RADON HAZARDS ASSOCIATED WITH GLACIAL DEPOSITS IN OAKLAND COUNTY, MICHIGAN

ROBERT SCOTT ROUGHT

Bachelor of Science

Michigan State University

East Lansing, Michigan

1991

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1994

OKLAHOMA STATE UNIVERSITY

RADON HAZARDS ASSOCIATED WITH GLACIAL DEPOSITS IN OAKLAND COUNTY, MICHIGAN

Thesis Approved:

Brian J. Carter
Thesis Advisor

Douglas C Kent

John D. Vitek

Gary F. Stewart

Thomas C. Collins
Dean of the Graduate College

ACKNOWLEDGEMENTS

I wish to express my appreciation to Dr. Keith Willett and Dr. John Vitek, who encouraged me to attend Oklahoma State University. A special thank you to Dr. Brian Carter for serving as my advisor. I would also like to thank Dr. Doug Kent, Dr. Gary Stewart, and Dr. John Vitek for serving on my graduate committee.

Thank you to Ms. Patricia Dooley of Radon Detection Systems, Boulder, Colorado, for providing me with the means of collecting data for this research, to my parents, Ann and Bob Rought who stood behind me and urged me on, and to my wife, Helen, who typed the manuscript and was patient and supportive to me during the writing of this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

Table Page

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

INTRODUCTION

Radon is a colorless, odorless, tasteless, radioactive noble gas that comes from the natural breakdown and decay of uranium in the crust of Earth (Allaby 1991). There are 27 known isotopes of radon. Throughout this paper, the term "radon" will be used to denote radon-222, the isotope of radon having 86 protons and 136 neutrons in its atomic nucleus. Radon-222 originates from the decay of uranium-238, which is abundant in nature, comprising over 99 percent of the natural uranium in the world (Brookins 1990).

Decay products, or progeny, from radon are all radioactive particles. Radon-222, which has a half-life of 3.82 days, decays by alpha emission to polonium-218 with a half-life of 3.05 minutes; then this goes by alpha decay to lead-214 with a 26.8 minute half-life, which undergoes beta emission to form bismuth-214 with a half-life of 19.9 minutes. Bismuth-214 undergoes beta emission to form polonium-214 with a 1.6×10^{-4} second half-life. Polonium-214 decays through alpha emission to lead-210. The final decay is the change of lead-210, which has a half-life of 22.3 years, into a stable, nonradioactive molecule, lead-206. (Brookins 1990). Because lead, polonium, and bismuth are electrostatically charged, these radon daughters can attach themselves to such things as clothing, furniture, walls, and particulate matter in the air such as dust and smoke. When this particulate matter is inhaled into the lungs, the radon progeny attach themselves to the cell lining and mucus membranes. As the progeny continue to decay, bursts of alpha, beta, and gamma radiation (from the decay process) destroy the surrounding lung tissue. This condition may in turn lead to lung cancer (Nero 1983).

In 1984, radon was recognized as a major human carcinogen. An engineer, working at a nuclear power plant in Pennsylvania, unintentionally tripped safety alarms as he passed detectors set to measure excessive radiation. This occurred despite lack of exposure to any forms of radiation in the plant. Further investigation proved his home was the point of contamination. Levels of radon in his home exceeded 2,000 pCi/l (picocuries per liter). This value was more than 50,000 percent greater than the 4.0 pCi/l level established by the EPA (Environmental Protection Agency) as the point at which action should be taken to lower indoor levels of radon (Gundersen 1992). The EPA suggested that living in a house containing 2,000 pCi/l radon posed about the same cancer risk as smoking more than 280 packs of cigarettes per day (Lafavore 1987). Radon has been deemed one of the leading causes of lung cancer in the United States, second only to cigarette smoking (EPA 1989).

Levels of radon range from 0.02 pCi/l outdoors to over 2,500 pCi/l indoors (Toohey 1987). Whereas the terms "high level" and "low level" are subjective, the EPA considers radon levels over 4.0 pCi/l to be unacceptable (high). A moderate radon level is considered to be from 2.0 pCi/l to 4.0 pCi/l. And, an indoor radon level of less than 2.0 pCi/l is considered low (EPA 1989). The EPA estimates 20,000 radon induced lung cancer deaths occur in the United States each year (EPA 1989). A person living in a home with 10 pCi/l of radon has the same risk of contracting lung cancer as a person who smokes one pack of cigarettes per day. A person living in a home with 4.0 pCi/l of radon has three times the risk of contracting lung cancer as that of a nonsmoker (EPA 1989).

Outdoor levels of radon generally are low because of natural dissipation. Radon enters a home through basement sump holes, floor drains, dirt-floored areas, cracks in the floor or foundation, or from building materials. Radon can build to unacceptably high levels because of insulation which reduces drafts and other air currents that would help to dissipate levels of radon. Also, attic fans, combustion furnaces, or any devices creating a negative pressure within the home can increase the indoor radon level.

Michigan has relatively low average-indoor levels of radon. Less than 10 percent of all homes tested in

Michigan produce levels of radon above the action level of 4.0 pCi/l specified by the EPA. In comparison, 25 percent of homes tested in Maine and Pennsylvania failed EPA standards (Radon Detection Systems 1992). Michigan was chosen as a study area because individual homes that were tested produced varied levels of indoor radon.

Glacial ice covered the entire state of Michigan on more than one occasion during the Pleistocene Epoch. The Nebraskan, Kansan, Illinoian, and Wisconsinan ice sheets deposited a large variety of glacially derived sediments in Michigan. The Wisconsinan advance occurred 10,000 to 80,000 years ago (Way 1985). Much of the glacial material deposited in Michigan was from the highly granitic, uranium-bearing bedrock of the Canadian Shield. Evidence of these rocks can be found throughout Michigan as glacial erratics. Moving southward from Canada, the ice eroded and transported surficial material, which was deposited as glacial till and glaciofluvial deposits. Glacial till is unstratified sand, gravel, silt, and clay that typically form moraines, till plains, and drumlins. Glaciofluvial deposits, which are sorted, stratified sediments of meltwaters, commonly include outwash plains, eskers, and valley trains. Michigan also has clayey glaciolacustrine deposits along the Great Lakes coastline. (Dorr and Eschman 1992).

Oakland County, in southeastern Michigan, was the focal point of this study (Figure 1). Within an area of

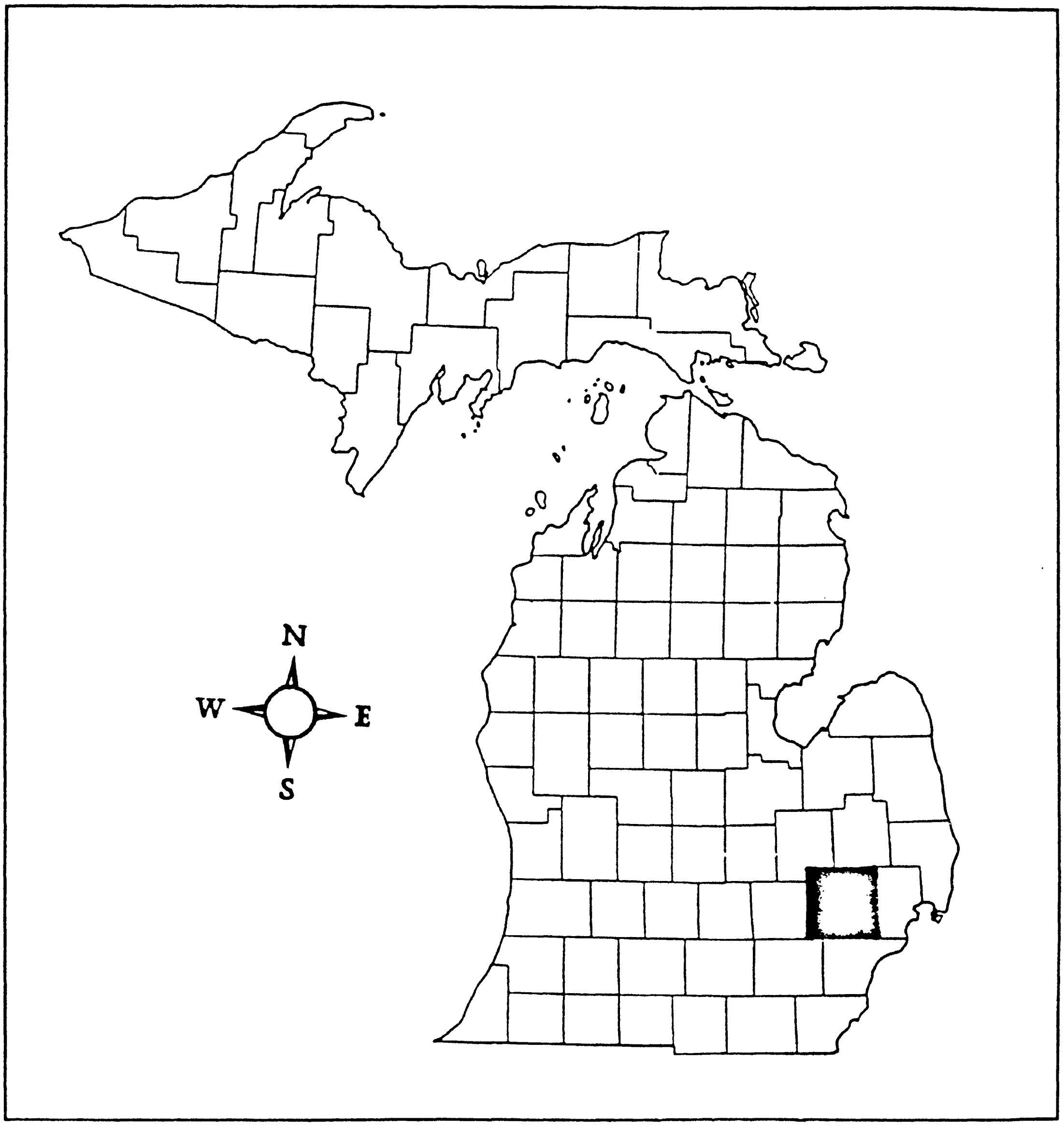

Figure 1. Location of Study Area: Oakland County, MI

867 square miles, lives a population of 1,083,592, equating to an average of approximately 1250 people per square mile. This area contains a variety of soil types and an assortment of glacial landforms and deposits ie: moraines, till plains, and outwash plains. Oakland County also has a thick glacial overburden ranging from approximately 15 meters to 120 meters. And, because of the different soil types, soil permeability varies as well. This research examines the incidence of radon in Oakland County, Michigan, and the geologic conditions that influence radon measurements throughout the county.

LITERATURE REVIEW

Studies have correlated indoor levels of radon to bedrock geology in areas of little or no sediment overburden (Harrell 1991; Keller and others 1992; Brookins 1991). Few tests have been run, however, in areas of thick sediment overburden above bedrock. Because radon has a short half-life of 3.82 days, it is commonly accepted that the amount of radon movement in most rocks and sediments is less than 3 meters before decay (Tanner 1986). Therefore, in areas of thick sediment overburden, bedrock should not be a direct primary cause of elevated indoor radon.

Otton (1988) suggested that certain characteristics of glacial deposits affect levels of radon in homes built on these sediments. Permeability is an important variable to consider when determining radon movement. Outwash gravels are rapidly permeable and produce soils that are rapidly permeable. Soils of Washington and Idaho that overlie outwash gravels typically have high indoor levels of radon. Till plains and moraines have low permeability and are poorly sorted. However, these sediments may be locally highly permeable or very fine grained, thus having a high radon-emanating ability. In areas where these sediments were derived from uraniferous rocks, levels of radon may be high. However, Schutz and Powell (1988) determined that studies of radon in homes built on glacial material have been too few to make possible generalizations about the actual effects of soil formed on glacial drift. Dr. James Harrell, Professor of Geology at the University of Toledo, has studied radon in of Ohio. Professor Harrell (personal communication, 1993) indicated that few studies have correlated indoor radon and glacial sediments.

Dr. Harrell's statement pertaining to the sparsity of studies concerning the correlation of radon and glacial sediments was proven true. The geology departments of seven major universities in the Great Lakes area, as well as state and federal agencies were of no assistance in obtaining material for this research. Dr. John Swez, (personal communication, 1993) Professor of Physics, Indiana State University, has found no studies related to the incidence of indoor radon and the occurrence of glacial sediments. He further stated that this probably is a function of the lack of available field data.

