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INDOOR RADON CONCENTRATIONS

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The indoor air of 60 residences in and around a Maryland suburb of Washington, DC, was monitored in a pilot study to determine residential radon concentrations. In each residence, a radon grab sample was acquired in the living room, and, if possible, in the basement. Infiltration rates were determined by tracer gas dilution. To help standardize sampling conditions, each home remained closed up for 8 h prior to sampling and during analysis. Over 60% of the residences sampled showed air infiltration rates below 0.6 air changes per hour. Approximately 55% of all surveyed basements and 30% of all surveyed living areas displayed radon concentrations in excess of 4.0 nCi m^{-3}. Assuming an equilibrium factor of 0.5, these radon levels may lead to working levels above the annual guidelines suggested by EPA for Florida homes build on land reclaimed from phosphate mining.

Introduction

Indoor sampling in an energy efficient experimental residence (ER) at a suburb of Washington, DC, showed high radon and Rn progeny concentrations (Hollowell *et al.*, 1980; Moschandreas and Rector, 1980). Whether these elevated concentrations were local to the residence or general to the surrounding area emerged as one of the questions requiring further scientific inquiry. Detailed studies of a few residences with a specifically designed (mobile) laboratory can be undertaken to provide full characterization of the indoor air quality (Yocom *et al.*, 1970; Moschandreas *et al.*, 1979, 1981; Hollowell *et al.*, 1978; Beck *et al.*, 1981; National Academy of Science, 1981). Such studies are expensive and would be inconclusive in responding to the specific question posed by the early finding. The need was apparent for a survey type of study, defined as brief air sampling of many indoor environments rather than detailed sampling of a few. The expected exact deliverable item of such air sampling was not well defined.

The following two objectives were broadly identified as the goals of this pilot study:

1. to design and assess a survey methodology for sampling the indoor air of many residences; and
2. to determine whether the experimental residence is a local anomaly or the measured high Rn concentrations are representative of either the neighborhood or the entire area.

This paper presents results from this indoor air quality-Rn-concentration study.

Experimental

Survey homes were recruited from three concentric zones centered on the ER:

1. Neighborhood, ≤0.5 km from ER;
2. Town, ≤2 km from ER, exclusive of neighborhood;
3. Rural, ≤25 km from ER, exclusive of town.

Geographic relationships are shown in Fig. 1A and 1B. Quotas of subject residences were arbitrarily established on a per zone basis. In the neighborhood zone 10 homes were sampled, in the town zone 30 homes, and in the rural zone 20 homes. The design sought to distribute surveyed homes as evenly as possible over the spatial extent of each zone. The uneven spatial distribution of houses in the rural zone is due to the lack of houses to the east of the ER.

Sampling

Sampling conditions were standardized by requiring that each residence remained closed with the heating,

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ventilation, and air conditioning system turned off for at least 8 h prior to sampling. Each house was to sustain this condition during sampling. It was stipulated that these requirements would help establish an equilibrium condition between Rn levels and air infiltration rates. The ER was sampled during the survey to permit comparisons.

