Note: Bound together in this binder are two separate parts of the final report for the project conducted under U. S. Department of Energy Grant Number DE-FG05-89ER60825 (Proposal Ttled: Characterization of the Radon Source in Southeastern United States) by the University of Florida, College of Engineering:

1. Characterization of the Radon Source in North-central Florida:
   Final Report Part I -- Final Project Report, and

2. Characterization of the Radon Source in North-central Florida;
   Final Report Part Ii -- Technical Report

CHARACTERIZATION OF THE RADON SOURCE IN NORTH-CENTRAL FLORIDA

FINAL REPORT PART I -- FINAL PROJECT REPORT

Report for
Grant Number DE-FG05-89ER60825
(Proposal Titled: Characterization of the Radon Source in Southeastern United States)
U. S. Department of Energy
Office of Health and Environmental Research
Radon Research Program
Washington, DC 20585
June 1989 - May 1992

Prepared by:
College of Engineering
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Investigators:

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Prepared 1 May 1995
Revised 1 December 1997

DISCLAIMER

DISCLAIMER

PREFACE

This a report of work performed under U.S. Department of Energy (USDOE) Grant Number DE-FG05-89ER60825. The proposal was originally titled "Characterization of the Radon Source in Southeastern United States". The project was conceived as beginning in North-Central Florida and expanding to cover the Southeastern U.S. However, as the study progressed it became evident that more intensive study was needed in a more localized area and that limited information would be obtained by low-density sampling over a wider area. Consequently, the scope was adjusted to focus on more intensive work in North Central Florida rather extending to the wider geographic area.

This report is organized in two major parts:

Part I - Final Project Report -- a final activities report; and
Part II - Final Technical Report -- a report of technical findings.

The project team had support for other, related work during the same time period and this project served as a stimulus for some of the additional, related projects. These various projects contributed data to the assessment of the radon source. The technical report integrates data collected under the USDOE grant and additional data collected under related projects. Some of the data incorporated were collected under U.S. Environmental Protection Agency Cooperative Agreements and some of the data evaluations were performed under Florida Department of Community Affairs Contract 93RD-6613-00-22-003.

TABLE OF CONTENTS
FINAL REPORT PART I (FINAL PROJECT REPORT)

Introduction	1
The Project	1
Organization	1
Investigators	1
Research Objectives	1
Relevance to Reduction of Risk Uncertainties	1
Scientific Accomplishments	2
Accomplishments	2
Unresolved Issues	3
Other Accomplishments	3
APPENDICES	
I-A. Papers, Reports, and Presentations Generated in Part by This Project	4
I-B. University of Florida Student Projects Supported by This Project	4
I-C. Other Projects Stimulated and/or Collaborating with This Project	5

CHARACTERIZATION OF THE RADON SOURCE IN NORTH-CENTRAL FLORIDA
FINAL REPORT PART I (FINAL PROJECT REPORT)

INTRODUCTION

The Project

Grant Number DE-FG05-89ER60825 (Proposal titled: Characterization of the Radon Source in Southeastern United States)

June 1989 - May 1992

Organization

Department of Nuclear Engineering Sciences and Department of Environmental Engineering Sciences
202 Nuclear Sciences Center
University of Florida
Gainesville, Florida 32611

Investigators

G. S. Roessler, Dept. of Nuclear Engineering Sciences
(Principal Investigator June 1989 - May 1990
D.E. Hintenlang, Dept. of Nuclear Engineering Sciences
(Principal Investigator June 1990 - August 1991)
C. E. Roessler, Dept. of Environmental Engineering Sciences
(Principal Investigator August 1991- May 1992)
D. L. Smith, Dept. of Geology

RESEARCH OBJECTIVES

1. Characterize the ^{222}Rn (radon) source in a region having a demonstrated elevated indoor radon potential and having geology, lithology, and climate that are different from those in other regions of the U.S. where radon is being studied.
2. Describe the radon availability and transport in this region.
3. Develop approaches for predicting the radon potential of lands in this region.

RELEVANCE TO REDUCTION OF RISK UNCERTAINTIES

By investigating an area with demonstrated elevated indoor radon potential in the Southeastern U.S. coastal plan, this study added to the body of knowledge being developed on radon production and transport in various geographic/geological regimes.

Demonstration of indicators of elevated radon potential within this region contributed to reducing the uncertainty in projecting the risk of elevated radon in new construction. This, in turn, improved the means of identifying the degree of radon resistance required in construction.

SCIENTIFIC ACCOMPLISHMENTS

Accomplishments

- The field studies supported the hypothesis that elevated radon potential in North-Central Florida is associated with the near-surface occurrence of uranium-bearing materials of the Hawthorn group of formations which underlie part of the region.

- The work indicated that radon originates in one or more radium-bearing source zones with radon being transported to the structure interface via an overlying high permeability sand cover layer. More specifically:

    - Radon originates in the clayey layers of the Hawthorn group of formations which may contain radium in excess of 10 pCi/g and in clayey sand layers with intermediate radium concentrations in the range of >1 to 10 pCi/g.
    - The overlying cover consists of a sand layer with a radium concentration of <1 pCi/g and a thickness ranging from zero to >3 m.

- These studies indicated that the elevated radon potential may be associated with the following geological units:
    - Surficial (within 1 m) occurrence of the Miocene Hawthorn group of formations.
    - Pleistocene sands that are influenced by the presence of underlying Hawthorn formations within 6 m of the surface.
    - Exposure of the Eocene-age Ocala limestone group adjacent to the region of Hawthorn exposure. There are sufficient remnants of the Hawthorn in this region to present scattered areas of elevated radon source.

- With regard to indicators of radon potential for this region:

    - Soil gas radon is the simple parameter most consistently associated with sub-surface radium and increased frequency of indoor radon. (Measurement variability needs further documentation.)
    - The radium concentration of surface soil and the shallow (to 1 m) depth profile is generally a poor indicator.
    - A deeper radium profile should successfully detect the sub-surface radon source. A 3-m profile usually detects the source but a source zone between 3 and 6 m under a high permeability cover may contribute to surface radon at locations and times of low water table. (The required degree of horizontal replication needs to be defined).
    - Other surface soil characteristics (radium surrogates) may be useful if they identify materials at a depth of several meters.

- While it is feasible to classify radon potential of lands in terms of probabilities of elevated indoor radon, accurate prediction of indoor radon potential for specific structures on the basis of simple observations on soil characteristics does not appear promising. (To improve the prospects for site- and structure-specific prediction, a more elaborate radon entry and maintenance model, involving house, occupant, and "operational" factors, must be examined.)

- For further details, see Final Report Part II (Technical Report).

Unresolved Issues

1. Further studies are needed of the temporal and spatial variability of simple radon-potential predictive methods -- such as soil gas radon concentrations and radon flux and the spatial variability of soil radium profiles -- so that sampling protocols and confidence limits can be specified.

2. Further work should performed (such as through radon transport modeling) to determine the relative surface radon contributions of the low permeability clays of higher radium content and the overlying highly permeable clayey sands of modestly-elevated radium content.

3. This work did not adequately explore the usefulness of radium/radon surrogates such as soil type, textual class of profile components and site elevation for radon potential assignment.

OTHER ACCOMPLISHMENTS

1. This work resulted in several papers, reports, and presentations after the close of the project -- See Appendix I-A.

2. This work supported student projects -- See Appendix I-B.

3. This effort was highly interactive with other projects. Other projects were stimulated by this work, data were shared with other projects, and this project benefited from data generated in related endeavors. See Appendix I-C.

APPENDIX I-A
PAPERS, REPORTS, AND PRESENTATIONS GENERATED IN PART BY THIS PROJECT

Publication:

- C. E. Roessler, H. Mohammed, R. Richards, D. L. Smith (1993). Radon Source Studies in North Florida. Pp. 331-350 in Environmental Health Physics, R. L. Kathren, D. H. Denham, and K. Salmon, Eds. (Proceedings of the Twenty-sixth Midyear Topical Meeting of the Health Physics Society, Coeur d'Alene Idaho, 24-28 January 1993). Columbia Chapter, Health Physics Society, P.O. Box 564, Richland, WA 99352.

Technical Report:

- C. E. Roessler and R. Richards, North Florida Radon Source Studies -- Report of 1992 Six-Meter Drilling in Alachua County, report to Florida Dept. of Community Affairs from University of Florida, December 20, 1993.

Paper Presented (Not Published in Proceedings)

- C.E. Roessler, D.E. Hintenlang, G.S. Roessler, and D.L. Smith, "Characterization of the Radon Source in North Central Florida", Health Physics Society Annual Meeting, July 23, 1991.

APPENDIX I-B
UNIVERSITY OF FLORIDA STUDENT PROJECTS SUPPORTED BY THIS PROJECT

1. K. A. Venz, Size Analysis of Florida Fill Materials and Soils, Senior Thesis, Dept. of Geology, April 1990.

2. J. L. Wherett, Geological Characterization of Soil Gas Radon Concentrations in Florida and Comparison with Soil Permeability Parameters, Master's Thesis, Dept. of Geology, April 1992.

3. C. S. Vonada, Permeability for Radon, Senior Thesis, Dept. of Geology, 1992.

4. R. Richards, Radium-226 Content and Radon Emanation Coefficients of Six-Meter Drill Cuttings of Alachua County, report for ENV 4905, Special Topics, Dept. of Environmental Engineering Sciences, Fall 1992.

APPENDIX I-C
OTHER PROJECTS STIMULATED BY AND/OR COLLABORATING WITH THIS PROJECT

Other Projects Stimulated by this Project:

- Testing Radon Source Assignments For North Central Florida, (C. E. Roessler, Principal Investigator). Funded by Florida Department of Community Affairs (DCA), December 1992 through November 1993. This project was a direct result of the work begun under DOE Grant Number DE-FG05-89ER60825. The DCA project provided funding to continue interpretation of the data collected in the final stages of the DOE grant project. This resulted in several technical reports and the compilation of a North Florida Radon Source Database incorporating the data from the DOE grant project and other related studies by the University of Florida.

Other Projects Benefiting from This Project:

1. Soil and Fill Database, (C. E. Roessler, Principal Investigator). A support project to FRRP, funded by Florida Dept. of Community Affairs and U.S. Environmental Protection Agency, January 1990 - May 1993. This series of projects examining the radon-production and transport properties of fills and soils associated with contemporary construction sites. The laboratory capability supported both the DOE grant project and the FRRP project; information learned from the FRRP project helped in interpretation of the data collected in the DOE project.

2. Florida Radon Research House -- House Dynamics and Modeling, (D. E. Hintenlang, Principal Investigator). Funded by Florida Dept. of Community Affairs and U. S. Environmental Protection Agency, August 1990 - May 1993. The site evaluation techniques from the DOE grant project were useful in locating a research house site and soil gas radon measurements in the house site search contributed to the data base for defining soil gas radon in the Gainesville vicinity.

3. New House Evaluation of Potential Building Design and Construction for the Control of Radon in Marion County and Alachua County, Florida, (F. T. Najafi, Principal Investigator; C. E. Roessler, Co-investigator for site radon potential evaluation and indoor radon measurements). Funded by Florida Dept. of Community Affairs, March 1992 - April 1993. The geological map and the experience developed in the DOE grant project was invaluable in identifying those new house construction sites that were good candidates for demonstrating and testing radon resistant construction techniques.

CHARACTERIZATION OF THE RADON SOURCE IN NORTH-CENTRAL FLORIDA

FINAL REPORT PART II -- TECHNICAL REPORT

Report for
Grant Number DE-FG05-89ER60825
(Proposal Titled: Characterization of the Radon Source in Southeastern United States)
U. S. Department of Energy
Office of Health and Environmental Research
Radon Research Program
Washington, DC 20585

Prepared by:

University of Florida
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Gainesville, FL 32611

Prepared 20 May 1995
Revised 1 December 1997

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Prepared 20 May 1995
Revised 1 December 1997

PREFACE

This a report of work performed under U.S. Department of Energy (USDOE) Grant Number DE-FG05-89ER60825. The proposal was originally titled "Characterization of the Radon Source in Southeastern United States". The project was conceived as beginning in North-Central Florida and expanding to cover the Southeastern U.S. However, as the study progressed it became evident that more intensive study was needed in a more localized area and that limited information would be obtained by low-density sampling over a wider area. Consequently, the scope was adjusted to focus on more intensive work in North Central Florida rather extending to the wider geographic area.

This report is organized in two major parts:

Part I - Final Project Report -- a final activities report; and
Part II - Final Technical Report -- a report of technical findings.

The project team had support for other, related work during the same time period and this project served as a stimulus for some of the additional, related projects. These various projects contributed data to the assessment of the radon source. The technical report integrates data collected under the USDOE grant and additional data collected under related projects. Some of the data incorporated were collected under U.S. Environmental Protection Agency Cooperative Agreements. For the work element reported in Part II, Annex A, the field work and laboratory analyses were conducted under the USDOE grant and data evaluations were performed under Florida Department of Community Affairs Contract 93RD-6613-00-22-003.

TABLE OF CONTENTS
FINAL REPORT PART II (TECHNICAL REPORT)

LIST OF FIGURES iv

LIST OF TABLES iv

EXECUTIVE SUMMARY 1

INTRODUCTION 3
  Background 3
  Geology and Soil Characteristics of North Florida 3

APPROACH AND METHODS 8
  Sampling and Measurements 8
  Alachua County Studies 9
  Extended North Florida Sampling 9

RESULTS 12
  Alachua County Studies 12
  Extended North Florida Sampling 13

DISCUSSION AND CONCLUSIONS 14
  The Radon Source 14
  Predicting Radon Potential 14
  Further work to be Done 14

REFERENCES 16

ANNEXES:

A. Report: North Florida Radon Source Studies -- Report of 1992 Six-Meter Drilling in Alachua County A.1

B. Manuscript: Radon Source Studies in North Florida B.1

C. File Report: Radon Source Studies in North Florida -- Extended North Florida Sampling C.1

LIST OF TABLES

Table 1. Observations, Measurements, and Sampling -- Standard Complement 10

LIST OF FIGURES

Figure 1. Alachua County Study Location 3
Figure 2. Generalized Geologic Profile for Gainesville, Florida, Vicinity 5
Figure 3. Gainesville Area Map with Surficial Geology, Sampling Sites, and Transects . . 6

EXECUTIVE SUMMARY

This is a report of a radon source study conducted by the University of Florida in Northern and North-Central Florida during the period June 1989 through May 1992. In the context of this study, the "radon source" is the extent to which the site or land area under consideration provides a potential for indoor radon. A major objective was to characterize the radon source in a region of elevated indoor radon potential that has geology, lithology, and climate that are different from those in other regions in the U.S. where radon is being studied.

Previous studies had identified elevated indoor radon potential in parts of Northern and North-Central Florida where the uranium-bearing Hawthorn Group of formations occurs near the surface. This prompted a more definitive study of the radon source in this region. Efforts concentrated on the Gainesville/Alachua County area as a primary focus with a limited amount of reconnaissance sampling in 14 surrounding counties of Northeastern and North-Central Florida.

Field work included making direct observations, sampling the soil profile for laboratory analysis, measuring in-situ soil permeability, collecting soil gas for radon analysis, and, in some cases, measuring soil surface radon flux.

Alachua County Studies

The sampling sites were classified according to three geologic/geographic regions and a transition zone:

- Cover Sand Region - The region covered with Pleistocene age sands and lying generally to the north and the east of the exposure of Hawthorn Group materials. Radium concentrations in the cover sand were generally <1 pCi/g with occasional samples in the 1 - 2 pCi/g range. In this region, the radon potential is generally low outside the transition zone
- Hawthorn Region - The contiguous region where material from the Hawthorn group is exposed within 1 m of the surface. Enhanced radioactivity materials with radium concentrations in the range of 2 - 10 pCi/g and some clayey sand and clays with concentrations >10 pCi/g may be found here. Here the radon potential is generally elevated.
- Limestone Region - The area to the south and west of the contiguous Hawthorn Region. The Proximate Limestone Region (within 6 km of the Hawthorn Region) has elevated radon potential because of mapped and unmapped remnants of Hawthorn materials. Presumably a low radon potential region exists to the west beyond the Proximate Limestone Region.
- Cover Sand/Hawthorn Transition Zone - Likely elevated radon potential where the upper surface of the enhanced-radium Hawthorn materials is on the order of 2 - 6 m from the land surface.

Average soil gas radon concentrations at a nominal 0.75-m depth were generally $\leq$500 pCi/L when the enhanced-radium (>2 pCi/g) material was 6 m or more from the surface. Near-surface soil gas radon may be influenced when enhanced radium occurs between 2 and 6 m from the surface; concentrations were usually >1000 pCi/L when the enhanced-radium materials were within 2 m.

Extended North Florida Sampling

This work, together with the Alachua County work, provided coverage of 13 of the 15 contiguous Northeast Florida counties north from Marion County and west to the Suwanee River plus Leon County (Tallahassee vicinity) farther to the west.

Concentrations of soil ^{226}Ra in excess of 2 pCi/g and/or soil gas radon in excess of 1000 pCi/L were found in Marion County, Duval County (at one of the two sampling sites) and Leon County (one of the two sampling sites). Values suggestive of an elevated radon source (^{226}Ra 1 - 2 pCi/g and/or soil gas radon 500 - 1000 pCi/g) were found in Columbia and Putnam Counties. In this out-county sampling, permeability measurements were obtained for nine of the sites (seven counties), but these data were not interpreted.

The data from the extended North Florida sampling indicate that the elevated radon source potential observed in Alachua county does extend to other areas in North Florida, particularly where there are surficial occurrences of the Hawthorn Group such as in Marion County. However, the areas of elevated radon potential were not well delineated -- one or two sites per county is not a sufficient sampling density to define these areas. A more productive approach would be to prepare a map of surficial geology and perform sampling designed to provide sites representative of the various geologies in the wider area.

The Radon Source

This work supports the hypothesis that elevated radon potential in North and North Central Florida is associated with the near-surface occurrence of uranium-bearing phosphatic sand and clay components of the Hawthorn group of formations which underlie much of the region. The radon is coupled to the structure interface via an overlying high permeability sand cover layer of thickness ranging from 0 to >3 m.

Predicting Radon Potential

- Geologic maps -- The show promise as a basis for sub-county scale radon potential mapping in North Central Florida, particularly if the expected radium content of the material in the first 6 m and the expected permeability of the source material and the cover layer can be inferred. Transition zones must be recognized and there will be problems of arbitrary assignment of boundaries; ground-truthing is important.
- Soil gas radon -- This measurement should provide a direct indication of radon available for transport into the structure. However, considerable replication may be necessary because of high spatial and temporal variability.
- The radium profile -- When taken to a sufficient depth, this is a non-variant indicator of the radon source. However, for the soil/geology characteristics present in North Central Florida, surface soil and the shallow depth profile (to 1 m) do not represent a sufficient depth to be satisfactory indicators of radon potential.
- Other surface soil characteristics -- These may be useful as radon/radium surrogates in estimating radon potential if they are indicative of materials at depths of several meters.

CHARACTERIZATION OF THE RADON SOURCE IN NORTH-CENTRAL FLORIDA
FINAL REPORT PART II (TECHNICAL REPORT)

INTRODUCTION

This is a report of a radon[1] source study conducted by the University of Florida in Northern and North-Central Florida during the period June 1989 through May 1992 under U. S. Department of Energy Grant Number DE-FG05-89ER60825. For the purpose of this study, the "radon source" is defined as the extent to which the site or land area under consideration provides a potential for indoor radon.

The overall objectives of the project were to (1) characterize the radon source in a region of elevated indoor radon potential that has geology, lithology, and climate that are different from those in other regions in the U.S. where radon is being studied, (2) describe the radon availability and transport in this environment, and (3) demonstrate approaches for predicting radon potential of lands in this region.

Background

A 1986-87 statewide indoor radon survey encompassing all 67 Florida counties reported that 18 (27%) had definite evidence and an additional 14 (21%) had limited evidence of elevated radon potential (Nagda, et al. 1987). While these "radon potential" counties are distributed from the northern border to near the southern tip of the state, the majority occur in the Bone Valley Formation region of West-Central Florida and in parts of Northern and North-Central Florida where the uranium-bearing Hawthorn Group of formations occurs near the surface. In North-Central Florida, indoor radon levels up to 200 pi/L have been found.

A number of published (Carlton, et al. 1987; Nagda, et al. 1987; C. Roessler 1989) and unpublished (University of Florida unpublished reports) studies in Northern/North-Central Florida have shown clusterings of elevated indoor radon generally associated with specific surficial geology. This correlation was further validated in a University of Florida effort to identify candidate houses for a radon mitigation project -- the near-surface presence of the Hawthorn Group was used successfully to identify neighborhoods with a high yield of elevated indoor radon houses (G. Roessler, 1989).

These observations prompted a more definitive study of the radon source in this region. Population centers in the North Central region include the vicinities of the cities of Ocala (Marion County) and Gainesville (Alachua County); the study concentrated on the Gainesville vicinity (See Figure 1).

Geology and Soil Characteristics of North Florida

In terms of surficial geology, three general lithologies dominate North Florida -- the Ocala Group of limestone formations, the Hawthorn Group, and younger surficial sands. A

[1]In this paper, the terms "radon" and "radium" are used to designate the isotopes ^{222}Rn and ^{226}Ra, respectively.

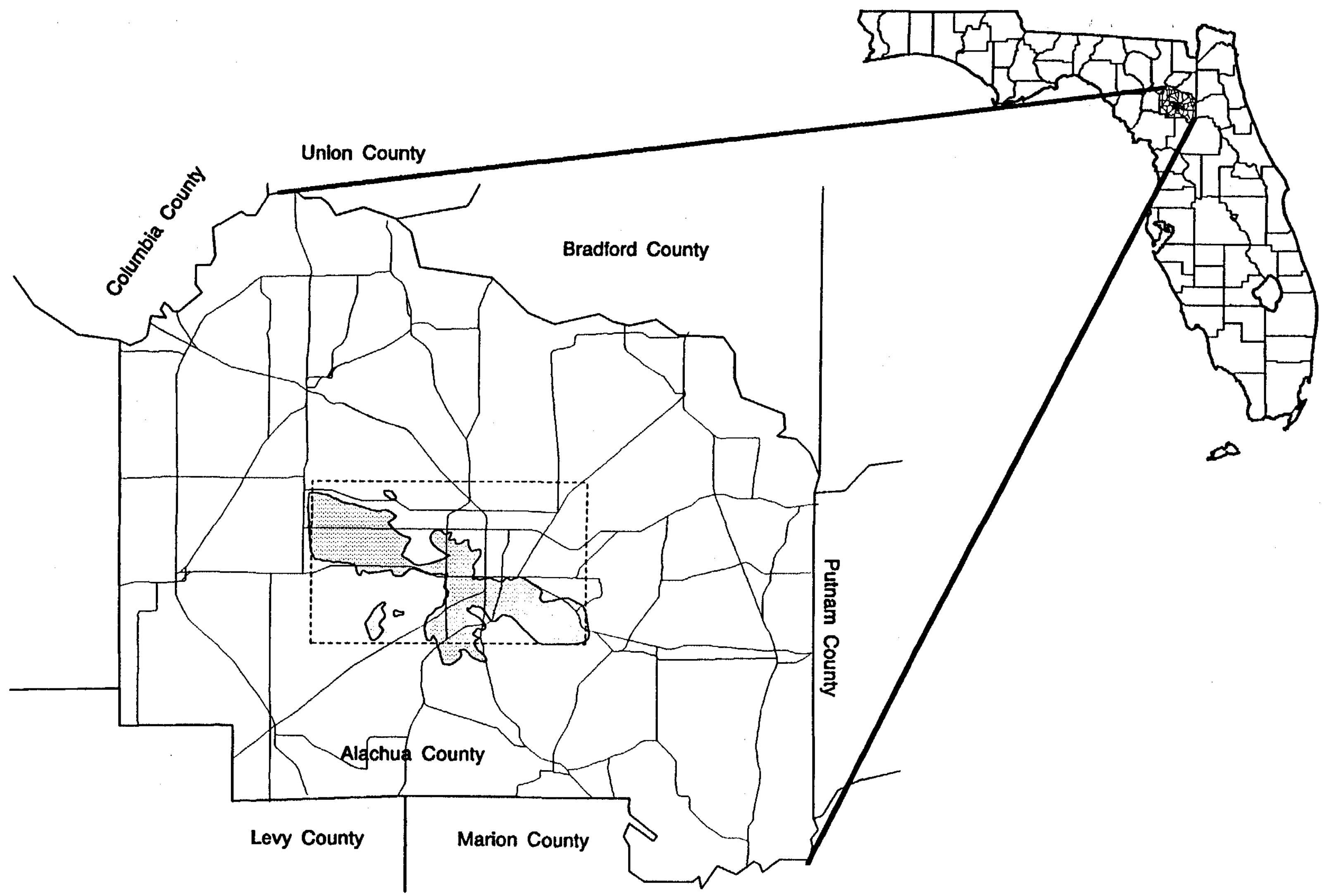

Figure 1. Alachua County Study Location (Inset shows Gainesville vicinity with surface occurance of Hawthorn formation).

generalized cross sectional profile of the surficial geology of the Gainesville vicinity the emphasis area) is shown in Figure 2. The surface occurrences are mapped in Figure 3.

