

AD-A172 720

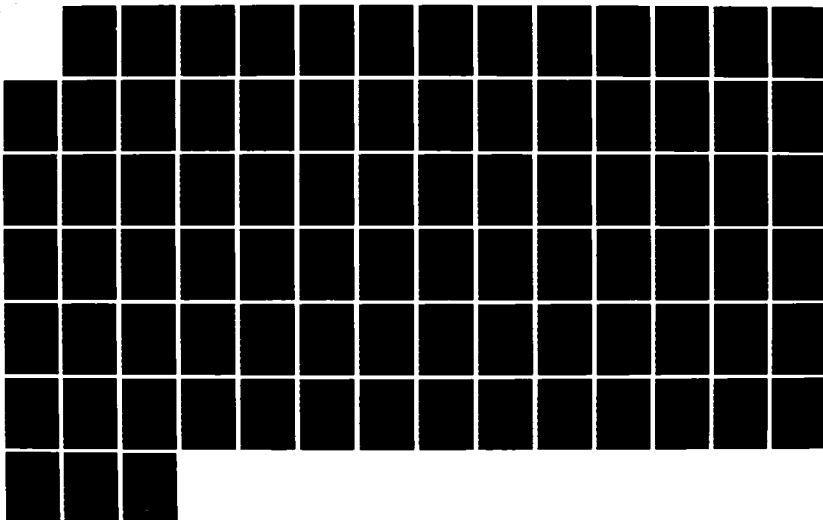
REDUCTION OF RDDON PROGENY IN INDOOR AIR(U) AIR FORCE
INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF
ENGINEERING J A WEIDNER MAR 86 AFIT/GNE/EMP/86M-13

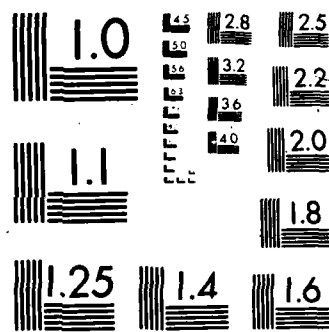
1/1

UNCLASSIFIED

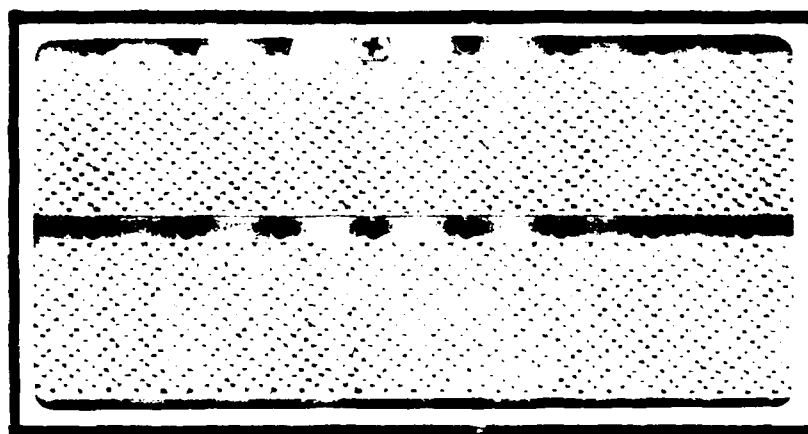
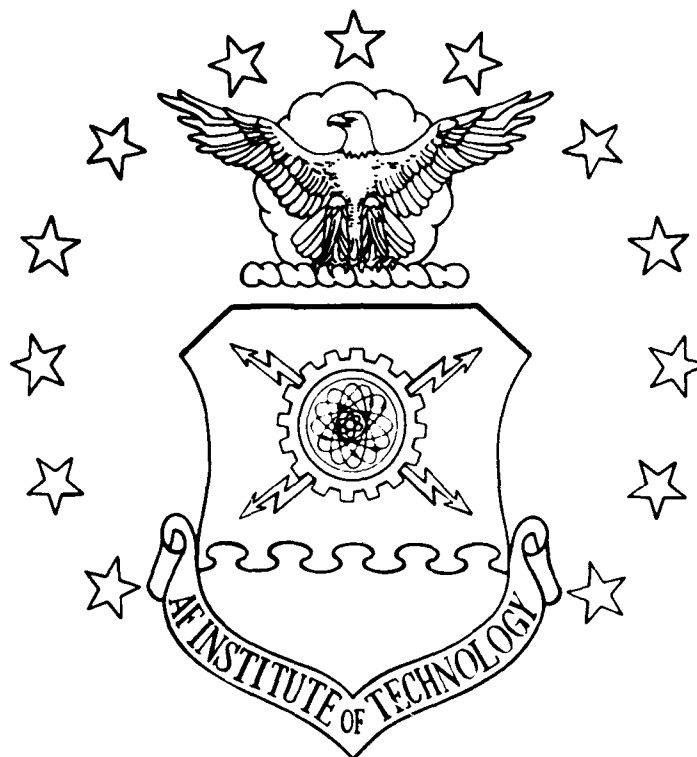
F/G 8/4

NL





AD-A172 720



DISTRIBUTION STATEMENT A

Approved for public release
Distribution Unlimited

DTIC
ELECTE
OCT 15 1986

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

DTIC FILE COPY

AFIT/GNE/ENP/86M-13

REDUCTION OF RADON PROGENY
IN INDOOR AIR

THESIS

John A. Weidner
Lieutenant, USN

AFIT/GNE/ENP/86M-13

DTIC
OCT 15 1986

B

Approved for public release; distribution unlimited

AFIT/GNE/ENP/86M-13

REDUCTION OF RADON PROGENY IN INDOOR AIR

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University

In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Nuclear Engineering

John A. Weidner, B.S.S.E.

Lieutenant, USN

March 1986

Approved for public release; distribution unlimited

Preface

The purpose of this thesis was to characterize the effectiveness of three different air cleaning appliances in reducing the concentrations of radon decay products that occur in indoor air. This thesis builds on work that was begun over a year ago by Dr. George John and Captain David Little to provide an experimental facility at AFIT for use in studying the behavior of radon and radon progeny in indoor air. During that very short period, discussions concerning the potential health hazard of exposure to radon and its progeny have left the realm of the scientific journal and are now a matter of public and media concern. It is always nice to be on the "inside" of something "new."

I would like to acknowledge the help I received from several people, especially my advisor, Dr. George John. His guidance and steady pressure could be felt from half a country away. Major John Prince was helpful as "stand in advisor," and Dr. Richard Hagee of Monsanto Mound Laboratory provided me with a calibration capability and several ideas and boosts of encouragement that were indispensable. Bob Hendricks receives thanks for providing a laboratory atmosphere that was friendly but effective, and the absolutely spectacular support provided by Jack Tiffany and the entire crew at the AFIT Fabrication Shop cannot be

repaid with normal gratitude. To all of the above, much thanks. I would also like to thank Diane, for being there and doing so well in the toughest job in the Navy.

— John A. Weidner

Approved	✓
By	
Date	
Signature	
DI	
A-1	



Table of Contents

	Page
Preface	ii
List of Figures	vi
List of Tables	vii
Abstract	ix
I. Introduction	1
Purpose	1
Background	1
Radon in Indoor Air	2
Ventilation Rates	4
Health Risk from Radon Progeny	4
Working Level	5
Equilibrium Factor	6
Exposure	6
Dosimetric Approach	7
Epidemiological Approach	8
Radon Progeny Reduction Schemes	9
Electrostatic Precipitation	10
Enhanced Convection	10
Unipolar Space Charging	11
Scope of Thesis	11
General Approach	12
Sequence of Report	12
II. Description of Test Equipment and Methods	13
Radon Test Chamber	13
Physical Description	13
Radon Gas Production	14

	Page
Radon Progeny Reduction Equipment	15
Forced Ventilation	15
Permanently-Installed Electrostatic Precipitator	17
Portable Electrostatic Precipitator	17
Ionization Air Cleaner	18
Radon Gas Measurement	18
Lucas Cell Counting	18
Grab Sampling and the Integrated Count Method	19
Continuous Monitoring	20
Radon Progeny Measurement	24
Modified Tsivoglou Method	24
Sampling and Counting Procedures	25
Sources of Uncertainty	26
III. Conducting Tests in the Radon Test Chamber	28
Desired Approach	28
Constant Parameters and Initial Conditions	28
Steady-State Conditions	30
Effect of Humidity on Equilibrium Factor	32
IV. Results	35
General Test Results	35
Approach Adopted in Effectiveness Evaluations	37
Relative Effectiveness of Air Treatment Methods	39
V. Conclusions and Recommendations	43
Conclusions	43
Recommendations	44
Appendix A: Computer Program Listings	46
Appendix B: Tabulated Data and Results of Individual Radon Progeny Reduction Tests	51
Appendix C: Commercial Names of the Air Cleaning Appliances	67
Bibliography	68
Vita	70