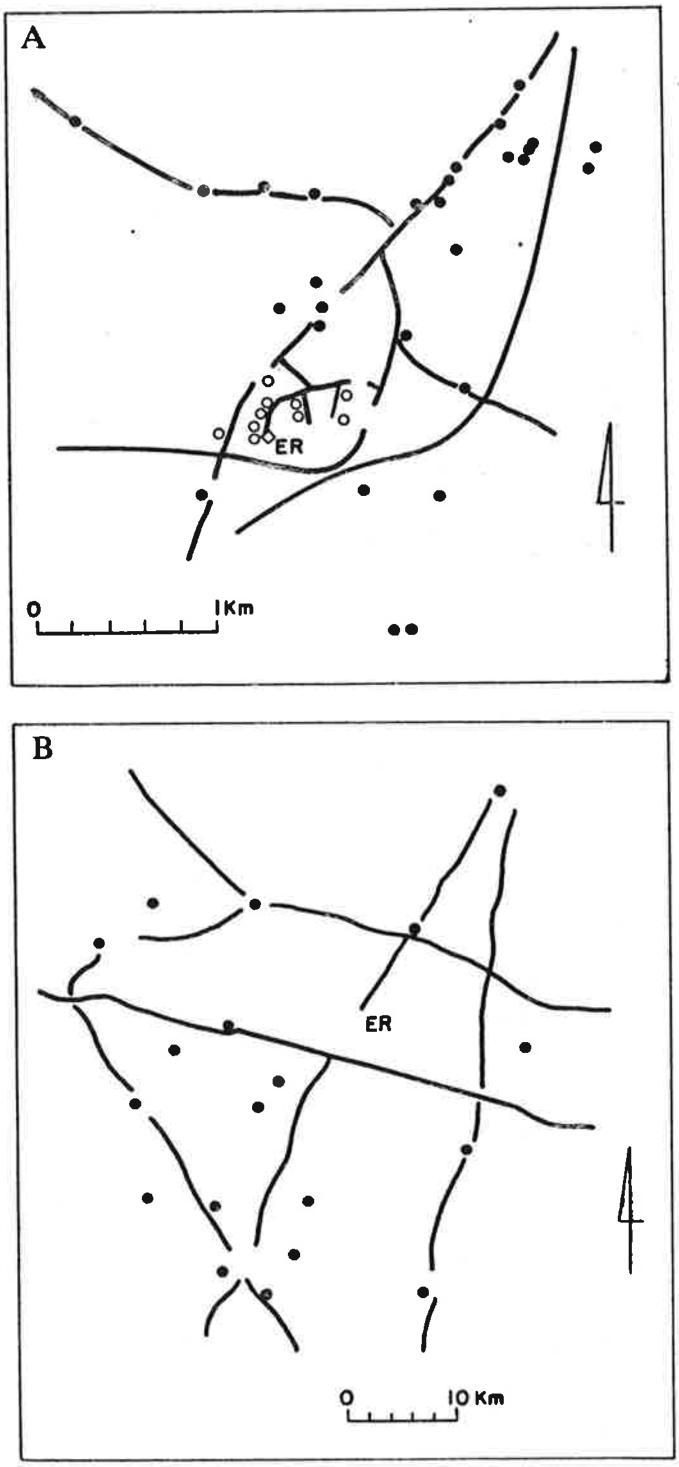

Fig. 1 (A) Locations of neighborhood samples (open circles) and town samples (closed circles) with respect to the ER. (B) Locations of the rural samples with respect to the ER.

The sampling protocol called for measurements of radon and radon progeny in the basement and main floor and of infiltration rates. The procedures ordinarily took less than 3 h of the resident's time. The RDA-200 Radon/Radon Daughter Detector was used; its detection principle is a ZnS(Ag) scintillator coupled high-gain photomultiplier and scaler. The instrument sensitivity is ≤ 0.1 nCi m^{-3} for radon, and ≤ 0.001 WL for radon progeny. A continuous SF_6 monitor (MIRAN) was used with accuracy of $\pm 10\%$ of reading.

Recruitment

Initial contacts of prospective residences were made through intermediaries (acquaintances, public officials, etc.) and door-to-door canvassing. The initial contact explained the intentions and nature of the survey. In most cases formal permission (a property-use agreement) was delayed until both heads of the household could reach a decision.

The actual process of procuring houses for air sampling was much more difficult than originally anticipated. This was especially true during the final phase of the project when most of the sampling sites were scattered about the rural zone.

Reluctance to participate was witnessed among elderly candidates because (1) they did not wish to let strangers into their homes, and (2) they were uninterested in the project itself. Work schedules interfered with the recruitment of young suburban couples who had some knowledge regarding the indoor air quality issues and who had expressed a desire to participate in the program.

The introduction of SF_6 was questioned by some, who wanted a signed note by local health authorities that SF_6 would not be harmful to their health. Several candidates explicitly stated that they did not want to know the nature of the indoor air quality of their house. These individuals expressed concern that their house property value would be reduced if radon concentrations were measured at high levels.