The Ohio Air Quality Development Authority provided results of two studies. The first, by Smith and Mapes (1989), suggested that glacial deposits may have direct bearing on the levels of radon measured in homes. Smith and Mapes (1989) determined that glacial deposits appear to contribute to indoor radon values as follows: end moraine < ground moraine < ice-contact stratified drift < outwash and alluvium. The highest radon readings were found in homes constructed on glacially derived sediments comprising valley fills, ie: glacial outwash terraces. The sand and gravel in the valley fill have high permeability. Lowest levels of radon were measured in homes built on end moraines. These deposits generally have low permeability and are thicker than other deposits. Smith and Mapes suggested that the greater thickness of the end moraine may retard transmission of radon to the surface. Smith and Mapes (1989) sampled 650 homes in thirteen counties of Ohio. Information regarding geological setting was obtained from state publications. Data pertaining to permeability of glacial sediments was gathered from county soil survey reports. Charcoal canisters were used as the primary testing device and were placed in accordance with the EPA protocol.

Smith and Mapes (1989) also discussed boulder belts and hypothesized that because of the concentration of Canadian erratics in these belts, levels of radon might be elevated. They determined that, whereas boulder belts produce higher radon readings than ground moraines or end moraines alone, the fact that boulder belts do not produce the highest levels of radon suggests that factors other than uranium within the glacial sediments contribute to elevated levels of radon.

A second study, by Khawaja and others (1989) also conducted in Ohio, suggests that soil permeability, sediment thickness, and type of glacial deposit have a direct influence on the indoor level of radon. The study area included 717 test points in four counties. Alpha Track detectors were used as the primary radon-testing device and were placed in accordance with the EPA protocol.

Overburden consists of Wisconsinan glacial deposits, grouped into three types: tills, kames, and lacustrine materials (Khawaja and others 1989). The "kame" category included outwash deposits, because of similar permeabilities. Homes underlain by kame deposits produced the highest radon values, followed by till and then lacustrine deposits. Elevated indoor levels of radon occurring on kame deposits result from the higher soil permeability, which allows greater radon transport (Khawaja and others 1989).

Khawaja and others (1989) also addressed sediment thickness. An increase in sediment thickness decreases indoor radon concentration. The highest set of indoor levels of radon were recorded in buildings where sediment is thinner than two meters; the set of lowest readings were in areas where overburden is 30 meters or more. Bedrock is the main source of radon in the study area described by Khawaja and others, and glacial overburden acts as a filter or barrier to radon migration, depending upon overburden permeability.

Soil permeabilities in the study area were estimated from county soil surveys (Khawaja and others, 1989). A significant correlation was detected between increased soil permeability and elevated indoor levels of radon. Soils of moderate and moderately rapid permeabilities showed the highest indoor levels of radon, whereas soils of moderately slow and slow permeabilities had the lowest indoor radon concentrations. Further, Khawaja and others (1989) suggested that soil permeability may be used as a predictive tool in indoor studies of radon.

Mose and others (1992) stated that soil permeability alone cannot be used to identify potential radon problem areas. Their study was conducted in northern Virginia and southern Maryland. Alpha Track testing devices were used to measure indoor and soil radon. Soil permeability, in conjunction with soil levels of radon, can adequately predict indoor radon. A radon prediction chart utilizing soil radon and soil permeability measurements from over 150 sample sites was constructed. Mose and others (1992) stated that the potential to predict the indoor level of radon is about 75 percent.

Objectives of the Research

This research assesses whether a correlation exists between glacial sediments and indoor radon levels. The following will be investigated:

1. The relationship between glacial formations and the incidence of indoor radon;

2. The role of soil type and permeability in relation to indoor levels of radon;

3. Whether the thickness of soil overburden is a contributing factor to indoor radon.

MATERIALS AND METHODS

Indoor levels of radon were recorded in 201 locations in Oakland County, Michigan. These levels of radon were obtained while employed by Radon Detection Systems of Boulder, Colorado, as the primary radon specialist in the central and lower part of Michigan. All of the radon tests included in this study were obtained with the client's strict adherence to the EPA protocol. The protocol states closed house conditions (all windows and exterior doors closed, except for normal entrance and exit) should be maintained for at least 12 hours prior to and during the sampling period. To help assure that the client understands and adheres to the protocol, the client is asked to read and sign an agreement stating that he will do so. Further, air "grabs" are taken at the beginning and end of the test as cross checks to help ensure that closed-house conditions existed during the test period.

The primary measurement device used for all tests in this study was the EPERM (electret passive environmental radon monitor), manufactured by Rad Elec Inc. of Frederick, Md. The EPERM is a recent innovation that is gaining popularity as the test of choice by many companies testing for radon because it allows for economical, accurate, precise, and immediate radon measurements. The EPERM is a small plastic chamber with an electrostatically charged teflon disk, called an electret, attached to the base (Figure 2). When the detector is deployed, radon passes through the cap and enters the chamber where the electret is housed. As radon decays, alpha radiation is emitted, resulting in a negative charge in the air surrounding the positively charged electret, thereby reducing the voltage of the electret (Kotrappa and others, 1988). The voltage is measured prior to and immediately following the exposure period. The drop in voltage is directly proportional to the radon level in the sample area and is corrected for length of exposure and background radiation. The EPERM was chosen as the primary detector for this study because of its high rating by the EPA. Other advantages of the EPERM are that it is accurate under humid conditions, can be locked into place with tamperproof ties, and is reusable - a number of tests can be performed before the charged electret is neutralized.

Secondary air-grab sampling, using the Rolle method, was also performed. This served as a cross check of the primary detector and ensured that closed-house conditions under the EPA protocol were followed. This method does not measure radon, but rather radon decay products, which are measured in working levels (W.L.) (Rolle 1972). The

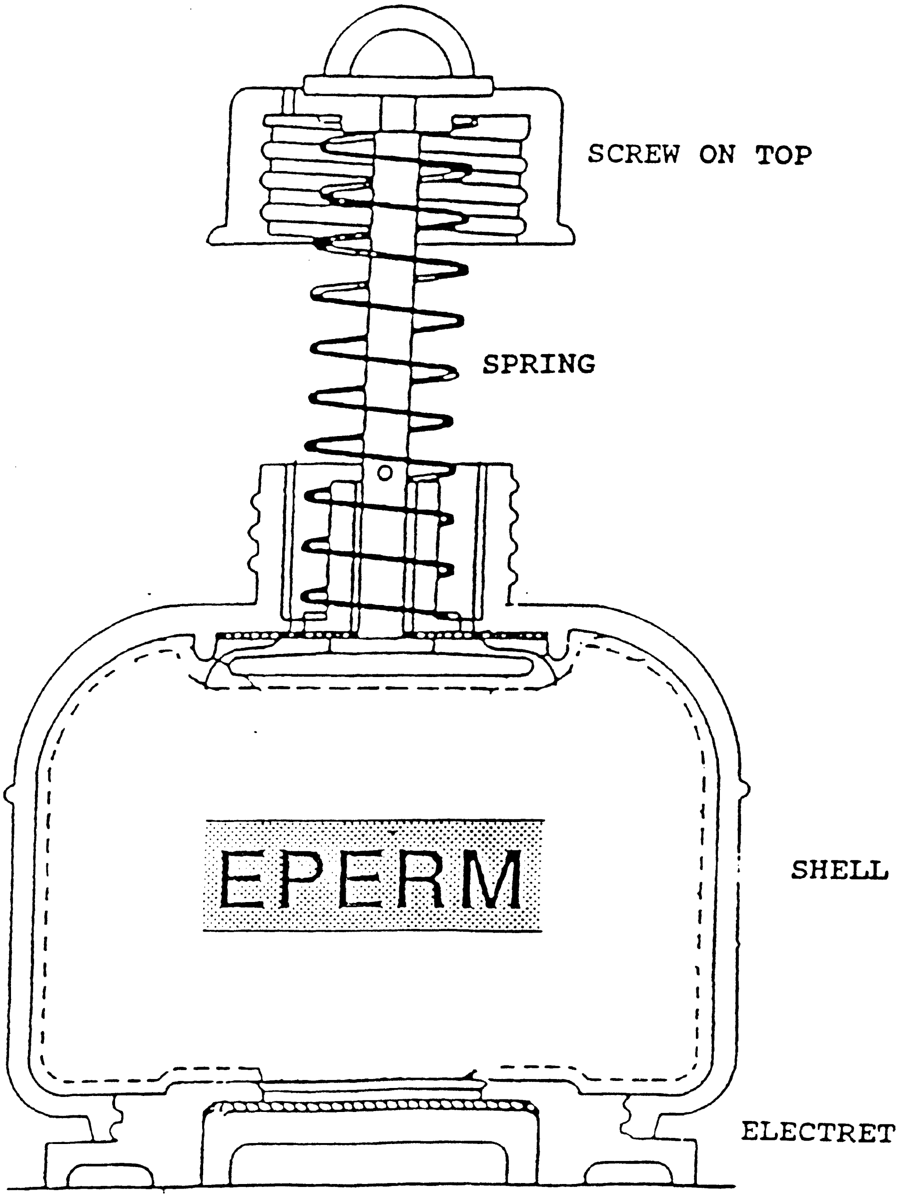

Figure 2. Diagram of EPERM

Rolle method calculates working levels by collecting radon decay products on a high-efficiency filter for five minutes, from a known volume of air. Six and one-tenth minutes after collection, the filter is analyzed for five minutes in a photomultiplier tube that is coated internally with zinc sulfide (ZnS). As the radon progeny decay, alpha radiation strikes the zinc sulfide coating, producing a flash of light that is detected and counted by a Ludlum 2000 scaler (Ludlum Inc. Sweetwater, Tx.). The calculation shown in Figure 3 yields working levels:

$$WL = \frac{CPM \times EFF}{FRP \times SI \times 213}$$

Where: WL = Working Level
CPM = Counts Per Minute
EFF = Efficiency Factor of Photomultiplier Tube
FRP = Flow Rate of Pump
SI = Sample Interval

Figure 3. Working Level Calculation

The results of air grabs are indicative of the radon progeny on site at the time the sample was obtained. If air grab results are radically different between start of the test and the end of the test, the occupant has altered the inhouse conditions. Opening windows or doors, or running fans for extended periods affects levels of radon, thus violating the EPA protocol and resulting in a test that is voided. Further, if the first and second set of air samples appeared to be consistent, but radically different from the EPERM results, it would be concluded that either the homeowner had tampered with the EPERM, had aired out the house prior to and during the test, or a faulty EPERM could have caused the abnormality.

A gamma survey was also performed using a Scintrex Gamma Scintillometer to measure the background radiation in the test area. In some areas of the country, cinder blocks containing uranium-mill tailings have been used for base house construction (NCRP 1989) and may effect radon tests. Rock collections stored in the basement are sometimes large enough to offset the radon test.

Between February 1990 and August 1992, approximately 500 radon tests were conducted in the Oakland County area. Of these, 201 were chosen for use in this study. The criteria considered in choosing these test points were as follows: All tests were to have been conducted using EPERM analysis, tests areas were to have had sump holes, and all tests were to have been conducted in livable basement areas, as required by EPA protocol (EPA 1989). All tests were conducted during closed-house conditions with test periods ranging from a minimum of 48 hours to a maximum of 8.0 days. All EPERM analyses were conducted by an EPA-certified laboratory, which maintained extensive and proper quality control.

After determining which tests would be applicable to this study, the type of terrain for each test site was determined. First, the following maps were gathered: Oakland County Base Map (Oakland County 1980) showing major crossroads, Surficial Geology of Oakland County (Oakland County 1980), Till Thickness Map of Michigan (Akers 1938), and Bedrock Geology of Michigan (Milstein 1987). Next, all test sites were located on each map to determine surficial geology, thickness of overburden, and bedrock geology. Also obtained was the USDA Soil Survey for Oakland County, Michigan (Soil Conservation Service 1982). The soil survey was used to determine the following for each test site: soil series, permeability, drainage, and family textural class. All aforementioned data for each test site was entered into Systat, a statistical analysis program.

RESULTS AND DISCUSSION

Two hundred and one radon tests were conducted over a variety of glacial sediments. Soils of various permeabilities, textures, drainage capabilities, and soil types, as well as overburden thickness, and bedrock varieties were considered. One test, having an exceedingly high result of 59.4 pCi/l, was eliminated from the study. The majority of all test sites were on urban land that may have been rearranged, filled, leveled, and then subdivided, resulting in an altered topography and disturbed soil.