List of Figures

Figure	Page
1. Continuous Monitor Calibration Curve, 4 l/min Sampling Flow	22
2. Continuous Monitor Calibration Curve, 8 l/min Sampling Flow	23
3. Results of Sampling During Steady State Conditions in the Radon Test Chamber	31
4. Effect of Changes in Humidity on Equilibrium Factor	34
5. Effect of Changing Radon Concentration on Working Level Reduction Evaluation	38

List of Tables

Table	Page
I. Principal Decay Properties of 222-Radon and Immediate Descendants	3
II. Test Chamber Ventilation System Air Flows by Air Cleaner Type and Damper Position	16
III. Results of Radon Progeny Reduction Testing . . .	36
IV. Data and Results for Test #1, Radon Progeny Reduction by Forced Ventilation	52
V. Data and Results from Test #2, Radon Progeny Reduction by Forced Ventilation	53
VI. Data and Results from Test #3, Radon Progeny Reduction by Forced Ventilation	54
VII. Data and Results from Test #4, Radon Progeny Reduction by Forced Ventilation	55
VIII. Data and Results from Test #5, Radon Progeny Reduction by Forced Ventilation	56
IX. Data and Results from Test #6, Radon Progeny Reduction by Permanently-Installed Electrostatic Precipitator	57
X. Data and Results from Test #7, Radon Progeny Reduction by Permanently-Installed Electrostatic Precipitator	58
XI. Data and Results from Test #8, Radon Progeny Reduction by Permanently-Installed Electrostatic Precipitator	59
XII. Data and Results from Test #9, Radon Progeny Reduction by Permanently-Installed Electrostatic Precipitator	60
XIII. Data and Results from Test #10, Radon Progeny Reduction by Portable Electrostatic Precipitator	61

Table		Page
XIV.	Data and Results from Test #11, Radon Progeny Reduction by Portable Electrostatic Precipitator	62
XV.	Data and Results from Test #12, Radon Progeny Reduction by Ionization Air Cleaner	63
XVI.	Data and Results from Test #13, Radon Progeny Reduction by Ionization Air Cleaner and Radon Progeny Reduction by Ionization Air Cleaner with Forced Ventilation	64
XVII.	Data and Results from Test #14, Radon Progeny Reduction by Forced Ventilation and Ionization Air Cleaner	66

Abstract

The effectiveness of using three different types of air treatment methods to reduce the concentrations of radon progeny in a residence was evaluated. The air treatment devices were two types of electrostatic precipitators that were designed for use with a whole house heating and cooling system and an ionization air cleaner that was designed for table-top use in a single room.

The air treatment devices were tested in a 100 cubic meter chamber at typical radon gas concentrations of 12.5 to 20.5 picocuries per liter. The modified Tsivoglou method was used to determine radon progeny concentrations and a continuous monitor for radon concentration was in operation, allowing calculation of the equilibrium factor under non-constant radon conditions.

Reduction in average working level measurements and reduction in equilibrium factor were used to evaluate the effectiveness of the air treatments. Radon progeny reductions of greater than 50 percent were observed for all three devices tested at air treatment rates that were comparable to those that would be used in a residence.

REDUCTION OF RADON PROGENY IN INDOOR AIR

I. Introduction

Purpose

The purpose of this thesis was to characterize the effectiveness of three different types of air cleaners in reducing radon progeny concentrations in indoor air.

Background

Exposure to high levels of the radioactive gas radon and the radioactive nuclides produced by the decay of radon has been linked to an increased incidence of lung cancer in miners and may account for as many as tens of thousands of cancers each year among the general population of the United States (15:277). These cancers are a result of the damage caused by ionizing radiation deposited in body tissue by the alpha-particle-emitting radon-progeny nuclides that are present in all types of air inhaled by humans. The background material presented here deals with the sources of radon and radon progeny in indoor air, the health risks presented by radon progeny exposure, and the methods that can be used to lower radon progeny concentrations in homes.

Radon in Indoor Air. Radon-222 occurs midway through the Uranium-238 decay series, which is the longest and most abundant decay series in nature. It was called radium emanation by its discoverer and its decay products are still referred to as Ra-A, Ra-B, Ra-C, and Ra-C'. The decay products of radon and its immediate descendants (radon progeny) are listed in Table I (16:75). The remainder of the decay chain, consisting of decay products formed after the decay of Ra-C', has been ignored because the first decay product, Lead-210, has a half-life of 22.3 years (19:43) and can be treated as a stable nuclide since radon progeny exposure times are short compared to this half-life. Also listed in Table I are the historic names of these nuclides. A minor branch to Astatine-218 is not included in the listing.

The historic name of radium emanation is indeed an appropriate one, for it describes an important aspect of this radionuclide. While most radionuclides are formed as metals and remain at the site of their formation, radon is a noble gas and is thus able to diffuse away from its formation site. It is through this process that radium bearing rock and soil, present virtually everywhere, act as the sources of the radon and radon progeny present throughout the free atmosphere. Radon inside buildings can reach much higher levels than are found in outdoor air. This is due partly to the fact that radon in buildings occurs not

TABLE I
PRINCIPAL DECAY PROPERTIES OF 222-RADON AND IMMEDIATE DESCENDANTS

Nuclide	Historic Name	Half-life	Main Radiation Energies					
			α		β		γ	
			Mev	%	Mev	%	Mev	%
222 Rn	Radium Emanation	3.824 d	5.49	100	-	-	-	-
218 Po	Radium A	3.05 min	6.00	100	-	-	-	-
214 Pb	Radium B	26.8 min	-	-	0.67	48	0.30	19
					0.73	42	0.35	37
214 Bi	Radium C	19.7 min	-	-	<1.5	32	0.61	46
					1.5-2.5	49	1.12	15
					3.27	18	1.76	16
214 Po	Radium C'	163.7 μ s	7.69	100	-	-	-	-

only from radon entering with outside air but also from other sources. These sources include construction materials with excessive radium content, soil and rock underneath the building, and utilities such as water and natural gas supplies that service the building. Once radon enters, the building acts as a container for this radon, which leaks out as indoor air is exchanged for outdoor air. Air exchange rate is thus an important factor in the radon concentrating process.

Ventilation Rates. Typical air exchange rates for U.S. homes, expressed in house volumes exchanged per hour, for seasons when windows and doors are normally closed, are in the range of 0.5 to 1.5 per hour (15:278). Indoor radon concentrations are roughly inversely proportional to the air exchange rate, but this does not always hold, especially if the radon sources mentioned above are of a larger than average magnitude.

Indoor radon concentrations for homes in the United States typically range from 0.2 to 4 pCi/l, when averaged over the year. Considerably higher concentrations have been found in U.S. homes, usually because of natural concentrations of radium in the soil or rock upon which the house is built (15:278).

Health Risk from Radon Progeny. The health risk to building occupants that arises from indoor radon is due

to inhalation of the short-lived radon daughters Ra-A, Ra-B, and Ra-C. These decay products are formed from the alpha decay of gaseous radon, with approximately 80 percent of the first decay product, Ra-A, being positively charged (3:533). As a result of neutralization processes such as recombination with negative air ions and charge transfer with air impurities, a large portion of the daughter atoms are neutral when they attach to aerosols (18:482). These decay products condense on all surfaces of airborne particles and droplets in the atmosphere. Because of this, the behavior of radon progeny in the atmosphere, including deposition on surfaces and in the lung once inhaled, is determined to a large extent by the activity-size distribution of the aerosol. Some dosimetric models also require a knowledge of the magnitude of the portion of the radon progeny that is attached and that which is unattached. When knowledge of activity-size distributions and unattached fractions is lacking, the more general concept of total potential alpha energy must be used in order to determine health risks from radon progeny exposure. This latter quantity is termed working level.