Results

The data base is illustrated in Fig. 2 in terms of percent of cases greater than a given value. From these graphs, it is evident that 55% of the basement concentrations and 35% of the main floor concentrations are in excess of 4.0 nCi m^{-3}. A large portion of measured infiltration rates fall below 0.4 ach^{-1}, and over 60% of the residences monitored showed air infiltration rates below 0.6 ach^{-1}. The majority of the residences monitored had infiltration rates below an assumed national ventilation mean of 1.0 ach^{-1}. It should be noted that the majority of the infiltration measurements were performed during the summer season.

Basic descriptive statistics for radon concentrations and infiltration rates by zone are displayed in Table 1.

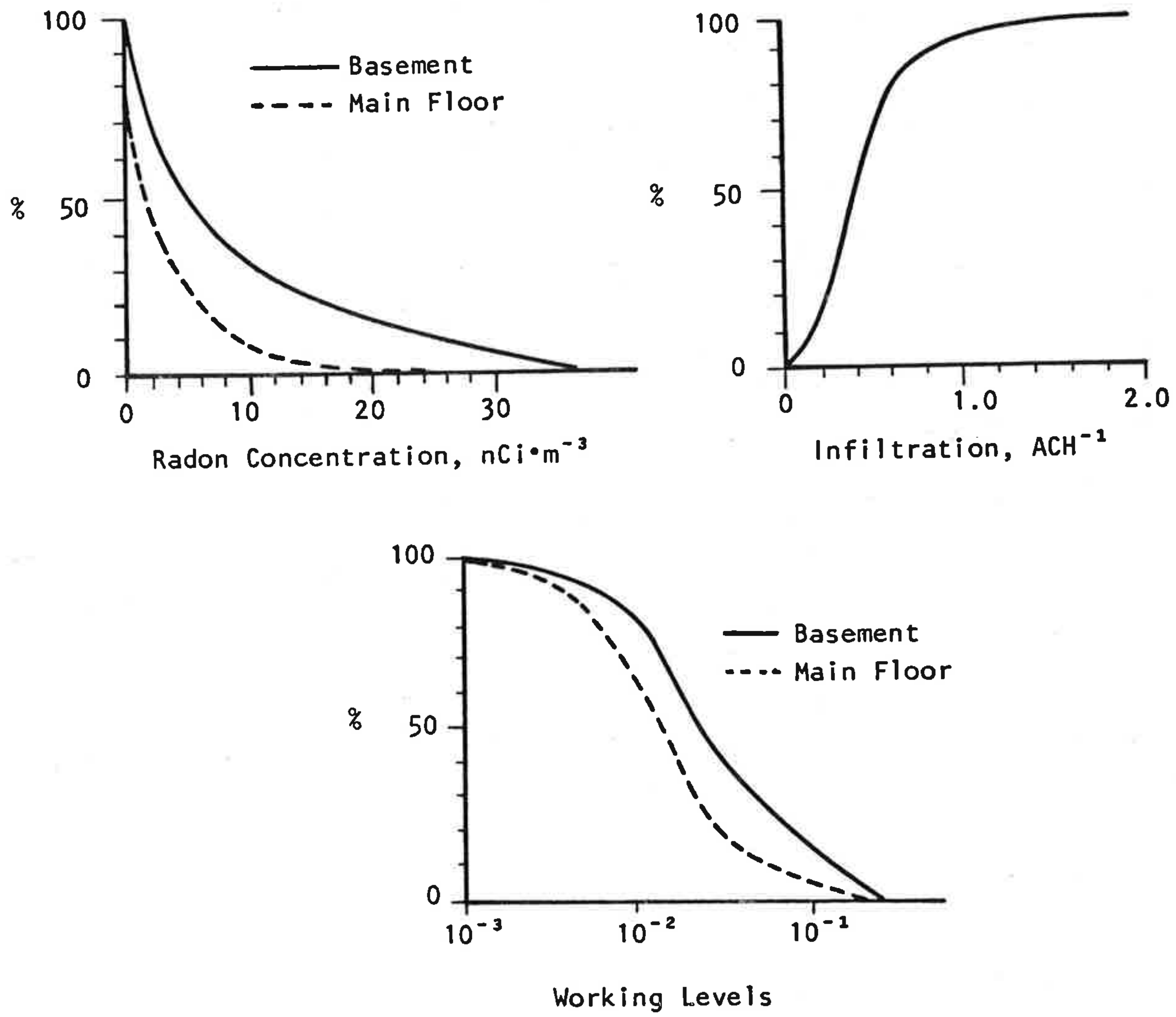

Fig. 2. Distributions of percent indoor radon concentrations and radon progeny working levels and infiltration rates above a given value for all homes surveyed.

Apparent disparities in sample sizes within zones are due to early difficulties in scheduling infiltration experiments in two homes in the neighborhood zone and encountering three homes in the town zone with no basements. Additionally, the data from some homes in the town zone were declared invalid for computational purposes (the houses were not totally closed). Calibration difficulties with the radon daughter channel of the EDA monitor caused some working level measurements to be invalidated, partially explaining the difference in the sample size between Rn and Rn progeny samples. Similar statistics developed from ER measurements under conditions stipulated by the survey methodology are included. Mean basement radon concentrations showed growth between rural, town, and neighborhood zones. The mean basement concentration from the ER are within one standard deviation of the neighborhood and town values. The ER mean basement concentration is almost three standard deviations above the rural basement mean. A similar pattern is evident from main floor data but with lowered contrast between town and rural samples.