Radon levels were compared to the variables of bedrock type, surficial geology, thickness of overburden, soil permeability, soil drainage, soil texture, and soil series. Secondly, thickness of overburden, soil permeability, soil drainage, soil texture, and soil series were sorted by surficial geology and studied independently.

Each comparison is listed in a separate set of tables. For each, the number of cases per category, minimum and maximum radon levels, mean radon levels and standard deviations are given. An analysis of variance was performed, using SYSTAT, and a simple mean separation using the F-statistic was calculated. In situations where only two categories can be compared, the t-statistic was calculated instead of the F-statistic. In both cases, the calculated t or F value was compared to a tabular value. If the calculated value was larger than the tabular value, the null hypothesis (all means are equal) was rejected and the research hypothesis (not all means are equal) was accepted. Additionally, the alpha level (the probability of incorrectly rejecting the null hypothesis) is given for each analysis of variance table. Calculated F or t values were considered insignificant if the corresponding alpha level was above 10%.

Radon Levels Versus Surficial Geology

TABLE 1

SUMMARY OF DATA FOR RADON LEVELS VERSUS SURFICIAL GEOLOGY

SURF. GEOLOGY:	**Clay Lakebed**	**Moraine**	**Outwash Plain**	**Sandy Lakebed**	**Till Plain**	**Water-laid Moraine**
# CASES:	9	90	28	31	19	23
MINIMUM:	0.8	0.5	0.8	0.5	0.4	0.4
MAXIMUM:	1.5	10.3	15.3	14.0	5.7	7.9
MEAN:	1.178	2.761	5.339	2.656	2.021	2.265
STD DEV:	0.282	2.223	3.399	2.735	1.193	1.715

TABLE 2

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SURFICIAL GEOLOGY

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	222.459	5	44.492
Within	1066.931	194	5.50

Calculated F Value: 8.090
Tabular F Value: 1.89

Moraines accounted for 45%, or 90 of the 200 total observations. Clay lakebeds made up 4.5%, or 9 of the observations. Outwash plains, sandy lakebeds, till plains, and waterlaid moraines comprised 14%, 15% 9.5% and 11.5% of the total number of radon tests, respectively.

The calculated F value (Table 2) for this data set was 8.090. The corresponding probability of a larger tabular F value was 0.000, meaning there was a 100% probability that at least two of the means are different.

A correlation between surficial geology and radon levels was expected. The theory was that certain formations such as clay lakebeds with low permeability would have significantly lower radon levels than formations such as outwash plains with higher permeabilities. Moraines, sandy lakebeds, till plains and waterlaid moraines showed mean radon values that were relatively close together. Typically, a field technician would not differentiate between radon values unless there was a whole integer difference.

Radon Levels Versus Bedrock Type

TABLE 3

SUMMARY OF DATA FOR RADON LEVELS VERSUS BEDROCK TYPE

BEDROCK TYPE:	**Antrim Shale**	**Bedford Shale**	**Berea Shale**	**Cold-water Shale**	**Sunbury Shale**
# CASES:	5	13	14	164	4
MINIMUM:	1.0	0.5	0.5	0.4	1.6
MAXIMUM:	5.7	9.1	7.9	15.3	2.3
MEAN:	2.800	2.246	2.300	3.021	1.950
STD DEV:	1.876	2.185	1.947	2.658	0.289

TABLE 4

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS BEDROCK TYPE

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	16.638	4	4.160
Within	1272.752	195	6.527

Calculated F Value: 0.637
Tabular F Value: 1.98

The number of cases for each bedrock type is unbalanced because Coldwater Shale is the predominant bedrock underlying Oakland County (Table 3). The calculated F value (Table 4) for this data set is 0.637 and the resulting probability of a larger tabular F value is 0.636, or 63.6%. For this data subset, the null hypothesis was accepted.

No correlation between radon levels and bedrock type was expected, because radon is capable of traveling only 3 meters during its 3.84-day halflife (Tanner 1986). Any radon emanating from the bedrock would decay long before reaching the surface because the minimum overburden thickness recorded was 30 meters.

Radon Levels Versus Thickness of Overburden

TABLE 5

SUMMARY OF DATA FOR RADON LEVELS VERSUS THICKNESS OF OVERBURDEN

OVER-BURDEN:	**30 Meters**	**45 Meters**	**60 Meters**	**75 Meters**	**90 Meters**
# CASES:	20	47	44	49	40
MINIMUM:	0.4	0.5	0.6	0.4	0.5
MAXIMUM:	3.7	9.3	10.3	14.0	15.3
MEAN:	1.560	2.598	2.614	3.400	3.593
STD DEV:	0.933	1.870	1.989	3.254	3.031

TABLE 6

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS THICKNESS OF OVERBURDEN

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	75.233	4	18.808
Within	1214.157	195	6.226

Calculated F Value: 3.021
Tabular F Value: 1.98

The F value for this data set was 3.021 and the corresponding probability of a larger tabular F value was 0.019, or 1.9%. This F value is significant at both the 5% and 10% alpha levels. Because of the short half life of radon, any radon emanating from bedrock would have decayed during the first 3 meters of travel. Because Oakland County has a minimum overburden thickness of 30 meters, radon levels were not expected to increase as overburden thickness decreased, as would be expected if the radon was emanating from the bedrock. However, the mean values listed in Table 5 indicate a constant trend for radon values to increase as overburden thickness increased. A comparison of the map showing thickness of overburden to the locations of glacial deposits in Oakland County indicates that a large area of outwash plains is located directly over a sediment thickness of 90 meters. Table 1 indicates that outwash plains had the highest mean radon values in Oakland County. Also, clay lakebeds, which had the lowest mean radon values, were located in the southeast corner of Oakland County, where overburden thickness is 30 to 60 meters. This evidence suggests that the significance of overburden thickness to elevated indoor radon levels may be coincidental.

A further investigation of overburden thickness was done by sorting the data set into each type of surficial geology, and then comparing thicknesses. These results are given in the following tables.

TABLE 7

SUMMARY OF DATA FOR RADON LEVELS VERSUS THICKNESS OF OVERBURDEN IN AREAS ASSOCIATED WITH CLAY LAKEBEDS

OVERBURDEN:	**45 Meters**	**60 Meters**
# CASES:	5	3
MINIMUM:	0.8	1.2
MAXIMUM:	1.4	1.5
MEAN:	1.100	1.400
STD DEV:	0.283	0.173

Calculated t Value: 1.632 Degrees of Freedom: 8
Tabular t Value 1.860

Nine radon tests were performed on clay lakebeds. One of these tests was on an overburden thickness of 75 meters. Because one value is not considered to be a representative sample, this test was omitted from the calculations. Table 7 shows the compilation of data for the remaining 8 tests. The calculated t value was 1.632 with the corresponding probability of a larger tabular t value of 0.154, or 15.4%. The t value calculated for this data subset was insignificant at the 10% level.

TABLE 8

SUMMARY OF DATA FOR RADON LEVELS VERSUS THICKNESS OF OVERBURDEN IN AREAS ASSOCIATED WITH MORAINES

OVERBURDEN:	**30 Meters**	**45 Meters**	**60 Meters**	**75 Meters**	**90 Meters**
# CASES:	4	16	27	25	18
MINIMUM:	0.5	0.5	0.6	0.5	0.5
MAXIMUM:	0.9	7.3	10.3	9.1	10.3
MEAN:	0.950	3.025	2.863	3.108	2.339
STD DEV:	0.173	2.020	2.127	2.502	2.258

TABLE 9

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS THICKNESS OF OVERBURDEN IN AREAS ASSOCIATED WITH MORAINES

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	23.79	4	5.947
Within	415.864	85	4.893

Calculated F Value: 1.216
Tabular F Value: 2.02

Ninety radon tests were performed on moraines. Moraines in Oakland County are common and cover all possible overburden thicknesses in that county. Table 8 summarizes the data collected at these test sites. The F value shown in Table 9 was 1.216 and the corresponding probability of a larger tabular F value was 0.310 or 31%, suggesting that the differences found between individual radon values on moraines are not due to overburden thickness.

TABLE 10

SUMMARY OF DATA FOR RADON LEVELS VERSUS THICKNESS OF OVERBURDEN IN AREAS ASSOCIATED WITH TILL PLAINS

OVERBURDEN:	**60 Meters**	**75 Meters**	**90 Meters**
# CASES:	5	10	3
MINIMUM:	1.4	0.4	1.9
MAXIMUM:	3.4	3.5	5.7
MEAN:	2.120	1.690	3.233
STD DEV:	0.773	0.935	2.139

TABLE 11

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS THICKNESS OF OVERBURDEN IN AREAS ASSOCIATED WITH TILL PLAINS

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	5.516	2	2.758
Within	19.404	15	1.294

Calculated F Value: 2.132
Tabular F Value: 2.70

Nineteen radon tests were performed on till plains. Only one test was performed on an overburden thickness of 45 meters, and it was omitted since one value is not considered a representative sample. Table 10 summarizes the data collected for this subset. Table 11 shows the analysis of variance. The calculated F value was 2.132 and the corresponding probability of a larger tabular F value was 0.153 or 15.3%. This F value is insignificant at the 10% alpha level. No trend exists for radon levels to increase with increasing overburden thickness.

TABLE 12

SUMMARY OF DATA FOR RADON LEVELS VERSUS THICKNESS OF OVERBURDEN IN AREAS ASSOCIATED WITH WATERLAID MORAINES

OVERBURDEN:	**30 Meters**	**45 Meters**	**60 Meters**
# CASES:	11	8	4
MINIMUM:	0.4	1.2	0.6
MAXIMUM:	3.7	4.5	7.9
MEAN:	1.600	2.788	3.050
STD DEV:	1.048	1.215	3.359

TABLE 13

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS THICKNESS OF OVERBURDEN IN AREAS ASSOCIATED WITH WATERLAID MORAINES

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	9.513	2	4.757
Within	55.159	20	2.758

Calculated F Value: 1.725
Tabular F Value: 2.59

Twenty three radon tests were performed on waterlaid moraines. Of these tests, none were located on an overburden thickness greater than 60 meters. Table 12 summarizes the data for this subset. The analysis of variance shown in table 13 produces an F value of 1.725 with a probability of 0.204, or 20.4% that the tabular F value was higher than the calculated F value. No significant difference between means was found in this subset, although a steady upward trend occurs in mean radon values as overburden thickness increases.

TABLE 14

SUMMARY OF DATA FOR RADON LEVELS VERSUS THICKNESS OF OVERBURDEN IN AREAS ASSOCIATED WITH OUTWASH PLAINS

OVERBURDEN:	**75 Meters**	**90 Meters**
# CASES:	8	19
MINIMUM:	2.3	0.8
MAXIMUM:	12.4	15.3
MEAN:	6.725	4.837
STD DEV:	3.485	3.370

Calculated t Value: 1.317 Degrees of Freedom: 12
Tabular t Value: 1.782

Twenty eight radon tests were performed on outwash plains. Of these, one was located on an overburden thickness of 60 meters, and was omitted since it did not provide a representative sample. Table 14 summarizes the data collected. The calculated t value for this data subset was 1.317 with a corresponding probability of a larger tabular t value of 0.200 or 20%. Mean radon levels tend to be higher on outwash plains than on other glacial deposits, and outwash plains in Oakland County are located over the thickest overburden. There was no significant difference between 70 meters and 90 meters of overburden on outwash plains in Oakland County.

TABLE 15

SUMMARY OF DATA FOR RADON LEVELS VERSUS THICKNESS OF OVERBURDEN IN AREAS ASSOCIATED WITH SANDY LAKEBEDS

OVERBURDEN:	**30 Meters**	**45 Meters**	**60 Meters**	**75 Meters**
# CASES:	5	17	4	5
MINIMUM:	1.4	0.7	0.9	0.5
MAXIMUM:	2.9	9.3	3.2	14.0
MEAN:	2.120	2.629	1.725	3.460
STD DEV:	0.563	2.130	1.090	5.896

TABLE 16

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS THICKNESS OF OVERBURDEN IN AREAS ASSOCIATED WITH SANDY LAKEBEDS

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	7.888	3	2.629
Within	216.443	27	8.016

Calculated F Value: 0.329
Tabular F Value: 2.30

Thirty one radon tests were performed on sandy lakebeds. These tests ranged in overburden thickness from 30 meters to 75 meters. Table 15 summarizes the data collected. The analysis of variance in Table 16 shows an F value of 0.329 and a probability of a larger tabular F value of 0.805 or 80.5%. Sandy lakebeds appear on a variety of overburden thicknesses in Oakland County. There was no significant difference between any of the means in this data subset.