Working Level. Since the most significant dose from inhaled radon progeny results from alphas emitted when polonium isotopes decay, radon progeny concentrations are often expressed in terms of potential alpha energy concentrations (PAEC). The unit for potential alpha energy

concentration is the working level (WL), which is defined as the liberation of 130,000 MeV/l by alpha particle decay. This is the PAEC if approximately 100 pCi/l of Rn-222 were present with equilibrium amounts of its progeny. Working level for this thesis has been calculated using an expression given by Busigin (3:948):

$$WL = 0.00103 C_2 + 0.00507 C_3 + 0.00373 C_4$$

where

C_2 = concentration of Ra-A, in pCi/l

C_3 = concentration of Ra-B, in pCi/l

C_4 = concentration of Ra-C, in pCi/l

Equilibrium Factor. An equilibrium factor (F) is often defined as the ratio of the actual PAEC to the PAEC that would be associated with the actual radon concentration if the daughters were in equilibrium with this radon. A ratio of one will occur only if there are no removal mechanisms such as air exchange rate or room surface plateout. One German study concluded that expected values of F for homes should range from 0.3 for "clean" air up to 0.8 for "smokey" air and that F is influenced considerably by different aerosol concentrations (19:486).

Exposure. Exposure to radon progeny is commonly measured in terms of Working Level Month (WLM), which is simply equal to an integral exposure of 100 pCi/l

of Ra-A, Ra-B, and Ra-C for a working month (170 hours). The WLM was originally defined to describe occupational exposures, particularly to miners, but it has gained widespread use as a unit of exposure for indoor radon irradiation. This definition of exposure is somewhat lacking in that it does not take into account the problem of disequilibrium of radon progeny and whether the progeny is attached or unattached to carrier aerosols. Attached radon progeny deposit with only a few percent probability upon respiratory surfaces, whereas unattached progeny deposit with nearly 100 percent probability (5:650). The mix of unattached and attached radon progeny is an important consideration in assessing lung dosimetry. It has been shown, however, that for most indoor exposure situations, the unattached fraction remains fairly constant over a wide range of conditions (8:138). So, for a first approximation of health risk, effective dose equivalent or a risk coefficient can be found from a measurement of total airborne alpha energy exposure. The two lines of approach that can be followed to make this approximation are the dosimetric approach and the epidemiological approach.

Dosimetric Approach. The dosimetric approach involves the use of theoretical and experimental information to estimate the amounts of radon decay products that are deposited in a geometric model of the respiratory tract. The fraction of the potential alpha energy carried

by unattached atoms, the size distribution of the radioactive aerosol and the breathing rate of the subject are the primary influences on deposition in the respiratory tract. The most important tissue is the basal cells of the bronchial epithelium, followed by the alveolar tissues (20:135). The absorbed dose to these tissues is multiplied by a quality factor of 20 for alpha particles to yield a regional dose equivalent, and finally, a lung weighting factor is applied to the bronchial and alveolar dose equivalents to obtain effective dose equivalent.

For a fixed average breathing rate of 12.5 l/min for an adult at home, O'Riordan and others report that the dosimetric approach yields an average conversion factor that ranges from 4 to 11 mSv per WLM (16:79). James concluded that the best estimate of the conversion coefficient, obtained by the dosimetric approach, is 5 mSv per WLM (9:365). Jacobi and Eisfeld give an effective dose equivalent of 10 mSv per WLM for a mean breathing rate of 20 l/min, based on a comparative analysis of both the dosimetric and epidemiological approaches (8:142).

Epidemiological Approach. The epidemiological approach involves estimating the risk coefficients for indoor irradiation in terms of WLM and then translating that into an effective dose equivalent. Epidemiological data derived from many types of underground mining show a relatively constant relationship between lung cancer

incidence and exposure to radon progeny. The risk of lung cancer attributable to radon progeny is difficult to assess through human epidemiological studies because detailed information is not always available. However, even with limited data, a mean risk factor can be estimated. The adopted average yearly risk coefficient obtained for all exposure categories and all age groups is 10^{-5} lung cancers per year per WLM (5:656).

Radon Progeny Reduction Schemes. There are essentially two ways that radon progeny exposures from indoor air can be controlled. One way is to prevent indoor radon, the source of indoor radon progeny, from reaching unacceptable concentration levels. Methods for achieving this type of control include preventing radon from entering the building by sealing cracks in the basement, by ventilating crawl spaces, and by using construction materials that have low radon exhalation rates. Also included in this first type of control are methods that do not allow radon to concentrate once it enters, such as increasing ventilation with outside air.

The other way to control radon progeny exposures is to remove radon progeny from the indoor airspace by various air treatments. Removal of radon progeny by air treatment has advantages over the source control method in that air cleaning techniques employing solid particle removal are available commercially and at low cost with the

added benefit of removal of other particulate air pollutants. Some techniques that are available include electrostatic precipitation, enhanced convection, and unipolar space charging (14:1182). The principals involved and results obtained by previous investigators for each technique are presented below.

Electrostatic Precipitation. The method of electrostatic precipitation requires a high voltage to be applied across ionizing wires and collector plates and a blower to carry untreated air through the system. The air first passes near a positively charged ionizing wire, causing particles in the air to become positively charged. These particles are then attracted to nearby collector plates and remain attached until they are removed by cleaning.

An electrostatic precipitator that is available commercially for use in a home air conditioning system was tested by Hinds and others (7:135). Air inside a 70-cubic-meter chamber was treated at a rate of 5.0 ACH through the electrostatic precipitator, resulting in a working level reduction of approximately 75 percent when the infiltration air change rate was 0.52/hr.

Enhanced Convection. Use of air-moving devices such as ceiling fans cause radon progeny reduction in a room airspace by circulating air without increasing

ventilation from outside. Experience shows that increased air turbulence increases the plateout of airborne radio-nuclides on airspace boundary surfaces (14:1183). Working level reductions of up to 75 percent by use of a ceiling fan have been observed (17:467).

Unipolar Space Charging. The mechanism for removal of radon progeny by use of a unipolar ion generator is not well understood but has been shown to be effective under certain conditions. The strong unipolar point source creates an ion concentration that decreases radially out from the source, resulting in an electric field gradient that is also directed radially from the source. Radon progeny atoms and aerosols to which they can attach become charged by diffusion charging and then migrate along the electric field gradient toward surfaces upon which they deposit (14:1186).

A working level reduction as high as 85 percent has been achieved with a negative ion generator and a fan operated together, but this was in a small, unventilated radon box and the author reported that his results were not sufficient to suggest a practical application for this type of treatment (1:259).

Scope of Thesis

The effectiveness of two different kinds of electrostatic precipitators and an ionization air cleaner in

reducing radon progeny concentration in an enhanced radon environment is evaluated. Sampling according to the modified Tsivoglou method is used to determine working level before and during periods of air treatment. When radon gas concentration is known, changes in equilibrium factor are also evaluated.

General Approach

The approach toward accomplishing this project included: (1) refining methods for the measurement of radon and radon progeny concentrations, (2) determining how the experimental chamber used for testing behaved during steady-state conditions, (3) collecting radon progeny samples during various conditions of air cleaning, and (4) analyzing test results and establishing the effectiveness of the air treatment methods tested.

Sequence of Report

Chapter II contains descriptions of the test equipment used, including the methods for radon gas and radon progeny concentration measurement. Chapter III contains information concerning the testing methods used and includes information about the steady state behavior of the test chamber that was used. Chapter IV contains a review of the data obtained during testing and the test results. Chapter V contains the conclusions drawn from the results of testing and lists recommendations for improvements and further studies.

II. Description of Test Equipment and Methods

Radon Test Chamber

The test chamber used for this study was set up by Little in the initial studies of reduction of radon progeny. His thesis includes detailed descriptions of the test chamber and radon gas generator (12). The paragraphs below contain abbreviated descriptions of the test chamber and radon gas generator.

Physical Description. The radon test chamber is a 100-cubic-meter room with painted cinder block walls and a painted concrete floor that has been fitted with equipment to produce an enhanced radon gas environment within the room. The radon test chamber is located in a building that supported a nuclear reactor. The room was previously used as a personnel changing and service area when reactor operations were conducted in the building. The room is 4 meters high and is equipped with a 15-centimeter diameter exhaust duct located approximately 2.4 meters above the floor. The air exhaust rate from the room can be varied by using an exhaust fan and damper that are installed in the duct. All major air intakes into the room are sealed and makeup air enters the chamber through cracks in the walls and from around door seals.

An air exchange rate for the room can be calculated by measuring air flow in the duct between the chamber wall and exhaust fan and then dividing by room volume. These measurements were made with an air velocity meter (Anemotherm Model 60) and a range of air exchange rates from 0.1 to 1.7 air changes per hour (ACH) was determined for the corresponding range of exhaust damper positions.