The general geology of the area consists of a basal continuous rock unit of the Eocene Ocala Group of limestone formations, the uppermost of which is the Crystal River formation. The Ocala Group of limestone formations, as shown in Figures 2 and 3, is exposed on the western portion by tilting and subsequent erosion of the overlying strata. However, occasional overlying remnants of the Hawthorn Group are present. This region can be characterized as nearly level to sloping with 0 - 1 m of well-drained and moderately drained surface sand.

Adjoining generally to the north and east of the limestone exposure, the limestone is covered with an eastward-thickening mantle of the Miocene Hawthorn Group of formations. Here the surficial unit is the Coosawhatchee formation which is characterized by various unconsolidated sands, discontinuous pods or stringers of clay lenses some several meters or more thick, some phosphatic and limey clays, and relatively small limestone or dolomite beds (Scott 1988). The region can be characterized as varying from nearly level to strongly sloping, moderately well-drained to poorly drained, and covered with 0 - 2 m of surface sands. Uranium is associated with the phosphatic components of sands and clays of this formation.

In the area shown as the Cover Sand region in the figures, the Hawthorn upper surface is covered by a layer of undifferentiated, unconsolidated material composed of Recent and Pleistocene beach sands. This material may be well sorted, but in places discontinuous lenses of clayey sand or sandy clay have been concentrated, probably by hydrologic activity. This area is tectonically stable. This region was expected to have a low radon potential because of the depth of the sands overlying the uranium-bearing Hawthorn formation. This region can be characterized as nearly level to gently sloping with somewhat poorly drained soils. These sands and the undifferentiated sands of the upper part of the Hawthorn Group range in thickness from a few meters near the Hawthorn exposure to >150 m toward the east.

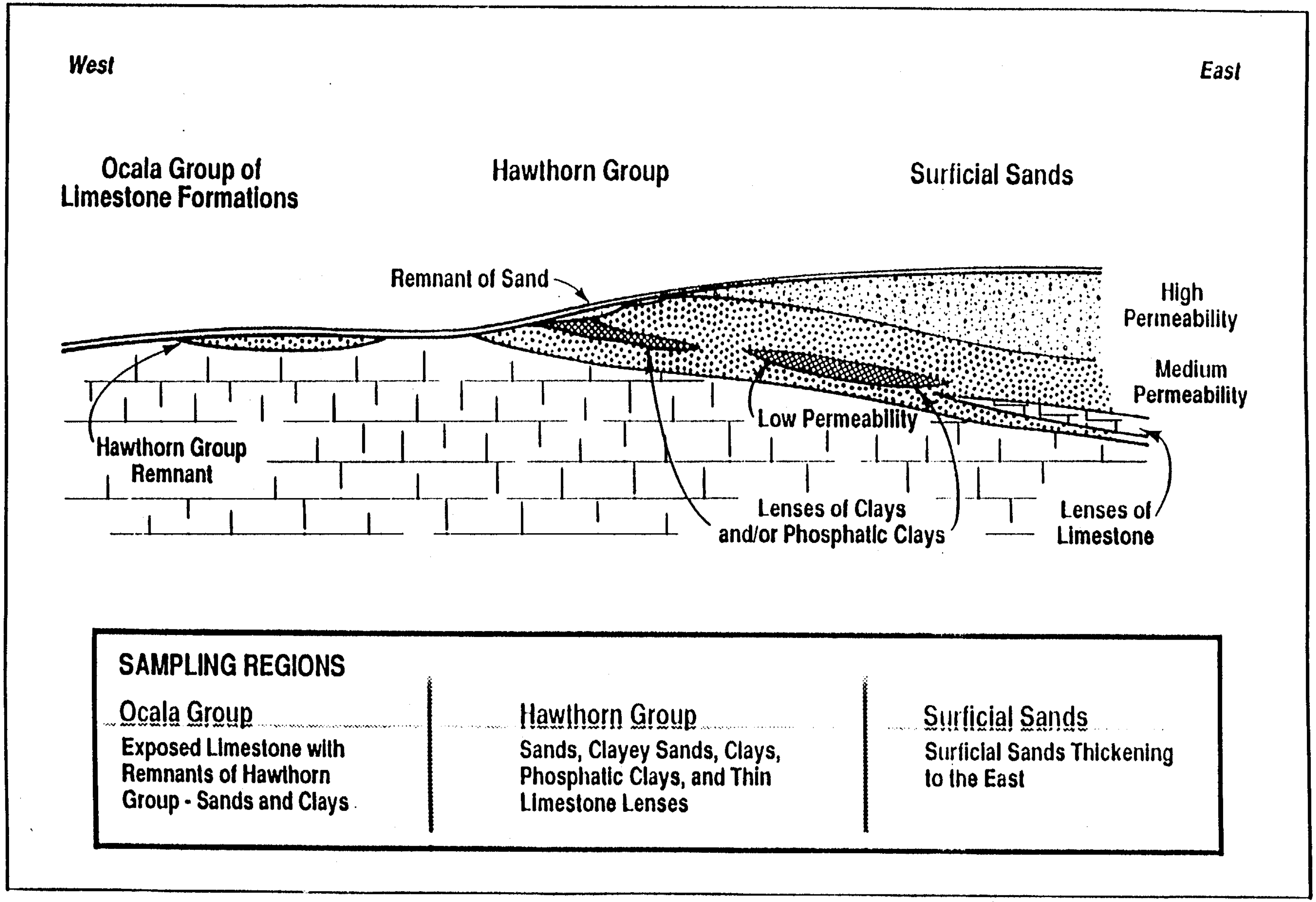

Figure 2. Generalized Geologic Profile for Gainesville, Florida, Vicinity

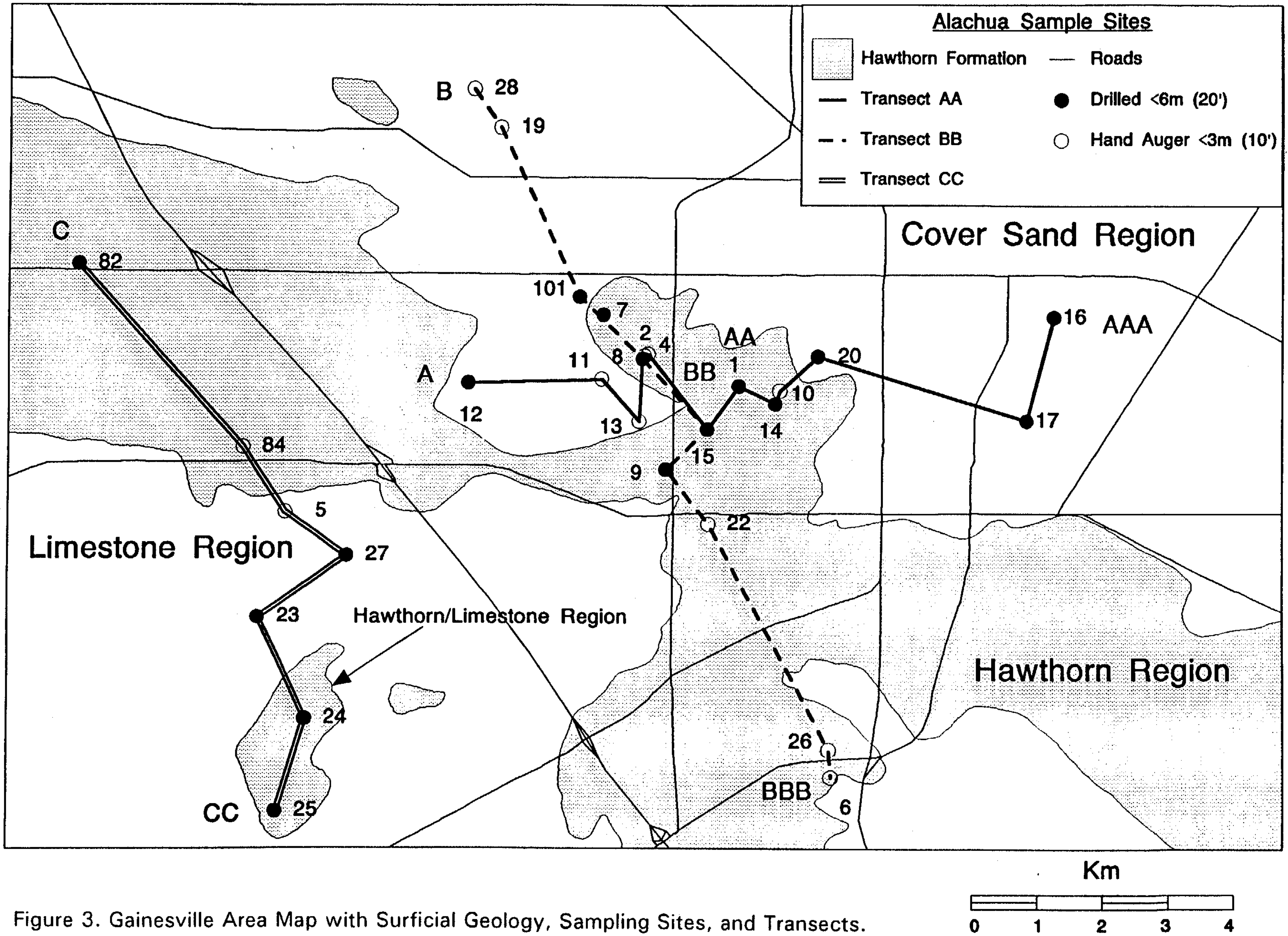

Figure 3. Gainesville Area Map with Surficial Geology, Sampling Sites, and Transects.

APPROACH AND METHODS

The study approach involved visiting field sites to collect data in order to test hypotheses about the radon source and to describe radon transport. Field work included sampling the soil profile, measuring parameters related to radon emanation and transport, and making measurements related to the soil surface radon source term .

The proposed time scale involved (1) first year, perform field studies in the Alachua County vicinity (Gainesville area); (2) second year, continue these field studies, extend to the more general region of Northeastern and North-Central Florida, and perform data summarization and interpretation; and (3) third year, continue the work in progress with greater emphasis on modeling and development of predictive approaches. The project was originally conceived as a study of the Southeastern U.S. with the third year directed at extending the source description to the broader region with the aid of a limited amount of wider-ranging field work. However, as the study progressed, several things became evident:

1. More intensive study to develop a better understanding of the radon-significant geological transitions in North Florida was a necessary prelude to a meaningful extension to a wider geographic area,
2. Only limited information would be obtained by low density sampling over a wider area,
3. The radon source occurs at a deeper depth at some North Florida sites than the original sampling depth, and
4. A better understanding was needed of the temporal variation of some of the parameters being studied.

Consequently, the study, as performed, concentrated on the primary, Gainesville/Alachua County area with a limited amount of reconnaissance sampling in 14 surrounding counties of Northeastern and North-Central Florida. Year three was devoted to deeper drilling and to replication in Alachua County rather than extending beyond the state of Florida.

The basic hypothesis regarding the Alachua County radon source was that the radon source is radium in the Hawthorn Group of formations which underlie part of the region. The simplest model is a radium-bearing source zone overlain by a cover layer. The house-available radon should be a function of the radon production and its transport to the surface. The radon source should then be related to (1) the presence of the source zone formations, (2) the radium content, emanation coefficient, and permeability of the source zone, (3) the thickness, radium content, and permeability of the cover layer, and (4) modifying factors such as the depth of the water table.

Sampling and Measurements

The sampling and measurements that constituted a standard, full complement of measurements are summarized in Table 1. Field sampling and measurement and laboratory analyses were performed according to procedures described in the FRRP Standard Measurement Protocols (Williamson and Finkel, 1990). In the field, soil profiles were collected in 0.3 m (1 ft) increments for laboratory analysis, soil gas was collected for radon analysis, and air permeability profiles of the soil was measured in-situ. The presence of the water table was noted when observable within the auger or drill depth. Radon flux measurements were made at a subset of sites.

The soil samples were analyzed for moisture content, ^{226}Ra and radon emanation coefficient. Composite samples representing different lithologies in the core were submitted further physical characterization including description according to textural class, determination of air permeability under several combinations of moisture and compaction, determination of particle size distribution by sieve analysis, and sand/silt/clay classification by sedimentation analysis.

Soil profiles were sampled by hand auger at all sites. Samples were collected to a depth of 3 m (10 ft) unless shallower depths were dictated by the presence of rock or collapse of the hole due to ground water. In a special sampling effort in Alachua County, deeper sampling was conducted at a subset of sites using a power drill to sample to a depth of 6 m (20 ft) and drill cuttings were collected over approximately 0.3-m (1-ft) increments at intervals of 0.6 m (2 ft).

Alachua County Studies

As stated above, initial effort concentrated on Alachua County. Tasks included (1) prepare a map of surficial geology using existing maps and geological reports, and (2) conduct field sampling at sites representative of the three geologic units in the area.

Where possible, sites from other FRRP sampling programs were used in order to take advantage of additional data, especially indoor radon concentrations. The standard complement of measurements, as indicated in Table 1, were performed. One exception was the radon soil surface flux measurements, this part of the program lagged and data were obtained for only a subset of sites.

Soil profiles were sampled by hand auger at all sites. Samples were collected to a depth of 3 m (10 ft) unless shallower depths were dictated by the presence of rock or collapse of the hole due to ground water. As the work progressed, it became evident that depths of $\leq$3 m ($\leq$10 ft) were not always sufficient to find the source; elevated soil radium was not observed at a number of sites characterized by elevated indoor radon and/or elevated soil gas radon. These initial observations prompted deeper sampling at a subset of sites to provide a better picture of the radon source. In the third year, toward the end of the project, 15 sites were selected for re-sampling in order to provide E-W and N-S traverses through the region and intersecting the three lithologies. A power drill was used to drill to a depth of 6 m (20 ft); drill cuttings were collected over approximately 0.3-m (1-ft) increments at intervals of 0.6 m (2 ft).

Extended North Florida Sampling

During the second year of the project (1990), sampling was extended, with a lower sampling density, to a wider area of North Florida to examine the geographic extent of the elevated radon source as observed in the Alachua County vicinity. The targeted area covered the region from the Florida-Georgia border south to approximately 29° N Latitude and from the Atlantic coast west to Longitude 85° W.

Sampling was performed on a county basis at one or more undisturbed sites representative of the county. At each site, a 3-m core was collected for laboratory analysis and measurements were made of soil gas radon and in-situ permeability.

Table 1. Observations, Measurements, and Sampling[a] -- Standard Complement

1. Site Description: a. Geologic classification b. Topography c. Degree of disturbance d. Slope		
2. Gamma Survey (Micro-R meter)		
3. Soil Core (hand auger, 2-3 m) a. Description b. Sample 0.3-m increments for lab analysis c. Observe water table	(c), (d)	≥1/site, (b)
4. In-situ Permeability Profile (Permeameter)	(e)	4/site
5. Soil Gas Rn (Permeameter probe and scintillation cell)	(f)	4/site
6. Surface Rn Flux (Charcoal canister) -- Performed on a subset of sites.		4/site
7. Indoor Rn	(g)	

Notes:

a) Sampling and Measurements conducted according to Florida Radon Research Program Standard Measurement Protocols (Williamson and Finkel, 1990).

b) Cores: one per lot if level; ≥2 if sloped or evidence of cutting and filling.

c) Soil cores: samples representing 0.3-m or distinct changes in horizon were collected for laboratory analysis.
Laboratory analyses of samples:
- Moisture; ^{226}Ra concentration and Rn emanation coefficient by high resolution gamma-ray spectrometry.
- Other physical characterization for each lithology within core: textural classification, sand/silt/clay classification, particle size analysis, and lab measurement of air permeability.

f) At a sub-set of Alachua Co. locations -- sampling by drill to 6 m (20'); drill cuttings representing 0.3-m increments collected at 0.6-m intervals; cuttings samples composited by visually apparent horizon for laboratory analysis.

e) In-situ Permeability: Start at 30 cm (1 ft) depth, every 15-30 cm (0.5-1 ft) down to 1.8 m (6 ft) or to impenetrable material. Consider additional permeability profiles if there is an indication of additional types of lithology.

f) Grab sample soil gas. Sample at 1 m or just above the impermeable layer. Sample 4 stations/site, 2 scintillation cells/station.

g) For sites with structures, record indoor radon if available from other studies.

RESULTS

Alachua County Studies

A report prepared on the 6-m drilling is included as Annex A. A manuscript reporting the overall results of the work in Alachua County is included as Annex B. A brief summary is presented in the following paragraphs.

For the data analysis, the sampling sites were classified according to the following geologic/geographic regions:

1. Cover Sand Region - the region covered with Pleistocene age sands and lying generally to the north and the east of the exposure of Hawthorn Group materials.
2. Hawthorn Region - the contiguous region where material from the Hawthorn group is exposed within 1 m of the surface.
3. Limestone Region - area to the south and west of the contiguous Hawthorn Region. This region includes sites coinciding with remnants of Hawthorn over the limestone.

Thirty sites were studied, these were distributed among the three geological regions. Sampling sites included 25 for which indoor radon data were available from other projects. Six were indoor radon mitigation demonstration sites and 19 were sites in a study intercomparing short-term and long-term indoor radon measurements in occupied houses.

Radium concentrations in the cover sand were generally <1 pCi/g with occasional samples in the 1 - 2 pCi/g range. Enhanced radioactivity materials had concentrations in the range of 2 - 10 pCi/g and some clayey sand and clays had concentrations >10 pCi/g. The maximum value for a sample representing a 0.3-m depth increment was about 80 pCi/g.

Average soil gas radon concentrations at a nominal 0.75-m depth were generally ≤ 500 pCi/L when the enhanced-radium (>2 pCi/g) material was 6 m or more from the surface. Near-surface soil gas radon may be influenced when enhanced radium occurs between 2 and 6 m from the surface; concentrations were usually >1000 pCi/L when the enhanced-radium materials were within 2 m. The work has not yet determined the relative contributions to near-surface radon of the higher radioactivity (>10 pCi/g) low permeability clays as compared to more permeable clayey sands with more modest radium concentrations (2 to 10 pCi/g).

Using soil gas radon concentration as a radon potential criterion (<500 pCi/L = Low; >1000 pCi/L = Elevated), regions in the study area and their radon potential may be described as follows:

- Cover Sand Region - Radon potential is generally low outside the transition zone.
- Cover Sand/Hawthorn Transition Zone - Likely elevated radon potential where the upper surface of the enhanced-radium Hawthorn materials is on the order of 2 - 6 m from the land surface.
- Hawthorn Region - Radon potential is generally elevated.
- Proximate Limestone Region[2] - Elevated radon potential because of mapped and unmapped remnants of Hawthorn materials.

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[2]This zone is prefixed as "Proximate" because the sampling sites were all within 6 km of the contiguous Hawthorn Region. There was not sufficient sampling to determine how far away Hawthorn remnants persist.

Presumably a low radon potential region exists to the west beyond the Proximate Limestone Region. A single sampling site at the far western boundary of Alachua County had a low soil gas radon concentration and no evidence of radium >1 pCi/g within the 3-m sampled profile.

Extended North Florida Sampling

A report of the sampling and measurements in North Florida counties outside of Alachua County is included as Annex C and summarized in the following sections. This work, together with the Alachua County work, provided coverage of 13 of the 15 contiguous Northeast Florida counties north from Marion County and west to the Suwanee River plus Leon County (Tallahassee vicinity) further to the west.

Concentrations of soil ^{226}Ra in excess of 2 pCi/g and/or soil gas radon in excess of 1000 pCi/L were found in Marion County, Duval County (one of the two sampling sites) and Leon County (one of the two sampling sites). Values suggestive of an elevated radon source (^{226}Ra 1 - 2 pCi/g and/or soil gas radon 500 - 1000 pCi/g) were found in Columbia and Putnam Counties.

DISCUSSION AND CONCLUSIONS

The Radon Source

This work supports the hypothesis that elevated radon potential in North and North Central Florida is associated with the near-surface occurrence of uranium-bearing phosphatic sand and clay components of the Hawthorn group of formations which underlie much of the region. The radon is coupled to the structure interface via an overlying high permeability sand cover layer of thickness ranging from 0 to >3 m.

The data from the extended North Florida sampling indicate that the elevated radon source potential observed in Alachua county does extend to other areas in North Florida, particularly where there are surficial occurrences of the Hawthorn Group such as in Marion County. However, the areas of elevated radon potential were not well delineated -- one or two sites per county is not a sufficient sampling density to define these areas. A more productive approach would be to prepare a map of surficial geology and perform sampling designed to provide sites representative of the various geologies in the wider area.

Predicting Radon Potential

Geological maps show promise as a basis for sub-county scale radon potential mapping in North Central Florida. Assignment of radon potential requires information about the expected radium content of the material in the first 6 m and the expected permeability of the source material and the cover layer. Transition zones must be recognized and there will be problems of arbitrary assignment of boundaries. The more ground-truthing that can be done, the better the delineations will be.

Soil gas radon measurement should provide a direct indication of radon available for transport into the structure. However, high spatial and temporal variability was observed. This variability must be factored into any effort to develop this method as a radon source prediction protocol; considerable replication may be necessary, particularly in areas with intermediate values. Another possible problem area would be over-estimation of the potential for sustained supply of radon under continued removal by the structure.

The radium profile of sufficient depth is a non-variant indicator of the radon source. In this study, 6-m profiles detected source materials at all of the elevated radon sites. However, 2-m and 1-m profiles missed the source material at 35% and 40%, respectively, of the elevated radon sites. Similar results were found in the site characterization phase of a Gainesville area study of radon resistant features in new house construction. Thus it is concluded that for the soil/geology characteristics present in North Central Florida, surface soil and shallow depth profile (to 1 m) radium measurements are not satisfactory indicators of radon potential.

Other surface soil characteristics may be useful as radon/radium surrogates in estimating radon potential if they are indicative of materials at depths of several meters.

Further Work to be Done

Further work and/or additional lines of investigation suggested by the review of the work performed include:

1. Resolve anomalies - Apparent inconsistencies between soil gas radon, radium profile,

and/or region assigned at several sites should be further investigated.

2. Evaluate additional collected data such as more detailed sample description, permeability, and particle size measurements.
3. Examine radon flux measurement as a practical indicator of radon potential[3].
4. Examine additional profile characteristics such as water table and geological profile for the sampled sites.
5. Perform radon production and transport modeling. This work would be done to (a) verify the qualitative model of the radon source and (b) address the question of the relative contributions of the low permeability, high radium clay and the highly permeable modestly elevated radium clayey sand.
6. Investigate the usefulness of radium/radon surrogates such as soil type, textural class of profile components, and site elevation[4] for radon potential assignment.
7. Validate radon potential assignment by overlay of indoor radon data bases.

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[3]Radon flux measurement, an alternative investigated only to limited extent in this project, theoretically represents the rate of radon supply to the ground surface. This method also has the potential for simulating the negative pressure influence of the structure. However, this parameter also is characterized by temporal and spatial variability.

[4]It has been suggested that, for the Gainesville vicinity, the region of elevated radon potential (near-surface occurrence of the Hawthorn) is associated with the elevation window above sea level of 30 to 45 m (100 to 150 ft) (personal communication, J. Schert, Alachua County Department of Environmental Services).

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ANNEX A. REPORT

NORTH FLORIDA RADON SOURCE STUDIES -- REPORT OF 1992 SIX-METER DRILLING IN ALACHUA COUNTY

North Florida Radon Source Studies --
Report of 1992 Six-meter Drilling in Alachua County

Florida Radon Research Program Technical Report

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Submitted to:

U.S. Department of Energy
Office of Health and Environmental Research
Radon Research Program
Washington, DC 20585

For Work Conducted Under
DOE Award No. DE-FG-05-89ER60825

and to:

Florida Department of Community Affairs
Codes and Standards Division
2740 Centerview Drive
Tallahassee, FL 35255-5305

For Work Conducted Under DCA Contract 93RD-66-13-00-22-003
Task L4, Research Objective L

First Draft January 1993
Revised 20 December 1993

NORTH FLORIDA RADON SOURCE STUDIES -- REPORT OF 1992 SIX-METER DRILLING IN ALACHUA COUNTY. C. E. Roessler and R. Richards, Department of Environmental Engineering Sciences, University of Florida, Gainesville, FL 32611, January 1993 (Revised 20 December 1993).

The field work and laboratory analyses were conducted under U. S. Department of Energy Award No. DE-FG-05-89ER60825 and data evaluations were performed under Florida Department of Community Affairs Contract 93RD-66-13-00-22-003 (Research Objective L, Task 4.1). Opinions, findings, conclusions and recommendations expressed in this report are the those of the authors and do not necessarily reflect the views of the Department of Energy or the Florida Department of Community Affairs.