Frequency distributions by zone are illustrated in Fig. 3. Radon concentrations are displayed in terms of percent of cases greater than a given concentration, infiltration is displayed in terms of cumulative frequency. The relative positions of the ER and neighborhood means against these distributions are also shown. The contrasts between zones as evidenced by the means is apparent. For basement Rn concentrations, 35% of the town sample outranked the ER mean, less than 10% of the rural sample exceeded this value. The neighborhood basement Rn mean was exceeded by 20% of the town sample; the neighborhood basement mean exceeded all rural basements sampled. For main floor concentrations, the ER and neighborhood Rn means were exceeded by less than 10% of the town and rural samples.

To test the statistical validity of these contrasts, parametric and nonparametric tests were applied to the data. Contrasts were made between neighborhood/town

Table 1. Data characteristics by zone.

	Radon, nCi m^{-3}		Radon Progeny, Working Levels		Infiltration (ach^{-1})
	Basement	Main Floor	Basement	Main Floor	
Neighborhood Zone					
Mean	19.2	8.7	0.195	0.038	0.25
Standard deviation	21.2	9.9	0.132	0.043	0.12
Extremes	1.0, 66.9	0.1, 26.9	0.092, 0.343	0.003, 0.119	0.10, 0.43
Number of samples	10	10	5	7	8
Town Zone					
Mean	9.2	2.8	0.047	0.025	0.45
Standard deviation	7.5	2.3	0.033	0.018	0.35
Extremes	0.8, 25.0	0.3, 9.5	0.019, 0.109	0.009, 0.067	0.07, 1.57
Number of samples	24	27	9	10	27
Rural Zone					
Mean	3.4	2.4	0.023	0.019	0.55
Standard deviation	3.3	2.6	0.031	0.027	0.41
Extremes	0.6, 13.4	0, 8.8	0.004, 0.143	0.001, 0.114	0.06, 1.54
Number of samples	19	19	19	19	19
Total Sample					
Mean	9.0	3.7	0.056	0.024	0.46
Standard deviation	11.7	5.1	0.082	0.029	0.36
Extremes	0.6, 66.9	0, 26.9	0.004, 0.343	0.001, 0.119	0.06, 1.57
Number of samples	53	56	33	36	54
ER (Natural infiltration only)					(0.1 ach^{-1} nominal)
Mean	12.1	10.8			
Standard deviation	7.8	6.6			
Extremes	5.1, 21.1	3.4, 19.0			
Number of samples	5	5			

Table 2. Two-tailed probabilities for contrasts of selected parameters using the Wilcoxon rank sum test.