Radon Levels Versus Soil Permeability

TABLE 17

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL PERMEABILITY

PERMEABILITY:	**Slow**	**Mod. Slow**	**Moderate**	**Mod. Rapid**	**Rapid**
# CASES:	2	129	9	58	2
MINIMUM:	1.4	0.4	0.6	0.5	0.5
MAXIMUM:	3.6	12.4	6.1	15.3	1.4
MEAN:	2.500	2.609	3.467	3.517	0.950
STD DEV:	1.556	2.170	2.140	3.253	0.636

TABLE 18

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL PERMEABILITY

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	43.862	4	10.965
Within	1245.528	195	6.387

Calculated F Value: 1.717
Tabular F Value: 1.98

Table 17 summarizes the data sorted by soil permeability. Over one half the tests performed were located on moderately slow permeable soils. Another one quarter of the tests were on moderately rapid permeable soils. Nine were on moderately permeable, two on slowly permeable and two on rapidly permeable soils.

The analysis of variance in Table 18 gives an F value of 1.717 and a probability of a larger tabular F value of 0.148 or 14.8%. Soils with higher permeability rates were expected to yield higher mean radon levels, due to the increased ease of gas exchange within the soil media. Mean radon values steadily increased in Table 17, with the exception of rapidly permeable soils. The F value was insignificant at the 10% alpha level.

TABLE 19

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL PERMEABILITY IN AREAS ASSOCIATED WITH MORAINES

PERMEABILITY:	**Slow**	**Moderately Slow**	**Moderate**	**Moderately Rapid**
# CASES:	2	62	4	22
MINIMUM:	1.4	0.5	0.6	0.5
MAXIMUM:	3.6	10.3	4.7	5.8
MEAN:	2.500	2.952	2.450	2.305
STD DEV:	1.556	2.446	1.694	1.637

TABLE 20

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL PERMEABILITY IN AREAS ASSOCIATED WITH MORAINES

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	7.360	3	2.453
Within	432.294	86	5.027

Calculated F Value: 0.488
Tabular F Value: 2.15

Ninety of the two hundred radon tests were performed on moraines. Of these ninety, sixty two were located on moderately slowly permeable soils, twenty two on moderately rapidly permeable soils, four on moderately permeable soils, and two on slowly permeable soils. This breakdown is still unbalanced. Table 20 shows an F value of 0.488 with the probability of a larger tabular F value being 0.691 or 69.1%. No trend existed for mean radon values to increase with increasing soil permeability in this data subset. A field technician would not find a difference between any of these means.

TABLE 21

SUMMARY OF DATA FOR RADON LEVELS VERSUS
SOIL PERMEABILITY IN AREAS ASSOCIATED
WITH WATERLAID MORAINES

PERMEABILITY:	**Moderately Slow**	**Moderately Rapid**
# CASES:	19	4
MINIMUM:	0.4	0.6
MAXIMUM:	4.5	7.9
MEAN:	2.205	2.550
STD DEV:	1.203	3.571

Calculated t Value: 0.358 Degrees of Freedom: 3
Tabular t Value: 2.353

Twenty three tests were performed on waterlaid moraines. Nineteen of these were on moderately slowly permeable soils and four were on moderately rapidly permeable soils. The t value calculated for this data subset was 0.358 with a probability of a larger tabular t value of 0.724 or 72.4%. Again, this finding is insignificant at the 10% alpha level.

TABLE 22

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL PERMEABILITY IN AREAS ASSOCIATED WITH OUTWASH PLAINS

PERMEABILITY:	**Moderately Slow**	**Moderate**	**Moderately Rapid**
# CASES:	6	3	19
MINIMUM:	2.7	2.8	0.8
MAXIMUM:	12.4	6.1	15.3
MEAN:	5.717	4.900	5.289
STD DEV:	3.891	1.825	3.560

TABLE 23

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL PERMEABILITY IN AREAS ASSOCIATED WITH OUTWASH PLAINS

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	1.481	2	0.740
Within	310.526	25	12.421

Calculated F Value: 0.060
Tabular F Value: 2.53

Twenty eight radon tests were performed on outwash plains. Data collected for this subset is summarized in Table 22. Mean values for each permeability category are higher than in other subsets observed in this group. The analysis of variance shown in Table 23 shows an F value of 0.060 and a probability of a larger tabular F value of 0.942 or 94.2%. Mean radon values showed no pattern or trend.

TABLE 24

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL PERMEABILITY IN AREAS ASSOCIATED WITH SANDY LAKEBEDS

PERMEABILITY:	**Moderately Slow**	**Moderately Rapid**	**Rapid**
# CASES:	16	12	2
MINIMUM:	0.8	0.7	0.5
MAXIMUM:	5.4	14.0	1.4
MEAN:	2.200	3.450	0.950
STD DEV:	1.302	4.037	0.636

TABLE 25

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL PERMEABILITY IN AREAS ASSOCIATED WITH SANDY LAKEBEDS

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	16.667	2	8.333
Within	205.135	27	7.598

Calculated F Value: 1.097
Tabular F Value: 2.51

Thirty one radon tests were performed on sandy lakebeds. The one performed on moderately permeable soils was deleted because it was not a representative sample. Table 25 shows an F value of 1.097 and a probability of a larger tabular F value of 0.348 or 34.8%. This finding does not follow the rule of thumb in the field, as 0.950 pCi/l. is considered to be much lower than 3.450 pCi/l. which is nearly failing. In this case, the variability within each category helped negate any difference between groups.

Radon Levels Versus Soil Texture

TABLE 26

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL TEXTURE

TEXTURE:	**Fine**	**Fine Loamy**	**Coarse Loamy**	**Sandy**
# CASES:	28	114	22	35
MINIMUM:	0.4	0.4	0.8	0.5
MAXIMUM:	4.5	12.4	9.6	15.3
MEAN:	2.211	2.740	3.614	3.166
STD DEV:	1.109	2.334	2.792	3.086

TABLE 27

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL TEXTURE

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	29.099	3	9.7
Within	1136.306	195	5.827

Calculated F Value: 1.665
Tabular F Value: 2.13

Radon levels were compared against soil texture. Radon levels were expected to increase with increasing coarseness because of increasing permeability. Fine loamy soils accounted for over one half of the tests performed. The other textural categories were relatively well balanced with respect to the number of cases observed per category. Means observed showed a steady increase with increasing coarseness until the category of sandy soils.

In general, soils with loamy textures had the highest radon levels, possibly because of the mixed mineralogy of loamy soils. If radon is emanating from within the glacial deposits, then the mineralogy of the soils will be an important factor in determining the amount of radon being given off.

Table 27 shows the analysis of variance. The calculated F value was 1.665 and the resulting probability of a larger tabular F value was 0.176 or 17.6%. This F value is insignificant at the 10% alpha level, even though a field technician would consider 2.211 pCi/l different from 3.614 pCi/l. The data in Table 26 indicates a steady upward trend as soil texture becomes coarser. Mean radon values decreased for sandy soils, possibly because sandy soils contain very little uranium, but are mainly quartz.

Soil texture was also sorted by surficial geology and the results shown in the following tables.

TABLE 28

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL TEXTURE IN AREAS ASSOCIATED WITH CLAY LAKEBEDS

TEXTURE:	**Fine**	**Fine Loamy**
# CASES:	2	7
MINIMUM:	0.9	0.8
MAXIMUM:	1.4	1.5
MEAN:	1.150	1.186
STD DEV:	0.354	0.291

Calculated t Value: 0.148 Degrees of Freedom: 1
Tabular t Value: 6.31

Of the nine clay lakebeds observed in this study, two had fine textured soils, and seven had fine loamy soils. The difference between the means of these two categories, 0.036 pCi/l, is almost negligible. The calculated t value in table 28 was 0.148 and the corresponding probability of a larger tabular t value was 0.886, or 88.6%. A field technician using an EPERM would agree that the two means are too close together to accurately measure this difference.

TABLE 29

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL TEXTURE IN AREAS ASSOCIATED WITH MORAINES

TEXTURE:	**Fine**	**Fine Loamy**	**Coarse Loamy**	**Sandy**
# CASES:	4	65	10	11
MINIMUM:	1.4	0.5	1.3	0.5
MAXIMUM:	3.6	10.3	5.8	5.8
MEAN:	2.475	2.906	2.810	1.964
STD DEV:	1.135	2.425	1.240	1.920

TABLE 30

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL TEXTURE IN AREAS ASSOCIATED WITH MORAINES

SOURCE	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	8.714	3	2.905
Within	430.939	86	5.011

Calculated F Value: 0.580
Tabular F Value: 2.12

Table 29 gives the summary of data collected for the ninety radon tests performed on moraines. Mean radon levels ranged from 1.964 pCi/l on sandy soils to 2.906 pCi/l on fine loamy textured soils. Loamy textured soils had higher mean values than either fine or sandy textured soils. The F value calculated in Table 30 corresponds to a probability of 0.630 or 63.0% that the tabular F value is greater than the calculated F value.

TABLE 31

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL TEXTURE IN AREAS ASSOCIATED WITH WATERLAID MORAINES

TEXTURE:	**Fine**	**Fine Loamy**	**Sandy**
# CASES:	15	5	2
MINIMUM:	0.4	0.6	0.7
MAXIMUM:	4.5	1.5	1.0
MEAN:	2.460	1.120	0.850
STD DEV:	1.234	0.327	0.212

TABLE 32

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL TEXTURE IN AREAS ASSOCIATED WITH WATERLAID MORAINES

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	9.689	2	4.845
Within	21.789	19	1.147

Calculated F Value: 4.224
Tabular F Value: 2.61

Table 31 shows the summary of data collected for the waterlaid moraines, sorted by soil texture. The category of coarse loamy textured soils was omitted because only one radon test was performed on this textural class. Mean values steadily decreased with increasing coarseness, unlike what was observed in previous subsets. Also unlike other subsets, loamy textured soils were not higher in radon levels than fine or sandy soils.

Table 32 shows the analysis of variance. The F value was 4.224, with a probability of a larger tabular F value of 0.030, or 3.0%. This F value is significant at both the 5% and 10% alpha level. These results concur with the rule of thumb in the field, which would consider 0.850 pCi/l to be different from 2.460 pCi/l.

TABLE 33

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL TEXTURE IN AREAS ASSOCIATED WITH OUTWASH PLAINS

TEXTURE:	**Fine Loamy**	**Coarse Loamy**	**Sandy**
# CASES:	9	6	13
MINIMUM:	2.7	0.8	1.7
MAXIMUM:	12.4	9.6	15.3
MEAN:	5.444	4.933	5.454
STD DEV:	3.235	3.402	3.755

TABLE 34

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL TEXTURE IN AREAS ASSOCIATED WITH OUTWASH PLAINS

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	1.259	2	0.629
Within	310.748	25	12.430

Calculated F Value: 0.051
Tabular F Value: 2.53

Table 33 summarizes the data collected on the 28 outwash plains. There is no trend or pattern to radon levels when compared to soil texture. Table 34 shows the analysis of variance. The calculated F value was 0.051 and the probability of a larger tabular F value was 0.951, or 95.1%. While any of these three means would indicate a "failed" test, they are too close together to be considered different from one another in the field.

TABLE 35

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL TEXTURE IN AREAS ASSOCIATED WITH SANDY LAKEBEDS

TEXTURE:	**Fine**	**Fine Loamy**	**Coarse Loamy**	**Sandy**
# CASES:	7	10	4	9
MINIMUM:	0.8	0.9	1.0	0.5
MAXIMUM:	2.9	5.4	9.3	3.2
MEAN:	1.829	2.340	3.175	1.844
STD DEV:	0.757	1.574	4.088	0.953

TABLE 36

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL TEXTURE IN AREAS ASSOCIATED WITH SANDY LAKEBEDS

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	6.094	3	2.031
Within	83.108	26	3.196

Calculated F Value: 0.635
Tabular F Value: 2.31

Table 35 summarizes the data collected on the 31 sandy lakebeds. The test performed on loamy textured soils was omitted from this subset because it did not provide a representative sample. The range of difference between maximum and minimum radon levels observed within each textural class was quite variable across the table. Again, mean radon levels tended to increase with increasing coarseness, until the category of sandy texture, where the level dropped back to 1.844 pCi/l. Loamy textured soils had higher mean radon values than either fine or sandy textured soils.