EXECUTIVE SUMMARY

This task involved 6-m (20-ft) drillings and radiological analysis of the cuttings for a number of sites in Alachua County Florida as part of a radon source study in North Central Florida. In previous work where soil profiles were collected with a hand auger for depths ranging up to 3 m, elevated soil radium was not observed at a number of sites characterized by elevated indoor and/or soil gas radon. Therefore, deeper drillings were conducted to provide a better picture of the radon source.

The targeted 6-m depth was achieved at 15 sites; drilling terminated at 2 m (6 ft) at two sites where the drill could not penetrate a hard limestone layer. Samples of cuttings were collected and analyzed for soil moisture, radium concentration, and radon emanation coefficient. Laboratory analyses were performed on 107 cuttings samples from 17 sites. Soil gas radon measurements were made for 15 of the sites.

While the source material was located within the first 3 m at 10 sites, it was observed between 3 and 6 m at three sites (18%) and was not present within 6 m at four sites (24%). When a source layer was identified within 6 m, soil gas radon concentrations typically were >1,000 pCi/L; at the sites where a source layer was not located within 6 m, concentrations were in the range of 400 to 650 pCi/L (i.e., not elevated). These observations reinforce the opinion that a shallow profile (<3m) will misclassify a significant number of elevated radon potential sites. If soil sample or profile descriptions or radium analyses are to be used to assign radon potential, the necessary depth falls some place in the range of 3 to 6 m.

The sites were identified with geologic units as defined and mapped by the UF Department of Geology. The 17 sites were distributed over the three dominant Alachua County surficial geology units -- eight in the Hawthorn region, five in the Sand region, and four in the Limestone region. Two of the latter were identified with local occurrences of Hawthorn materials over the limestone. These data from a limited number of sampling sites suggest some tentative conclusions. The Hawthorn Region (defined here by the upper surface of the Hawthorn Group of formations occurring within 2 m of the land surface) is an indicator of a radon source. The Sand Region, as defined here, generally does not present elevated radon potential. However, transition zones and local irregularities in the thickness of the cover layer over the source material may present exceptions to these general assignments. The Limestone Region may have mapped and unmapped remnants of Hawthorn Group material and thus will have localized zones of elevated radon potential and, as an overall unit, presents risk of elevated radon potential.

This work has generated data for merging with previously-collected, shallower depth data to improve the description of the North Central Florida radon source and for use in radon source modeling.

TABLE OF CONTENTS

EXECUTIVE SUMMARY iii

LIST OF FIGURES v

LIST OF TABLES v

1. INTRODUCTION 1
    1.1 Background 1
    1.2 Geology and Soil Characteristics of North Central Florida 3

2. METHODOLOGY 6
    2.1 Site Selection 6
    2.2 Sample Collection 6
    2.3 Laboratory Measurements 6
    2.4 Assigned Profiles 8

3. RESULTS AND DISCUSSION 9
    3.1 Depth of Significant Influence 9
    3.2 Characteristics by Geologic Unit 9

4. CONCLUSIONS AND RECOMMENDATIONS 13

5. REFERENCES 14

APPENDIX 15
    APPENDIX A - Drilling Tabulations for Each Site 16
    APPENDIX B - Cuttings Sample Database 34
    APPENDIX C - Instructions for Six-Meter Drilling 37

LIST OF FIGURES

Figure 1. Alachua County Study Location 2
Figure 2. Hawthorn Region in Gainesville Area 4
Figure 3. Generalized Geologic Profile for Gainesville, Florida Vicinity 5
Figure 4. Gainesville Area Map with Sampling Station and Transects 7

LIST OF TABLES

Table 1. Summary of Sample Analyses 10
Table 2. Summary of Source Layers by Geologic Unit 11

Tables A-1 — A-17. Information sheets for each sampling site 17-33

1. INTRODUCTION

This is a report of a task involving 6-m (20-ft) drillings and radiological analysis of the cuttings for a number of sites in Alachua County Florida as part of a radon[1] source study in North Central Florida.

1.1 Background

The most prevalent source of elevated indoor radon in Florida is from the entry of radon-bearing soil gas from beneath the structure. The radon in this soil gas originates from radium in underlying and surrounding soil and fill materials. A 1986-87 statewide indoor radon survey encompassing all 67 Florida counties (Nagda, et al. 1987) reported definite evidence of elevated radon potential in 18 (27%) with limited evidence in an additional 14 (21%). While these "radon potential" counties are distributed from the northern border to near the southern tip of the state, the majority occur in the Bone Valley Formation region of West Central Florida and in parts of North and North Central Florida where the uranium-bearing Hawthorn Group of formations occur near the surface. Population centers in the North Central Region include the vicinities of the cites of Gainesville (Alachua County) and Ocala (Marion County).

A number of published studies (Carlton, et al. 1987; Nagda, et al. 1987; Roessler 1989) and unpublished investigations (University of Florida unpublished reports) in Northern/North Central Florida have shown clusterings of elevated indoor radon generally associated with specific surficial geology. These observations prompted a more definitive study of the radon source in this region.

A study was initiated by the University of Florida (UF) in 1989 under U.S. Department of Energy (DOE) support[2] with the objectives of 1) characterizing the radon source in a region of elevated indoor radon potential that has geology, lithology and climate that are from those in other regions in the U.S. where radon is being studied, 2) describing the radon availability and transport to the environment, and 3) developing approaches for predicting radon potential of lands in this region. Work was focused in Alachua County and the vicinity of the city of Gainesville (Figure 1). Initially, soil profiles were collected with a hand auger for depths ranging up to 3 m. However, elevated soil radium was not observed at a number of sites characterized by elevated indoor radon and/or elevated soil gas radon. Therefore, 6-m drillings were scheduled at 15 sites to provide a better picture of the radon source. Drilling

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[1]In this paper, the terms "radon" and "radium" are used to designate the isotopes ^{222}Rn and ^{226}Ra, respectively.

[2]U. S. Department of Energy Award No. DE-FG-05-89ER60825, June 1989 - May 1982.

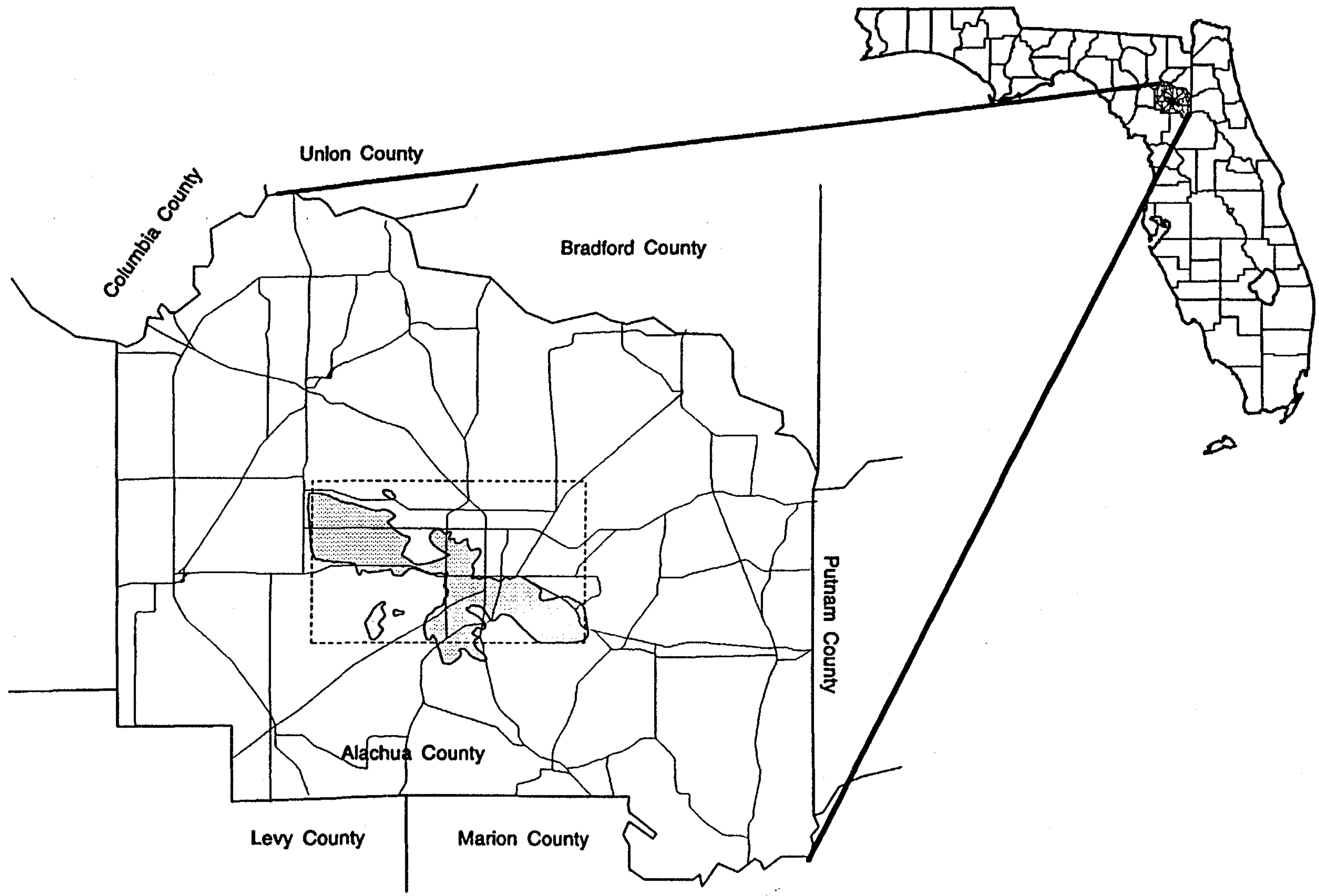

Figure 1. Alachua County Study Location (Inset shows Gainesville vicinity with surface occurance of Hawthorn formation).

and radiological laboratory analyses were conducted just prior to expiration of the DOE project. Because these data were relevant to efforts to develop radon protection building codes, the Florida Department of Community Affairs (DCA) provided subsequent support[3] for collation of the field notes and laboratory results and analysis of the data.

1.2 Geology and Soil Characteristics of North Central Florida

Within Alachua County, three general lithologies dominate the surficial geology -- the Ocala Group of limestone formations, the Hawthorn Group, and younger surficial sands. The general geology of the area consists of a basal continuous rock unit of the Eocene Ocala Group of limestone formations. The Ocala Group of limestone formations is exposed on the western portion by tilting and subsequent erosion of the overlying strata. However, occasional overlying remnants of the Hawthorn Group are present.

Adjoining generally to the north and east of the limestone exposure, the limestone is covered with an eastward-thickening mantle of the Miocene Hawthorn Group of formations. Here the surficial unit is characterized by various unconsolidated sands, discontinuous pods or stringers of clay lenses some several meters or more thick, some phosphatic and limey clays, and relatively small limestone or dolomite beds (Scott 1988). Uranium is associated with the phosphatic components of sands and clays of this formation.

In much of eastern Alachua County, the Hawthorn upper surface is covered by a layer of undifferentiated, unconsolidated material composed of Recent and Pleistocene beach sands. This material may be well sorted, but in places discontinuous lenses of clayey sand or sandy clay have been concentrated.

Thin, alluvial sands cover all three major units throughout much of the county in the upper 0.3 to 1.0 m (1 to 3 ft). The various sands, including the undifferentiated sands of the upper part of the Hawthorn Group, provide a sand cover that ranges in thickness from a few meters near the Hawthorn exposure to >150 m toward the east.

A surficial geology map has been prepared by the UF Department of Geology using a $\leq$2-m depth to the upper surface of the Hawthorn Group of formations to separate the Hawthorn and Sand regions. The surface occurrence of the Hawthorn Group is shown in Figure 2. Figure 3 shows a generalized cross-sectional profile of the surficial geology in the vicinity.

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[3]Florida Department of Community Affairs Contract 93RD-66-13-00-22-003 (Research Objective L, Task 4.1), 31 December 1992 - 15 November 1993.

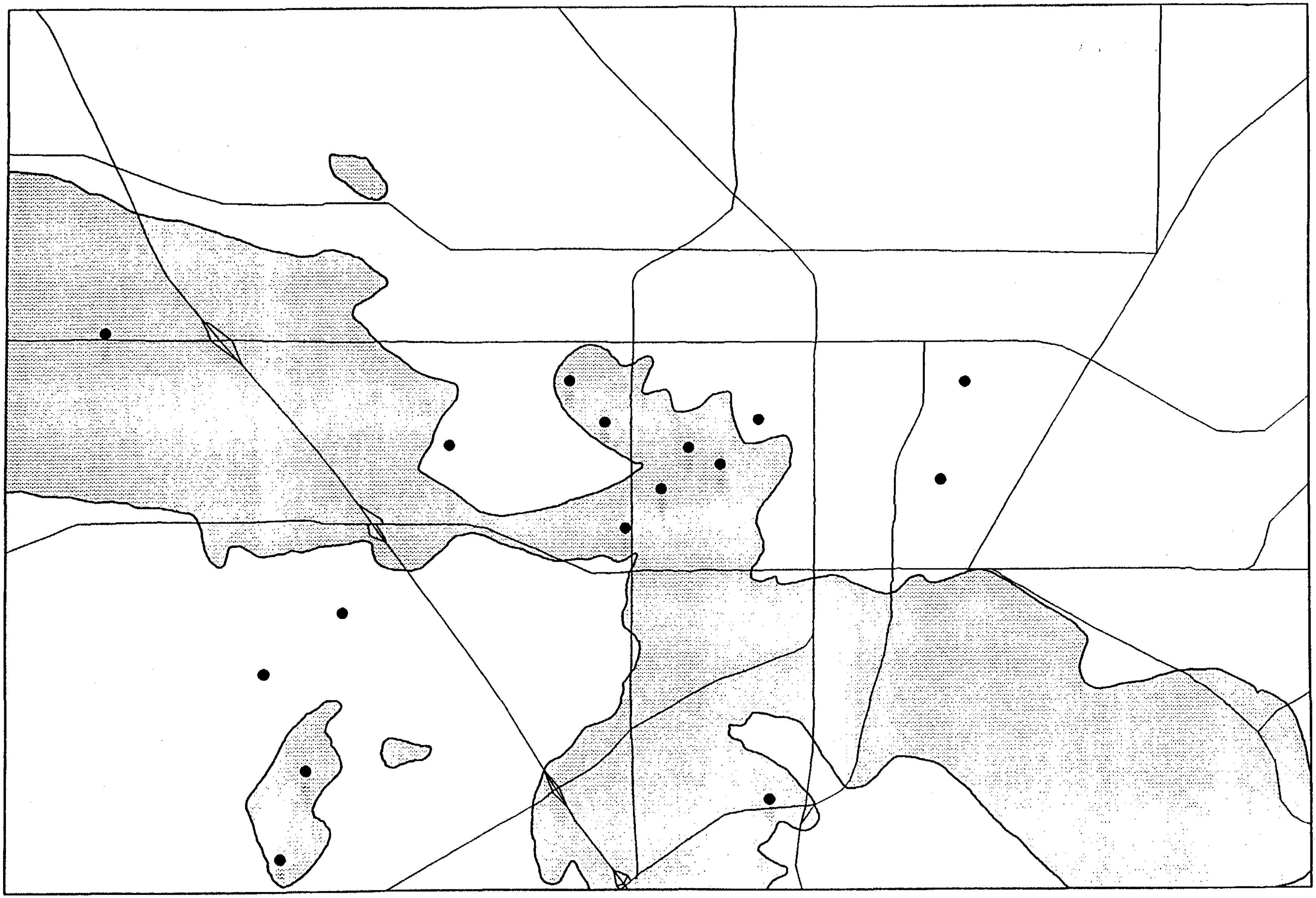
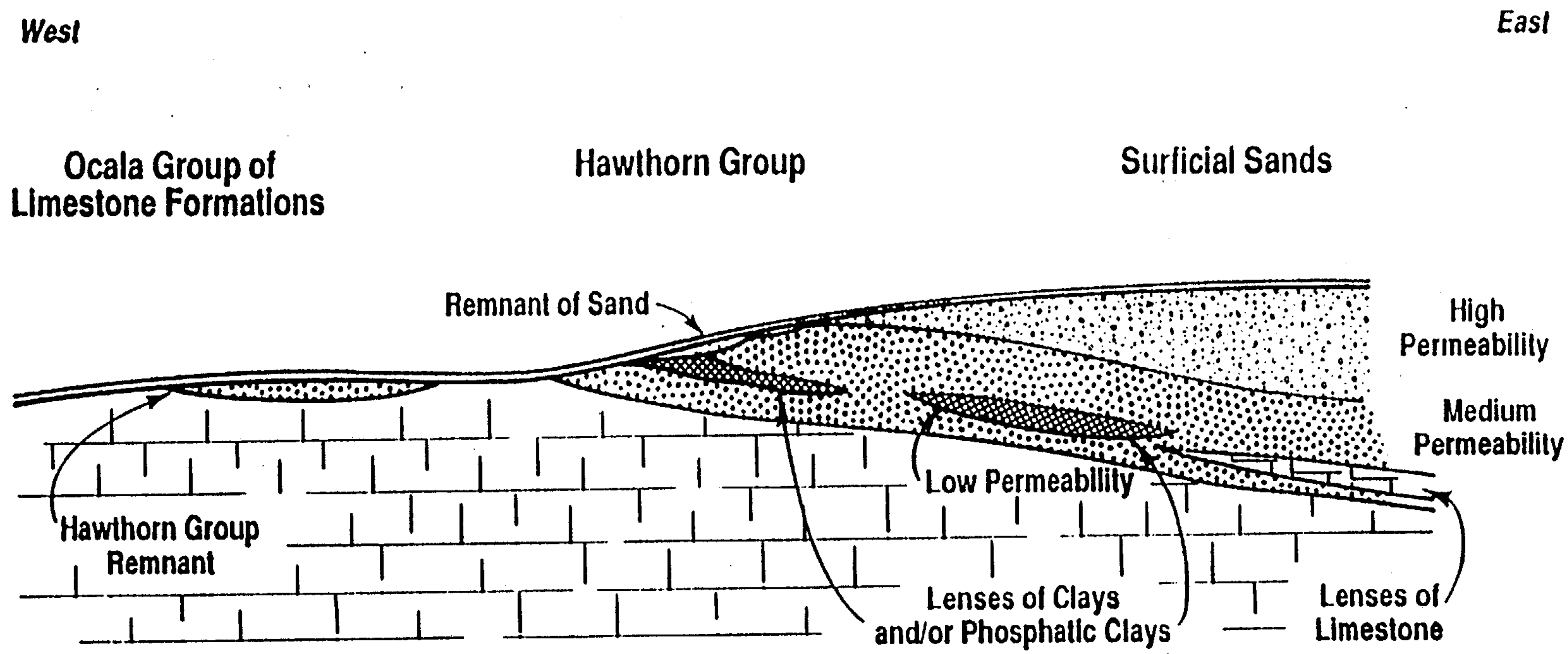


Figure 2. Hawthorn Region in Gainesville Area.



SAMPLING REGIONS

Ocala Group	Hawthorn Group	Surficial Sands
Exposed Limestone with Remnants of Hawthorn Group - Sands and Clays	Sands, Clayey Sands, Clays, Phosphatic Clays, and Thin Limestone Lenses	Surficial Sands Thickening to the East

Figure 3. Generalized Geologic Profile for Gainesville, Floirda Vicinity.

2. METHODOLOGY

2.1 Site Selection

Sites were selected on the basis of being distributed along the three transects being used to organize the Gainesville vicinity data (see Figure 4). Particular emphasis was given to elevated radon sites where a source layer had not been identified.

2.2 Sample Collection

Drilling was conducted by a contractor, Geohazards of Gainesville, FL. The apparatus consisted of a portable drill with an auger bucket attached to the end. The objective was to drill to 6 m (20 ft). This depth was achieved at 15 sites; drilling terminated at 2 m (6 ft) at two sites where the drill could not penetrate a hard limestone layer. Typically, samples of cuttings were collected over 0.3-m (1-ft) increments at 0.6-m (2-ft) intervals (10 samples per 6-m profile); at three sites composite samples were collected from each visually distinguishable horizon (five to seven samples per site). The contractor provided texture and color descriptions of the samples.

At the time of drilling, the field contractor collected soil gas in UF "5" series radon scintillation cells for subsequent radon analysis. Samples were collected according to Florida Radon Research Program (FRRP) Standard Measurement Protocols (Williamson and Finkel, 1990) -- two collections per site, each one meter from the drilling and on opposite sides at a depth of 1.22 m.

Cuttings samples and the filled scintillation cells were sent to the UF for analysis.

2.3 Laboratory Measurements

Samples were received at the UF Department of Environmental Engineering Sciences Environmental Radioactivity Laboratory where they were logged in. Soil samples were further composited to represent layers based on the sample description. Composite samples were analyzed for soil moisture, radium concentration, and radon emanation coefficient according to FRRP Standard Measurement Protocols (Williamson and Finkel, 1990).

Briefly, for radiological analysis of soil samples, dried portions were sealed in a container, counted with a high resolution gamma-ray spectrometry system shortly after sealing, held for ingrowth of radon-222 and its short-lived decay products, and counted at least one more time. Radon emanation coefficient and radium concentration were calculated from the activity associated with the 295.21, 351.92 and 609.31-keV peaks of the short-lived radon daughters. The radium concentration

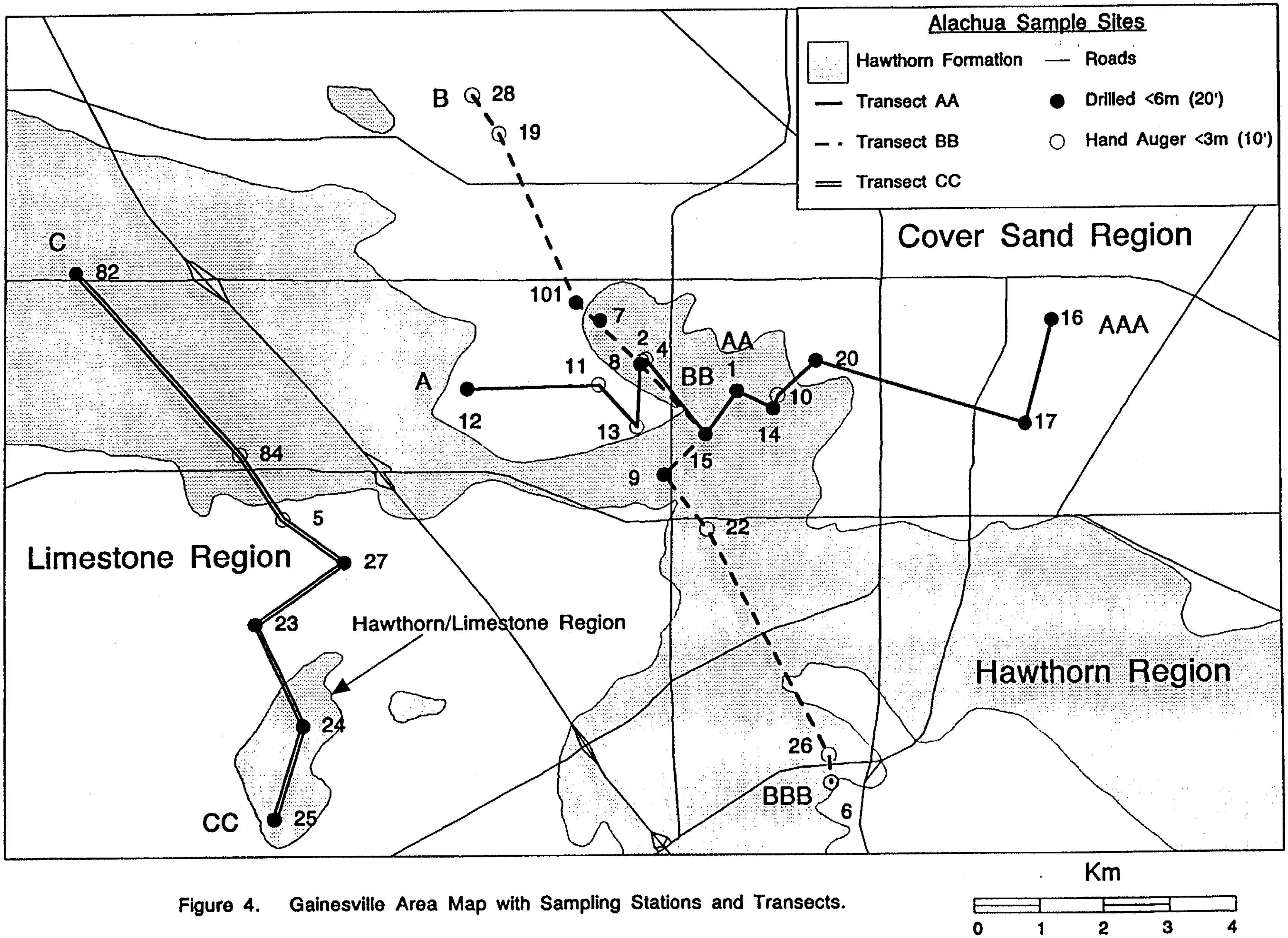


Figure 4. Gainesville Area Map with Sampling Stations and Transects.

was based on the projected equilibrium radon-222 activity; radon emanation coefficient was determined from the pair of values corresponding to pre-ingrowth and equilibrium radon concentrations.