Parameter	Contrast	Value of Test Statistic	Two-Tailed Probability
Basement radon	Neighborhood vs town	−0.767	0.443
Basement radon	Town vs rural	−3.1047	0.0021[a]
Main floor radon	Neighborhood vs town	−1.3346	0.182
Main floor radon	Town vs rural	−1.1383	0.255
Basement radon in Neighborhood zone	With progeny measurement vs without	−1.042	0.1492
Basement radon in Town zone	With progeny measurement vs without	−0.119	0.4522
Main floor radon in Neighborhood zone	With progeny measurement vs without	−0.682	0.2483
Main floor radon in town zone	With progeny measurement vs without	−0.251	0.4013
Indoor radon in neighborhood zone	Main floor vs basement	1.361	0.0869
Indoor radon in town zone	Main floor vs basement	3.340	0.0004[a]
Indoor radon in rural zone	Main floor vs basement	1.660	0.0485[a]
Basement Rn progeny	Neighborhood vs town	2.333	0.0198[a]
Basement Rn progeny	Town vs rural	2.635	0.0084[a]
Basement Rn progeny	Neighborhood vs rural	2.540	0.0100[a]
Main Floor Rn progeny	Neighborhood vs town	0.100	0.9204
Main Floor Rn progeny	Town vs rural	2.020	0.0434[a]
Main Floor Rn progeny	Neighborhood vs rural	0.665	0.5070
Infiltration	Neighborhood vs town	−1.608	0.1074
Infiltration	Town vs rural	0.815	0.4175

[a] Statistical significance.