Radon Gas Production. The radon gas concentration in the test chamber was enhanced by use of a radon gas generator and a distribution manifold. The radon gas generator is a series of three water filled flasks that serve as humidifiers, a liquid source flask, and two glass fiber filled flasks that serve as filters. The liquid source flask consists of a 100 microcurie source of Ra-226 in a one-molar nitric acid solution. Air at approximately 2 psig pressure bubbles through the radium source, resulting in radon-rich air that is directed to the distribution manifold.

The distribution manifold is constructed of 3.71 centimeter outer-diameter poly-vinyl chloride piping arranged on the floor of the chamber. The manifold is elevated off the floor by 1.27 centimeter wood spacers and has 0.8 mm holes drilled in the underside of the piping at approximately 60 centimeter intervals. The radon-rich air is mixed with dilution air as it enters the manifold. This arrangement of radon-rich air entering the chamber from a

distribution manifold on the floor simulates radon seeping into the room air from underground sources.

Typical flow rates of 0.7 liters per minute through the radium source and 3.3 liters per minute of dilution air resulted in radon concentrations ranging from 12.5 to 20.5 picocuries per liter.

Radon Progeny Reduction Equipment

The radon test chamber is equipped with devices for use in lowering the radon progeny concentration within the chamber volume. The major equipment assembly is a forced ventilation blower and housing into which electronic air cleaners can be installed. An ionization air cleaner and a small mixing fan were also installed in the chamber. This equipment is described below. Appendix C identifies the air cleaning appliances by their commercial names.

Forced Ventilation. The forced ventilation system consists of housings for the electronic air cleaners, an intake duct with an installed humidifier, an air flow control damper, a high speed, high volume blower, and an exhaust duct. Air is circulated through the system by the blower and is returned to the upper portions of the chamber by the exhaust duct.

Air flow through the forced ventilation system was determined for three different damper positions by measuring the average air velocity across the intake face of the

installed air cleaner and then multiplying by the effective intake surface area. Intake face surface areas of 2942 square centimeters for the permanently installed electrostatic precipitator and 2475 square centimeters for the portable electrostatic precipitator were used. A room volume of 100 cubic meters was then used to calculate air throughput in air changes per hour for each air treatment device. The results of these calculations are summarized in Table II.

TABLE II
TEST CHAMBER VENTILATION SYSTEM AIR FLOWS
BY AIR CLEANER TYPE AND DAMPER POSITION

Damper Position	Permanent ESP		Portable ESP	
	System Air Flow (l/min)	Air Throughput (ACH)	System Air Flow (l/min)	Air Throughput (ACH)
2	33,000	20	27,000	16
4	17,000	10	13,000	10
6	4,200	2.5	2,400	1.5

The values for air throughput for the permanently-installed electrostatic precipitator were used when radon progeny reduction by forced ventilation alone was evaluated because the 1/4 inch metal pre-filter screens for this air cleaner remained installed in the system. All other internal elements of the electrostatic precipitator were removed for this type of testing.

Permanently-Installed Electrostatic Precipitator.

The permanently-installed electrostatic precipitator consists of a sheet metal housing that contains a metal mesh pre-filter, collection elements, and associated controls and circuitry. The collection elements are a block of parallel plates to which a high voltage is applied, resulting in an intense electric field for collection of particles from the air that flows across them. This unit is designed for permanent installation in the heating/cooling system of a home and would normally be installed by a contractor. The cost of this particular unit was approximately \$700, not including installation.

Portable Electrostatic Precipitator. The portable electronic air cleaner is designed for installation in a whole house air conditioning or heating system in place of the usual furnace filter. It resembles a metal screen filter with a power cord attached. Electric power for the unit is obtained through a plug-in type converter. The cost of this particular unit was approximately \$250, and there were no installation costs. A separate filter holder was manufactured for this air cleaner and was placed flush with the intake face of the permanent electrostatic precipitator during testing. All internal elements of the permanent electrostatic precipitator were removed during these tests.

Ionization Air Cleaner. The ionization air cleaner is a small appliance that is designed for use in the home. The manufacturer recommends placing the device on a desk or a table at least two feet from a wall. The manufacturer states that the ion output of the device is 15.5×10^{-6} ions/sec/cm² at 1 meter for a coverage of 250 square feet. This produces a natural ionization level of 24,000 ions/ml in a normal room. Power consumption is less than 2 watts and the appliance cost was approximately \$100.

Radon Gas Measurement

Lucas Cell Counting. Radon gas concentration in the test chamber was determined by the methods of grab sampling and continuous monitoring. Both methods are based upon alpha counting of air samples collected in Lucas cells (13). These Lucas cells are locally manufactured cylinders of approximately 4 liters volume that have been coated with a thin layer of silver-activated zinc sulfide, which scintillates upon interaction with alpha particles emitted by radon in the cell. The light from these scintillations passes through a window in the bottom of the cell and is detected by a photomultiplier tube that is in direct contact with the cell window. The Lucas cell and phototube are enclosed in a light-tight housing. Output pulses from the photomultiplier tube are processed by a counting system that includes a pre-amplifier, linear amplifier, single channel analyzer, and a timer/scaler, producing a gross

alpha count that can be used to determine the radon concentration of the sampled air.

Grab Sampling and the Integrated Count Method. The grab sampling method of determining radon concentration consists of evacuating a Lucas cell through a single valve at the top of the cell, then opening the valve to obtain an atmosphere sample. Time of sampling and time delay until counting starts are recorded, and then a gross alpha count is obtained. Radon concentration is determined by using an integrated count method developed by Jonassen and Clements (10). Other radon detection schemes require the radon sample to reach equilibrium with its progeny before counting, but the integrated count method has the advantage of allowing determination of radon concentration at anytime after a sample free of daughter products is introduced into an alpha detection chamber. In order to ensure that the radon collected in the Lucas cell is free of daughter products, the sample is drawn through a filter.

The equations that result from a derivation of the integrated count method (which is detailed in reference 12) are arrived at by assuming a radon progeny-free sample and then applying production and loss rate equations, similar to the well-known Bateman equations (7:470), to determine the total activity in the cell volume from the decay of radon and the in-growth of radon progeny. This total activity is then integrated between the limits of the time

counting starts and the time counting is complete. The equations arrived at by Jonassen and Clements were supplied with numerical values for decay constants based on the half-lives listed in Table I and were then incorporated into a computer program. A listing of this program has been included in Appendix A.

An error propagation was performed on the final equations according to standard methods (11:131) and was also included in the computer program. This error propagation must take into account random errors in counting and the uncertainty in the efficiency of the counting system. Poisson counting statistics was assumed to apply. The efficiency of the Lucas cells and counting system was determined by counting a sample of known radon concentration. The error in this efficiency determination was estimated to be 5 percent, based on the spread in calculated efficiencies for several counts of a radon gas sample obtained from another radon chamber. This sample was certain to within 2 percent.

Continuous Monitoring. Continuous monitoring was performed with a 4-liter Lucas cell that had both an inlet and an outlet at the top of the cell. Air was drawn from the test chamber by a sampling pump through a filter and an air flow meter, and then through the Lucas cell and finally returned to the chamber. The Lucas cell was positioned in a light-tight housing as in grab sampling and a total alpha

count was obtained for a pre-determined counting interval. The total count during each time interval was automatically printed by a teletype printer.

The integrated count method cannot be applied to a continuous flow sampling system, so calibration was attempted by using the system to sample a radon chamber of known, constant radon concentration. Gross counts per time interval increased during sampling as a consequence of radon progeny adhering to the interior walls of the cell, but an equilibrium was reached within 3 hours and a gross count rate that was within the statistical boundaries of constant counting was observed. Unfortunately, the equipment settings used during the initial calibration were not used during the testing phase of this thesis work, so additional calibration by comparison with grab-sample results was performed.

Figures 1 and 2 are calibration curves that were obtained by plotting gross flow cell counts obtained during a 1000-second count interval against the radon concentration measured in the chamber by grab sampling. Figure 1 applies to the flow cell when it was operated with a sampling flow of 4 l/min or less. The resultant curve makes it impossible to determine radon gas concentration from flow cell sampling alone. Figure 2 applies to the flow cell when it was operated with a sampling flow of 8 l/min. The resultant slope of 42 counts/pCi/l from the curve has been used to determine radon gas concentration from gross flow cell.