Soil gas radon concentration was determined by counting the filled radon cells on a scintillation cell counter one to two days after collection.

2.4 Assigned Profiles

The site profiles were described in terms of contiguous layers corresponding to the analyzed samples; layer boundaries were taken as the midpoint between adjacent samples (see diagrams in Appendix A).

3. RESULTS AND DISCUSSION

The 17 sampling sites are identified in Figure 4. Laboratory analyses were performed on 107 cuttings samples from these sites; soil gas radon measurements were made for 15 of the sites. Results are summarized in Tables 1 and 2. Appendix A contains entries by sampling site -- radium concentrations of individual samples are presented by depth and site soil gas radon concentrations are presented at the bottom of each site entry. The results of laboratory analyses of cuttings samples are also presented in Appendix B -- radium concentration, radon emanation, and emanating radium concentration (radium concentration x % emanation/100) are listed by sample.

3.1 Depth of Significant Influence

At three (18%) of the sites, the source material[4] was located between 3 m and 6 m. At the four sites where a source layer was not located within 6 m, soil gas radon concentrations were in the range of 400 to 650 pCi/L, i.e., not elevated; whereas when a source layer was identified within 6 m, the concentrations typically were over 1000 pCi/L (with the exception of Site #012). These observations reinforce the opinion that a shallow profile (<3 m) will misclassify a significant number of elevated radon potential sites and they suggest that the depth of influence for radon production, at least in this type of lithology, should not exceed 6 m.

3.2 Characteristics by Geologic Unit

The 17 sites consisted of eight in the Hawthorn region, five in the Sand region, and four in the Limestone region -- two of the latter were identified with local occurrences of Hawthorn materials over the limestone.

At six of the seven sites in the Hawthorn region, the source layer was observed in the drilling depth (actually within 3 m) and the soil gas radon concentrations ranged from 2,800 to 6,500 pCi/L. At one site (#009) no source layer was detected by the 6-m drilling and the soil gas radon concentration was about 400 pCi/L -- this probably represents an uncertainty in defining the boundary of the Hawthorn region.

At three of the five Sand region sites, no source layer was detected and the soil gas radon concentration was $\leq$650 pCi/L. At site #020 a source region was detected at 4 m and the soil gas radon concentration was about 2,400 pCi/L -- this probably reflects the influence of the transition zone near the boundary with the Hawthorn Region. At Site #012, also a potential transition zone site, a source layer was found at 4 m but the soil gas radon concentration was only 730 pCi/L -- there is

---

[4]Source layer refers to a layer of material with a radium concentration significantly greater than that of the typical surface layer (generally >2 pCi/g).

Table 1. Summary of Sample Analyses

Site	Source Layer Depth (m)	Source Layer ^{226}Ra (pCi/g)	Soil Gas Rn (pCi/L)
Hawthorn Region:			
001	1.5	25.5	6,505
007	0.9, 2.1	4.2, 79.7	6,055
008	2.7	15.1	4,005
009	>6	(2.0)*	415
014	1.5	8.6	(84)#
015	0	3.2	4,809
082	0 - 6	2.5	NM
083	0, 4.6	3.9, 10.8	2,845
Avg	--	--	4,105
Range	0 - >6	--	415 - 6,053
Sand Region:			
012	3.4, 4.0	4.7, 24.9	731
016	>6	(0.2)*	620
017	>6	(0.4)*	365
020	4.0, 4.6	4.0, 33.8	2,380
101	>6	(0.6)*	651
Avg	--	--	949
Range	3.4 - >6	--	365 - 2,380
Limestone Region:			
023	0, 1.2	3.4, 4.6	1,415
024 H/L	0	4.7	NM
025 H/L	0, 0.9	3.8, 7.3	3,410
027	0.9, 3.4	1.6, 3.3	1,415
Avg	--	--	2,080
Range	0 - 3.4	--	1,415 - 3,410

Notes:
* *No source layer identified; listed value is maximum concentration observed in 6 m.*
# Flow problem during sampling; not included in average and range.
NM = Not measured.
H/L = Hawthorn over Limestone (local area mapped as Hawthorn within general Limestone Region).

Table 2. Summary of Source Layers by Geologic Unit

Geologic Unit	Number of Occurrences: 0-3 m	3-6 m	NO	Total	Soil Gas Radon Avg (Range), pCi/L
Hawthorn	7	0	1	8	4,105 (415 - 6,053)*
Sand	0	2	3	5	949 (365 - 2,380)**
Limestone	1	1	0	2	1,415 (1,415 - 1,415)
Hawth./Limestone	2	0	0	2	3,410 (#)

NO = NOT OBSERVED (no source layer encountered in 6-m drilling).
* Includes one site mapped as Hawthorn but source layer was not observed in 6 m.
** Includes sites mapped as Sand but source layer was observed at 4 m.
# Soil gas Rn measured at only one site.

no immediate explanation for the discrepancy between the soil profile and the soil gas radon.

In the limestone region, the two sites identified as having a localized Hawthorn overlay have source layers within 3 m; soil gas radon was measured at one site and a value of 3,400 pCi/L was observed. The other two Limestone region sites had source layers within 3 m and 6 m, respectively, and both had soil gas radon concentrations on the order of 1,400 pCi/L.

4. CONCLUSIONS AND RECOMMENDATIONS

1. Depth of drilling - These observations reinforce the opinion that shallow (<3 m) soil samples or profiles will misclassify a significant number of elevated radon potential sites and they suggest that the depth of influence for radon production, at least in this type of lithology, does not exceed 6 m. If soil sample or profile descriptions or radium analyses are to be used to assign radon potential, the necessary depth falls some place in the range of 3 to 6 m.

2. Geologic units - Although there were relatively small numbers of sites in each region, tentative conclusions can be drawn:

   a. The Hawthorn Region, as defined by the UF geological classification, is an indicator of a Rn source.
   b. The Sand Region, as defined here, generally does not present elevated radon potential.
   c. Local irregularities and transition zones present exceptions to these general assignments. Within the area mapped as Hawthorn, there may be locations where the depth to the top of the Hawthorn Group of formations is actually greater than the radon transport distance and there is no elevated radon potential. Elevated radon potential may occur within the area mapped as Sand in transition zones where the thickness of the sand cover over the source material is between 2 and 6 m or at other locations where the cover is actually thinner than projected in the mapping.
   d. The Limestone Region may have mapped and unmapped remnants of Hawthorn Group material and thus will have localized zones of elevated radon potential. Therefore, as an overall unit, this region presents risk of elevated radon potential.

3. It is recommended that these data be merged with existing data from shallower drilling to develop a description of the radon source[5].

4. The data generated by this report are available for use in modeling as an aid in testing the description of the radon source.

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[6]Note to the December 1993 revision: This data merging was accomplished and reported in Roessler, et al. (1993), Radon Source Studies in North Florida, pp 331-350 in Environmental Health Physics, Kathren, Denham, and Salmon, eds., Proceedings of the Twenty-sixth Midyear Topical Meeting of the Health Physics Society, January 24-28, 1993, Coeur d'Alene, ID (Columbia Chapter Health Physics Society, P.O. Box 564, Richland, WA 99352) and in Roessler, et al., Radon Source Studies in North Central Florida, report from University of Florida to Florida Department of Community Affairs, March 1993.

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APPENDICES

APPENDIX A - Drilling Tabulations for Each Site

Table A-1. Information for Site 12001001.

Lat 29.671200

Lon -82.362100

Geological Region: Hawthorn

Depth ft	Depth m		Sampled Cuttings	Cuttings as Analyzed: Description	Ra-226 (pCi/g)	Assigned Profile
0	0.00					
1	0.30					
2	0.61		Light Brown to Orangish Brown Sand	Light Brown to Orangish Sand	2.6	2.6
3	0.91					
4	1.22	#	Light Brown to Orangish Brown Sand			
5	1.52					
6	1.83		Light Brown with some Lightly Cemented Sand	Light Brown with some Lightly Cemented Sand	25.5	25.5
7	2.13					
8	2.44		Dark Tan Sand			
9	2.74					
10	3.05		Orangish Tan Clayey Sand with Lesser Brown Clayey San	Orangish Tan to Brown Clayey Sand	18.0	18.0
11	3.35					
12	3.66		Tan to Brown Clayey Sand			
13	3.96					
14	4.27		Orangish Tan Clayey Sand			
15	4.57					
16	4.88		Beige to Orangish Brown Clayey Sand	Beige to Orangish Clayey Sand	6.9	6.9
17	5.18					
18	5.49		Beige to Orangish Brown Clayey Sand	Beige to Orangish Clayey Sand	14.0	14.0
19	5.79	**				
20	6.10		Beige Clayey Sand	Beige Clayey Sand	11.2	11.2

- Soil Gas Radon = 6,505 pCi/l

** - Shallow water table at drilling time.

Table A-1. Information for Site 12001007.

Lat 29.682029
Lon -82.383962

Geological Region: Hawthorn

Depth ft	Depth m		Sampled Cuttings	Cuttings as Analyzed: Description	Ra-226 (pCi/g)	Assigned Profile
0	0.00					
1	0.30					
2	0.61		Orangish Brown Sand	Orangish Brown Sand	2.9	2.9
3	0.91					
4	1.22	#	Orangish Brown Sand	Orangish Brown Sand	4.2	4.2
5	1.52					
6	1.83		Orangish Light Brown Sand	Orangish Light Brown Sand	17.9	17.9
7	2.13					
8	2.44		Tan Clayey Sand	Tan Clayey Sand	79.7	79.7
9	2.74					
10	3.05		Light Tannish Brown Clayey Sand	Light Tannish Brown Clayey Sand	22.9	22.9
11	3.35					
12	3.66		Light Tannish Brown Clayey Sand	Light Tannish Brown Clayey Sand	14.7	14.7
13	3.96					
14	4.27		Orangish Tan Very Clayey Sand	Tan Clayey Sand	10.2	10.2
15	4.57					
16	4.88		Tannish Grey Sandy Clay			
17	5.18		Tannish Grey Sandy Clay			
18	5.49		Orangish Tan Clayey Sand			
19	5.79	**				
20	6.10		Orangish Tan Clayey Sand	Orangish Tan Clayey Sand	8.6	8.6

- Soil Gas Radon = 6,055 pCi/l

** - Shallow water table at drilling time.

Table A-1. Information for Site 12001008.

Lat 29.675400 — Geological Region: Hawthorn

Lon -82.377500

Depth ft	Depth m		Sampled Cuttings	Cuttings as Analyzed: Description	Ra-226 (pCi/g)	Assigned Profile
0	0.00					
1	0.30					
2	0.61		Brown Sand	Brown Sand	1.2	1.2
3	0.91					
4	1.22	#	Orangish Brown Sand	Orangish Brown Sand	1.2	1.2
5	1.52					
6	1.83		Orangish Brown Sand			
7	2.13					
8	2.44		Dark Tan and Brown Sand	Dark Tan to Brown Sand	1.1	1.1
9	2.74					
10	3.05		Light Tan Sand with Small poorly cemented "ls" grains	Light Tan Sand with Small poorly cemented "ls" grains	15.1	15.1
11	3.35					
12	3.66		Light Tan to Gray Fine Clayey Sand	Tan to Gray Fine Clayey Sand	14.5	14.5
13	3.96					
14	4.27		Light Tan to Gray Fine Clayey Sand			
15	4.57	**				
16	4.88		Light Tan to Gray Fine Clayey Sand	Tan to Gray Fine Clayey Sand	4.1	4.1
17	5.18					
18	5.49		Light Tan to Gray Fine Clayey Sand			
19	5.79		Light Tan to Gray Fine Clayey Sand			
20	6.10					

- Soil Gas Radon = 4,005 pCi/l

** - Shallow water table at drilling time.

Table A-1. Information for Site 12001009.

Lat 29.658539

Lon -82.373732

Geological Region: Sand

Depth ft	Depth m	Sampled Cuttings	Cuttings as Analyzed: Description	Ra-226 (pCi/g)	Assigned Profile
0	0.00				
1	0.30				
2	0.61	Orangish Brown Sand	Orangish Brown Sand	0.4	0.4
3	0.91				
4	1.22	Orangish Tan Sand #	Orangish Tan Sand	0.3	0.3
5	1.52				
6	1.83	Orangish Tan Sand			
7	2.13		Orangish Tan Sand	0.5	0.5
8	2.44	Orangish Tan Sand			
9	2.74				
10	3.05	Orangish Tan Slightly Clayey Sand			
11	3.35		Orangish Tan Slightly Clayey Sand	1.3	1.3
12	3.66	Orangish Tan Slightly Clayey Sand			
13	3.96				
14	4.27	Beige to Orangish Tan Clayey Sand	Beige to Orangish Tan Clayey Sand	2.0	2.0
15	4.57				
16	4.88	Beige Sandy Clay	Beige Sandy Clay	1.9	1.9
17	5.18				
18	5.49	Beige Clayey Sand			
19	5.79		Beige Clayey Sand	1.3	1.3
20	6.10	Beige Clayey Sand **			

- Soil Gas Radon = 415 pCi/l

** - Shallow water table >20' at drilling time.

Table A-1. Information for Site 12001012.

Lat 29.671762

Lon -82.405445

Geological Region: Sand

Depth (ft)	Depth (m)		Sampled Cuttings	Cuttings as Analyzed: Description	Ra-226 (pCi/g)	Assigned Profile
0	0.00					
1	0.30					
2	0.61		Orangish Brown Sand	Orangish Brown Sand	0.5	0.7
3	0.91					
4	1.22	#	Dark Tan to Orangish Brown Sand	Dark Tan to Orangish Brown Sand	0.4	0.7
5	1.52					
6	1.83		Gray Clay with Orangish Tan Sand	Gray Clay with Orangish Tan Sand	1.1	0.7
7	2.13					
8	2.44		Dark Brown Sand and Orangish Brown Sand	Dark Brown Sand and Orangish Brown Sand	0.8	0.7
9	2.74					
10	3.05		Light Brown to Gray Clayey Sand	Light Brown to Gray Clayey Sand	0.8	0.7
11	3.35					
12	3.66		Light Brown and Tan Clayey Sand	Light Brown and Tan Clayey Sand	4.7	4.7
13	3.96					
14	4.27		Light Brown and Tan Clayey Sand	Light Brown and Tan Clayey Sand	24.9	24.9
15	4.57					
16	4.88		Light tan Sand	Light tan Sand	5.1	7.8
17	5.18					
18	5.49		Light tan Sand	Light tan Sand	8.6	7.8
19	5.79	**				
20	6.10		Light tan Sand	Light tan Sand	9.8	7.8

- Soil Gas Radon = 731 pCi/l

** - Shallow water table at drilling time.

Table A-1. Information for Site 12001014.

Lat 29.668700

Lon -82.356500

Geological Region: Hawthorn

Depth ft	Depth m	Sampled Cuttings	Cuttings as Analyzed: Description	Ra-226 (pCi/g)	Assigned Profile
0	0.00				
1	0.30				
2	0.61	Med Tan Sand	Med Tan Sand	4.4	4.4
3	0.91				
4	1.22	Tan Clayey Sand #	Tan Clayey Sand	1.6	1.6
5	1.52				
6	1.83	Light tan Clayey Sand	Light tan Clayey Sand	8.6	8.6
7	2.13				
8	2.44	Light tan Clayey Sand	Light tan Clayey Sand	18.2	18.2
9	2.74				
10	3.05	Light Tan to Orange Clayey Sand	Light Tan to Orange Clayey Sand	19.4	19.4
11	3.35				
12	3.66	Light Tan Clayey Sand			
13	3.96		Light Tan to Gray Clayey to very Clayey Sand	28.3	28.3
14	4.27	Light Tan to Gray Clayey to very Clayey Sand			
15	4.57				
16	4.88	Light Gray Clayey Sand			
17	5.18		Light Gray Clayey Sand	8.7	8.7
18	5.49	Light Gray Clayey Sand			
19	5.79				
20	6.10	Light Gray Clayey Sand	Light Gray Clayey Sand	5.9	5.9
**					

- Soil Gas Radon = 84 pCi/l -- {Flow Problem?}

** - Shallow water table >20' at drilling time.

Table A-1. Information for Site 12001015.

Lat 29.664900 | Geological Region: Hawthorn

Lon -82.367200

Depth ft	Depth m		Sampled Cuttings	Cuttings as Analyzed: Description	Cuttings as Analyzed: Ra-226 (pCi/g)	Assigned Profile
0	0.00					
1	0.30					
2	0.61		Brown Sand	Brown Sand	3.2	3.2
3	0.91					
4	1.22	#	Orangish Brown Sand			
5	1.52			Orangish Brown Sand	2.8	2.8
6	1.83		Orangish Brown Sand			
7	2.13					
8	2.44		Brown Sand			
9	2.74					
10	3.05		Brown Sand	Brown Sand	4.1	4.1
11	3.35					
12	3.66		Brown Sand			
13	3.96					
14	4.27		Brown Sand			
15	4.57			Brown Sand	3.1	3.1
16	4.88		Brown Sand			
17	5.18					
18	5.49		Orangish Brown Sand			
19	5.79			Orangish Brown Sand	2.1	2.1
20	6.10		Orangish Brown Sand			
		**				

- Soil Gas Radon = 4,809 pCi/l

** - Shallow water table >20' at drilling time.

Table A-1. Information for Site 12001020.

Lat 29.675711

Lon -82.349516

Geological Region: Sand

Depth ft	Depth m	Sampled Cuttings	Cuttings as Analyzed: Description	Ra-226 (pCi/g)	Assigned Profile
0	0.00				
1	0.30				
2	0.61	Brown Sand	Brown Sand	1.1	1.1
3	0.91				
4	1.22	# Orangish Brown Sand			
5	1.52		Orangish Brown Sand	0.9	0.9
6	1.83	Orangish Brown Sand			
7	2.13				
8	2.44	Light Brown Sand			
9	2.74				
10	3.05	Light Brown Sand	Light Brown Sand	1.0	1.0
11	3.35				
12	3.66	Light Brown Sand			
13	3.96				
14	4.27	Light Brown to Reddish Sand	Light Brown to Reddish Sand	4.0	4.0
15	4.57				
16	4.88	Light Brown Clayey Sand and Orangish Brown Sandy Clay	Light Brown Clayey Sand and Orangish Brown Sandy Clay	33.8	33.8
17	5.18	**			
18	5.49	Orangish Brown Sandy Clay to Clayey Sand			
19	5.79		Orangish Brown Sandy Clay to Clayey Sand	24.3	24.3
20	6.10	Orangish Brown Sandy Clay to Clayey Sand			

\# - Soil Gas Radon = 2,380 pCi/l

** - Shallow water table at drilling time.

Table A-1. Information for Site 12001023.

Lat 29.606347

Lon -82.436064

Geological Region: Limestone

Depth ft	Depth m		Sampled Cuttings	Cuttings as Analyzed: Description	Cuttings as Analyzed: Ra-226 (pCi/g)	Assigned Profile
0	0.00					
1	0.30		Brown Sand with Slight Clay Content	Brown Sand with Slight Clay Content	3.4	3.4
2	0.61					
3	0.91		Dark Tan Sand	Dark Tan Sand	3.7	3.7
4	1.22	#				
5	1.52		Med Tan Sand	Med Tan Sand	4.6	4.6
6	1.83					
7	2.13		Orange-Brown Clay	Orange-Brown Clay	5.3	5.3
8	2.44					
9	2.74		Sandy Clay			
10	3.05	**		Sandy Clay	5.3	5.3
11	3.35		Sandy Clay			
12	3.66		Sandy Clay	Sandy Clay	9.0	9.0
13	3.96					
14	4.27		Gray-Brown Clay	Gray-Brown Clay	8.3	8.3
15	4.57					
16	4.88		Brown Clay			
17	5.18					
18	5.49		Clay	Brown Clay	14.9	14.9
19	5.79					
20	6.10		Clay			

- Soil Gas Radon = 1,415 pCi/l

** - Shallow water table at drilling time.

Table A-1. Information for Site 12001024.

Lat 29.620261 Geological Region: Hawthorn/Limestone

Lon -82.431388

Depth ft	Depth m		Sampled Cuttings	Cuttings as Analyzed: Description	Cuttings as Analyzed: Ra-226 (pCi/g)	Assigned Profile
0	0.00					
1	0.30					
2	0.61		Dark Brown Clay	Dark Brown Clay	4.7	4.7
3	0.91					
4	1.22	#	Brown Clay with 1st fragments	Brown Clay with 1st fragments	4.8	4.8
5	1.52					
			Limestone Layer Reached -- Could not penetrate.			
6	1.83					
7	2.13					
8	2.44					
9	2.74					
10	3.05					
11	3.35					
12	3.66					
13	3.96					
14	4.27					
15	4.57					
16	4.88					
17	5.18					
18	5.49					
19	5.79					
20	6.10					
		**				

- Soil Gas Radon = ?? pCi/l

** - Water table not reached.

Table A-1. Information for Site 12001025.

Lat 29.606386

Lon -82.436057

Geological Region: Hawthorn/Limestone

Depth (ft)	Depth (m)		Sampled Cuttings	Cuttings as Analyzed: Description	Ra-226 (pCi/g)	Assigned Profile
0	0.00					
1	0.30					
2	0.61		Light Brown Clayey Sand	Light Brown Clayey Sand	3.8	3.8
3	0.91					
4	1.22	#	Brown Clay with Fragments	Brown Clay with Fragments	7.3	7.3
5	1.52					
6	1.83		Brown Clay with Fragments	Brown Clay with Fragments	8.9	8.9
7	2.13					
8	2.44		Limestone Layer Reached -- Could not penetrate.			
9	2.74					
10	3.05					
11	3.35					
12	3.66					
13	3.96					
14	4.27					
15	4.57					
16	4.88					
17	5.18					
18	5.49					
19	5.79					
20	6.10					
		**				

- Soil Gas Radon = 3,410 pCi/l

** - Water table not reached.

Table A-1. Information for Site 12001027.

Lat 29.606347

Lon -82.436064

Geological Region: Limestone

Depth ft	Depth m		Sampled Cuttings	Cuttings as Analyzed: Description	Ra-226 (pCi/g)	Assigned Profile
0	0.00					
1	0.30					
2	0.61		Light Tan Med Sand	Light Tan Med Sand	0.4	0.4
3	0.91					
4	1.22	#	Red Slightly Clayey Sand	Red Slightly Clayey Sand	1.6	1.6
5	1.52					
6	1.83		Brown Clayey Sand	Brown Clayey Sand	1.8	1.8
7	2.13					
8	2.44		Tan Clayey Sand			
9	2.74			Tan Clayey Sand	1.3	1.3
10	3.05		Tan Slightly Clayey Sand			
11	3.35					
12	3.66	**	Gray Clayey Sand			
13	3.96					
14	4.27		Gray Clayey Sand			
15	4.57			Gray Clayey Sand	3.3	3.3
16	4.88		Gray Clayey Sand			
17	5.18					
18	5.49		Gray Clayey Sand			
19	5.79					
20	6.10					

- Soil Gas Radon = 1,415 pCi/l

** - Shallow water table at drilling time.

Table A-1. Information for Site 12001082.

Lat 29.689800

Lon -82.467600

Geological Region: Hawthorn

Depth ft	Depth m		Sampled Cuttings	Cuttings as Analyzed: Description	Ra-226 (pCi/g)	Assigned Profile
0	0.00					
1	0.30					
2	0.61		Brown Sand	Brown Sand	2.8	2.8
3	0.91					
4	1.22		Orangish Brown Sand	Orangish Brown Sand	2.5	2.5
5	1.52	#				
6	1.83		Tannish Brown Slightly Clayey Fine Sand			
7	2.13			Tannish Brown Slightly Clayey Fine Sand	2.3	2.3
8	2.44		Tannish Brown Slightly Clayey Fine Sand			
9	2.74	**				
10	3.05		Tannish Brown Slightly Clayey Fine Sand			
11	3.35					
12	3.66		Tannish Brown Slightly Clayey Fine Sand	Tannish Brown Slightly Clayey Fine Sand	2.1	2.1
13	3.96					
14	4.27		Tannish Brown Slightly Clayey Fine Sand			
15	4.57					
16	4.88		Light Gray Brown Clayey Fine Sand			
17	5.18					
18	5.49		Light Gray Brown Clayey Fine Sand	Light Gray Brown Clayey Fine Sand	2.8	2.8
19	5.79					
20	6.10		Light Gray Brown Clayey Fine Sand			

- Soil Gas Radon = ?? pCi/l <=== Was the result calculated.

