	0.7	7.2	16.67
45	Nassau	47,371	1.0	2.8	0.0	0.6	11.2	0.81
54	Putnam	68,980	0.9	5.8	2.78	0.4	3	0.0
58	St. Johns	94,758	1.0	5.8	0.65	0.5	19.7	0.65
	N. CENTRAL							
9	Citrus	102,846	1.8	6.1	8.11	0.9	8.6	0.94
27	Hernando	114,866	1.1	10.4	3.53	0.8	12.9	2.2
38	Levy	29,111	1.8	4.7	8.38	1.0	3.3	0.0
42	Marion	217,862	6.2	134	51.33	3.6	86.1	41.01
60	Sumter	35,189	1.37	2.8	0.0	1.2	28	4.67
	CENTRAL							
5	Brevard	436,333	1.5	18.3	7.6	0.4	51	2.14
35	Lake	171,168	0.8	11.6	2.13	0.7	30	0.63
48	Orange	740,167	1.0	24	1.86	0.6	25.1	1.18
49	Osceola	131,111	1.1	3.9	0.0	0.4	26.5	1.0
57	Seminole	316,555	0.8	8.8	0.36	0.8	30	2.63
64	Volusia	396,631	0.7	5.3	0.91	0.5	44	1.22
	S. CENTRAL							
14	DeSoto	26,260	2.1	10.2	7.69	0.5	4.5	1.11
25	Hardee	22,454	5.6	22.5	14.29	1.3	12.2	19.18

28	Highlands	75,860	0.6	2.3	0.0	0.5	5.9	1.43
47	Okeechobee	32,325	0.8	1.3	0.0	0.4	11	1.49
53	Polk	437,204	2.6	43.2	17.71	1.3	60.1	11.03
	TAMPA BAY							
29	Hillsborough	879,069	2.0	90.9	10.69	0.8	34	5.1
41	Manatee	228,283	1.3	10.3	2.4	0.7	9.2	4.3
51	Pasco	298,852	1.0	11.8	1.98	1.3	34	12.94
52	Pinellas	870,722	1.1	97	1.92	0.7	43	5.88
	SOUTHWEST							
8	Charlotte	124,883	2.0	9.2	7.26	0.8	10.5	4.14
11	Collier	180,540	2.3	19	8.46	0.5	27.8	4.09
22	Glades	8,366	0.3	0.3	0.0	0.3	0.3	0.0
26	Hendry	28,686	1.22	2.5	0.0	0.6	3.5	0.0
36	Lee	367,410	2.3	47.5	12.07	0.7	71	3.2
56	Sarasota	296,002	2.3	30.3	16.5	1.0	49.9	5.01
	TRE. COAST							
31	Indian River	97,415	0.7	4.2	2.94	0.4	19.3	0.63
43	Martin	110,227	0.8	9.2	1.24	0.5	30	0.36
50	Palm Beach	937,190	2.7	37	21.72	0.6	12.9	1.72
59	St. Lucie	166,803	0.7	2.5	0.0	0.4	6	0.94
	SOUTHEAST							
6	Broward	1,340,220	2.1	21.1	17.71	0.7	31.2	3.1
13	Dade	1,990,445	1.8	29.6	11.69	1.1	44.6	14.47
44	Monroe	82,252	1.0	5.3	13.04	0.6	5.2	2.27

Figure 2 shows the ratio of the average indoor radon concentrations obtained by trained individuals in the certified-reported database over average indoor radon concentrations obtained by household owners in the mandatory-reported residential housing units database per each Florida county. The overall ratio for HRS residential databases is 1.98 compared to 1.43 for the FSRS survey data. It was also observed that when larger numbers of tests (large volume of sampling representation) are performed, the resulted statistical sampling representation is expected to produce higher average indoor radon concentration as opposed to a smaller sampling representation for the same community population. The latter factor shall reach saturation at a point when sampling volume become equal to the optimal statistical representation of the population community, and consequently, the overall average may reach a plateau in which further increase in the sample volume has only a minimal contribution in adjusting the average figure.