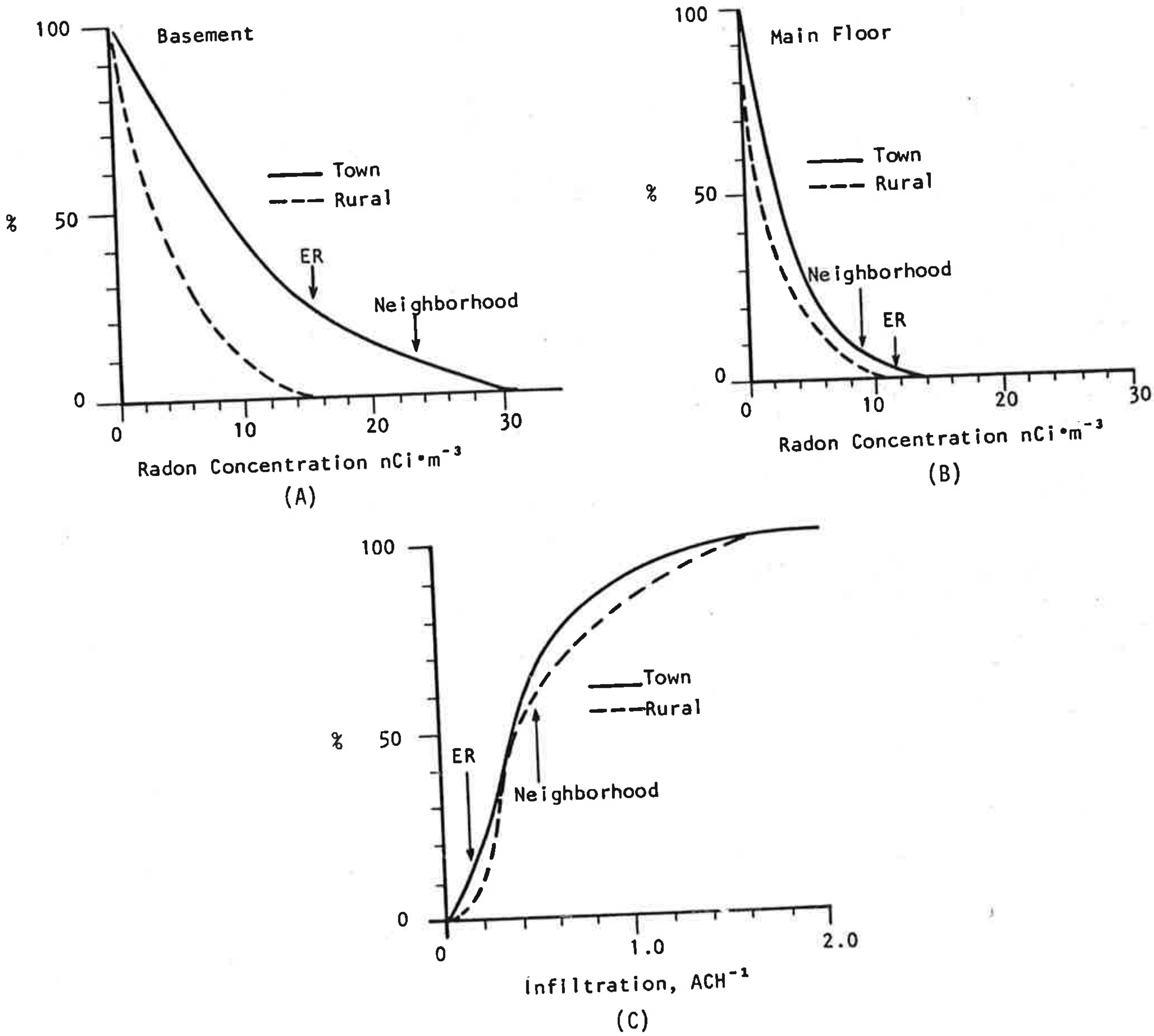

Fig. 3. Distributions of percent indoor radon concentrations above a given value by sample, (A) for basement and (B) for main floor. (C) Cumulative frequency distributions of infiltration by sample zone. Averages for the ER and the neighborhood zone are indicated for comparison.

zones and between town/rural zones for the following parameters:

- basement radon concentrations;
- main floor radon concentrations;
- ratio of main floor to basement radon concentrations;
- air infiltration rates;
- working levels of Rn progeny in basements;
- working levels of Rn progeny in main floors.

The nonparametric Wilcoxon rank sum test results are reported in this document. The parametric tests are consistent with these conclusions. The test statistics reported in Table 2 are considered statistically significant for cases in which the associated two tailed probability levels do not exceed 0.05.

Discussion

Radon concentrations in the neighborhood zone appear to be higher than those of the town zone, which in turn are higher than those measured in residences of the rural zone. A similar pattern appears for working levels of Rn progeny; however, contrasts between subsets of the data base displayed statistical difference only upon comparing basement radon levels in the town zone against those of the rural zone and all pairs of working levels of Rn progeny. No systematic relationships were found between radon levels and infiltration. This is not surprising, since values of infiltration ranged over two orders of magnitude while radon levels ranged over three orders of magnitude. No other significant differences were found. This leads to the following inferences:

(1) Basement radon concentrations found in the town and neighborhood zones are from like distributions;
(2) Basement radon concentrations found in the town/neighborhood zone are significantly greater than those found in the rural zone;
(3) Main floor radon concentrations are not statistically different across the three zones;
(4) Basement working levels of Rn progeny are statistically different among all three zones;
(5) Main floor Rn progeny were statistically different only for the town/rural sample pair;
(6) Air infiltration rates in the neighborhood, town, and rural zones are from like distributions.

No inferences regarding potential radon source strengths can be made from these data. The apparent existence of zones between the town and rural samples may indicate that (1) there is systematically easier entry of soil gases into basements in the town from sources equal in strength to those in the rural area, or (2) the actual radon levels in the rural soils may be significantly lower than those of the town area.

Finally, approximately 55% of all surveyed basements and 30% of all surveyed main floors displayed radon concentrations in excess of 4.0 nCi m^{-3}. Assuming an equilibrium factor of 0.5, these radon concentrations may lead to working levels above the annual guidelines suggested by EPA for existing Florida homes built on land reclaimed from phosphate mining; 53% of observed basement working levels and 32% of the main floor working levels are above the Florida guidelines.

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