** - Shallow water table at drilling time.

Table A-1. Information for Site 12001083.

Lat 29.788900

Lon -82.457700

Geological Region: Hawthorn

Depth ft	Depth m		Sampled Cuttings	Cuttings as Analyzed: Description	Ra-226 (pCi/g)	Assigned Profile
0	0.00					
1	0.30					
2	0.61		Brown Sand	Brown Sand	3.9	3.9
3	0.91					
4	1.22	#	Light Orangish Brown Sand	Light Orangish Brown Sand	3.0	3.0
5	1.52					
6	1.83		Orangish Sand			
7	2.13			Orangish Sand	3.0	3.0
8	2.44		Orangish Sand			
9	2.74					
10	3.05		Orangish Sand			
11	3.35			Orangish Sand	4.3	4.3
12	3.66		Orangish Sand			
13	3.96					
14	4.27		Light Brown to Tan Sand	Light Brown to Tan Sand	3.6	3.6
15	4.57					
16	4.88		Tan Slightly Clayey Sand	Tan Slightly Clayey Sand	10.8	10.8
17	5.18					
18	5.49		Light Brown Clayey Sand	Light Brown Clayey Sand	11.7	11.7
19	5.79					
20	6.10		Light Brown Tan Sand	Light Brown Tan Sand	13.1	13.1
		**				

- Soil Gas Radon = 2,845 pCi/l

** - Shallow water table >20' at drilling time.

Table A-1. Information for Site 12001101.

Lat 29.684764 Lon -82.387854

Geological Region: Sand

Depth ft	Depth m		Sampled Cuttings	Cuttings as Analyzed: Description	Ra-226 (pCi/g)	Assigned Profile
0	0.00					
1	0.30		Sand	Sand	0.4	0.4
2	0.61					
3	0.91					
4	1.22	#				
5	1.52		Light Brown to Orangish Sand	Light Brown to Orangish Sand	0.6	0.6
6	1.83					
7	2.13					
8	2.44					
9	2.74					
10	3.05					
11	3.35		Light Brown to Orangish Sand	Light Brown to Orangish Sand	0.6	0.6
12	3.66					
13	3.96					
14	4.27					
15	4.57					
16	4.88		Orangish Brown Sand	Orangish Brown Sand	0.5	0.5
17	5.18					
18	5.49					
19	5.79		Tan to Beige Sand	Tan to Beige Sand	0.4	0.4
20	6.10	**				

- Soil Gas Radon = 651 pCi/l

** - Shallow water table >20' at drilling time.

APPENDIX B - Cuttings Sample Database

Lab#	Site - Depth		Ra226	± Err	Eman%	Eman Ra
8876	1001	2-4′	2.6	0.05	36%	0.9
8877		6-8′	25.5	0.21	65%	16.5
8878		10-14′	18.0	0.14	48%	8.7
8879		16′	6.9	0.11	31%	2.1
8880		18′	14.0	0.15	10%	1.4
8881		20′	11.2	0.10	20%	2.3
8892	1007 -	2′	2.9	0.05	32%	0.9
8893		4′	4.2	0.06	42%	1.8
8894		6′	17.9	0.16	22%	3.9
8895		8′	79.7	0.30	53%	41.9
8896		10′	22.9	0.19	36%	8.1
8897		12′	14.7	0.16	44%	6.5
8898		14′	18.3	0.14	37%	6.8
8899		16-18′	10.2	0.10	27%	2.8
8900		20′	8.6	0.09	23%	2.0
8947	1008 -	2′	1.2	0.04	26%	0.3
8948		4- 6′	1.2	0.03	36%	0.4
8949		8′	1.1	0.03	23%	0.2
8950		10′	15.1	0.15	12%	1.8
8951		12-14′	14.5	0.16	11%	1.6
8952		16-20′	4.1	0.06	16%	0.6
8930	1009 -	2′	0.4	0.03	34%	0.1
8931		4′	0.3	0.02	13%	<0.1
8932		6- 8′	0.5	0.03	20%	0.1
8933		10-12′	1.3	0.04	52%	0.7
8934		14′	2.0	0.06	47%	0.9
8935		16′	1.9	0.06	47%	0.9
8936		18-20′	1.3	0.04	34%	0.5
8882	1012 -	2′	0.5	0.03	15%	0.1
8883		4′	0.4	0.02	40%	0.2
8884		6′	1.1	0.04	22%	0.2
8885		8′	0.8	0.04	44%	0.3
8886		10′	0.8	0.03	26%	0.2
8887		12′	4.7	0.09	43%	2.0
8888		14′	24.9	0.21	23%	5.8
8889		16′	5.1	0.07	38%	2.0
8890		18′	8.6	0.11	15%	1.3
8891		20′	9.8	0.12	42%	4.1

Lab#	Site- Depth	Ra226	± Err	Eman%	EmanRa
8832	1014 - 2'	4.4	0.16	88%	3.9
8833	4'	1.6	0.06	41%	0.7
8834	6'	8.6	0.13	46%	3.9
8835	8'	18.2	0.18	39%	7.1
8836	10'	19.4	0.90	43%	8.3
8837	12-14'	28.3	0.18	53%	15.1
8838	16-18'	8.7	0.10	40%	3.5
8839	20'	5.9	0.09	30%	1.8
8901	1015 - 2'	3.2	0.07	47%	1.5
8902	4- 6'	2.8	0.07	43%	1.2
8903	8-12'	4.1	0.06	57%	2.3
8904	14-16'	3.1	0.07	50%	1.6
8905	18-20'	2.1	0.04	48%	1.0
8858	1016 - 1'	0.1	0.01	46%	0.1
8859	2-3'	0.1	0.02	n	0.1
8860	4'	0.3	0.03	34%	0.1
8861	5-10'	0.2	0.02	29%	0.1
8862	9-10'	0.5	0.03	26%	0.1
8863	12'	0.4	0.03	18%	0.1
8864	13'	0.2	0.02	41%	0.1
8865	14	0.2	0.02	21%	0.1
8866	15-19'	0.3	0.02	23%	0.1
8853	1017 - 2'	0.2	0.02	14%	<0.1
8854	4- 6'	0.4	0.03	22%	0.1
8855	8-10'	0.8	0.03	47%	0.4
8856	12-13'	0.4	0.03	37%	0.1
8857	14-19'	0.2	0.02	12%	<0.1
8953	1020 - 2'	1.1	0.03	29%	0.3
8954	4- 6'	0.9	0.04	30%	0.3
8955	8-12'	1.0	0.06	47%	0.5
8956	14'	4.0	0.07	49%	2.0
8957	16'	33.8	0.17	36%	12.0
8958	18-20'	24.3	0.20	33%	8.0
8840	1023 - 1'	3.4	0.14	91%	3.1
8841	3'	3.7	0.15	93%	3.4
8842	5'	4.6	0.12	89%	4.1
8843	7'	5.3	0.11	63%	3.3
8844	9-11'	5.3	0.08	66%	3.5
8845	12'	9.0	0.10	63%	5.6
8846	14'	8.3	0.13	61%	5.1
8847	16-20'	14.9	0.14	63%	9.3

n = negative emanation calculated (no emanation coefficient reported).

Lab#	Site - Depth	Ra226	± Err	Eman%	EmanRa
8909	1024 - 2′	4.7	0.07	68%	3.2
8910	4′	4.8	0.11	64%	3.1
8906	1025 - 2′	3.8	0.08	65%	2.1
8907	4′	7.3	0.11	56%	4.1
8908	6′	8.9	0.15	50%	4.5
8848	1027 - 2′	0.4	0.03	38%	0.2
8849	4′	1.6	0.04	44%	0.7
8850	6′	1.8	0.06	52%	0.9
8851	8-10′	1.3	0.05	53%	0.7
8852	12-18′	3.3	0.07	64%	2.1
8942	1082 - 2′	2.8	0.07	31%	0.9
8943	4′	2.5	0.05	24%	0.6
8944	6-8′	2.3	0.06	32%	0.7
8945	10-14′	2.1	0.05	36%	0.8
8946	16-18′	2.8	0.05	24%	0.7
8911	1083 - 2′	3.9	0.06	57%	2.2
8912	4′	3.0	0.06	46%	1.4
8913	6- 8′	3.0	0.05	50%	1.5
8914	10-12′	4.3	0.08	43%	1.9
8915	14′	3.6	0.05	33%	1.2
8916	16′	10.8	0.13	46%	4.9
8917	18′	11.7	0.11	46%	5.3
8918	20′	13.1	0.11	43%	5.6
8937	1101 - 0- 4′	0.4	0.03	20%	0.1
8938	4-10′	0.6	0.03	23%	0.1
8939	10-15′	0.6	0.03	34%	0.2
8940	15-18′	0.5	0.03	20%	0.1
8941	18-29′	0.4	0.02	29%	0.1

APPENDIX C
Instructions for Six-Meter Drilling

5 May 1992

RADON SOURCE ("DOE") PROJECT - DRILLING EXERCISE

SUMMARY: Fifteen sites are to be drilled to a depth of 20 ft for characterization of the profile and collection of samples for laboratory analysis. The purposes of this exercise are:

1. To locate the radon source at sites where elevated soil gas and/or indoor radon were not explained by elevated radium-226 in the material reached by hand auger.
2. Provide a better description of the soils and geological profile of the first 20 ft in areas of elevated radon potential in the Gainesville vicinity.
3. To provide some comparison data by also drilling at several "low radon" sites.

SAMPLES AND DATA (To be collected at each site):

1. Soil gas radon measurement (See Procedures, below).

2. Geological description of the entire 20-ft profile with layers or horizons identified by distance from the surface.

3. Representative samples of at least 1 gallon volume from each layer. Samples are to be put in individual containers and labeled as to site and depth increment.

4. Estimate of the depth of the shallow water table at the time of the soil gas measurement.

SAMPLING LOCATIONS:

Drilling to be done in yard of indicated address or, alternatively, as close nearby as possible.

Priority 1 - Two sites previously sampled in the Pliopleistocene sand region ("Sand Region"), selected as having low radon probability.

1. ALA-016: (*)

2. ALA-017: (*)

Priority 2 - Four sites to the west of I-75. Sites of houses that participated in the 1990-91 year-long "Short term/Long-term indoor radon monitoring study. Identified as a) Upper Eocene limestone region ("Limestone Region"), b) regions of Hawthorn remnants over limestone, or c) Hawthorn region.

1. - 3. Three of the following four:

ALA-027: (*)

ALA-023: (*)

ALA-024: (*)

ALA-025: (*)
(Note: this yard has little space)

4. ALA-082: (*)
House is 1½ miles west of I-75. Has green chain link fence. Be sure to call and make arrangements. Mrs. _______________ will be home the week of 11 May.

Priority 3 - Cluster of NW Gainesville sites previously sampled in the Hawthorn region. Demonstrated elevated radon probability.

Five to seven sites in two orthogonal traverses; to be selected.

Priority 4 - Two to four additional sites to be selected as contributing to objectives and providing representation of the region.

(*) Address given in the original Instruction set.

SOIL GAS RADON SAMPLING PROCEDURE:

Soil gas radon is to be measured on the day of drilling. This measurement is to be made according to the FRRP Standard Measurement Protocols.

- Samples are to be collected from two separate points on either side of the proposed drilling location. The two should be approximately 100 cm (90 to 110 cm) apart.

- Samples are to be collected using a soil probe, the UF "5" series Rn scintillation cells, and a pump such as is included in the Rogers and Associates MK-II permeameter.

- Sample with probe driven to 122 cm (48 inches). If this depth is below the surface of the shallow water table or if it has penetrated an impermeable clay layer, the gas sampling should be performed at a shallower depth just above the water table or the low permeability layer.

Pick up purged, background-counted scintillation cells form the Department of Environmental Engineering Sciences Environmental Radiation Lab on the first floor of A.P. Black Hall. Within one day of filling, return the filled cells to the same location for analysis, coordinate this with:
Ryan Richards or Hazim Mohammed, 392-0836.

As an option, additional soil gas measurements may be made by an EES team using a Pylon AB-5 and the 4-hr ingrowth counting procedure.

ANNEX B. MANUSCRIPT

RADON SOURCE STUDIES IN NORTH FLORIDA

Reprint of a paper published in Environmental Health Physics, proceedings of Twenty-sixth Midyear topical meeting of the Health Physics Society, January 24-28, 1993, Coeur d'Alene, ID, pages 331-350. Columbia Chapter Health Physics Society, P.O. Box 564, Richland, WA 99352.

RADON SOURCE STUDIES IN NORTH FLORIDA

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ABSTRACT

This paper reports progress in characterizing the radon source in the vicinity of an area of elevated indoor radon potential in the southeastern United States and in developing approaches for predicting radon potential of land areas in this region. The radon source in north-central Florida is the near-surface occurrence of uranium-bearing materials of the Hawthorn Group of formations which underlies part of the region. Radon originates in radium-bearing clay or clayey sand source zones. It is transported to the land-building interface via an overlying low radium sand-cover layer ranging in thickness from nil to >3 m. Elevated radon potential may be associated with several surficial geological units—(1) miocene Hawthorn formations, (2) portions of the pleistocene sand region that are influenced by underlying Hawthorn formations, and (3) portions of the eocene Ocala Group of limestone formations, where scattered remnants of radium-bearing Hawthorn materials or their leachates persist. Soil-gas radon concentration is an indicator of subsurface radium and increased probability of elevated indoor radon. Radium concentrations in the 6-m profile identify source materials that contribute to elevated near-surface radon. However, for this region, radium concentrations in surface soil and the shallow (1- or 2-m) profile failed to predict elevated radon in a significant number of cases.

INTRODUCTION

his is a progress report on a radon source study being conducted in northern and north-central Florida. The overall objectives of the project are to (1) characterize the radon source in a region of elevated indoor radon potential that has geology, lithology, and climate that are different from those in other regions in the United States where radon is being studied, (2) describe the radon availability and transport in this environment, and (3) develop approaches for predicting radon potential of lands in this region. In this paper, the terms "radon" and "radium" are used to designate the isotopes ^{222}Rn and ^{226}Ra, respectively.

A 1986-1987, statewide, indoor radon survey encompassing all 67 Florida counties reported that 18 (27%) had definite evidence and an additional 14 (21%) had limited evidence of elevated radon potential (Nagda et al. 1987). While these "radon potential" counties are distributed from the northern border to near the southern tip of the state, the majority occur in the Bone Valley Formation region of west-central Florida and in parts of northern and north-central Florida where the uranium-bearing Hawthorn Group of formations occurs near the surface.

A number of published studies (Carlton et al. 1987, Nagda et al. 1987, Roessler 1989) and unpublished reports (University of Florida) in northern/north-central Florida have shown clusterings of elevated indoor radon generally associated with specific surficial geology. These observations prompted a more definitive study of the radon source in this region. Population centers in the north-central region include the vicinities of the cities of Ocala (Marion County) and Gainesville (Alachua County). The Gainesville vicinity was selected for this study (Figure 1).

GEOLOGY AND SOIL CHARACTERISTICS OF NORTH-CENTRAL FLORIDA

A generalized cross-sectional profile of the surficial geology of the Gainesville vicinity is shown in Figure 2; the surface occurrences are mapped in Figure 3. In terms of surficial geology, three general lithologies dominate the area: the Ocala Group of limestone formations, the Hawthorn Group, and younger surficial sands.

The general geology of the area consists of a basal continuous rock unit of the eocene Ocala Group of limestone formations, the uppermost of which is the Crystal River formation. The Ocala Group of limestone formations (Figures 2 and 3) is exposed on the western portion by tilting and subsequent erosion of the overlying strata. However, occasional overlying remnants of the Hawthorn Group are present. This region can be characterized as nearly level to sloping, with 0 to 1 m of well-drained and moderately drained surface sand.

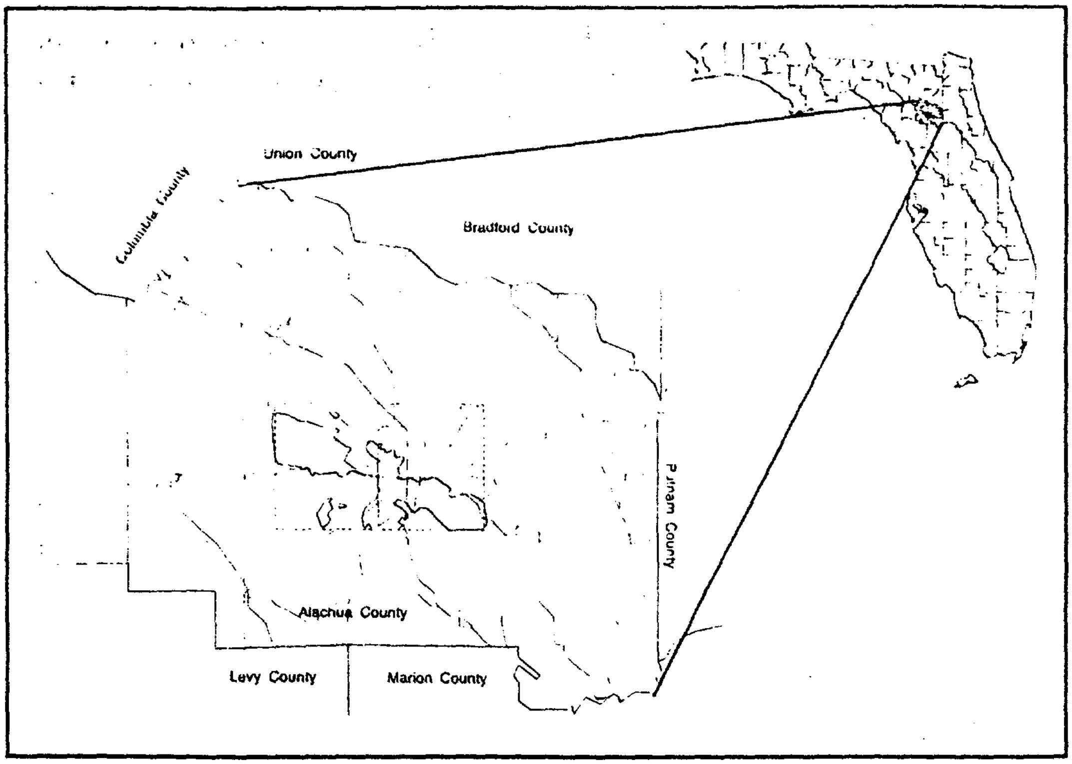


FIGURE 1. Alachua County, Florida, study location.

Adjoining generally to the north and east of the limestone exposure, the limestone is covered with an eastward-thickening mantle of the miocene Hawthorn Group of formations. Here the surficial unit is the Coosawhatchee formation, which is characterized by various unconsolidated sands, discontinuous pods or stringers of clay lenses some several meters or more thick, some phosphatic and limey clays, and relatively small limestone or dolomite beds (Scott 1988). The region can be characterized as varying from nearly level to strongly sloping, moderately well-drained to poorly drained, and covered with 0 to 2 m of surface sands. Uranium is associated with the phosphatic components of sands and clays of this formation.

In the area shown as the Cover Sand region in the figures, the Hawthorn upper surface is covered by a layer of undifferentiated, unconsolidated material composed of recent and pleistocene beach sands. This material may be well sorted, but in places, discontinuous lenses of clayey sand or sandy clay have been concentrated, probably by hydrologic activity. This area is tectonically stable. It is expected to have a low radon potential because of the depth of the sands overlying the uranium-bearing Hawthorn formation. This region can be characterized as nearly level to gently sloping with somewhat poorly drained soils. These sands and the undifferentiated sands of the upper part of the Hawthorn Group range in thickness from a few meters near the Hawthorn exposure to >150 m toward the east.

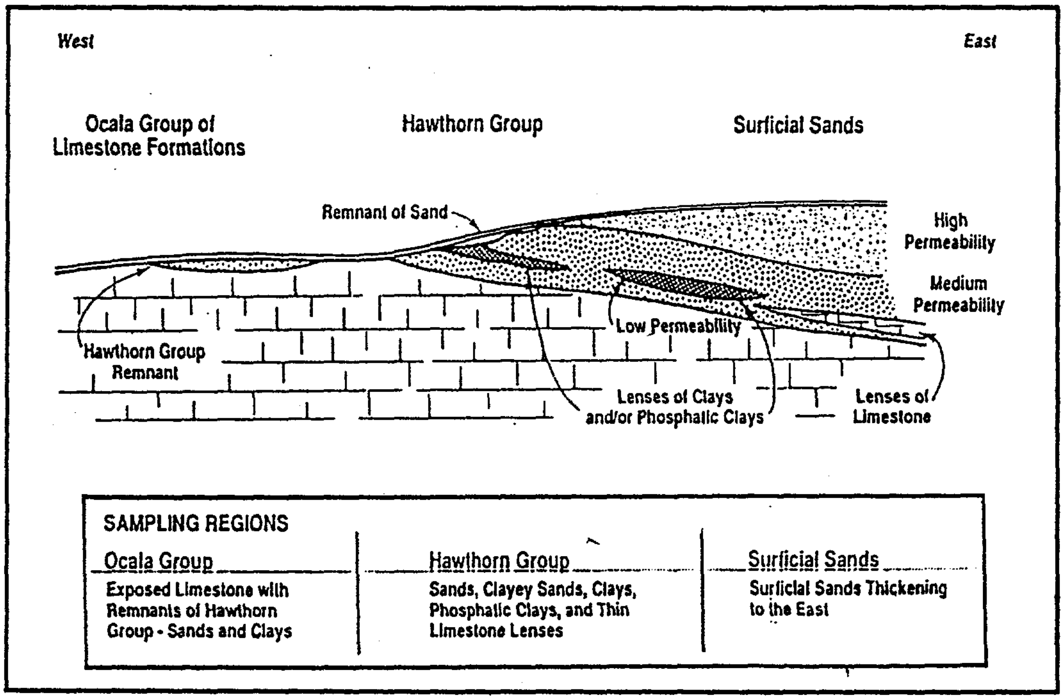


FIGURE 2. Generalized geologic profile for Gainesville, Florida, vicinity.

METHODS

Study sites

Thirty sites were studied; they were distributed among the three geological regions. Sampling sites included 25 for which indoor radon data were available from other projects. Six were indoor radon mitigation demonstration sites, and 19 were sites in a study intercomparing short-term and long-term indoor radon measurements in occupied houses. The majority of the sites are shown in Figure 3. One additional Hawthorn Region site (site 083) is north of Gainesville, beyond the confines of the map. Also off the map is a Limestone Region site (site 021) in western Alachua County. At site 021 the limestone is overlain by thick beach sands; in a more definitive classification scheme, this site would be designated as in the region of Brooksville Ridge sand.

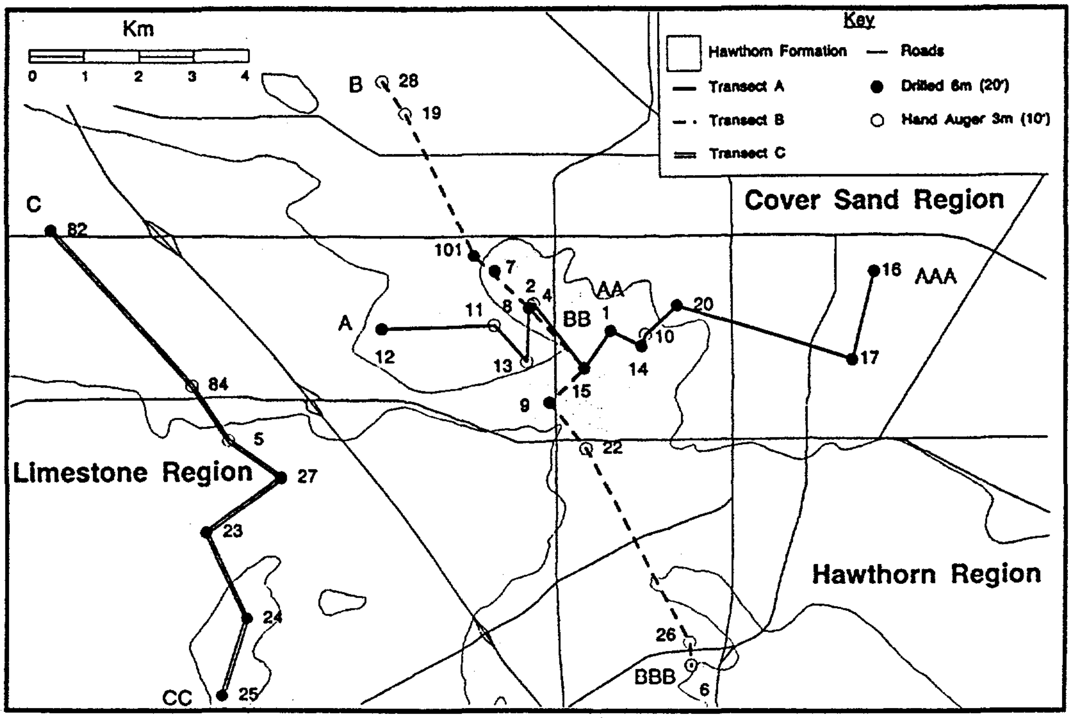


FIGURE 3. Gainesville area map with surficial geology, sampling sites, and transects.