Table 36 shows the analysis of variance. The calculated F value was 0.635 with a corresponding probability of a larger tabular F value of 0.599 or 59.9%.

Radon Levels Versus Soil Drainage

TABLE 37

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL DRAINAGE

DRAINAGE:	**Very Poorly**	**Poorly**	**Somewhat Poorly**	**Moderately Well**	**Well**
# CASES:	5	23	42	73	57
MINIMUM:	0.6	0.4	0.4	0.5	0.5
MAXIMUM:	1.9	4.5	9.3	12.4	15.3
MEAN:	1.120	2.091	2.133	3.114	3.649
STD DEV:	0.482	1.085	1.770	2.607	3.145

TABLE 38

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL DRAINAGE

Source:	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between:	90.882	4	22.720
Within:	1198.508	195	6.146

Calculated F Value: 3.697
Tabular F Value: 1.98

Radon levels were sorted by soil drainage classes. Because Michigan has very low radon levels in its groundwater, it was expected that well drained soils would have higher radon levels than poorly drained soils. Wet or saturated soils have a low soil gas exchange rate, and therefore should emanate less radon than drier soils. Table 37 shows the summary of data sorted by soil drainage. As expected, mean radon values increased with increasing drainage capabilities. The calculated F value shown in Table 38 was 3.697 and the corresponding probability that the tabular F value was larger than the calculated F value was 0.006 or 0.6%. This F value is significant at both the 5% and 10% levels.

The data was also sorted by surficial geology and then by drainage to further investigate the significance of drainage. The results are given in the following tables.

TABLE 39

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL DRAINAGE IN AREAS ASSOCIATED WITH CLAY LAKEBEDS

DRAINAGE:	**Somewhat Poorly**	**Poorly**
# CASES:	7	2
MINIMUM:	0.8	0.9
MAXIMUM:	1.5	1.4
MEAN:	1.186	1.150
STD DEV:	0.291	0.354

Calculated t Value: 0.148 Degrees of Freedom:
Tabular t Value: 6.314

The only soil drainage classes observed on clay lakebeds were somewhat poorly and poorly drained soils, both of which produced low radon values overall. The maximum radon value for any of these soils was 1.5 pCi/l. Although no well drained soils exist to use as a comparison, the low radon values observed on clay lakebeds supports the theory that poorly drained soils have low radon values.

Table 39 shows a calculated t value of 0.148 with a corresponding probability of a larger tabular t value of 0.886 or 88.6%.

TABLE 40

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL DRAINAGE IN AREAS ASSOCIATED WITH MORAINES

DRAINAGE:	**Very Poorly**	**Somewhat Poorly**	**Moderately Well**	**Well**
# CASES:	5	12	48	25
MINIMUM:	0.6	0.5	0.5	0.5
MAXIMUM:	1.9	4.0	10.3	5.8
MEAN:	1.120	2.100	3.285	2.400
STD DEV:	0.482	0.966	2.657	1.600

TABLE 41

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL DRAINAGE IN AREAS ASSOCIATED WITH MORAINES

Source:	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between:	35.166	3	11.722
Within:	404.488	86	4.703

Calculated F Value: 2.492
Tabular F Value: 2.12

Table 40 summarizes data collected on moraines. With the exception of well drained soils, mean radon levels increased steadily upward with increasing drainage capabilities. This trend is in agreement with the previous findings in this subset.

Table 41 shows the analysis of variance. The calculated F value was 2.492 and had a corresponding probability of a larger tabular F value of 0.065 or 6.5%. This F value is significant at the 10% alpha level.

TABLE 42

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL DRAINAGE IN AREAS ASSOCIATED WITH OUTWASH PLAINS

DRAINAGE:	**Moderately Well**	**Well**
# CASES:	6	21
MINIMUM:	2.7	0.8
MAXIMUM:	12.4	15.3
MEAN:	5.717	5.176
STD DEV:	3.891	3.417

Calculated t Value: 0.332 Degrees of Freedom: 7
Tabular t Value: 1.895

Table 42 summarizes the data collected on outwash plains. Soils in this subset were moderately well or well drained. Mean radon levels for both categories were above failing. Also, the maximum levels observed were at least three times higher than the EPA action level of 4.0 pCi/l. Although there were no poorly drained soils for comparison, this subset supports the theory that radon levels will be higher in areas of better drainage.

The calculated t value for this data subset was 0.332 with a corresponding probability of 0.743 or 74.3% of a larger tabular t value.

TABLE 43

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL DRAINAGE IN AREAS ASSOCIATED WITH SANDY LAKEBEDS

DRAINAGE:	**Poorly**	**Somewhat Poorly**	**Moderately Well**	**Well**
# CASES:	7	12	5	7
MINIMUM:	0.8	0.5	0.9	1.0
MAXIMUM:	2.9	9.3	3.4	14.0
MEAN:	1.829	2.858	1.720	3.400
STD DEV:	0.757	2.516	1.050	4.718

TABLE 44

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL DRAINAGE IN AREAS ASSOCIATED WITH SANDY LAKEBEDS

Source:	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between:	13.280	3	4.427
Within:	211.051	27	7.817

Calculated F Value: 0.566
Tabular F Value: 2.30

Table 43 summarizes the data collected on sandy lakebeds. Mean radon levels varied from 1.720 pCi/l to 3.400 pCi/l, and, except for moderately well drained soils, tended to increase as drainage increased. The calculated F value, shown in Table 44, for this data subset was 0.566 with a corresponding probability of a larger tabular F value of 0.642, or 64.2%. This F value is insignificant, although in the field, 1.720 pCi/l would be considered different from 3.400 pCi/l. In general, mean radon levels were below the EPA action level of 4.0

pCi/l. Individual radon values, however, ranged from 0.5 to 14.0 pCi/l.

TABLE 45

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL DRAINAGE IN AREAS ASSOCIATED WITH TILL PLAINS

DRAINAGE:	**Somewhat Poorly**	**Moderately Well**	**Well**
# CASES:	3	14	2
MINIMUM:	0.4	1.0	1.2
MAXIMUM:	3.5	3.4	5.7
MEAN:	1.600	1.907	3.450
STD DEV:	1.664	0.631	3.182

TABLE 46

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL DRAINAGE IN AREAS ASSOCIATED WITH TILL PLAINS

Source:	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between:	4.797	2	2.399
Within:	20.834	16	1.302

Calculated F Value: 1.842
Tabular F Value: 2.67

Table 45 summarizes the data collected on till plains. Radon levels increased with increasing drainage capabilities. This trend supports the theory that radon levels will be higher in areas where the soils have better drainage. With the exception of the test measuring 5.7 pCi/l, no individual radon levels observed on till plains were above the EPA action level of 4.0 pCi/l.

Table 46 shows the analysis of variance and calculated F value of 1.842. The Probability of a larger tabular F value was 0.191 or 19.1%. This F value was insignificant, although 1.600 pCi/l and 3.450 pCi/l would be considered different in the field.

TABLE 47

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL DRAINAGE IN AREAS ASSOCIATED WITH WATERLAID MORAINES

DRAINAGE:	**Poorly**	**Somewhat Poorly**	**Well**
# CASES:	14	7	2
MINIMUM:	0.4	0.6	0.7
MAXIMUM:	4.5	3.9	7.9
MEAN:	2.357	1.500	4.3
STD DEV:	1.212	1.092	5.091

TABLE 48

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL DRAINAGE IN AREAS ASSOCIATED WITH WATERLAID MORAINES

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	12.498	2	6.249
Within	52.174	20	2.609

Calculated F Value: 2.395
Tabular F Value: 2.59

Table 47 summarizes the data collected on waterlaid moraines. Although radon levels do not continually rise with increasing drainage capabilities, well drained soils had higher mean radon levels than poorly or somewhat poorly drained soils. The mean radon level for well drained soils was above the 4.0 pCi/l EPA action level.

Table 48 shows the analysis of variance. The calculated F value for this data subset was 2.395 with a corresponding probability of a larger tabular F value of 0.117 or 11.7%. While the F value for this subset is insignificant, the data suggests that areas of better soil drainage will have higher mean radon levels.

Radon Levels Versus Soil Series

TABLE 49

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL SERIES

SOIL SERIES:	**Blount**	**Boyer**	**Capac**	**Fox**	**Glynwood**	**Lenawee**
# CASES:	3	21	27	5	2	23
MINIMUM:	1.6	0.8	0.4	0.6	1.4	0.4
MAXIMUM:	3.9	9.6	5.4	6.1	3.6	4.5
MEAN:	2.933	3.343	1.915	4.580	2.500	2.091
STD DEV:	1.193	2.548	1.197	2.286	1.556	1.085

TABLE 49 (Continued)

SOIL SERIES:	**Marlette**	**Riddles**	**Sloan**	**Spinks**	**Tedrow**	**Thet-ford**
# CASES:	71	2	5	26	2	7
MINIMUM:	0.5	2.1	0.6	0.5	0.5	0.5
MAXIMUM:	12.4	2.4	1.9	15.3	1.4	6.5
MEAN:	3.131	1.250	1.120	3.562	0.950	2.329
STD DEV:	2.635	0.212	0.482	3.334	0.636	2.108

TABLE 50

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL SERIES

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	100.715	11	9.156
Within	1011.164	182	5.556

Calculated F Value: 1.648
Tabular F Value: 1.61

Finally, radon levels were compared against soil series. Table 49 summarizes the data collected. Because there was only one test performed on the following soils: Matherton, Metamora, Ormas, Owosso, Sisson, and Wasepi, they were omitted from this set of calculations. The number of observations for each soil series remaining varied from 2 to 71.

The analysis of variance in Table 50 shows an F value of 1.648 and a probability of a larger tabular F value of 0.089 or 8.9%, which is significant at the 10% alpha level.

Seven of the twelve soil series had maximum radon levels exceeding the EPA action level of 4.0 pCi/l. Fox was the only series having a mean radon value above 4.0 pCi/l. Fox soils are usually well drained, loamy soils with moderate to rapid permeabilities and are often located on outwash plains or moraines. Previous data sets indicate that these characteristics tend to produce higher radon levels. Tedrow soils had the lowest mean radon levels. Tedrow soils tend to form in sandy material, are somewhat poorly drained, and have rapid permeability. As shown in previous data sets, sandy soils often produce lower radon levels than loamy soils.

The characteristics of drainage, texture and permeability, as well as the mean radon level and typical glacial formation for each of the twelve soil series are given in Table 51 on the following page. The soil series were listed in order of increasing mean radon level. Other than Tedrow and Fox series, none of the soils follow any particular pattern with respect to their characteristics.

TABLE 51

CHARACTERISTICS OF SOIL SERIES

SOIL SERIES	Tedrow	Sloan	Riddles	Capac	Lenawee	Thetford	Glynwood	Blount	Marlette	Boyer	Spinks	Fox
MEAN RADON LEVEL	0.950	1.120	1.250	1.915	2.091	2.329	2.500	2.933	3.131	3.343	3.562	4.580
DRAINAGE	Somewhat poorly	Very poorly	Well	Somewhat poorly	Poorly	Somewhat poorly	Moderately well	Somewhat poorly	Moderately well	Well	Well	Well
SURF. GLG.	Outwash plain/ lake plain	Water-laid moraine	Moraine	Moraine/ till plain	Till plain/ moraine	Lake plain/ outwash plain	Moraine/ till plain	Lake plain/ moraine	Till plain/ moraine	Outwash plain/ moraine	Outwash plain/ moraine	Outwash plain/ moraine
TEXTURE	Sandy	Fine loamy	Fine loamy	Fine loamy	Fine	Sandy	Fine	Fine	Fine loamy	Coarse loamy	Sandy	Fine loamy
PERMEABILITY	Rapid	Moderately slowly	Moderate	Moderately slowly	Moderately slowly	Moderately rapid	Slowly	Moderately slowly	Moderately slowly	Moderately rapid	Moderately rapid	Moderate

TABLE 52

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL SERIES IN AREAS ASSOCIATED WITH CLAY LAKEBEDS

SOIL SERIES:	**Capac**	**Lenawee**
# CASES:	7	2
MINIMUM:	0.8	0.9
MAXIMUM:	1.5	1.4
MEAN:	1.186	1.150
STD DEV:	0.291	0.354

Calculated t Value: 0.148 Degrees of Freedom: 1
Tabular t Value: 6.31

Soil series was also sorted by surficial geology and compared to radon levels. The first of these comparisons was performed on clay lakebeds. Seven tests were performed on Capac soils, while two were performed on Lenawee soils. There is very little difference between the minimum and maximum values observed for these two soil types. The means are also quite close together. Table 52 shows a t value of 0.148 with a corresponding probability of a larger tabular t value of 0.886 or 88.6%, which is insignificant. Table 51 indicates that Capac and Lenawee soils are similar in their characteristics, with Capac soils having a more loamy texture and slightly better drainage capability.