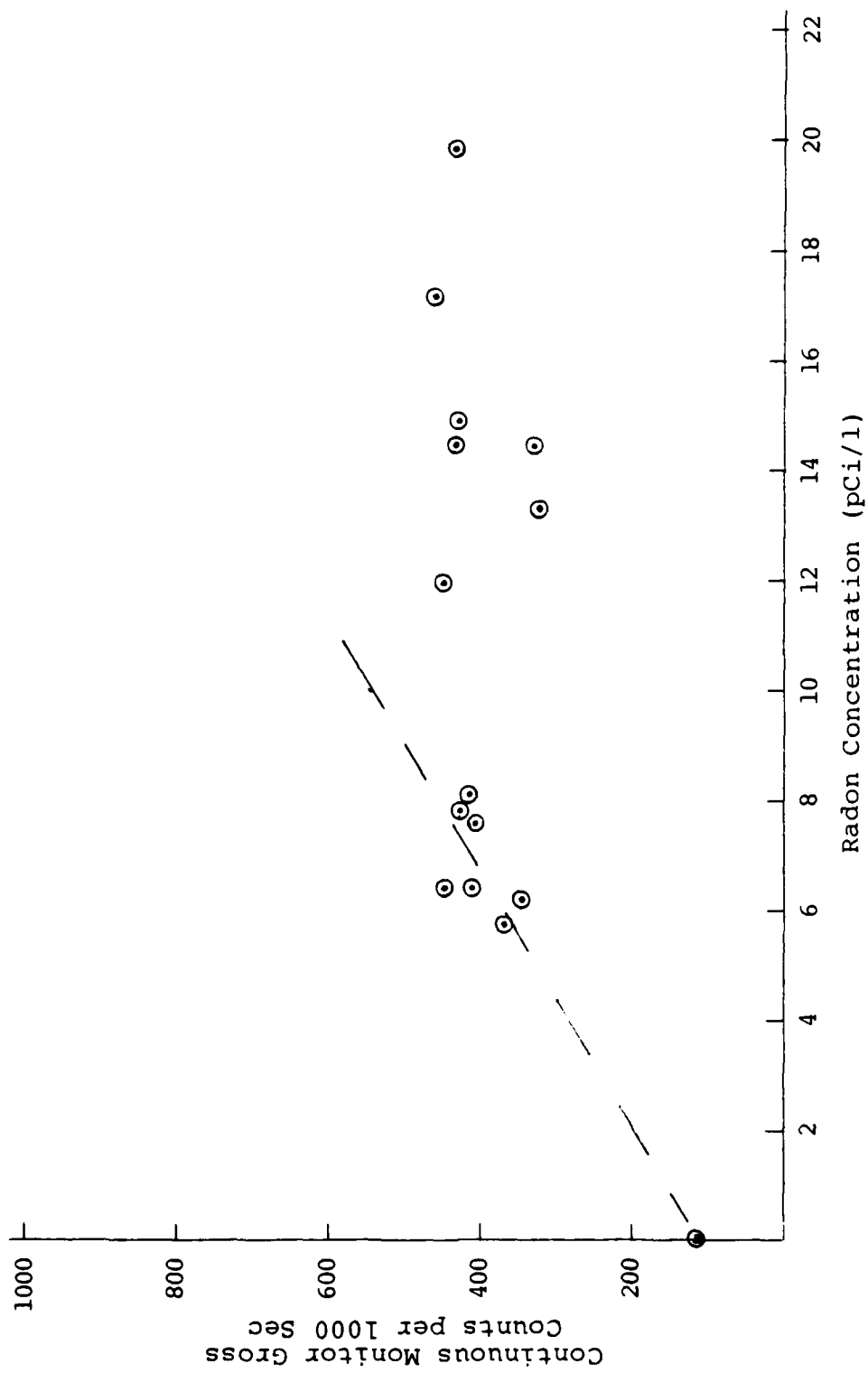


Fig. 1. Continuous Monitor Calibration Curve, 4 l/min Sampling Flow

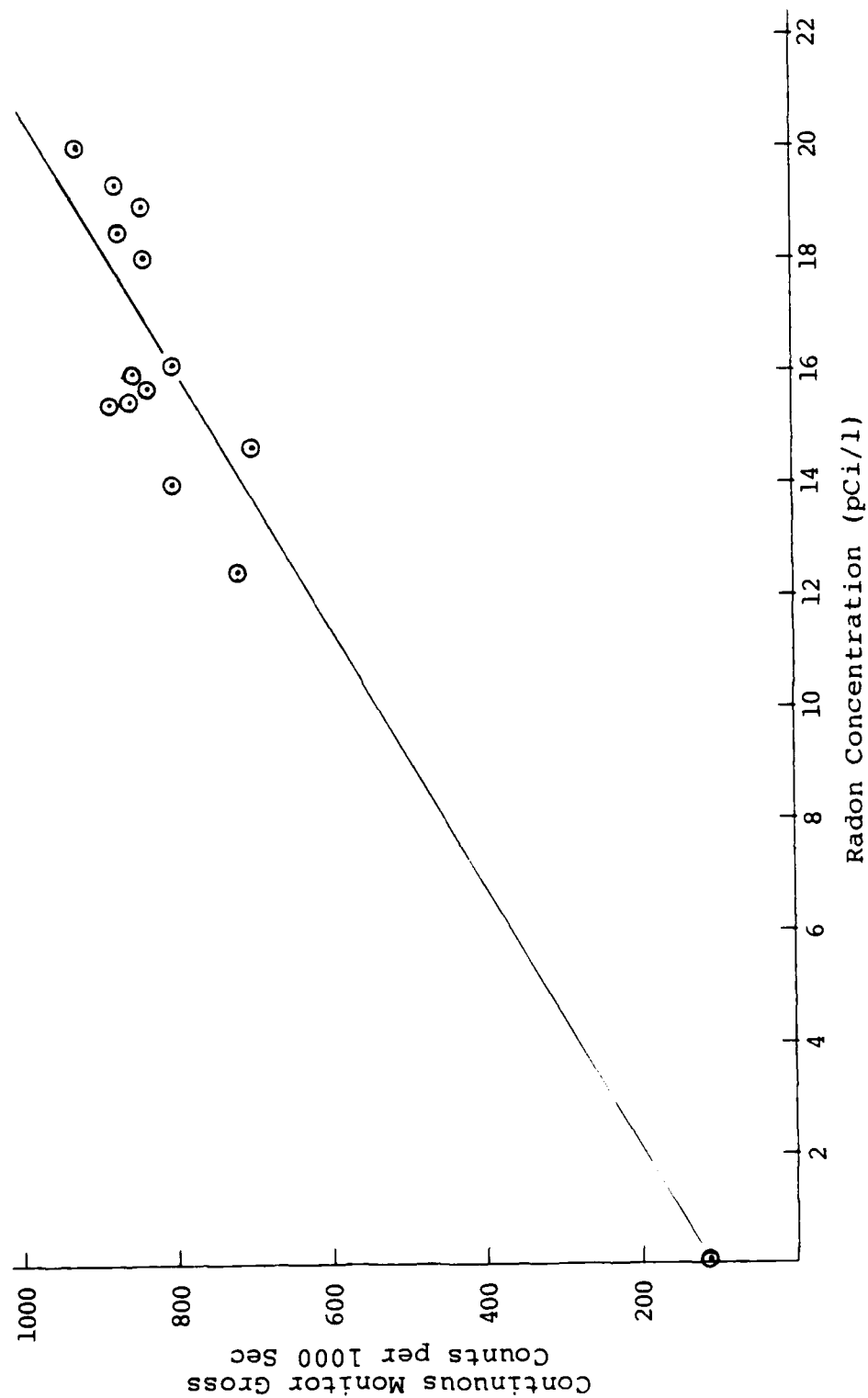


Fig. 2. Continuous Monitor Calibration Curve, 8 l/min Sampling Flow

counts obtained during a 1000-second count interval. Radon gas concentrations determined in this manner are taken to be certain to within 15 percent of the actual concentration and are used to calculate the equilibrium factor, F , in later analysis of test results.

Operation of the continuous monitor at 4 l/min sampling flow may not be as unreliable as is indicated by Figure 1. Not taken into account by a comparison of these two curves alone is the verification of grab sampling efficiency and the verification of sample flow rate that was performed prior to shifting flow to 8 l/min.