Sampling and Measurements

Soil-gas radon was measured, and soil profiles were collected and measured for radium. Sampling and measurements are summarized in Table 1. (Other observations were made in addition to those covered in this report. Radon flux measurements were made at a subset of sites. Permeability profiles were determined by in-situ measurements and the presence of the water table noted when observable within the auger or drill depth. Additional laboratory analyses of soil profile samples included moisture content, radon emanation coefficient, air permeability under several combinations of moisture and compaction, particle size by sieve analysis, sand/silt/clay classification by sedimentation analysis, and description according to textural classification.)

Soil profiles were sampled by hand-auger at all sites. Samples were collected to a depth of 3 m (10 ft) unless shallower depths were dictated by the presence of rock or collapse of the hole due to ground water. Initial observations prompted deeper sampling at a subset of sites. At 16 sites, a power drill was used to a depth of 6 m (20 ft), and drill cuttings were collected over approximately 0.3-m (1-ft) increments at intervals of 0.6 m (2 ft).

TABLE 1. Observations, measurements, and sampling.

Site Description: Recording topography, degree of disturbance, and slope

Soil Profile

Sampling by hand-auger to 2 or 3 m; samples represent 30-cm increments or distinct changes in horizon collected for laboratory analysis.

At a subset of locations, sampling was done by drill to 6 m (20 ft); drill cuttings represent 0.3-m increments collected at 0.6-m intervals; cutting samples composited by visually apparent horizon for laboratory analysis.

Laboratory analysis for radium by high-resolution gamma spectrometry.

Soil Gas Radon

Grab sampling with soil probe and scintillation cell

Collection from 1-m depth (or just above impermeable layer, if present within first 1 m).

Standard procedure: four stations/site.

In conjunction with 6-m drilling: one station/site.

RESULTS

For the initial data analysis, the sampling sites were classified according to the following geologic/geographic regions:

(1) *Cover Sand*—the region covered with pleistocene-age sands, and lying generally to the north and east of the exposure of Hawthorn Group materials

(2) *Hawthorn*—the contiguous region where material from the Hawthorn group is exposed within 1 m of the surface

(3) *Limestone*—region to the south and west of the contiguous Hawthorn Region; includes sites coinciding with remnants of Hawthorn over the limestone.

Soil-gas radon data and radium concentrations in the first meter of profile are summarized in Table 2 and presented as frequency distributions by region in Figures 4 and 5. Individual site data, including radium concentration ranges for the entire profile sampled, are presented by transects in Figures 6 through 8. Indoor radon, soil-gas radon, and soil radium data are presented for individual sites by region in Appendix Tables A-1 through A-3.

TABLE 2. Summary of soil-gas radon and near-surface radium by geologic/geographic region for Gainesville-vicinity sites.

	Cover Sand Region	Hawthorn Region	Limestone Region
SOIL-GAS RADON			
Range of concentrations (pCi/L)[a]	16 - 8360	300 - 7920	76 - 3360
Number (percentage) of sites with indicated concentrations			
<1000 pCi/L	8 (80.0)	2 (15.4)	2 (33.3)
1000-2000	1 (10.0)	3 (23.1)	2 (33.3)
2000-3000	0 (0.0)	2 (15.4)	0 (0.0)
>3000	1 (10.0)	6 (46.2)	2 (33.3)
Total	10 (100.0)	13 (100.0)	10 (100.0)
RADIUM IN NEAR-SURFACE (0 to 1-m) profile			
Range of concentrations (pCi/g)[b]	0.1 - 1.1	0.3 - 4.4	0.2 - 4.7
Number (percentage) of sites with indicated concentrations			
<1 pCi/g	10 (100.0)	4 (28.6)	3 (50.0)
1-2	0 (0.0)	2 (14.3)	0 (0.0)
2-10	0 (0.0)	8 (57.1)	3 (50.0)
Total	10 (100.0)	14 (100.0)	6 (100.0)

[a]Measured at depths of 0.3 to 1.2 m (1 to 4 ft).

[b]Maximum concentrations in 0.3-m (1-ft) increments in first 1 m (3 ft) of profiles.

Cover Sand Region

Soil-gas radon concentrations in this region were generally <700 pCi/L and the shallow (0 to 1 m) soil radium concentrations were all <1 pCi/g. Soil radium concentrations exceeding 1 pCi/g, when found, occurred at depths of 3 m or more. Site 020 (2000 pCi/L) was near the Sand/Hawthorn boundary and had elevated radium concentrations at 4 m; it may reflect the imprecision in assigning boundaries. Site 028 (>8000 pCi/L) cannot be explained as a boundary location. The radium content was ≤1 pCi/g for the entire 2.7-m sampled depth. Further evaluation of the microgeology and the profile beyond 2.7 m would be informative.

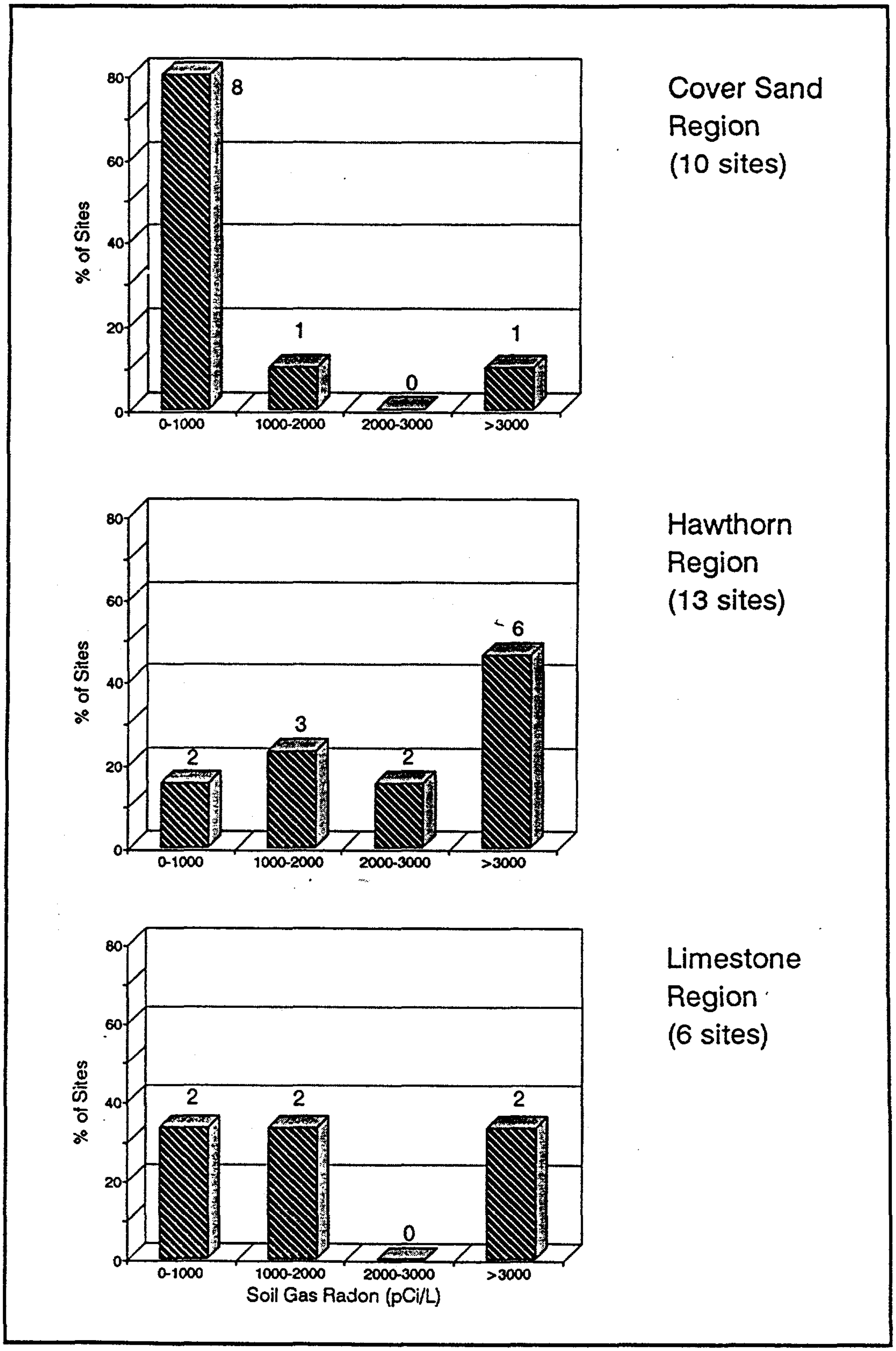


FIGURE 4. Soil-gas radon—frequency distributions by geologic/geographic region in the Gainesville vicinity.

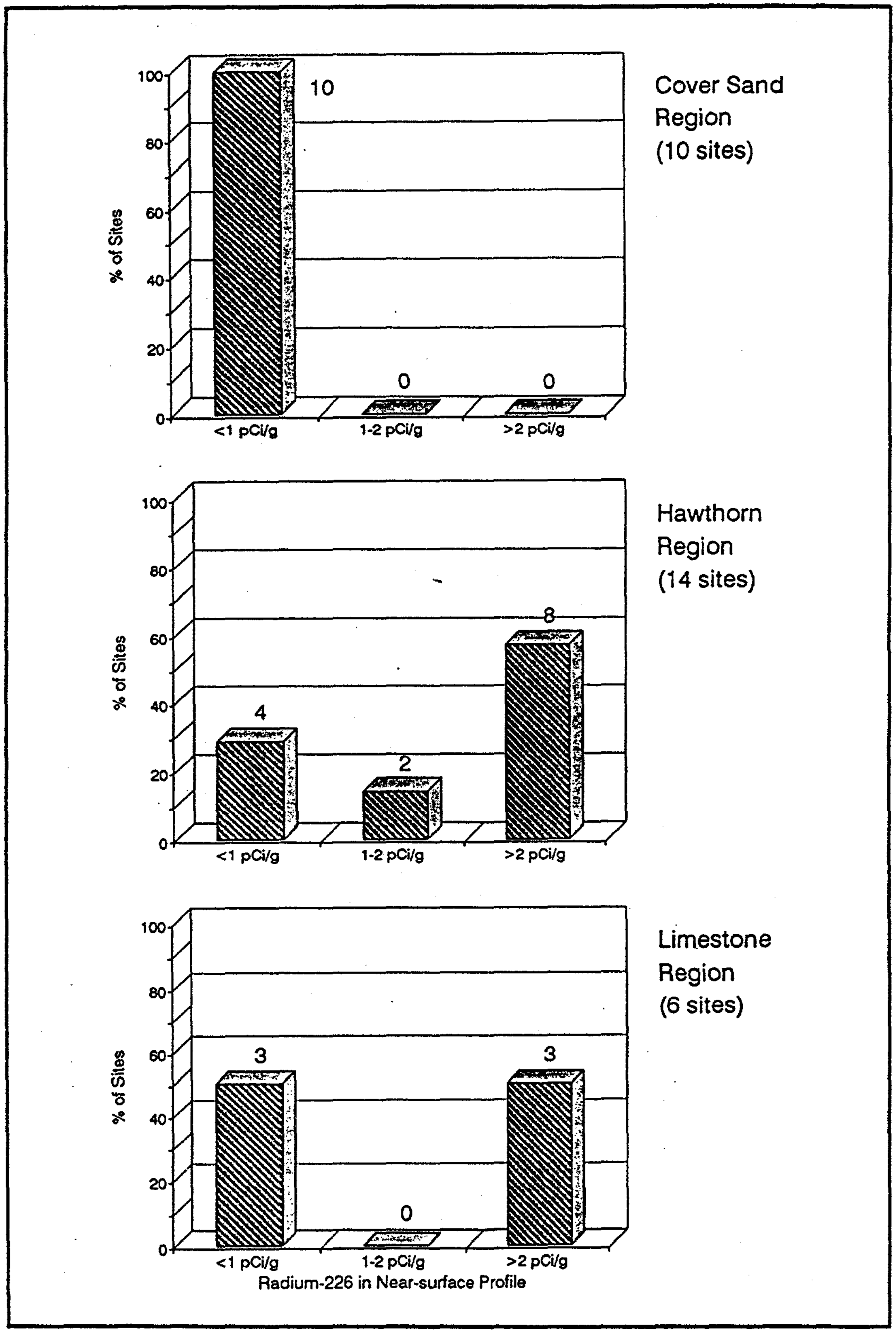
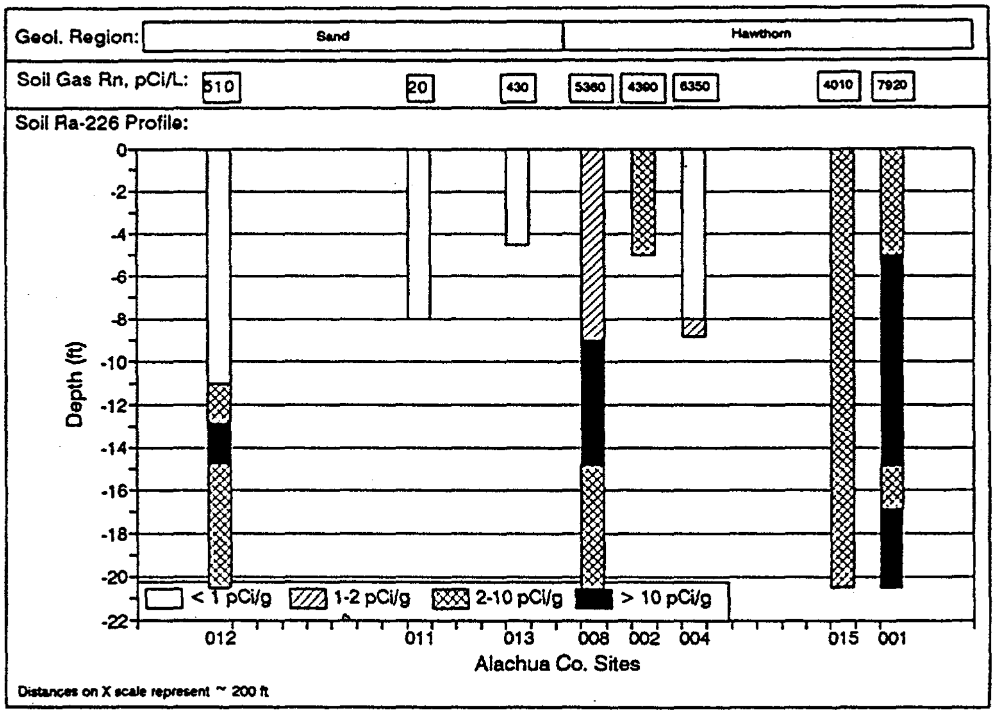


FIGURE 5. Radium-226 in the near-surface profile—frequency distributions by geologic/geographic region in the Gainesville vicinity.



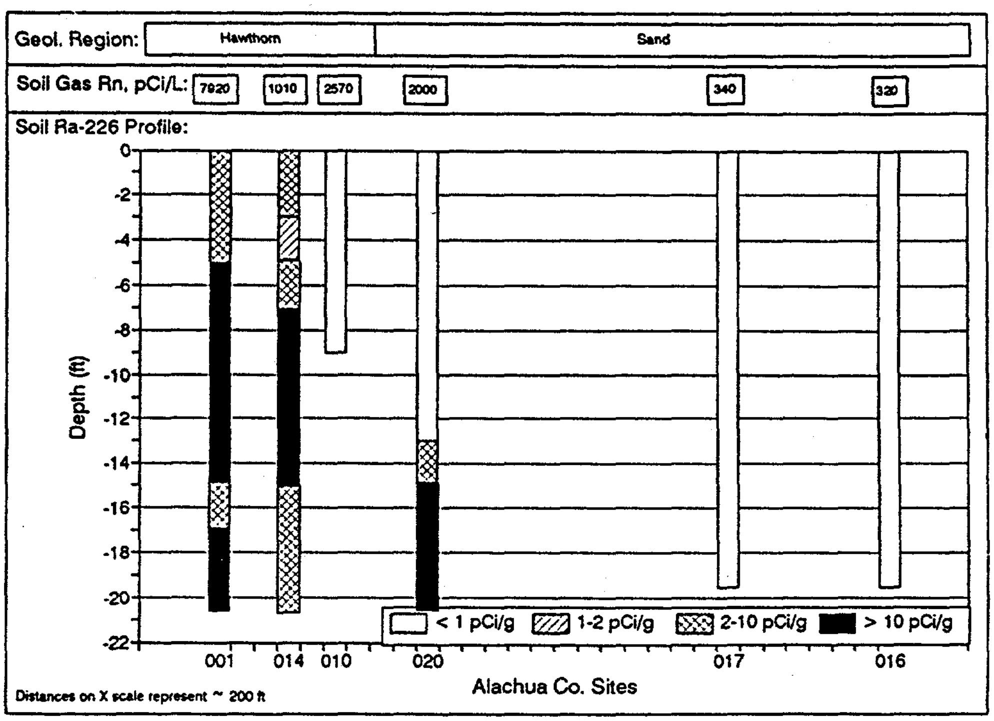
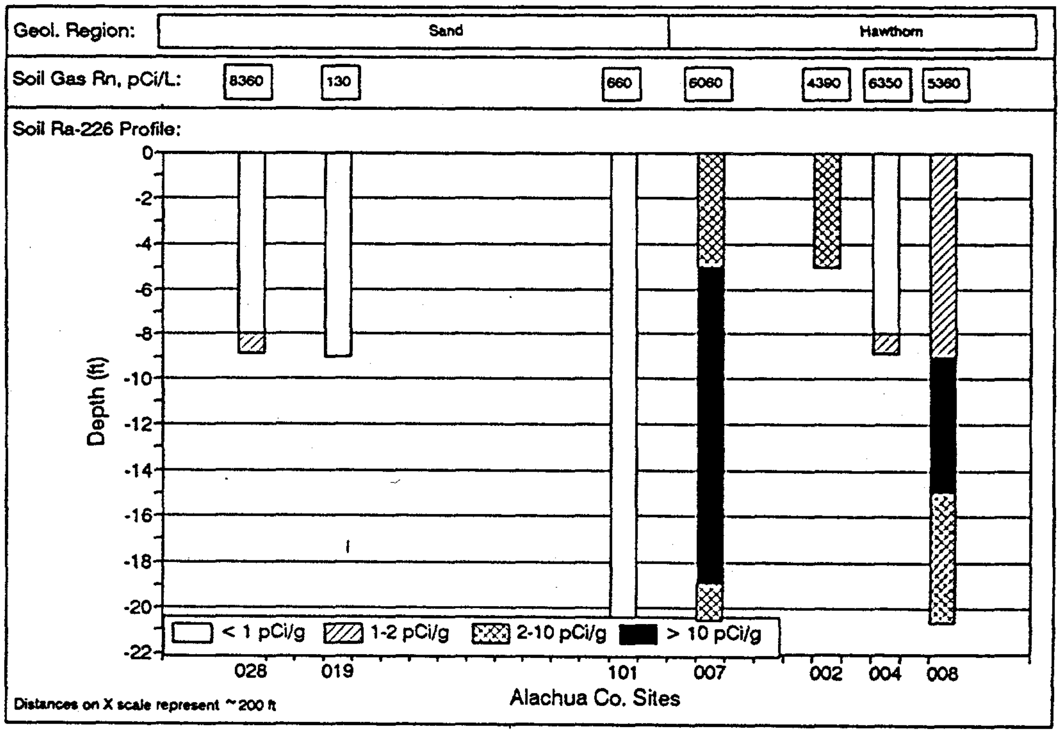


FIGURE 6. Soil radium-226 profile and soil-gas radon, cross section A-AAA.



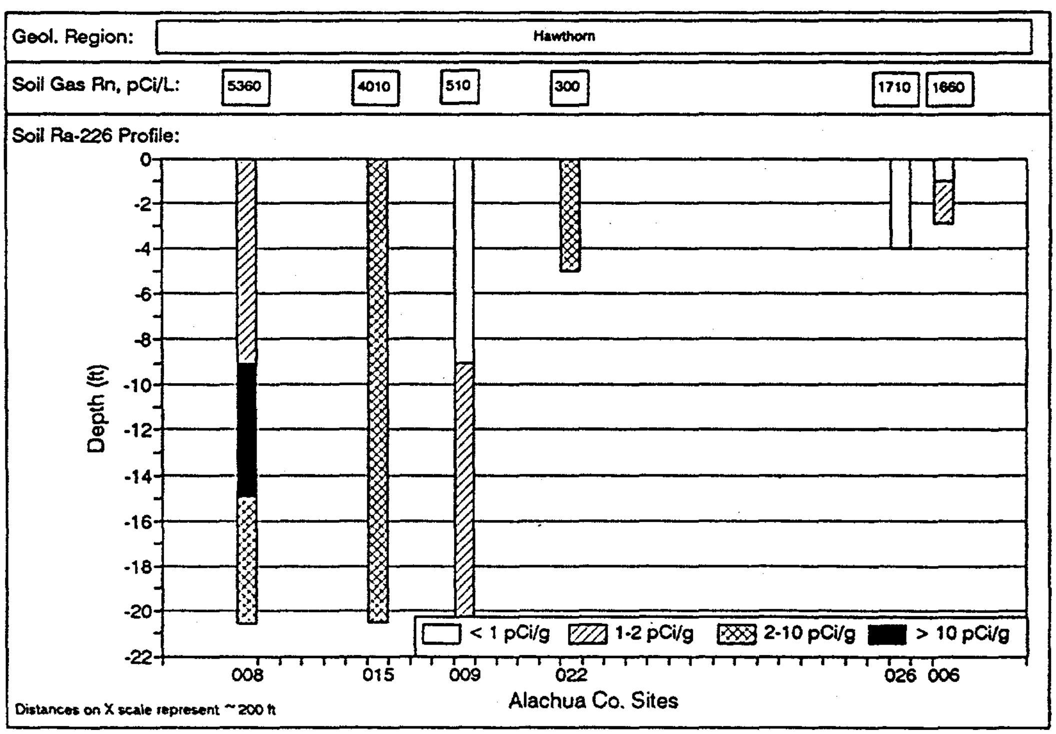


FIGURE 7. Soil radium-226 profile and soil-gas radon, cross section B-BBB.

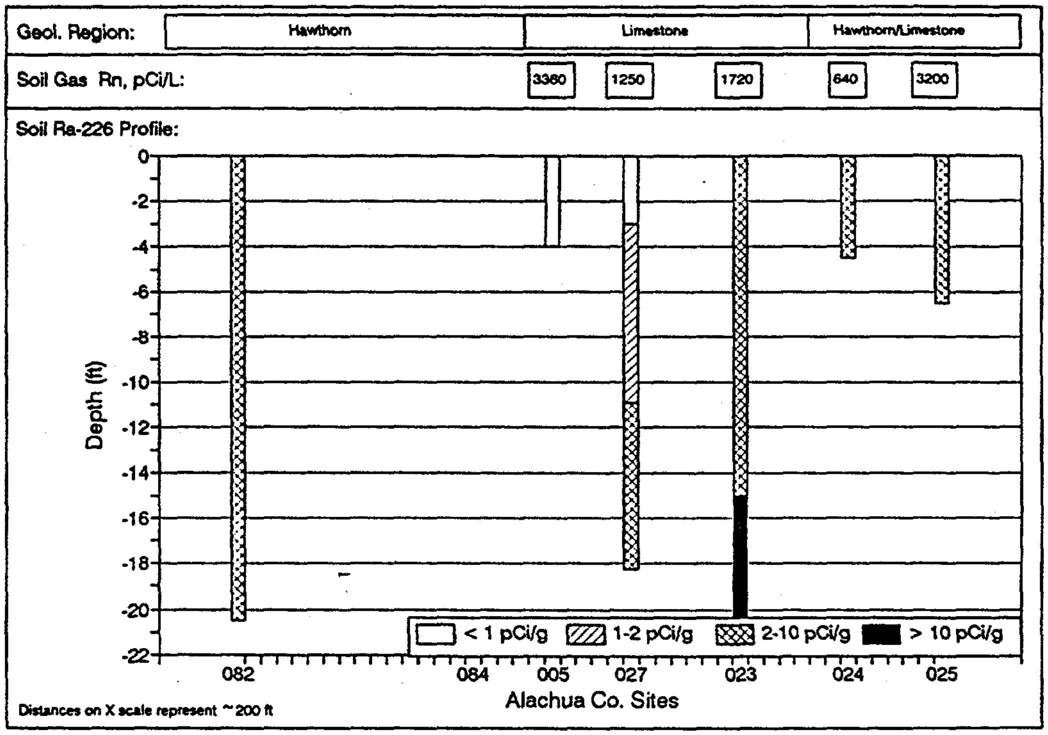


FIGURE 8. Soil radium-226 profile and soil-gas radon, cross section C-CC.