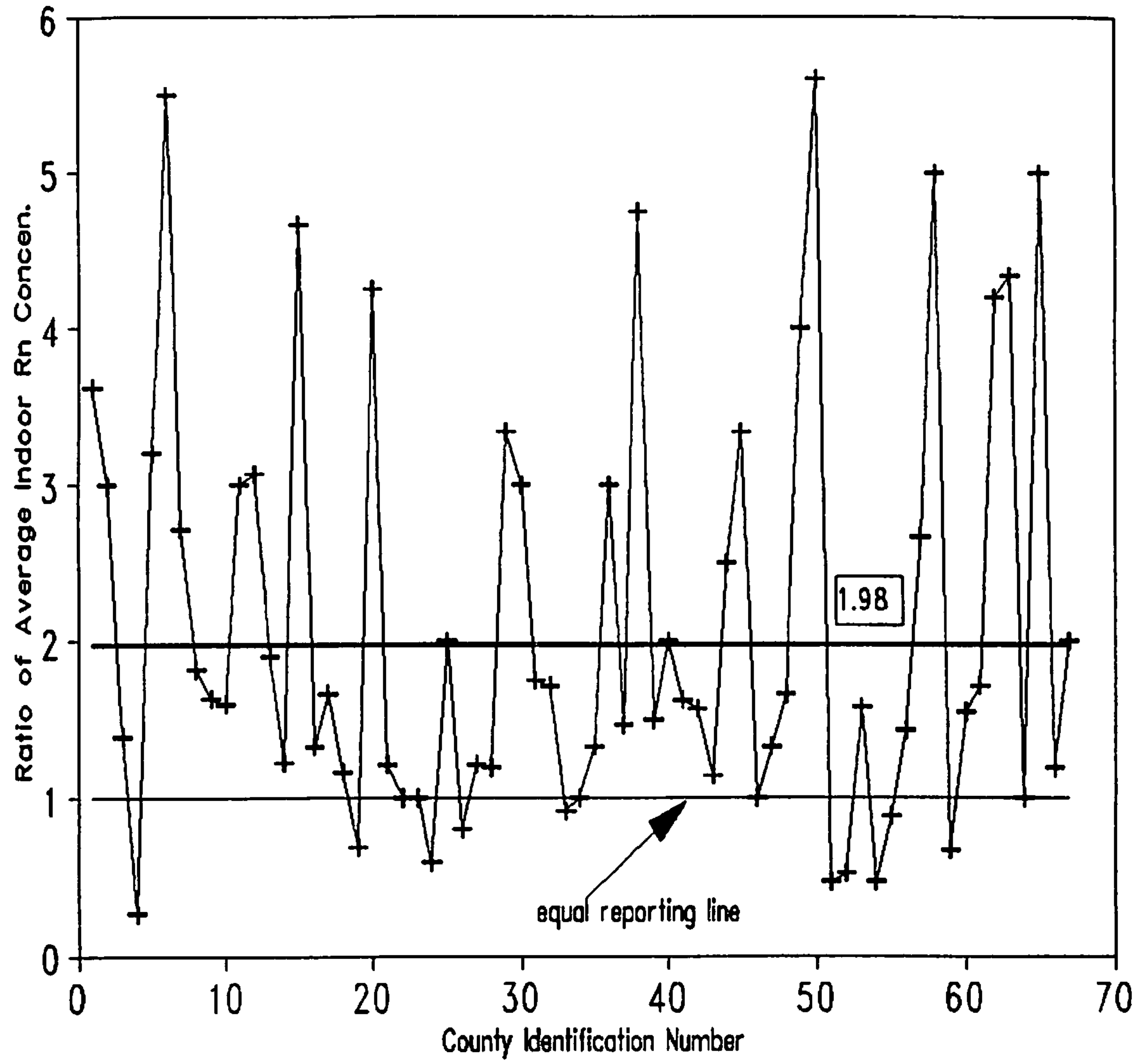

Figure 2: The ratio of the average indoor radon concentrations obtained by trained individuals over the concentrations obtained by household owners per specific county.

Calculations of the percentage of buildings with reported indoor radon concentrations greater than 4 pCi/l is 11.8% and 6% statewide for residential housing units and non-residential units, respectively. Correlation analysis of both data sets, treating average indoor radon concentration for residential and non-residential units as variables per each county, resulted in a correlation coefficient of approximately 0.5. This indicates that a weak correlation exists between residential and non-residential averages per the specific county (average concentrations do not track each other very well). Further, this suggests a strong dependence on building features and characteristics that significantly reduce the influence of the soil source term as a controller to the reported indoor radon concentrations. The latter observation is particularly valid for counties with moderate to high level of soil-gas concentrations. In comparison, the number of residential housing units that experience indoor radon concentrations of concern in the FSRS survey was calculated based on the units that equal and exceed 4 pCi/l. However, in the HRS residential databases, this figure is calculated based on the number of units that exceed 4 pCi/l but not those with average concentration equal to 4 pCi/l, resulting in a conservative estimate. Despite that, the figure of residential housing units with concentration exceeding 4 pCi/l in HRS databases is substantially larger than the previous FSRS figure of approximately 3.2% combined for both of its surveys. Based on the occupancy factor of 2.7 person-household and the statewide residential housing units in 1996 estimated earlier in this section, utilizing compound population growth figure of 4% and the 1994 Florida population, the number of Florida residential housing that exceed 4 pCi/l exceed a one half-million (628,255) units statewide.

CONCLUSIONS

Indoor radon concentration results collected in Florida in the last six and a half years through the Department of Health and Rehabilitative Services can be used to produce indoor radon figures to be used for statewide representation. Although no specific design measure was considered in collecting these data to avoid socio-economical influence biases in the data sets, a high correlation coefficients exist between the number of buildings tested and reported and the geographical distribution of population in Florida. This indicates that both variables are independent in the distribution. Therefore, the HRS databases can be safely considered to represent random sampling over the 67 counties in Florida. The random distribution nature, as well as, the volume of covering lends significant support for using the figures obtained from analysis of indoor radon concentration results in the HRS databases to estimate statewide exposure to indoor radon. It has been shown that better implementation of the USEPA short-term testing protocols, through trained individuals, would results in the likelihood of increasing the calculated weighted average indoor radon concentration. This trend was observed during the analysis of the current data sets and the previous FSRS sets. In both cases, the average indoor radon concentrations for residential housing units are higher for testing performed by trained individuals versus household owners on their own. It was also observed that with an increase in the sample volume, thus in the random representation statewide, the weighted average indoor radon concentration would experience increases until approaching a value corresponding to the optimal representation sample size, with respect to the population represented. Growth and occupancy factors may be used to estimate residential housing units. Therefore, calculations of the number of such units exceeding the recommended action level of 4 pCi/l may be obtained, employing indoor radon statewide representation figures. According to this analysis, the number of residential housing units in Florida that experience indoor radon concentration greater than 4 pCi/l is conservatively estimated to exceed a one half-million units.

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