Radon Progeny Measurement

Modified Tsivoglou Method. Radon progeny concentrations in the test chamber were determined by air sampling in accordance with the modified Tsivoglou method (18). The method involves air sampling followed by alpha counting for three different time intervals after the completion of the sample. Using the number of alpha counts obtained during the three time intervals, the counting system efficiency and background, the flow rate through the air sampler and the sampling time, the concentrations of Ra-A, Ra-B, and Ra-C can be calculated from simple equations. Thomas has derived the equations that result when a 5-minute sampling time and counting intervals of 2-5, 6-20, and 21-30 minutes are used (18). These times were used during radon-progeny sampling for this thesis. The resultant equations are:

$$C_2 = 1/VE (0.1689 G(2,5) - 0.0820 G(6,20)$$

$$+ 0.0775 G(21,30) - 0.0566 R)$$

$$C_3 = 1/VE (0.0012 G(2,5) - 0.0206 G(6,20)$$

$$+ 0.0491 G(21,30) - 0.1575 R)$$

$$C_4 = 1/VE (-0.0225 G(2,5) + 0.0332 G(6,20)$$

$$- 0.0377 G(21,30) - 0.0576 R)$$

where

C_2 = concentration of Ra-A, in picocuries per liter

C_3 = concentration of Ra-B, in picocuries per liter

C_4 = concentration of Ra-C, in picocuries per liter

$G(2,5)$ = gross counts for 2-5 minute time interval

$G(6,20)$ = gross counts for 6-20 minute time interval

$G(21,30)$ = gross counts for 21-30 minute time interval

R = background count rate, in CPM

V = volumetric sampling rate, in liters per minute

E = counter efficiency, in CPM/dpm

These equations are included in a computer program that is listed in Appendix A.

Sampling and Counting Procedures. Air samples were taken with low-volume air samplers at a sampling rate of either 28.3 l/min or 9.3 l/min. The samples were collected

on Millipore type HAWP filters (0.45 micron pore size) that were fitted into flow-through filter holders. These filters have a reported collection efficiency of 99.99 percent for both attached and unattached radon progeny (3:533). The filter holders were inserted approximately 40 centimeters into the chamber through the same sampling port that was used to conduct radon gas grab sampling.

After a sample was drawn, the filter paper was removed from the holder and placed in a sampling tray. The tray was directly under an acrylic disc that was coated with zinc sulfide. A photomultiplier tube positioned above the zinc sulfide coated disc detected scintillations from alpha particle interactions. The sampling tray, disc and photomultiplier tube were all contained in a single light-tight housing. Pulses from the photomultiplier tube were processed through a pre-amplifier, linear amplifier, and timing single-channel analyzer, and the resultant counts were recorded by an automatic timing/scaling system. The efficiency of this counting system was determined to be 0.442 ± 0.033 cpm/dpm by counting a Ra D-E source of known activity in place of the filter paper.

Sources of Uncertainty. The sources of uncertainty or error in the measurement of radon progeny can be either random or systematic. Random sources of error include representation of the discrete random process of radioactive decay as a continuous process; fluctuations in Ra-A

concentration during sampling which, because of its short half-life, can cause significant error; measurement and control of flow; statistical errors during counting; and fluctuations in background. Systematic sources of error include self-absorption of radon progeny that penetrate the filter, plateout of radon progeny on sampling equipment, and the presence of other airborne alpha emitters (2:944).

An error propagation was performed according to standard methods (11:131) for the radon progeny concentration equations listed above. The results of this propagation were incorporated in the computer program listed in Appendix A. Poisson counting statistics was assumed and an uncertainty of 5 percent was used for volumetric sampling rate. A counting system efficiency uncertainty of 0.033 was also included.

III. Conducting Tests in the Radon Test Chamber

Desired Approach

An ideal test chamber for conducting radon progeny reduction experiments would allow for precise control of radon gas concentration and all other factors that might affect the concentrations of radon progeny in the room. These factors include temperature, humidity, air pressure, aerosol population, ventilation rate, and operation of air treatment devices. Such control would allow an investigator to test air treatment devices over a wide range of known conditions and to characterize more completely how to reduce radon progeny.

The AFIT test chamber is not an ideal chamber. Of the factors listed above for which precise control is desirable, only ventilation rate and operation of air treatment devices could be controlled reasonably well. Temperature, humidity, and air pressure fluctuated with changes in the weather and no attempt was made to influence these environmental conditions with heaters, dehumidifiers or other appliances.

Constant Parameters and Initial Conditions

While the factors discussed above are known to affect the concentrations of radon progeny in the atmosphere, it was initially thought that radon gas concentration

in the test chamber could be kept constant by keeping radon gas production and removal rates constant.

A constant air flow through the radium source and a constant flow of dilution air were used to provide a constant production rate of radon. This air was supplied through valves set at constant throttle positions and was regulated at a constant pressure. Air flow meters were used to monitor for any large changes and the highest fluctuations observed over several hours of testing was less than 8 percent for air flow through the radium source and 6 percent for dilution air.

A constant removal rate for radon was provided by maintaining a constant ventilation rate from the test chamber. The exhaust damper was set to 1/2 inch from fully shut and was not changed throughout testing. Air velocity measurements averaged 120 feet per minute, which corresponded to an air flow of 40,000 liters per hour through the exhaust duct, assuming uniform flow across the 182-square centimeter duct cross-section area. This exhaust rate corresponds to a room air exchange rate of 0.4 ACH, which on the low end of the range of values for typical U.S. residences (0.5 - 1.5) reported earlier in this thesis. Air velocity measurements were taken periodically to confirm that exhaust rate was not changing. The only other factor contributing to radon removal was radioactive decay.

Since the constant production and removal terms above suggested that a constant radon concentration existed in the test chamber, radon progeny sampling results alone were initially thought to be sufficient to determine the effectiveness of radon progeny reduction equipment. One or two samples were taken prior to starting the air treatment in order to confirm initial conditions, and then sampling after the air treatment had begun should have been sufficient to gauge the effectiveness of the treatment.

Trends in sampling taken to establish initial conditions indicated that radon progeny concentrations were not constant during periods of no air treatment. Some difficulty was experienced in determining whether this was due to a fluctuating radon concentration or due to changes in removal mechanisms that could be influenced by environmental conditions. It was eventually determined that radon concentration was fluctuating, even in what was thought to be steady-state conditions in the chamber.

Steady-State Conditions

"Steady-state conditions" refers to those times when no air treatment appliances were in operation and the air flow rates discussed above were held constant. Sampling to determine both radon progeny and radon gas concentration behavior during steady-state conditions was conducted. The results of a set of samples collected over a 24-hour period have been plotted in Figure 3. Included