Hawthorn Region

In this region, soil-gas radon concentrations were >1000 pCi/L at 11 of the 13 sampled stations (85%). Radium concentrations in the shallow profile were much less indicative of elevated radioactivity. Six of the 14 sampled sites (43%) had concentrations <2 pCi/g, and four of these (29% of the total) had concentrations <1 pCi/g. Of the five sites that had elevated soil-gas radon (>1000 pCi/L) but low (<2 pCi/g) radium in the shallow profile, one had definitely elevated radium (>10 pCi/g) at 2.7 m. For the other four, no radium in excess of 2 pCi/g was found at sampling depths which ranged from 1 to 3 m.

Two Hawthorn Region sites had low soil-gas radon values. Site 022 (300 pCi/L) had radium on the order of 4 pCi/g through the 1.8-m sampled profile. The soil-gas radon level is inconsistent with the radium profile, which suggests a surface occurrence of Hawthorn formation materials. Site 009 (about 500 pCi/L) had a radium concentration of <1 pCi/g in the first 3 m of profile and 1 to 2 pCi/g in the next 3 m. This suggests either the absence of uranium in the Hawthorn materials or it is an example of imprecision in defining boundaries.

Limestone Region

One of the sites in this region (site 021), which is located at the western edge of the county, about 12 km "off the map" in Figure 2, had a very low soil-gas radon concentration (<100 pCi/L) and radium concentrations of <1 pCi/g through the entire 3-m sampled profile.

The other five sites were much closer to the boundary of the contiguous Hawthorn Region and included sites coinciding with mapped areas of Hawthorn remnant. Four had soil-gas radon concentrations >1000 pCi/L. Two of these sites had radium >2 pCi/g in the shallow profile; the other two had <1 pCi/g in the shallow profile. Site 025 was located on a mapped Hawthorn remnant over the limestone; the other three were not mapped as Hawthorn remnants but occur in the general vicinity where Hawthorn remnants were identified. Site 005, with 3400 pCi/L, was close to the Limestone-Hawthorn boundary and may reflect imprecision in mapping. Site 024 is a currently unexplained anomaly; its soil-gas radon concentration of 640 pCi/L is inconsistent with the mapped location of Hawthorn over Limestone and the 4 to 5 pCi/g radium found throughout the 1.5-m sampled profile.

DISCUSSION AND CONCLUSIONS

The Radon Source

This work supports the hypothesis that elevated radon potential in north and north-central Florida is associated with the near-surface occurrence of uranium-bearing phosphatic sand and clay components of the Hawthorn group of formations which underlie much of the region. The radon is coupled to the structure interface via an overlying high-permeability sand-cover layer, of thickness ranging from 0 to >3 m.

Radium concentrations in the cover sand were generally <1 pCi/g, with occasional samples in the 1- to 2-pCi/g range. Enhanced-radioactivity materials had concentrations in the range of 2 to 10 pCi/g, and some clayey sand and clays had concentrations >10 pCi/g. The maximum value for a sample representing a 0.3-m depth increment was about 80 pCi/g.

Average soil-gas radon concentrations at a nominal 0.75-m depth were generally ≤500 pCi/L when the enhanced-radium (>2 pCi/g) material was 6 m or more from the surface. Near-surface soil-gas radon may be influenced when enhanced radium occurs between 2 and 6 m from the surface; concentrations were usually >1000 pCi/L when the enhanced-radium materials were within 2 m. We have not yet determined the relative contributions to near-surface radon of the higher radioactivity (>10 pCi/g), low-permeability clays compared to more permeable clayey sands with more modest radium concentrations (2 to 10 pCi/g).

Using soil-gas radon concentration as a radon-potential criterion (<500 pCi/L = low, >1000 pCi/L = elevated), regions in the study area and their radon potential may be described as follows:

- *Cover Sand Region*—radon potential generally low outside the transition zone
- *Cover Sand/Hawthorn Transition Zone*—likely elevated radon potential where the upper surface of the enhanced-radium Hawthorn materials is on the order of 2 to 6 m from land surface
- *Hawthorn Region*—radon potential generally elevated
- *Proximate Limestone Region*—elevated radon potential because of mapped and unmapped remnants of Hawthorn materials. (This zone is prefixed "Proximate" because the sampling sites were all within 6 km of the contiguous Hawthorn Region. There was not sufficient sampling to determine how far away Hawthorn remnants persist.)

Presumably, a low-radon-potential region exists to the west beyond the Proximate Limestone Region. A single sampling site at the far western boundary of Alachua County had a low soil-gas radon concentration and no evidence of radium >1 pCi/g within the 3-m sampled profile.

Predicting Radon Potential

Geological maps show promise as a basis for subcounty-scale radon-potential mapping in north-central Florida. Assignment of radon potential requires information about the expected radium content of the material in the first 6 m and the expected permeability of the source material and the cover layer. Transition zones must be recognized, and there will be problems of arbitrary assignment of boundaries. The more ground-truthing that can be done, the better the delineations will be.

Soil-gas radon measurement should provide a direct indication of radon available for transport into a structure. However, high spatial and temporal variability was observed. This variability must be factored into any effort to develop this method as a radon-source-prediction protocol;

considerable replication may be necessary, particularly in areas with intermediate values. Another possible problem is overestimation of the potential for sustained supply of radon under continued removal by the structure.

The radium profile of sufficient depth is a nonvariant indicator of the radon source. In this study, 6-m profiles detected source materials at all elevated radon sites. However, 2-m and 1-m profiles missed the source material at 35% and 40%, respectively, of the elevated radon sites. Similar results are being found in the site characterization phase of a Gainesville area study of radon-resistant features in new house construction (unpublished data, Florida Radon Research Program). Thus, it is concluded that for the soil/geology characteristics present in north-central Florida, surface soil and shallow depth profile (to 1 m) radium measurements are not satisfactory indicators of radon potential.

Other surface soil characteristics may be useful as radon/radium surrogates in estimating radon potential if they are indicative of materials at depths of several meters.

Work to be Done

Further work remains to be done in evaluating data already collected and addressing the original objectives of the project; furthermore, additional lines of investigation have been suggested by this review:

(1) Resolve anomalies: Apparent inconsistencies between soil-gas radon, radium profile, and/or region assigned at several sites should be further investigated.

(2) Evaluate additional collected data, such as more detailed sample description, permeability, and particle-size measurements.

(3) Examine radon flux measurement as a practical indicator of radon potential. (Radon flux measurement, an alternative investigated only to a limited extent in this project, theoretically represents the rate of radon supply to the ground surface. This method also has potential for simulating the negative pressure influence of the structure. However, this parameter is also characterized by temporal and spatial variability.)

(4) Examine additional profile characteristics, such as water table and geological profile, for the sampled sites.

(5) Perform radon production and transport modeling. This work would (a) verify the qualitative model of the radon source and (b) address the question of the relative contributions of the low permeability, high radium clay, and the highly permeable, modestly elevated, radium clayey sand.

(6) Investigate the usefulness of radium/radon surrogates, such as soil type, textural class of profile components, and site elevation for radon-potential assignment. (It has been suggested that, for the Gainesville vicinity, the region of elevated radon potential [near-surface occurrence of the Hawthorn] is associated with the elevation window above sea level of 30 to 45 m (100 to 150 ft) [personal communication, J. Schert, Alachua County Department of Environmental Services].)

(7) Validate radon-potential assignment by overlay of indoor-radon databases.

ACKNOWLEDGMENTS

The authors gratefully acknowledge assistance at various stages of the project from coinvestigators D.E. Hintenlang and G.S. Roessler, Department of Nuclear Engineering Sciences, and W.E. Bolch, Department of Environmental Engineering Sciences, University of Florida. Appreciation is also expressed to the numerous undergraduate and graduate students in the Departments of Environmental Engineering Sciences, Nuclear Engineering Sciences, and Geology who contributed to field, laboratory, and data analysis efforts at various stages of this work.

This material is based in part on work supported by the U.S. Department of Energy under Award No. DE-FG05-89ER60825. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the Department of Energy.

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APPENDIX. RADIOACTIVITY MEASUREMENTS BY REGION

TABLE A-1. Radioactivity measurements, sites in Cover Sand Region.

Site	11	12	13	16	17	18	19	20	28	101
Indoor Rn, pCi/L	1.9	4.9	2.3	--	--	--	2.6	2.9	6.1	1.1
Soil Gas Rn, pCi/L	16	505	426	320	340	521	125	2,001	8357	656

<table>
<tr><th colspan="2">Soil Ra, pCi/g at Indicated Depth:</th><th>11</th><th>12</th><th>13</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th><th>28</th><th>101</th></tr>
<tr><th>m</th><th>ft</th><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>0.00</td><td>0</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>0.1</td><td rowspan="8">0.7</td><td>0.5</td><td rowspan="4">0.1</td><td rowspan="3">0.4</td><td>0.2</td><td>0.3</td><td rowspan="3">1.1</td><td>0.8</td><td rowspan="4">0.4</td></tr>
<tr><td>0.61</td><td>2</td><td>0.2</td><td>0.4</td><td>0.3</td><td>0.3</td><td>0.7</td></tr>
<tr><td></td><td></td><td>0.1</td><td>0.3</td><td></td><td>0.3</td><td>0.7</td></tr>
<tr><td>1.22</td><td>4</td><td>0.1</td><td>0.3</td><td rowspan="4">0.8</td><td></td><td>0.4</td><td rowspan="4">0.9</td><td>0.6</td></tr>
<tr><td></td><td></td><td>0.1</td><td>0.5</td><td>0.3</td><td></td><td>0.5</td><td>0.6</td><td rowspan="6">0.6</td></tr>
<tr><td>1.83</td><td>6</td><td>0.2</td><td></td><td rowspan="4">0.2</td><td></td><td>0.4</td><td>0.6</td></tr>
<tr><td></td><td></td><td>0.4</td><td></td><td></td><td>0.4</td><td>0.6</td></tr>
<tr><td>2.44</td><td>8</td><td>0.3</td><td></td><td rowspan="4">0.4</td><td></td><td></td><td rowspan="6">1.0</td><td>0.7</td></tr>
<tr><td></td><td></td><td>0.4</td><td rowspan="3"></td><td></td><td></td><td></td><td>0.8</td></tr>
<tr><td>3.05</td><td>10</td><td></td><td></td><td rowspan="3">0.5</td><td></td><td></td><td>1.0</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="5">0.6</td></tr>
<tr><td>3.66</td><td>12</td><td></td><td rowspan="2">4.7</td><td></td><td rowspan="3">0.2</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>0.4</td><td></td><td></td><td></td></tr>
<tr><td>4.27</td><td>14</td><td></td><td rowspan="2">24.9</td><td></td><td rowspan="2">0.2</td><td></td><td></td><td rowspan="2">4.0</td><td></td></tr>
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<tr><td>5.49</td><td>18</td><td></td><td></td><td></td><td></td><td rowspan="3">24.3</td><td></td></tr>
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<tr><td>6.10</td><td>20</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

TABLE A-2. Radioactivity measurements, sites in Hawthorn Region.

Site		1	2	4	6	7	8	9	10	14	15	22	26	82	83
Indoor Rn, pCi/L		20.0	25.0	12.0	9.0	10.0	12.0	2.4	6.5	5.8	4.3	5.8	4.85	11.9	9.7
Soil Gas Rn, pCi/L		7,920	4,385	6,347	1,663	6,055	5,361	510	2,574	1,012	4,010	299	1,709	–	2,845
Soil Ra, pCi/g at Indicated Dapth:															
m	ft														
0.00	0														
			3.6	1.8	0.3				0.5			2.6	0.3		
0.61	2		3.9	2.6	0.5	2.9	1.2		0.5	4.4	3.2	4.7	0.3	2.8	3.9
		26.0	3.0	8.5*	1.3				0.5			4.1	0.2		
1.22	4		2.5	10.2#	1.5	4.2			0.5	1.6		4.4	0.2	2.5	3.0
			2.5				1.2	0.4	0.3		2.8	4.0	0.4		
1.83	6		2.5			17.9			0.6	8.6		4.0			
		25.5							0.7					2.3	3.0
2.44	8					79.7	1.1		0.5	18.2					
									0.5						
3.05	10					22.9	15.1		0.5	19.4	4.1				
								1.5							4.3
3.66	12	18.0				14.7								2.1	
							14.5			28.3					
4.27	14							2.0							3.6
											3.1				
4.88	16	6.9				10.2		1.9							10.8
										8.7					
5.49	18	14.0					4.1							2.8	11.7
								1.3			2.1				
6.10	20	11.2				8.6				5.9					13.1

* Site 4: 2-2.5 ft
#Site 4: 2.5-3.25 ft

TABLE A-3. Radioactivity measurements, sites in limestone region.

Site	5	21	23	24	25	27
Indoor Rn, pCi/L	26.0	--	3.1	4.0	2.9	3.0
Soil Gas Rn, pCi/L	3,360	76	1,720	641	3,198	1,249

Soil Ra, pCi/g at Indicated Depth:

m	ft
0.00	0
0.61	2
1.22	4
1.83	6
2.44	8
3.05	10
3.66	12
4.27	14
4.88	16
5.49	18
6.10	20

Site 5	Site 21	Site 23	Site 24	Site 25	Site 27
0.9	0.3	3.4	4.7	3.8	0.4
0.7	0.2	3.7	4.8	7.3	1.6
0.8	0.2	4.6		8.9	1.8
0.5	0.3	5.3			1.3
0.8	0.2	5.3			3.3
	0.2	9.0			
	0.2	8.3			
	0.3	14.3			
	0.3				

ANNEX B. MANUSCRIPT

RADON SOURCE STUDIES IN NORTH FLORIDA

Reprint of a paper published in Environmental Health Physics, proceedings of Twenty-sixth Midyear topical meeting of the Health Physics Society, January 24-28, 1993, Coeur d'Alene, ID, pages 331-350. Columbia Chapter Health Physics Society, P.O. Box 564, Richland, WA 99352.

ANNEX C. FILE REPORT

RADON SOURCE STUDIES IN NORTH FLORIDA -- EXTENDED NORTH FLORIDA SAMPLING

RADON SOURCE STUDIES IN NORTH FLORIDA -- EXTENDED NORTH FLORIDA SAMPLING

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and
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University of Florida, Gainesville, FL 32611

Abstract -- As part of a radon[1] source study, reconnaissance sampling was conducted during 1990 in 13 North Florida counties to examine the geographic extent of the elevated radon source already under intensive study in the Alachua County (Gainesville) vicinity. It also included Leon County (Tallahassee vicinity) further to the west. A 3-m soil core was collected and in-situ measurements were made of soil gas radon and permeability at one or more undisturbed sites in each county. Soil ^{226}Ra concentrations in excess of 2 pCi/g and/or radon concentrations in excess of 1000 pCi/L were found in three counties in addition to Alachua.. Values suggestive of an elevated radon source (^{226}Ra 1-2 pCi/g and/or soil gas radon 500-1000 pCi/L) were found in two additional counties. Thus, the elevated radon source potential observed in Alachua County does extend to other areas in North Florida. However, sampling one or two sites per county is not a sufficient sampling density to delineate the areas of elevated radon potential. A more productive approach would be to prepare a map of surficial geology and conduct sampling and measurements at sites representative of the various geologic exposures in the wider area.

Introduction

This work was conducted as a sub-part of a radon source study conducted by the University of Florida in Northern and North-Central Florida during the period June 1989 through May 1992 under U.S. Department of Energy Grant Number DE-FG05-89ER60825. The objectives of the overall project were to (1) characterize the radon source in a region of elevated indoor radon potential that has geology, lithology, and climate that are different from those in other regions in the U.S. where radon is being studied, (2) describe the radon availability and transport in this environment, and (3) demonstrate approaches for predicting radon potential of lands in this region.

While the field work in the overall project concentrated on Alachua County (Gainesville vicinity), during the second year (1990), sampling was extended, with a lower sampling density, to a wider area of North Florida to examine the geographic extent of the elevated radon source as observed in the Alachua County vicinity. The targeted area covered the region from the Florida-Georgia border south to approximately 29° N Latitude and from the Atlantic coast west to Longitude 85° W.

[1]In this report, the terms "radon" and "radium" are used to designate the isotopes, ^{222}Rn and ^{226}Ra.

Methods

Sampling was performed on a county basis at one or more undisturbed sites representative of the county. At each site, *in situ* measurements were made of soil gas radon and permeability. Soil gas radon was collected at one or more stations per site at depths ranging from 0.30 m (12 in) to 0.61 m (24 in). Permeability measurements were made at 5 depths from 0.15 m (6 in) to 0.76 m (30 in) in 0.15-m (6-in) increments, unless prevented by the water table, rock, or a highly impermeable clay layer. At each site, a 3-m soil core was collected with a hand auger and samples consisting of 0.3-m (1-ft) increments were submitted to laboratory analysis. In the laboratory, samples were analyzed for moisture content, ^{226}Ra concentration, and radon emanation coefficient.

Field sampling and measurement and laboratory analyses were performed according to procedures described in the Florida Radon Research Program (FRRP) Standard Measurement Protocols (Williamson and Finkel, 1991).

Results

Work was performed in 13 counties outside of Alachua County (See Figure 1). Together with Alachua county, this provided coverage of 13 of the 15 contiguous Northeast Florida counties north from Marion County and west to the Suwanee River plus Leon County (Tallahassee vicinity) further to the west.

The soil gas radon and soil radium results are summarized in Table 1 and Figure 2. Concentrations of soil ^{226}Ra in excess of 2 pCi/g and/or soil gas radon in excess of 1000 pCi/L were found in Marion County, Duval County (one of the two sampling sites) and Leon County (one of the two sampling sites). Values suggestive of an elevated radon source (^{226}Ra 1 - 2 pCi/g and/or soil gas radon 500 - 1000 pCi/g) were found in Columbia and Putnam Counties. The results reported for Marion County are not intended to be statistically representative of the county; these were radon mitigation demonstration sites expected to have elevated radon potential because of the known surficial occurrence of the Hawthorn group of formations.

Further information may be found in the sampling station data sheets presented in the Appendix. These data sheets contain site coordinates, data on individual soil samples including sampling dates, depth, moisture, ^{226}Ra concentration, and radon emanation coefficient, and data on soil gas radon measurements including sampling date, depth, and measured concentration for stations and replications at each site.

Results of *in situ* measurements are presented in Table 2. Permeability measurements were obtained for nine of the sites (seven counties). These data, while not analyzed or interpreted; are included in this report to make them available for possible future interpretation.

Discussion and Conclusions

The data from the extended North Florida sampling indicate that the elevated radon source potential observed in Alachua county does extend to other areas in North Florida, particularly where there are surficial occurrences of the Hawthorn Group such as in Marion County. However, sampling one or two sites per county is not a sufficient sampling density to define the area of elevated radon potential. The results observed in Alachua County suggest that a more productive approach would be to prepare a map of surficial geology and perform sampling designed to provide sites representative of the various geologies in the wider area.

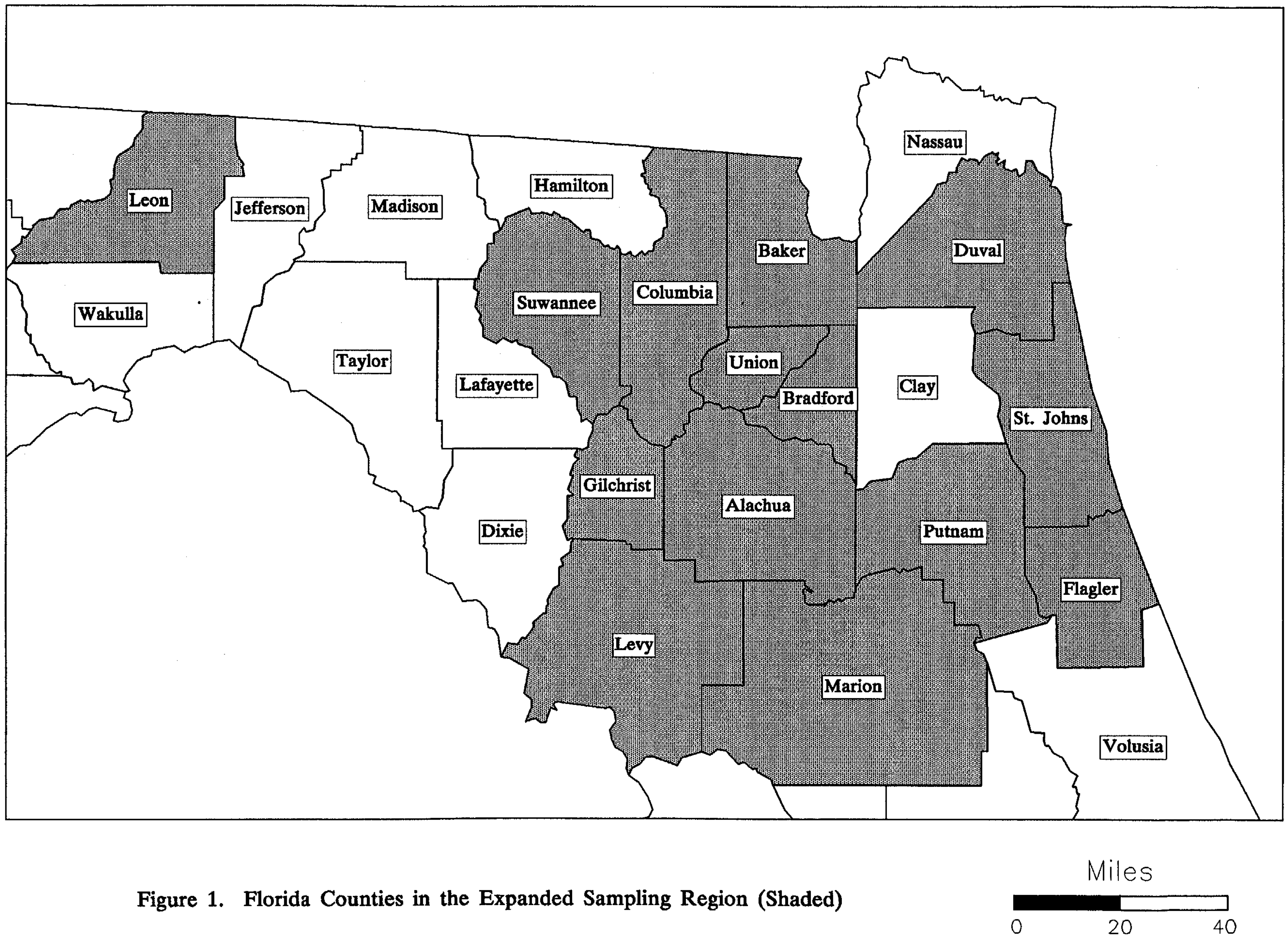

Figure 1. Florida Counties in the Expanded Sampling Region (Shaded)

Table 1. Summary by County of Soil Gas Radon and Soil Radium

County-Site	Soil Gas Rn, pCi/L	Soil Radium for Indicated Depth, pCi/g		
		0 - 1 m	1 - 2 m	>2 m
Baker-1	22	0.3	0.3	NS
Bradford-1	5	0.5	0.4	NS
Columbia-1	955	1.1	1.2	NS
Duval-1	1254	1.0	1.2	NS
Duval-2	58	0.4	0.3	NS
Flagler-1	10	0.2	0.6	NS
Gilchrist-1	NA	0.6	0.6	NS
Leon-1	NA	0.4	0.4	NS
Leon-2	1752	NA	NA	NA
Levy-2	NA	0.2	0.2	0.3
Marion-1	3527	2.2	2.2	NS
Marion-2	3925	4.0	NS	NS
Putman-1	950	0.4	0.6	1.4
Putnam 2	247	0.4	0.4	1.2
St Johns-1	23	0.4	0.3	NS
Suwanee-1	68	0.3	0.2	NS
Suwanee-2	NA	0.3	0.4*	NS
Union-1	46	0.4	0.5	NS