TABLE 53

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL SERIES IN AREAS ASSOCIATED WITH OUTWASH PLAINS

SOIL SERIES:	**Boyer**	**Fox**	**Marlette**	**Spinks**
# CASES:	6	2	6	12
MINIMUM:	0.8	5.8	2.7	1.7
MAXIMUM:	9.6	6.1	12.4	15.3
MEAN:	4.933	5.950	5.717	5.367
STD DEV:	3.402	0.212	3.891	3.908

TABLE 54

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL SERIES IN AREAS ASSOCIATED WITH OUTWASH PLAINS

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	2.525	3	0.842
Within	301.613	22	13.710

Calculated F Value: 0.061
Tabular F Value: 2.35

Six different soil series were observed on outwash plains. Sisson and Thetford were omitted because there was only one radon value observed on each. With the exception of Fox soils, the soil series in this subset showed considerable variability between the minimum and maximum values observed within each series. The calculated means are fairly close, with the greatest difference being between Boyer and Fox soils. All four soil series had maximum and mean radon levels above the EPA action level of 4.0 pCi/l. It is interesting to note that Marlette soils were observed on the outwash plains in this data set, although Table 51 does not list this soil type as typically forming on outwash plains. This discrepancy could be explained by the wide margin of error on the maps used in this study.

Table 54 shows the analysis of variance calculated for this data subset. The F value was 0.061 and the corresponding probability of a larger tabular F value was 0.980 or 98.0%.

TABLE 55

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL SERIES IN AREAS ASSOCIATED WITH SANDY LAKEBEDS

SOIL SERIES:	**Boyer**	**Capac**	**Lenawee**	**Marl-ette**	**Spinks**	**Tedrow**	**Thet-ford**
#CASES:	3	4	7	5	3	2	4
MIN:	1.0	1.2	0.8	0.9	1.4	0.5	0.7
MAX:	1.4	5.4	2.9	3.4	2.7	1.4	3.2
MEAN:	1.133	3.45	1.829	1.720	2.133	0.950	2.075
STD DEV:	0.231	1.754	0.757	1.050	0.666	0.636	1.141

TABLE 56

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL SERIES IN AREAS ASSOCIATED WITH SANDY LAKEBEDS

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	13.519	6	2.253
Within	22.378	21	1.066

Calculated F Value: 2.114
Tabular F Value: 2.08

Ten soil series were observed on sandy lakebeds. Because there was only one radon test performed on each, Matherton, Ormas, and Wasepi were omitted, leaving a Of of 28 test points on seven soil series. The data is ly summarized in Table 55. The difference between maximum and minimum values observed within each soil series was quite variable across the seven soil series, however, the maximum value overall was only as high as 5.4 pCi/l. When soil series were arranged in order of increasing radon levels, the order did not parallel Table 51 as expected. In general, soils with lower mean radon values tended to form on till plains and moraines, whereas the soils with higher mean radon values tended to form on outwash plains. This trend is consistent with Table 51. Also, the soils with slower permeabilities had lower mean radon values than soils with more rapid permeabilities.

Table 56 shows the analysis of variance. The calculated F value was 2.114 with a probability of a larger tabular F value of 0.095 or 9.5%, which is significant.

TABLE 57

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL SERIES IN AREAS ASSOCIATED WITH TILL PLAINS

SOIL SERIES:	**Capac**	**Marlette**
# CASES:	3	14
MINIMUM:	0.4	1.0
MAXIMUM:	3.5	3.4
MEAN:	1.600	1.907
STD DEV:	1.664	0.631

Calculated t Value: 0.571 Degrees of Freedom: 14
Tabular t Value: 1.76

TABLE 59

ANALYSIS OF VARIANCE CALCULATED FOR RADON LEVELS VERSUS SOIL SERIES IN AREAS ASSOCIATED WITH MORAINES

Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**
Between	35.603	8	4.45
Within	395.653	79	5.008

Calculated F Value: 0.889
Tabular F Value: 1.75

The ninety radon tests performed on moraines were spread over a wide range of soil series. Owosso and Thetford were omitted due to lack of representative data. The difference between maximum and minimum values observed was quite variable across the nine soil series used in the analysis of variance. Five of those nine had maximum values above the EPA action level of 4.0 pCi/l, although the highest mean value was only 3.32 pCi/l. All of the data is summarized in Table 58.

When arranged in order of increasing radon levels, the soil series in this subset did not parallel the order of those in Table 51. In general, poorly drained soils had lower mean radon values than well drained soils. There did not seem to be any trend or correlation between radon levels and any of the other soil characteristics .

Table 59 shows the analysis of variance. The calculated F value was 0.889 with a corresponding probability of a larger tabular F value of 0.530 or 53.0%.

TABLE 60

SUMMARY OF DATA FOR RADON LEVELS VERSUS SOIL SERIES IN AREAS ASSOCIATED WITH WATERLAID MORAINES

SOIL SERIES:	**Capac**	**Lenawee**
# CASES:	4	14
MINIMUM:	1.1	0.4
MAXIMUM:	1.5	4.5
MEAN:	1.25	2.357
STD DEV:	0.173	1.212

Calculated t Value: 1.783   Degrees of Freedom: 2
Tabular t Value: 0.093

Table 60 summarizes the data collected on waterlaid moraines. Five soil series, Blount, Boyer, Metamora, Spinks, and Thetford, were omitted because only one radon test was performed on each. Of the remaining 18 tests, four were located on Capac soils and fourteen were located on Lenawee soils. The highest radon level, 4.5 pCi/l, was found on Lenawee soils. Capac soils are different from Lenawee soils in that Capac soils are fine loamy textured and have somewhat poor drainage capabilities while Lenawee soils are fine textured and have poor drainage capabilities. Both soil types have moderately slow permeability.

The calculated t value for this subset was 1.783 with a corresponding probability of a larger tabular F value of 0.093 or 9.3%, which is significant at the 10% alpha level.

CONCLUSIONS

From the data collected in this study, the following conclusions can be offered:

Surficial Geology

Based on results from other studies (Smith and Mapes 1989, Khawaja, Abram and Singler 1989), a correlation between radon levels and surficial geology was expected. Surficial geology was the major emphasis of this study, and was found to be a highly significant factor in determining the incidence of indoor radon levels in Oakland County, Michigan.

Bedrock

Because of the thickness of overburden, it was not expected that there be a correlation between bedrock type and indoor radon levels. This study found that in order for bedrock to be a significant factor in determining indoor radon levels, the alpha level would have to be set at 0.636. In conclusion, bedrock type had no effect on the levels of radon in homes located in Oakland County.

Thickness of Overburden

A correlation was found between thickness of overburden and indoor radon levels when examined across all glacial deposits. When each type of glacial deposit was looked at separately, no significant F or t values were found, although trends existed in some subsets for radon values to increase with increasing overburden thickness. Outwash plains, which had the highest mean radon levels, appeared in areas where the overburden is the thickest. Also, clay lakebeds, which had the lowest mean radon values appeared in areas where overburden thickness was lowest. In conclusion, the correlation found between indoor radon levels and overburden thickness may be coincidental.

Permeability

Mean radon values were expected to rise with increasing soil permeability. Across all glacial deposits, permeability was not found to be significant statistically. However, the probability of a higher tabular F value was only 14.8%, which is close to being significant at the 10% alpha level. When separated by surficial geology, no statistical correlation was found for any of the subsets, although on sandy lakebeds and waterlaid moraines, a trend existed for radon levels to rise with increasing permeability.

Texture

No statistical correlation was found between indoor radon levels and soil texture across all glacial deposits, although the probability of a higher tabular F value was low, 17.6%. When separated by surficial geology, only waterlaid moraines showed a statistical difference between means. In general, loamy textured soils had higher mean radon values than fine or sandy textured soils, probably because of mineralogy and permeability.

Drainage

Drainage was a significant factor in determining indoor radon levels. When sorted by surficial geology, glacial deposits having better drainage capabilities tended to have higher mean radon values than glacial deposits with poor drainage capabilities. With the exception of moraines, no glacial deposits showed statistically significant differences between means with respect to soil drainage.

Soil Series

Because soil series takes into account many characteristics, correlations between radon levels and soil series were not necessarily expected. However, soil series was found to be a significant factor in determining indoor radon levels. When sorted by surficial geology, sandy lakebeds and waterlaid moraines showed significant differences between means. Those soil series having better drainage capabilities tended to have higher mean indoor radon values. Also, soils with higher radon levels tended to develop on outwash plains.

Recommendations for Future Studies

Radon test data should be collected in a manner that allows the researcher to maintain as much control of the variability as possible. For example, tests should be performed over a small area and during a relatively short period of time in order to limit variabilities such as climate and origin of glacial sediment. Tests should be conducted in an area of varied glacial deposits and an effort should be made to maintain consistency with respect to the number of tests conducted on each type of surficial geology, soil type, etc. In order to avoid problems with only one radon test being available for a particular category, a large number of reliable test sites should be available. Correct, complete, and accurate maps of the study area must be obtained in order to ensure the accuracy of the results. And, lastly, a study of the lithology and composition of overburden should be made.

REFERENCES CITED

Akers, J., 1938, Drift Thickness Map of Michigan: Michigan Department of Natural Resources, Division of Geological Survey, 1 pl.

Allaby, M., 1991, Dictionary of the Environment: New York, NY, New York University Press, p. 324.

Brookins, D. G., 1991, Correlation of Soil Radon and Uranium with Indoor Radon in the Albuquerque, New Mexico Area: Environmental Geology and Water Science, vol. 17, no. 3, p. 209-217.

Brookins, D. G., 1990, The Indoor Radon Problem: Oxford, NY, Columbia University Press, p. 1-59.

EPA, 1989, A Citizen's Guide to Radon - What it is and What to do About it: U.S. Environmental Protection Agency, Office of Air and Radiation, EPA-86-004, 13 p.

Gundersen, L. C. S., 1992, Radon - Scanning the Country for Problem Locations: Earth, November, 1992, p. 55-61.

Harrell, J. A., 1991, Radon Hazards Associated with Outcrops of Ohio Shale in Ohio: Environmental Geology and Water Science, vol. 18, no. 1, p. 17-26.

Harrell, J. A., 1993, Personal Communication.

Keller, G., H. Schneidens, M. Schutz, A. Siehl, and R. Stamm, 1992, Indoor Radon Correlated with Soil and Subsoil Radon Potential - A Case Study: Environmental Geology and Water Science, vol. 19, no. 2, p. 113-119.

Khawaja, I. V., E. C. Abram, and C. R. Singler, 1989, Indoor Radon Research in Ashtabula, Trumbull, Mahoning, and Columbiana Counties, Ohio: Final Report for a Grant Awarded by the Ohio Air Quality Development Authority, 117 p.

Kotrappa, P., J. C. Dempsey, J. R. Hickey, and L. R. Steiff, 1988, An Electret Passive Environmental ^{222}Rn Monitor Based on Ionization Measurement: Health Physics, vol. 54, no. 1, p. 47-56.

Lafavore, M., 1987, Radon - The Invisible Threat: Emmaus, PA, Rodale Press, 256 p.

Milstein, R. L., 1987, Bedrock Geology of Southern Michigan: Michigan Department of Natural Resources, Division of Geological Survey, 1 pl.

Mose, D. G., G. W. Mushrush, and C. E. Chrosniak, 1992, Soil Radon, Permeability, and Indoor Radon Prediction: Environmental Geology and Water Science, vol. 19, no. 2, p. 91-96.