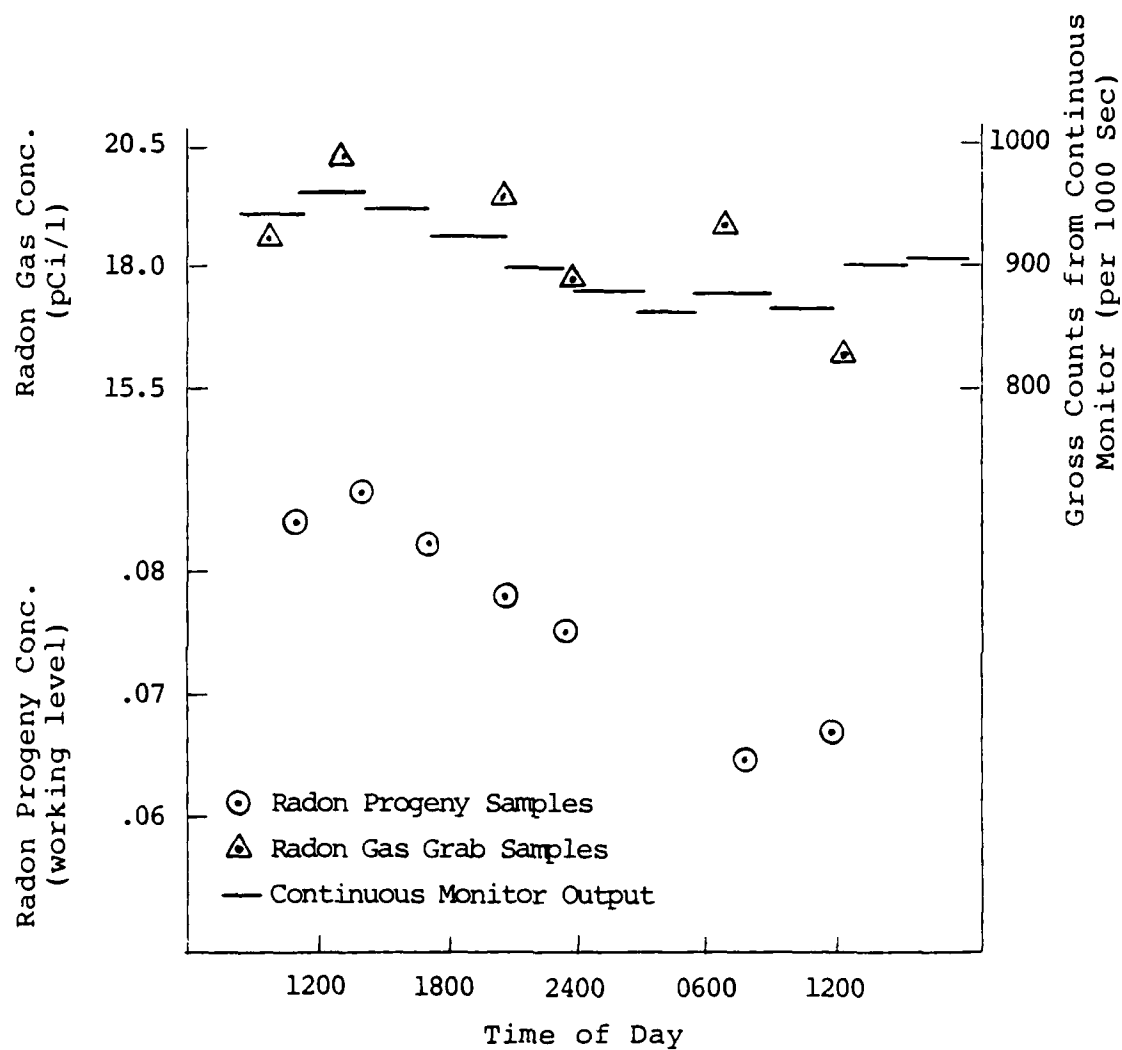


Fig. 3. Results of Sampling During Steady State Conditions in the Radon Test Chamber

in the plot are radon progeny samples, radon gas grab samples, and continuous monitor sampling results. Chamber temperature, pressure and humidity were essentially constant. As can be seen from an inspection of Figure 3, radon gas concentration in the chamber did not remain constant. The reason for the systematic rise and fall in radon gas concentrations is not known and cannot be attributed to random counting statistics.

Effect of Humidity on Equilibrium Factor

Even though the reason radon gas concentration fluctuations occur could not be determined, one aspect of the steady-state behavior of the test chamber is noteworthy. Sampling results indicate that the equilibrium factor remains constant, even when very large changes in the test chamber air quality occur. As was stated earlier, test chamber conditions such as temperature and humidity were allowed to fluctuate with the weather outside the chamber. The weather during testing was oftentimes warm and damp or rainy, causing large changes in relative humidity as measured by a hygrometer suspended in the test chamber. Relative humidity was sometimes greater than 90 percent, and would then drop to 60 percent the following day. Even under these extreme conditions, equilibrium factor varied by no more than about 10 percent.

Shown in Figure 4 is a plot of measured equilibrium factor versus relative humidity for several samples taken during steady-state conditions. Included are samples taken during the 24-hour test as well as several samples taken to establish initial conditions in the chamber prior to air treatment testing. Apparently, the presence of different amounts of water vapor in the air does not significantly affect removal mechanisms such as non-turbulent plateout, which is exactly opposite what is expected for different aerosol concentrations (20:486).

Some very limited information concerning the behavior of the AFIT test chamber under "smokey" conditions was obtained by injecting cigar smoke into the chamber. Equilibrium factor was determined to be 0.43 just before injection of the smoke, and had increased to 0.53 after one hour of smoke injection. Equilibrium factor was again determined to be 0.53 one hour after smoke injection had stopped. The ionization air cleaner was operating throughout this period.

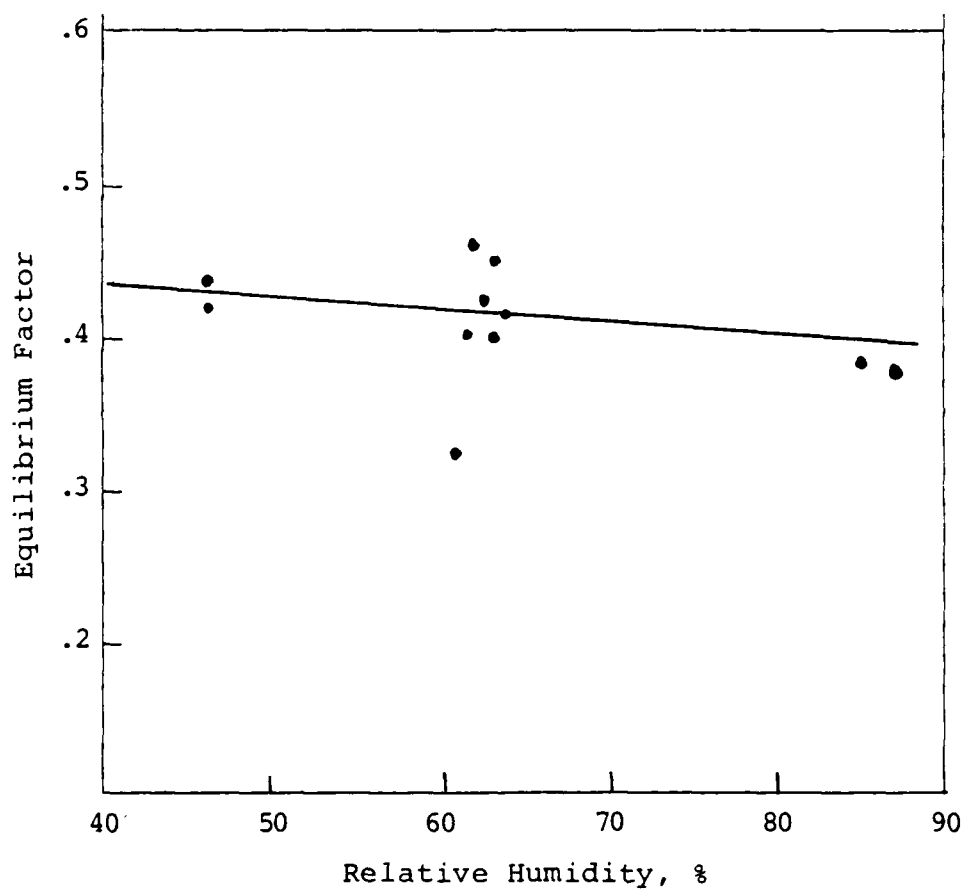


Fig. 4. Effect of Changes in Humidity on Equilibrium Factor

IV. Results

General Test Results

A total of fourteen different testing runs was performed with the test chamber and installed air treatment equipment. These tests can be grouped into five distinct categories:

1. Radon progeny reduction by use of high volume blower only (Fan)
2. Radon progeny reduction by use of permanently-installed electrostatic precipitator (Perm ESP)
3. Radon progeny reduction by use of portable electrostatic precipitator (Port ESP)
4. Radon progeny reduction by use of ionization air cleaner (Ions)
5. Radon progeny reduction by use of high volume blower and ionization air cleaner together (Ions w/Fan)

Shown in parentheses after each type of test is the abbreviation for test method as used in Table III.

Table III is a summary of test results by type of test, and a test number has been assigned to each for ease of discussion. Included in the summary are test dates, air throughput for the test (when applicable), average working level prior to the start of air treatment, average working level at the completion of air treatment and, when

TABLE III
RESULTS OF RADON PROGENY REDUCTION TESTING

Test No.	Date	Reduction Method	Air Throughput (ACH)	WL Before	WL After	% Drop in WL	F Before	F After	% Drop in F
1	28 Oct	Fan	20	.041	.005	88	-	-	-
2	30 Oct	Fan	20	.028	.005	82	-	-	-
3	5 Nov	Fan	10	.023	.012	48	-	-	-
4	12 Nov	Fan	10	.084	.024	71	-	-	-
5a	25 Nov	Fan	2.5	.069	.042	39	.41	.25	39
5b	25 Nov	Fan	2.5	.069	.039	43	.41	.23	44
6	31 Oct	Perm ESP	20	.028	.003	89	-	-	-
7	6 Nov	Perm ESP	10	.031	.012	61	-	-	-
8	13 Nov	Perm ESP	10	.092	.015	84	-	-	-
9	26 Nov	Perm ESP	2.5	.074	.027	64	.41	.13	68
10	7 Nov	Port ESP	10	.053	.013	75	-	-	-
11a	3 Dec	Port ESP	1.5	.051	.024	53	.44	.17	62
11b	3 Dec	Port ESP	1.5	.051	.029	43	.44	.20	55
12	19 Nov	Ions	NA	.080	.078	2	-	-	-
13a	27 Nov	Ions	NA	.056	.060	0	.48	.34	29
13b	27 Nov	Ions	NA	.056	.042	25	.48	.26	46
13c	28 Nov	Ions w/Fan	2.5	.056	.023	59	.48	.14	71
14	15 Nov	Ions w/Fan	10	.044	.016	67	-	-	-

known with confidence, corresponding values of equilibrium factor. This table was generated from the individual test results that have been included as Appendix B.