NS = Not Sampled
NA = Data Not Available

*Increasing trend with depth in this layer

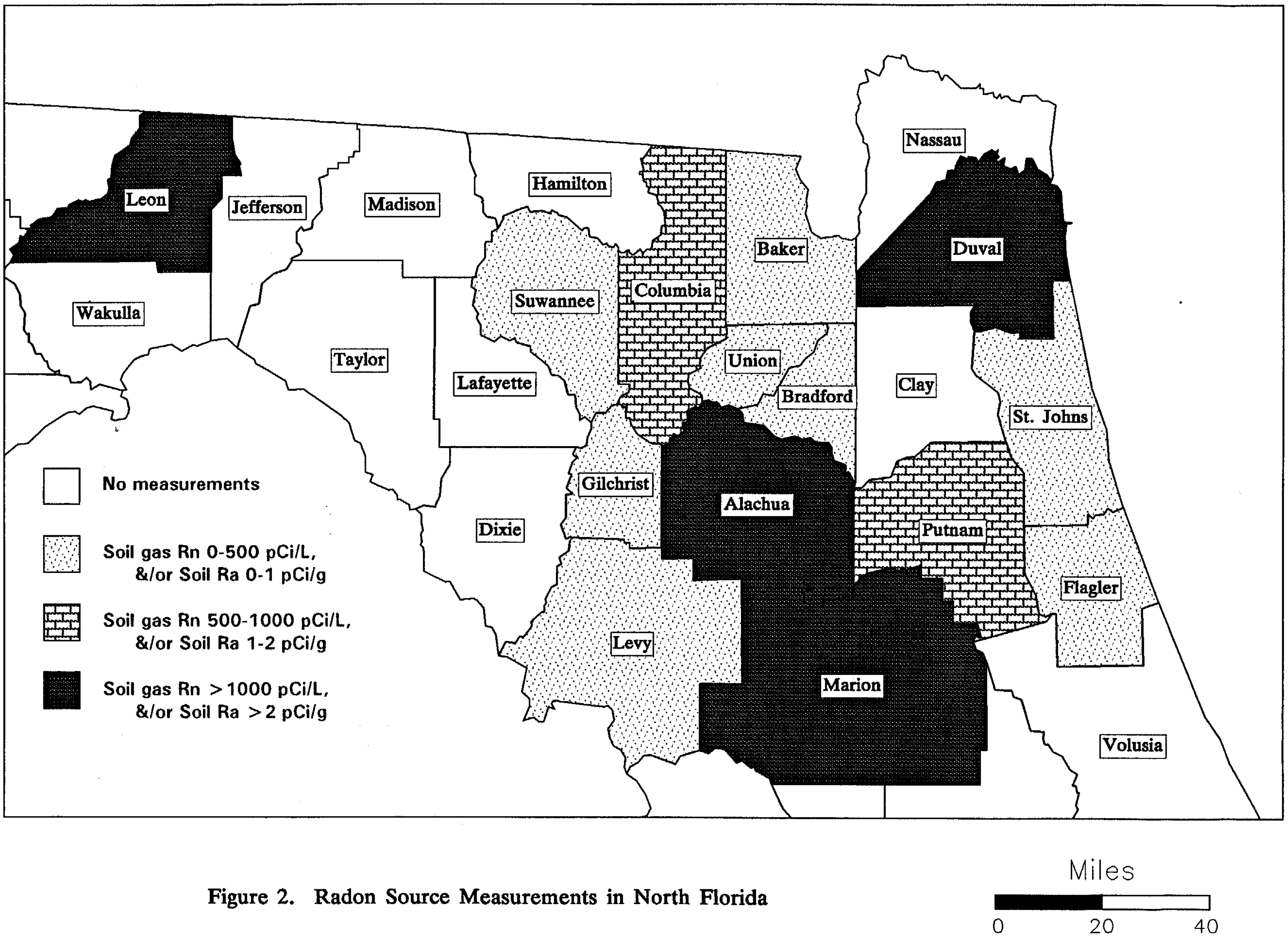

Figure 2. Radon Source Measurements in North Florida

Table 2. In-Situ Measurements

County-Site	Permeability at Indicated Depth, Units of 10^{-12} m^2					Avg Soil Gas Radon, pCi/L
	0.15 m	0.30 m	0.46 m	0.61 m	0.76 m	
Baker-1	13.13	5.23	1.98	NS	NS	22
Bradford-1	362.73	5.14	7.52	0.006	NS	5
Columbia-1	NA	NA	NA	NA	NA	955
Duval-1 Duval-2	6.68 48.25	8.18 46.40	11.67 53.90	12.00 61.60	NS 65.20	1254 58
Flagler-1	62.63	66.82	35.00	12.17	4.20	10
Leon-2	350.00	51.83	61.89	71.46	103.47	1752
Marion-1 Marion-2	35.07 49.49	21.66 52.19	18.43 38.42	4.47 26.25	NS NS	3527 3925
Putnam-1 Putnam-2	NA NA	NA NA	NA NA	NA NA	NA NA	950
St Johns-1	NA	NA	NA	NA	NA	23
Suwanee-1	NA	NA	NA	NA	NA	68
Union-1	35.54	33.54	18.70	4.05	NS	46

NS = Not Sampled NA = Data Not Available

References

Williamson, A.D., and J.M. Finkel, editors. 1991. Standard Measurement Protocols, Florida Radon Research Program. EPA-600/8-91-212 (NTIS PB 92-115294), U. S. Environmental Protection Agency.

APPENDIX

RADIOLOGICAL DATA SHEETS FOR EXTENDED NORTH FLORIDA SAMPLING SITES

Rev. 4/25/94

Radiological Data

12003001

SITENO : 12003001	COUNTY :Baker	LATITUDE : 30.206944	LONGITUDE : -82.359325

GEO1 :	GEO2 :QTu	MUID : 58	UFPOLY# : 1	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
1/17/91	0	8512	0	0	8	.33		-39.2	0
1/31/91	12	8513	12	12	9	.3		4	12
1/31/91	24	8514	24	24	14	.3		1	24
1/31/91	36	8516	36	36	19	.3		32	36
1/31/91	48	8515	48	48	16	.3		-11	48

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE
1	2/12/91	111	1	1	18	48	41	~~[illegible]~~	
1	2/12/91	112	1	2	18	33		22	
1	2/12/91	211	2	1	18	3	3		
1	2/12/91	212	2	2	18	3			

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Rev. 4/25/94

Radiological Data

12007001

SITENO : 12007001	COUNTY :Bradford	LATITUDE : 29.921209	LONGITUDE : -82.221541

GEO1 :	GEO2 :QTu	MUID : 81	UFPOLY# : 37	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
1/17/91	0	8507	0	0	6	.3		-15	0
1/17/91	48	8509	48	48	16	.8		27	48
1/17/91	60	8511	60	60	13	.6		31	60
1/31/91	12	8520	12	12	10	.4		-7	12
1/31/91	24	8521	24	24	13	.4		14	24
1/31/91	36	8522	36	36	14	.7		34	36
1/31/91	66	8523	66	66	13	.4		9	66

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE
1	2/12/91	111	1	1	18	1	1	4.5	
1	2/12/91	112	1	2	18	1			
1	2/12/91	211	2	1	24	6	8		
1	2/12/91	212	2	2	24	9			

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Radiological Data

SITENO : 12023001	COUNTY :Columbia	LATITUDE : 30.205140	LONGITUDE : -82.648267

GEO1 :	GEO2 :Th	MUID : 58	UFPOLY# : 83	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
3/5/91	0	8530	0	0	12	2.05		23	0
3/5/91	12	8531	12	12	14	.8		25	12
3/5/91	24	8532	24	24	16	.8		10	24
3/5/91	36	8533	36	36	13	.8		38	36
3/5/91	48	8534	48	48	17	1.1		36	48
3/5/91	60	8535	60	60	19	1.2		5	60
3/5/91	72	8536	72	72	19	1.4		-8	72

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE
1	3/5/91	111	1	1	12	356	813	955	
1	3/5/91	112	1	2	12	1269			
1	3/5/91	211	2	1	12	1226	1097		
1	3/5/91	212	2	2	12	968			

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Rev. 4/25/94

Radiological Data

12031001

SITENO : 12031001	COUNTY :Duval	LATITUDE : 30.336111	LONGITUDE : -81.750000

GEO1 :	GEO2 :Qu	MUID : 88	UFPOLY# : 1218	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
1/17/91	0	8500	0	0	11	1.2		15	0
1/17/91	12	8501	12	12	8	.9		-16	12
1/17/91	24	8502	24	24	10	.9		5	24
1/17/91	36	8503	36	36	14	1.1		22	36
1/17/91	48	8504	48	48	12	1.2		29	48
1/17/91	60	8505	60	60	14	1.1		21	60

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE
1	1/17/91	111	1	1	24	1111	1111	1254	
1	1/17/91	112	1	1	24	1306	1306		
1	1/17/91	211	2	1	24	1219	1345		
1	1/17/91	212	2	2	24	1471			

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Rev. 4/25/94

Radiological Data

12031002

SITENO : 12031002	COUNTY :Duval	LATITUDE : 30.408333	LONGITUDE : -81.623610

GEO1 :	GEO2 :Qu	MUID : 88	UFPOLY# : 1215	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
1/17/91	0	8493	0	0	11	.4		21	0
1/17/91	12	8494	12	12	9	.3		-9	12
1/17/91	24	8495	24	24	13	.4		28	24
1/17/91	36	8496	36	36	16	.4		-9	36
1/17/91	48	8497	48	48	17	.3		25	48
1/17/91	60	8498	60	60	21	.3		35	60
1/17/91	72	8499	72	72	21	.3		11	72

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE
1	1/17/91	111	1	1	24	93	96	58	
1	1/17/91	112	1	2	24	98			
1	1/17/91	211	2	1	24	27	20		
1	1/17/91	212	2	2	24	12			

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Rev. 4/25/94

Radiological Data

12035001

SITENO : 12035001	COUNTY :Flagler	LATITUDE : 29.475000	LONGITUDE : -81.247221

GEO1 :	GEO2 :Qbd	MUID : 106	UFPOLY# : 1598	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
12/18/90	0	8459	0	0	3	.2		11	0
12/18/90	12	8460	12	12	5	.2		8	12
12/18/90	24	8461	24	24	12	.2		2	24
12/18/90	36	8462	36	36	14	.3		10	36
12/18/90	42	8463	42	42	13	.4		8	42
12/18/90	48	8464	48	48	15	1.2			48
12/18/90	60	8465	60	60	19	.3		22	60
12/18/90	72	8466	72	72	21	.3		7	72
12/18/90	84	8467	84	84	19	.4		32	84

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE
1	12/18/90	111	1	1	30	15	11	10	
1	12/18/90	112	1	2	30	7			
1	12/18/90	211	2	1	24	9	9		
1	12/18/90	212	2	2	24	8			

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Rev. 4/25/94

Radiological Data

12041001

SITENO : 12041001	COUNTY :Gilchrist	LATITUDE : 29.623611	LONGITUDE : -82.849999

GEO1 :	GEO2 :To	MUID : 59	UFPOLY# : 497	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
5/2/91	0	8562	0	0	6	.34		6.5	0
5/2/91	12	8563	12	12	9	.57		-48.9	12
5/2/91	24	8564	24	24	12	.77		22.8	24
5/2/91	36	8565	36	36	10	.73		45.4	36
5/2/91	48	8566	48	48	11	.68		32.7	48
5/2/91	60	8567	60	60	11	.58		22.6	60
5/2/91	72	8568	72	72	12	.64		13.4	72

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Rev. 4/25/94

Radiological Data

12073001

SITENO : 12073001	COUNTY :Leon	LATITUDE : 30.444410	LONGITUDE : -84.240246

GEO1 :	GEO2 :Th	MUID : 96	UFPOLY# : 933	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
5/8/91	0	8592	0	0	6	.51		29.2	0
5/8/91	12	8593	12	12	5	.39		8.9	12
5/8/91	24	8594	24	24	5	.39		.9	24
5/8/91	36	8595	36	36	4	.4		23.8	36
5/8/91	48	8596	48	48	3	.32		-10.4	48
5/8/91	60	8597	60	60	4	.32		-15	60
5/8/91	72	8598	72	72	6	.4		20.5	72
5/8/91	84	8599	84	84	9	.56		19.9	84

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Rev. 4/25/94

Radiological Data

12075001

SITENO : 12075001	COUNTY :Levy	LATITUDE : 29.399750	LONGITUDE : -82.602277

GEO1 :	GEO2 :Thw	MUID : 120	UFPOLY# : 1676	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
4/4/90	0	8279	0	0					0
4/4/90	12	8280	12	12					12
4/4/90	24	8281	24	24					24
4/4/90	36	8282	36	36					36
4/4/90	48	8283	48	48					48
4/4/90	60	8284	60	60					60
4/4/90	72	8285	72	72					72
4/4/90	84	8286	84	84					84
4/4/90	96	8287	96	96					96
4/4/90	108	8288	108	108					108

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Rev. 4/25/94

Radiological Data

12075002

SITENO : 12075002	COUNTY :Levy	LATITUDE : 29.523500	LONGITUDE : -82.562500

GEO1 :Limestone	GEO2 :Thw	MUID : 136	UFPOLY# : 1673	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
3/14/90	0	8255	0	0	2.4	.25			0
3/14/90	12	8256	12	12	3.7	.3		13	12
3/14/90	24	8257	24	24	3.6	.2			24
3/14/90	36	8258	36	36	3.8	.2			36
3/14/90	48	8259	48	48	3.7	.3			48
3/14/90	60	8260	60	60	3.4	.2			60
3/14/90	72	8261	72	72	3.4	.2			72
3/14/90	84	8262	84	84	3.5	.2			84
3/14/90	96	8263	96	96	3.6	.3		38	96
3/14/90	108	8264	108	108	3.8	.25		16	108

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Rev. 4/25/94

Radiological Data

12083001

SITENO : 12083001	COUNTY :Marion	LATITUDE : 29.183333	LONGITUDE : -82.095277	
GEO1 :Hawthorn	GEO2 :Th	MUID : 121	UFPOLY# : 487	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
10/26/90	0	8451	0	0	3	3		50	0
10/26/90	12	8452	12	12	2	2		72	12
10/26/90	24	8453	24	24	2	2		52	24
10/26/90	36	8454	36	36	2	2		37	36
10/26/90	42	8492	42	42	3	2.2		6	42

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE
1	10/25/90	211	2	1	6	2286	2286	3848	
1	10/25/90	311	3	1	18	2637	2637		
1	10/25/90	311	3	1	24	4960	4960		
1	10/25/90	411	4	1	24	3696	5507		
1	10/25/90	412	4	2	24	4757			

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2
101		20	Annual		Pre-Mitigation	
111		.8	Spring		Mitigated	
121		.6	Fall		Mitigated	
131		.6	Winter		Mitigated	

Rev. 4/25/94

Radiological Data

12083002

SITENO : 12083002	COUNTY :Marion	LATITUDE : 29.196666	LONGITUDE : -82.102777	
GEO1 :Hawthorn	GEO2 :To	MUID : 121	UFPOLY# : 510	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
10/26/90	0	8455	0	0	5	2.6		50	0
10/26/90	12	8456	12	12	4	2.6		48	12
10/26/90	24	8457	24	24	6	4.7		55	24
10/26/90	36	8458	36	36	6	6.3		47	36

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE
1	10/25/90	111	1	1	24	6256	5134	3925	
1	10/25/90	112	1	2	24	4012			
1	10/25/90	211	2	1	18	1183	1183		
1	10/25/90	311	3	1	18	4147	4147		
1	10/25/90	411	4	1	12	5237	5237		

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2
101		11	Annual		Pre-Mitigation	
111		1.2	Spring		Mitigated	
121		1.8	Fall		Mitigated	
131		1.2	Winter		Mitigated	

Physical Characteristics Data

SITENO : 12083002	COUNTY : Marion	LATITUDE : 29.196666	LONGITUDE : -82.102777
GEO1 : Hawthorn	GEO2 : To	MUID : 121	UFPOLY# : 510
NOTE :			

Particle Size Analysis Data

UFID#	DATE	DEPTH	CLASS	%SAND	%SILT	%CLAY	S_6.320	S_2.000	S_0.840	S_0.420	S_0.250	S_0.177	S_0.149	S_0.074	S<0.074	NOTE
8456	1/9/91	12	Clayey Med. Sand	88.1	3.9	8		.8	.9	10.36	41.76	17.1	9.9	12.2	4.57	12
8457	1/9/91	24	Clayey Med. Sand	85.4	2.1	12.5		.68	7.32	26.9	36.62	12.04	5.56	7.14	2.02	24
8458	1/9/90	36	Clayey Med. Sand	82.8	3.2	14		1.3	6.88	28	34.62	10.45	4.64	6.06	2.06	36

In-Situ Permeability Analysis Data

SUBID#	DATE	PER_0.15	PER_0.30	PER_0.46	PER_0.61	PER_0.76	NOTE

Permeability Labtory Analysis Data

UFID#	DEPTH	D_UNCNSLD	D_COMPCT	M_UNCNSLD	M_COMPCT	NOTE
8456	1	2.7200e-7	1.0600e-7	1.9100e-7	1.0100e-7	
8457	2	2.5000e-7	1.0000e-7	2.1000e-7	9.6000e-8	
8458	3	1.9000e-7	9.5000e-8	1.9000e-7	8.9000e-8	

Rev. 4/25/94

Radiological Data

12083003

SITENO : 12083003	COUNTY :Marion	LATITUDE : 29.201388	LONGITUDE : -82.115277

GEO1 :Hawthorn	GEO2 :To	MUID : 121	UFPOLY# : 510	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
8/14/90	0	8446	0	0	0	0		-7	0
8/14/90	0	8448	0	0	2	2		19	pantry
8/14/90	7.2	8447	7.2	7.2	15	15		21	7.2

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2
101		30	Annual		Pre-Mitigation	
111		1.9	Spring		Mitigated	
121		6.3	Fall		Mitigated	
131		2.5	Winter		Mitigated	

Physical Characteristics Data

SITENO : 12083003	COUNTY : Marion	LATITUDE : 29.201388	LONGITUDE : -82.115277
GEO1 : Hawthorn	GEO2 : To	MUID : 121	UFPOLY# : 510
NOTE :			

Particle Size Analysis Data

UFID#	DATE	DEPTH	CLASS	%SAND	%SILT	%CLAY	S_6.320	S_2.000	S_0.840	S_0.420	S_0.250	S_0.177	S_0.149	S_0.074	S<0.074	NOTE
8446	11/19/90	0	Med. Sand	92.6	.4	7		.96	11.73	26.15	32.26	15.42	6.21	5.79	1.22	0-7
8447	11/19/90	0	Clayey Med. Sand	74	5	21		4.09	10	18.88	29.26	13.81	6.09	8.14	3.41	>7
8448	11/19/90	0	Clayey Med. Sand	89.2	1.8	9		1.14	5.55	14.76	34.86	18.01	8.67	9.82	2.58	pantr

In-Situ Permeability Analysis Data

SUBID#	DATE	PER_0.15	PER_0.30	PER_0.46	PER_0.61	PER_0.76	NOTE

Permeability Labtory Analysis Data

UFID#	DEPTH	D_UNCNSLD	D_COMPCT	M_UNCNSLD	M_COMPCT	NOTE
8446	0	2.2400e-7	1.6400e-7	2.2400e-7	9.3000e-8	
8447	7	1.7000e-7	6.7000e-8	1.3000e-7	4.8000e-8	
8448	0	2.0000e-7	1.1000e-7	1.9000e-7	1.0000e-7	

Rev. 4/25/94

Radiological Data

12107001

SITENO : 12107001	COUNTY :Putnam	LATITUDE : 29.625000	LONGITUDE : -81.958332

GEO1 :	GEO2 :Tc	MUID : 120	UFPOLY# : 1450	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
12/18/90	0	8468	0	0	2	.4		21	0
12/18/90	12	8469	12	12	3	.4		20	12
12/18/90	24	8470	24	24	2	.4		23	24
12/18/90	36	8471	36	36	2	.5		16	36
12/18/90	48	8472	48	48	2	.5		15	48
12/18/90	60	8473	60	60	1	.4		-2	60
12/18/90	72	8474	72	72	1	.4		-17	72
12/18/90	84	8475	84	84	3	.9		27	84
12/18/90	96	8476	96	96	6	1.3		29	96
12/18/90	108	8477	108	108	6	1.4		9	108

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE
1	12/18/90	111	1	1	30	1890	1698	950	
1	12/18/90	112	1	2	30	1488			
1	12/18/90	211	2	1	30	218	210		
1	12/18/90	212	2	2	30	202			

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Rev. 4/25/94

Radiological Data

12107002

SITENO : 12107002	COUNTY :Putnam	LATITUDE : 29.699999	LONGITUDE : -81.549999

GEO1 :	GEO2 :Qr	MUID : 103	UFPOLY# : 1502	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
12/18/90	0	8478	0	0	7	.5		61	0
12/18/90	12	8479	12	12	6	.5		32	12
12/18/90	24	8480	24	24	9	.2		0	24
12/18/90	36	8481	36	36	11	.3		3	36
12/18/90	48	8482	48	48	19	.3		2	48
12/18/90	60	8483	60	60	17	.2		-25	60
12/18/90	72	8484	72	72	19	.3		-10	72

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE
1	12/18/90	111	1	1	18	304	316	247	
1	12/18/90	112	1	2	18	327			
1	12/18/90	211	2	1	12	184	178		
1	12/18/90	212	2	2	12	172			

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Rev. 4/25/94

Radiological Data

12109001

SITENO : 12109001	COUNTY :St. Johns	LATITUDE : 29.948461	LONGITUDE : -81.343114

GEO1 :	GEO2 :Qa	MUID : 106	UFPOLY# : 328	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
12/18/90	0	8485	0	0	3	.3		26	0
12/18/90	12	8486	12	12	6	.5		23	12
12/18/90	24	8487	24	24	12	.3		-6	24
12/18/90	36	8488	36	36	17	.4		-1	36
12/18/90	48	8489	48	48	19	.4		12	48
12/18/90	60	8490	60	60	22	.3		-3	60
12/18/90	72	8491	72	72	19	.3		-26	72

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE
1	12/18/90	111	1	1	30	26	23	23	
1	12/18/90	112	1	2	30	19			
1	12/18/90	211	2	1	18	20	24		
1	12/18/90	212	2	2	18	28			

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Rev. 4/25/94

Radiological Data

12121001

SITENO : 12121001	COUNTY :Suwannee	LATITUDE : 30.253041	LONGITUDE : -82.950952

GEO1 :	GEO2 :Qu	MUID : 77	UFPOLY# : 128	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
3/5/91	0	8524	0	0	6	.3		17	0
3/5/91	12	8525	12	12	6	.3		8	12
3/5/91	24	8526	24	24	5	.2		-45	24
3/5/91	36	8527	36	36	12	.3		46	36
3/5/91	48	8528	48	48	17	.2		-5	48
3/5/91	60	8529	60	60	18	.3		20	60

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE
1	3/5/91	111	1	1	30	102	77	68	
1	3/5/91	112	1	2	30	51			
1	3/5/91	211	2	1	30	56	59		
1	3/5/91	212	2	2	30	61			

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Rev. 4/25/94

Radiological Data

12121002

SITENO : 12121002	COUNTY :Suwannee	LATITUDE : 29.466667	LONGITUDE : -82.950000

GEO1 :	GEO2 :To	MUID : 59	UFPOLY# : 868	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
5/2/91	0	8569	0	0	4	.26		2.5	0
5/2/91	12	8570	12	12	5	.3		-15	12
5/2/91	24	8571	24	24	5	.27		39.2	24
5/2/91	36	8572	36	36	5	.23		-43.1	36
5/2/91	48	8573	48	48	5	.3		.8	48
5/2/91	60	8574	60	60	6	.34		5.9	60
5/2/91	72	8575	72	72	9	.49		22.2	72
5/2/91	84	8576	84	84	9	.67		11.9	84

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2

Rev. 4/25/94

Radiological Data

12125001

SITENO : 12125001	COUNTY :Union	LATITUDE : 30.069138	LONGITUDE : -82.348024

GEO1 :	GEO2 :QTu	MUID : 81	UFPOLY# : 37	NOTE :

Soil Radium Concentration Data

DATE	DEPTH	UFID#	FDEPTH	TDEPTH	%MOIST	RA_226	RA_ERR	%EMANATION	NOTE
1/17/91	3	8506	3	3	18	.4		10	3
1/17/91	24	8508	24	24	9	.4		3	24
1/17/91	48	8510	48	48	15	.35		31	48
1/31/91	0	8517	0	0	6	.44		28.9	0
1/31/91	12	8518	12	12	5	.3		-25	12
1/31/91	36	8519	36	36	10	.4		-26	36
5/8/91	60	8600	60	60	13	.58		15.2	60

Soil Gas Radon Concentration Data

VISIT#	DATE	SUBID#	STATION#	REPLICATION#	DEPTH	SOIL_GAS	MEAN_REP	MEAN_VST	NOTE
1	2/12/91	111	1	1	24	67	67	46	
1	2/12/91	112	1	2	24	66			
1	2/12/91	211	2	1	24	26	26		
1	2/12/91	212	2	2	24	25			

Indoor Radon Concentration Data

SUBID#	DATE	INDR_RN	SEASON	YEAR	NOTE1	NOTE2