NCRP, 1989, Control of Radon in Houses: National Council on Radiation Protection and Measurements, NCRP Report no. 103.

Nero, A. V., 1983, Indoor Radiation Exposure from ^{222}Rn and its Daughters - A View of the Issue: Health Physics, vol. 45, p. 277-288.

Oakland County, 1980, Surficial Geology of Oakland County: Oakland County, MI.

Otton, J. K., 1988, Potential for Indoor Radon Hazards - A First Geologic Estimate: in W. J. Makofske and M. R. Edelstein, eds., Radon and the Environment: Park Ridge, NJ, Noyes Publications, p. 29-34.

Radon Detection Systems, 1992, The Radon Review: Radon Detection Systems: Boulder CO, p. 4-6.

Rolle, R., 1972, Rapid Working Level Monitoring: Health Physics, vol. 22, p. 233-238.

Schutz, D. F., and J. A. Powell, 1988, The Influence of Geologic Environment on the Distribution of Uranium in New Jersey: in W. J. Makofske and M. R. Edelstein, eds., Radon and the Environment: Park Ridge, NJ, Noyes Publications, p. 35-47.

Smith, C. W., and R. H. Mapes, 1989, Radon Hazards Associated with Glacial Deposits in Ohio: Final Report for a Grant Awarded by the Ohio Air Quality Development Authority, 177 p.

Soil Conservation Service, 1982, Soil Survey of Oakland County, Michigan: U.S. Department of Agriculture, Soil Conservation Service, in Cooperation with Michigan Agricultural Experiment Station.

Swez, J., 1993, Personal Communication.

Tanner, A. B., 1986, Geologic Factors that Influence Radon Availability: in S. Myers and E. G. Legournaew, eds., Proceedings of the Air Pollution Control Association's International Specialty Conference on Indoor Radon: Pittsburgh, PA, Air Pollution Control Association, publ. SP-54, p. 1-12.

Toohey, R. E., 1987, Radon vs. Lung Cancer: New Study Weighs the Risks: Logos, vol. 5, no. 1, p. 7-11.

Way, D. S., 1985, Terrain Analysis: Upper Arlington, OH, DWA, p. 201-263.

APPENDIX

LIST OF TEST POINTS

Test	Address	City	Rn level (pCi/l)	Surficial Geology	Bedrock Geology	Soil Series	Permeability	Soil Texture	Drainage	Overburden (meters)
1	685 Ashburnham	Auburn	7.9	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
2	3060 Wakefield	Berkley	3.9	Waterlaid Moraine	Coldwater Shale	Blount	Moderately Slow	Fine	Somewhat Poorly	45
3	2576 Bacon	Berkley	4.5	Waterlaid Moraine	Coldwater Shale	Lenawee	Moderately Slow	Fine	Poorly	45
4	120 Lowell	Beverley Hills	2.5	Waterlaid Moraine	Coldwater Shale	Lenawee	Moderately Slow	Fine	Poorly	45
5	32920 Lasher	Beverley Hills	9.3	Sandy Lakebed	Coldwater Shale	Wasepi	Moderately Rapid	Coarse Loamy	Somewhat Poorly	45
6	1787 Southfield	Birmingham	0.7	Waterlaid Moraine	Coldwater Shale	Lenawee	Moderately Slow	Fine	Poorly	30
7	30245 Fox Run	Birmingham	0.9	Sandy Lakebed	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
8	503 Halfmoon	Birmingham	1.1	Sandy Lakebed	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	45
9	969 Chester	Birmingham	1.1	Waterlaid Moraine	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	30
10	1387 Chesterfield	Birmingham	1.2	Sandy Lakebed	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	45
11	1479 Stanley	Birmingham	1.2	Waterlaid Moraine	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	30
12	3234 Sheridan	Birmingham	1.2	Waterlaid Moraine	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	45
13	2626 Windmere	Birmingham	1.4	Clay Lakebed	Coldwater Shale	Lenawee	Moderately Slow	Fine	Poorly	45
14	719 Kinnesol	Birmingham	1.5	Waterlaid Moraine	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	45
15	32261 Auburn	Birmingham	1.6	Sandy Lakebed	Coldwater Shale	Thetford	Moderately Rapid	Sandy	Somewhat Poorly	45
16	638 Westwood	Birmingham	1.6	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
17	2815 Amberly	Birmingham	2.1	Sandy Lakebed	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	45
18	31926 Robinhood	Birmingham	2.7	Sandy Lakebed	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	45
19	32700 Norwood	Birmingham	2.8	Sandy Lakebed	Coldwater Shale	Thetford	Moderately Rapid	Sandy	Somewhat Poorly	45
20	679 Oak	Birmingham	3.2	Sandy Lakebed	Coldwater Shale	Thetford	Moderately Rapid	Sandy	Somewhat Poorly	45
21	23025 Old Orchard	Birmingham	4.0	Sandy Lakebed	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	45
22	468 Argyle	Birmingham	5.4	Sandy Lakebed	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	45
23	6680 Nashway	Bloomfield	1.9	Till Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
24	6250 West Surrey	Bloomfield	3.8	Outwash Plain	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	60
25	614 Sorrel	Bloomfield Hills	0.7	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
26	1503 Sandringham	Bloomfield Hills	1.8	Moraine	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	45
27	657 E. Foxhill	Bloomfield Hills	2.0	Moraine	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	75
28	457 Whippers in Ct	Bloomfield Hills	2.7	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
29	1209 Timberview	Bloomfield Hills	2.9	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
30	4683 Ravine	Bloomfield Hills	3.6	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
31	1724 Blair Ct	Bloomfield Hills	4.5	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
32	1717 Beechwood	Bloomfield Hills	5.8	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
33	2231 Lancaster	Bloomfield Hills	59.4	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
34	2294 Chestnut	Bloomfield Hills	6.3	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
35	2803 Macintosh	Bloomfield Hills	7.1	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
36	5300 Pheasant Run	Clarkston	0.8	Outwash Plain	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	90
37	8350 Allen	Clarkston	1.0	Moraine	Coldwater Shale	Owosso	Moderately Rapid	Fine Loamy	Well	90
38	8242 Caribou Trail	Clarkston	2.4	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
39	4410 Klais	Clarkston	3.3	Outwash Plain	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	90
40	6544 Deer Ridge	Clarkston	5.7	Outwash Plain	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	90
41	8470 Heritage	Clarkston	5.8	Outwash Plain	Coldwater Shale	Fox	Moderate	Fine Loamy	Well	90
42	6400 Chestnut Hill	Clarkston	6.1	Outwash Plain	Coldwater Shale	Fox	Moderate	Fine Loamy	Well	90
43	6557 Deer Ridge	Clarkston	9.6	Outwash Plain	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	90
44	33715 Cadillac	Farmington	1.4	Sandy Lakebed	Bedford Shale	Tedrow	Rapid	Sandy	Somewhat Poorly	30
45	34225 Conroy	Farmington	1.4	Sandy Lakebed	Bedford Shale	Spinks	Moderately Rapid	Sandy	Well	45

Test	Address	City	Rn level (pCi/l)	Surficial Geology	Bedrock Geology	Soil Series	Permeability	Soil Texture	Drainage	Overburden (meters)
46	22246 Ontaga	Farmington Hills	0.5	Sandy Lakebed	Bedford Shale	Tedrow	Rapid	Sandy	Somewhat Poorly	30
47	29243 Laurel	Farmington Hills	0.5	Moraine	Coldwater Shale	Thetford	Moderately Rapid	Sandy	Somewhat Poorly	75
48	30136 Kingsway	Farmington Hills	0.5	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
49	30298 Kingsway	Farmington Hills	0.5	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	30
50	29576 Fox Club	Farmington Hills	0.7	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
51	39118 Point	Farmington Hills	0.7	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
52	23319 Derby Lane	Farmington Hills	0.8	Sandy Lakebed	Berea Sandstone	Lenawee	Moderately Slow	Fine	Poorly	30
53	38313 Golf View	Farmington Hills	0.8	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
54	27430 Bridle Hills	Farmington Hills	0.9	Sandy Lakebed	Berea Sandstone	Lenawee	Moderately Slow	Fine	Poorly	30
55	29549 Eastfield	Farmington Hills	0.9	Clay Lakebed	Coldwater Shale	Lenawee	Moderately Slow	Fine	Poorly	60
56	31002 Pinecone	Farmington Hills	0.9	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
57	22135 Wingate	Farmington Hills	1.0	Sandy Lakebed	Antrim Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	45
58	27948 gettysburgh	Farmington Hills	1.0	Sandy Lakebed	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	75
59	28327 Wellington	Farmington Hills	1.1	Sandy Lakebed	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	45
60	37997 Glengrove	Farmington Hills	1.1	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
61	36801 Turtle Creek	Farmington Hills	1.3	Till Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
62	25511 Ranchwood	Farmington Hills	1.4	Moraine	Berea Sandstone	Glynwood	Slow	Fine	Moderately Well	60
63	30276 South Hampto	Farmington Hills	1.4	Sandy Lakebed	Bedford Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	45
64	222204 Buckingham	Farmington Hills	1.5	Moraine	Antrim Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	45
65	30820 Country Ridge	Farmington Hills	1.5	Moraine	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	75
66	30423 Aston Ct	Farmington Hills	1.7	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
67	30769 Mystic Forest	Farmington Hills	1.8	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
68	25221 Appleton	Farmington Hills	1.9	Sandy Lakebed	Sunbury Shale	Lenawee	Moderately Slow	Fine	Poorly	30
69	28253 Westerleigh	Farmington Hills	1.9	Moraine	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	60
70	30987 Hitching Post	Farmington Hills	1.9	Till Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
71	28654 Lorraine	Farmington Hills	2.0	Sandy Lakebed	Berea Sandstone	Lenawee	Moderately Slow	Fine	Poorly	30
72	30370 Tanglewood	Farmington Hills	2.1	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
73	29504 Shenandoah	Farmington Hills	2.2	Moraine	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	75
74	39243 Wilton	Farmington Hills	2.2	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
75	21987 Cresent	Farmington Hills	2.3	Sandy Lakebed	Antrim Shale	Spinks	Moderately Rapid	Sandy	Well	45
76	25231 Hopkins	Farmington Hills	2.5	Moraine	Berea Sandstone	Marlette	Moderately Slow	Fine Loamy	Moderately Well	45
77	363 Fredericksburg	Farmington Hills	2.8	Outwash Plain	Coldwater Shale	Sisson	Moderate	Fine Loamy	Well	75
78	28591 Marc	Farmington Hills	2.9	Sandy Lakebed	Berea Sandstone	Lenawee	Moderately Slow	Fine	Poorly	30
79	28641 Auburn	Farmington Hills	3.1	Moraine	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	75
80	32025 Alameda	Farmington Hills	3.4	Sandy Lakebed	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	45
81	22500 Clearlake	Farmington Hills	3.5	Moraine	Antrim Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	45
82	29215 Marvin	Farmington Hills	3.5	Till Plain	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	75
83	25523 Hunt Club	Farmington Hills	3.6	Moraine	Berea Sandstone	Glynwood	Slow	Fine	Moderately Well	60
84	38035 River Bend	Farmington Hills	3.7	Moraine	Antrim Shale	Spinks	Moderately Rapid	Sandy	Well	60
85	39123 Plumbrook	Farmington Hills	5.8	Moraine	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	75
86	3364 Heritage Farms	Highland	2.3	Outwash Plain	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	90
87	3832 Lido	Highland	2.9	Outwawsh Plain	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	90
88	2240 Sherlock Trail	Highland	6.5	Outwash Plain	Coldwater Shale	Thetford	Moderately Rapid	Sandy	Somewhat Poorly	90
89	1445 Thistleridge	Holly	1.2	Till Plain	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	75
90	8165 Hickory Rd	Holly	4.3	Outwash Plain	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	75

Test	Address	City	Rn level (pCi/l)	Surficial Geology	Bedrock Geology	Soil Series	Permeability	Soil Texture	Drainage	Overburden (meters)
91	26642 York	Huntington Woods	0.7	Waterlaid Moraine	Berea Sandstone	Spinks	Moderately Rapid	Sandy	Well	45
92	3194 Beach Tree	Lake Orion	1.4	Moraine	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	75
93	1455 Orion Rd	Lake Orion	12.4	Outwash Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
94	2744 Cedar Key	Lake Orion	14.0	Sandy Lakebed	Coldwater Shale	Ormas	Moderately Rapid	Loamy	Well	75
95	881 Sherry	Lake Orion	6.2	Outwash Plain	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	45
96	27325 Bloomfield	Lathrup Village	4.0	Waterlaid Moraine	Coldwater Shale	Lenawee	Moderately Slow	Fine	Poorly	30
97	435 First	Milford	8.5	Outwash Plain	coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
98	24778 Applecrest	Novi	0.5	Moraine	Berea Sandstone	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
99	41472 Chattman	Novi	0.9	Moraine	Berea Sandstone	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
100	24762 White Pines	Novi	1.1	Moraine	Bedford Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	90
101	23666 Hickory	Novi	1.5	Moraine	Berea Sandstone	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
102	22924 Talford	Novi	1.6	Moraine	Bedford Shale	Blount	Moderately Slow	Fine	Somewhat Poorly	75
103	45391 White Pines	Novi	1.6	Moraine	Bedford Shale	Capac	Moderately Slow	Fine Loamy	Moderately Well	90
104	47295 Bramblewood	Novi	1.9	Till Plain	Bedford Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
105	31155 Seneca Ct	Novi	2.4	Moraine	Coldwater Shale	Malette	Moderately Slow	Fine Loamy	Moderately Well	90
106	44486 Midway	Novi	2.7	Moraine	Bedford Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
107	25230 Buckminster	Novi	2.9	Moraine	Berea Sandstone	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
108	40450 Ladene	Nove	3.3	Moraine	Bedford Shale	Blount	Moderately Slow	Fine	Somewhat Poorly	75
109	24742 Bashian	Nove	7.9	Outwash Plain	Berea Sandstone	Boyer	Moderately Rapid	Coarse Loamy	Well	75
110	21861 Cloverlawn	Oak Park	1.6	Waterlaid Moraine	Sunbury Shale	Lenawee	Moderately Slow	Fine	Poorly	30
111	21680 Sussex	Oak Park	2.0	Waterlaid Moraine	Sunbury Shale	Lenawee	Moderately Slow	Fine	Poorly	30
112	14410 Pearson	Oak Park	2.3	Waterlaid Moraine	Sunbury Shale	Lenawee	Moderately Slow	Fine	Poorly	30
113	21000 Kipling	Oak Park	3.7	Waterlaid Moraine	Berea Sandstone	Lenawee	Moderately Slow	Fine	Poorly	30
114	4920 Elmgate	Orchard Lake	1.3	Moraine	coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	90
115	131 Chippewa	Pontiac	1.8	Outwash Plain	coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	90
116	193 Mohawk	Pontiac	2.1	Till Plain	Coldwater shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
117	1854 Allenway	Rochester	0.7	Sandy Lakebed	Coldwater shale	Thetford	Moderately Rapid	Sandy	Somewhat Poorly	45
118	2842 Sandhurst	Rochester	1.0	Sandy Lakebed	Coldwater Shale	Matherton	Moderate	Fine Loamy	Somewhat Poorly	45
119	5100 Old Mill	Rochester	2.4	Moraine	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	45
120	5825 Cobb Creek	Rochester	5.8	Moraine	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	45
121	428 Lake Forest	Rochester Hills	0.5	Moraine	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	45
122	1523 Pembrooke	Rochester Hills	0.6	Waterlaid Moraine	Coldwater Shale	Metamora	Moderately Rapid	Fine Loamy	Somewhat Poorly	60
123	3223 Edmunton	Rochester Hills	0.6	Moraine	Coldwater Shale	Sloan	Moderately slow	Fine Loamy	Very Poorly	60
124	678 Baker	Rochester Hills	0.6	Moraine	Coldwater Shale	Fox	Moderate	Fine Loamy	Well	45
125	1547 Cherry Circuit	Rochester Hills	0.8	Moraine	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	30
126	3730 New Castle	Rochester Hills	0.9	Moraine	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	60
127	572 Bolinger	Rochester Hills	0.9	Moraine	Coldwater Shale	Sloan	Moderately slow	Fine Loamy	Well	45
128	3196 Salem	Rochester Hills	1.1	Moraine	Coldwater Shale	Sloan	Moderately slow	Fine Loamy	Very Poorly	60
129	3572 Charlwood	Rochester Hills	1.1	Moraine	Coldwater Shale	Sloan	Moderately slow	Fine Loamy	Very Poorly	60
130	1700 Grandview	Rochester Hills	1.6	Moraine	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	45
131	1721 Old Homestead	Rochester Hills	1.7	Moraine	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	60
132	3614 Charlwood	Rochester Hills	1.9	Moraine	Coldwater Shale	Sloan	Moderately slow	Fine Loamy	Very Poorly	60
133	2825 Steamboat	Rochester Hills	10.3	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
134	733 Timberline	Rochester Hills	2.1	Moraine	Coldwater Shale	Riddles	Moderate	Fine Loamy	Well	60
135	829 Longford	Rochester Hills	2.2	Moraine	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	45

Test	Address	City	Rn level (pCi/l)	Surficial Geology	Bedrock Geology	Soil Series	Permeability	Soil Texture	Drainage	Overburden (meters)
136	2799 Winter Park	Rochester Hills	2.4	Moraine	Coldwater Shale	Riddles	Moderate	Fine Loamy	Well	60
137	1704 Grandview	Rochester Hills	2.5	Moraine	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	60
138	3034 Quail Ridge	Rochester Hills	2.6	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
139	1600 Arbor Creek	Rochester Hills	2.7	Moraine	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	60
140	1601 Arbor Creek	Rochester Hills	3.1	Moraine	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	60
141	539 Middlebury	Rochester Hills	3.1	Moraine	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	60
142	1773 N. Fairview	Rochester Hills	3.4	Moraine	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	45
143	1544 Grandview	Rochester Hills	4.0	Moraine	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	45
144	3254 Quail Ridge	Rochester Hills	4.7	Moraine	Coldwater Shale	Fox	Moderate	Fine Loamy	Well	45
145	455 Ivywood Ct	Rochester Hills	7.3	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	45
146	2310 Dutton	Rochester Hills	8.0	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
147	818 E. Second	Royal Oak	1.0	Waterlaid Moraine	Bedford Shale	Thetford	Moderately Rapid	Sandy	Somewhat Poorly	60
148	3709 Elmhurst	Royal Oak	1.9	Sandy Lakebed	Coldwater Shale	Lenawee	Moderately Slow	Fine	Poorly	60
149	9648 Daleview	South Lyon	2.2	Till Plain	Bedford Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
150	9788 Dickerson St.	South Lyon	9.1	Moraine	Bedford Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
151	21115 Glenmorra	Southfield	0.4	Waterlaid Moraine	Coldwater Shale	Lenawee	Moderately Slow	Fine	Poorly	30
152	17282 New Jersey	Southfield	0.9	Waterlaid Moraine	Coldwater Shale	Lenawee	Moderately Slow	Fine	Poorly	30
153	27980 Pebblebrooke	Southfield	2.4	Sandy Lakebed	Coldwater Shale	Lenawee	Moderately Slow	Fine	Poorly	30
154	17321 Avilla	Southfield	3.0	Waterlaid Moraine	Coldwater Shale	Lenawee	Moderately Slow	Fine	Poorly	30
155	6704 Granger	Troy	0.8	Clay Lakebed	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	45
156	330 Tara	Troy	0.9	Clay Lakebed	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	45
157	2767 Windsor	Troy	1.0	Clay Lakebed	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	45
158	6872 Houghton	Troy	1.2	Clay Lakebed	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	60
159	4107 Gatesford	Troy	1.4	Clay Lakebed	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	45
160	5279 Collington	Troy	1.4	Till Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
161	2026 Atlas	Troy	1.5	Clay Lakebed	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	60
162	7401 Thurber	Troy	1.5	Clay Lakebed	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	60
163	2657 Valley View	Troy	1.7	Till Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
164	5280 Breeze Hill	Troy	2.1	Moraine	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	60
165	3107 Newport Ct.	Troy	2.2	Waterlaid Moraine	Coldwater Shale	Lenawee	Moderately Slow	Fine	Poorly	45
166	3645 Upton	Troy	2.5	Waterlaid Moraine	Coldwater Shale	Lenawee	Moderately Slow	Fine	Poorly	45
167	3645 Estates	Troy	2.7	Waterlaid Moraine	Coldwater Shale	Lenawee	Moderately Slow	Fine	Poorly	60
168	2360 Waltham	Troy	3.2	Sandy Lakebed	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	60
169	2352 Lk Charnwood	Troy	3.7	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
170	6578 Merrick	Troy	5.7	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	45
171	1878 Sutton Plkace	Troy	7.9	Waterlaid Moraine	Coldwater Shale	Boyer	Moderately Rapid	Coarse Loamy	Well	60
172	204 Melinda	Union Lake	1.1	Moraine	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	90
173	8911 Sussex	Union Lake	2.3	Outwash Plain	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	90
174	5535 Tuscola	Union Lake	2.7	Outwash Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
175	7774 Pontiac Lake	Union Lake	3.1	Outwash Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
176	2052 Pauls Way	Walled Lake	10.3	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
177	10233 Meadowlark	Waterford	3.8	Outwash Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
178	5991 Coppersmith	Waterford	4.2	Outwash Plain	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	90
179	3060 Wanamaker	Waterford	5.7	Till Plain	Coldwater Shale	Fox	Moderate	Fine Loamy	Well	90
180	5439 Deerfield	West Bloomfield	0.4	Till Plain	Coldwater Shale	Capac	Moderately Slow	Fine Loamy	Somewhat Poorly	75

Test	Address	City	Rn level	Surficial	Bedrock	Soil	Permeability	Soil		Overburden
			(pCi/l)	Geology	Geology	Series		Texture		(meters)
181	5671 Hobnail	West Bloomfield	0.9	Till Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Somewhat Poorly	90
182	4260 Claire	West Bloomfield	1.0	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
183	5803 Redcoat	West Bloomfield	1.0	Till Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
184	6111 Cochise	West Bloomfield	1.2	Till Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
185	2030 Elsie	West Bloomfield	1.5	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
186	2915 Bloomfield Pk	West Bloomfield	1.7	Moraine	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	75
187	3668 Oak Leaf	West Bloomfield	1.7	Outwash Plain	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	90
188	6118 Dunmore	West Bloomfield	1.7	Till Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
189	1752 Dawncrest	West Bloomfield	1.8	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
190	6832 Heatherwood	West Bloomfield	15.3	Outwash Plain	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	90
191	6930 Drake	West Bloomfield	2.3	Till Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
192	2146 Deering	West Bloomfield	2.6	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
193	5566 Swan Lake	West Bloomfield	2.7	Till Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
194	5254 Water View	West Bloomfield	3.4	Till Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	60
195	7140 Green Farm	West Bloomfield	3.6	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
196	4423 Apple Valley	West Bloomfield	3.8	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
197	7088 Green Farm	West Bloomfield	4.5	Moraine	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	75
198	4145 Echo	West Bloomfield	4.8	Outwash Plain	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	90
199	2870 Warner	West Bloomfield	7.7	Outwash Plain	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	90
200	291 Hillwood	White Lake	3.8	Outwash Plain	Coldwater Shale	Marlette	Moderately Slow	Fine Loamy	Moderately Well	90
201	741 Sibley	Wixom	9.4	Outwash Plain	Coldwater Shale	Spinks	Moderately Rapid	Sandy	Well	75

VITA 2

Robert Scott Rought

Candidate for the Degree of

Master of Science

Thesis: RADON HAZARDS ASSOCIATED WITH GLACIAL DEPOSITS IN OAKLAND COUNTY, MICHIGAN

Major Field: Environmental Science

Biographical:

Personal Data: Born in Lansing, Michigan, April 24, 1968, the son of Robert F. and V. Ann Rought.

Education: Graduated from Gaylord High School, Gaylord, Michigan, in June 1986; received Bachelor of Science Degree in Resource Development from Michigan State University in March, 1991; completed requirements for the Master of Science Degree at Oklahoma State University in May, 1994.

Professional Experience: Radon Field Specialist, Radon Detection Systems, Boulder, Colorado, Michigan Office, January, 1990, to present. Research Assistant, Department of Economics, Oklahoma State University, August, 1991, to May, 1992. Teaching Assistant, Department of Resource Development, Michigan State University, January, 1990, to March, 1991.