Approach Adopted in
Effectiveness Evaluations

Since radon concentrations in the test chamber were fluctuating, proper interpretation of samples collected should not be based solely on a comparison of average working level before and after air treatment. To illustrate this point, the results of Test #11a have been plotted in Figure 5. Measured radon progeny concentrations (working level) are plotted as circles and radon gas concentrations, as determined by the continuous monitor, are plotted as triangles. The data points plotted as squares represent the projected working level that would exist for the measured radon if F had remained 0.44 throughout the test. The dashed lines represent average values of working level before and after air cleaning.

If a knowledge of radon gas concentration is not known, it could be concluded that the air treatment device lowered working level by 53 percent when in fact working level was actually reduced by 65 percent. This difference of 20 percent between actual and measured working level must be considered when reviewing Table III.

The problem of describing working level reduction in terms of percent change in average working level before

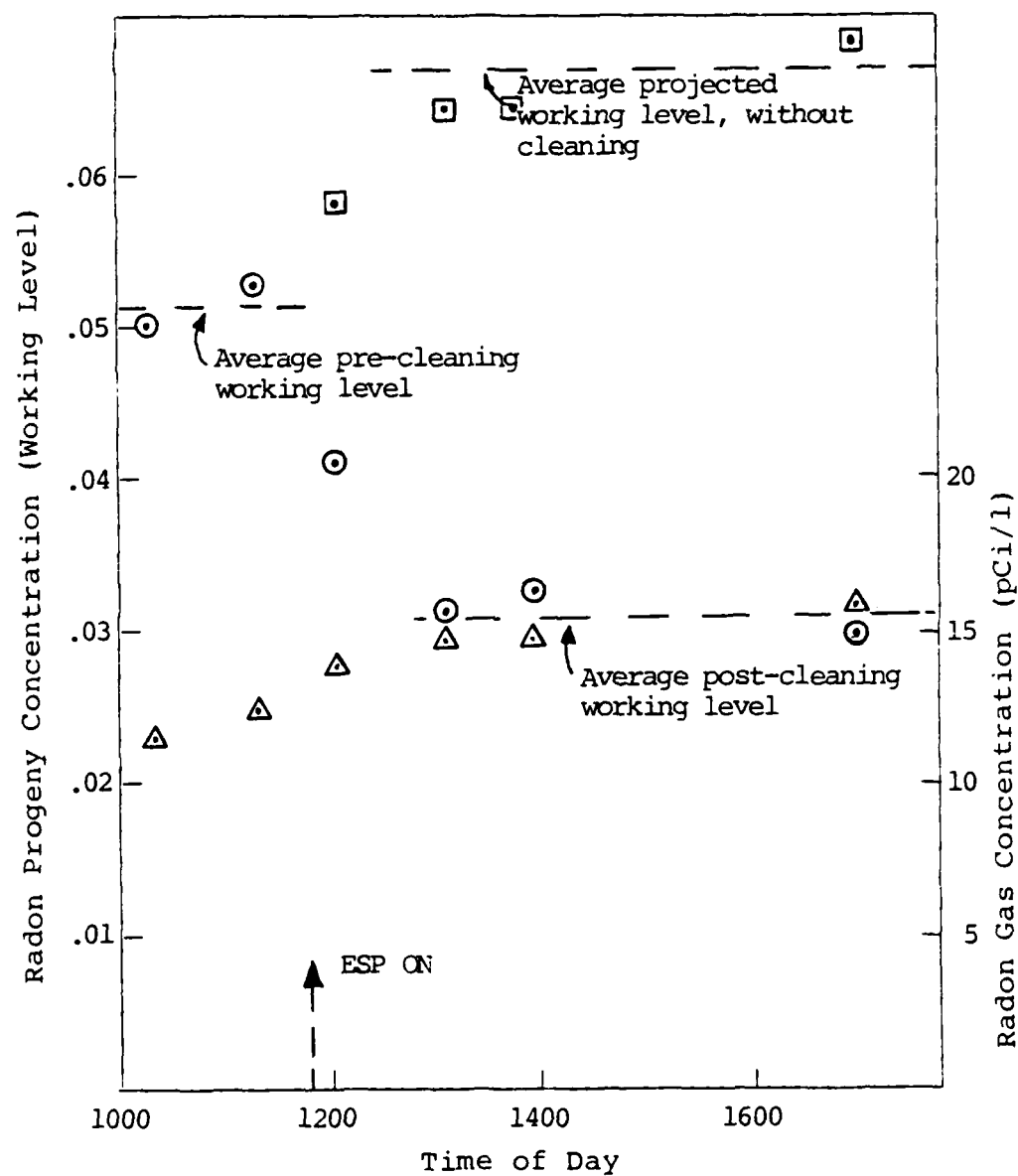


Fig. 5. Effect of Changing Radon Concentration on Working Level Reduction Evaluation

air cleaning can be avoided when radon concentration in the chamber can be determined adequately. The continuous monitor allowed for radon gas concentration to be determined to within 15 percent and this result was then used to determine F for each sample time. A change in F is a much more reliable indication of radon progeny reduction because it is not based on an average working level.

Relative Effectiveness of Air Treatment Methods

The best results for radon progeny reduction occurred when the ventilation system was operated at the highest air throughput, as can be seen by noting the greater than 80 percent reduction in average working level achieved during Tests #1, #2, and #6. This type of air throughput may not be reasonable for in-home application, however, since most whole house heating and cooling systems do not turn over 20 house volumes of air each hour. Air turnover rates of closer to 5 ACH are more typical (3:1188).

The permanently-installed electrostatic precipitator achieved considerable reduction levels in all tests. If Test #7 and Test #8 are considered together, giving an average reduction in working level of approximately 77 percent for an air throughput to 10 ACH, then it is clearly seen that the permanently-installed electrostatic precipitator performs better as air throughput is increased.

The appliance is still effective at low air throughput, however, with a 64 percent reduction at 2.5 ACH.

Comparing the results of the testing using the blower only with the results for the permanently-installed electrostatic precipitator, it can be seen that the blower accounts for at least 60 percent of the reduction process. This observation is made based on an average drop in F of 42 percent for the blower only compared to a drop in F of 68 percent for the permanently-installed electrostatic precipitator when both systems are operated at an air throughput of 2.5 ACH.

The effectiveness of the portable electrostatic precipitator is not as easy to characterize from the limited sample results available. The portable version of the electrostatic precipitator may actually be as effective as the permanently-installed version if the average results of testing at 10 ACH are taken as an indication of performance under similar conditions. The permanently-installed electrostatic precipitator achieved a 75 percent reduction, which is the same reduction achieved by the portable. For lower air throughput, it should be noted that the portable electrostatic precipitator does not draw as much air as the permanently-installed version (1.5 ACH versus 2.5 ACH), so direct comparison is difficult. It can be seen that operation of the portable electrostatic precipitator is effective even at a lower air flow because the

portable electrostatic precipitator causes a greater reduction in radon progeny than operation of the blower only.

Prospects for radon progeny reduction using the ionization air cleaner seemed poor during the initial review of testing results. When operating without the ventilation system, the air cleaner appears to have little or no effect on radon progeny concentration. In this case, it is essential to know radon concentration. Without this knowledge, the average 33 percent reduction in equilibrium factor could not be determined. Test #13a shows F dropping from 0.48 to 0.34 after 5 hours of appliance operation. F continues to drop to 0.26 after 23 hours of appliance operation. Further decreases in F may be observable if the ionization air cleaner is allowed to operate for prolonged periods of time.

The high volume blower was turned on after the ionization air cleaner had been running for almost a full day. An additional reduction in both working level and F was obtained, such that the combination of these two methods was more effective than either of the electrostatic precipitators when they were operated at low air flows. An examination of the individual test results for each device clearly shows that the electrostatic precipitators cause a rapid drop in working level while the ionization air cleaner reduces working level more slowly.

The overall effectiveness or usefulness of an air treatment method should not be inferred from effectiveness of radon progeny reduction alone. Other factors must be considered in the final analysis, including cost effectiveness, power consumption, and ozone production. When these factors are considered, use of the ionization air cleaner, in conjunction with an air-moving appliance (perhaps a ceiling fan), may be the best choice of radon progeny reduction products for the home. The odor of ozone was noticeable in the test chamber for most of the tests conducted with the electrostatic precipitators but was not noticeable when the ionization air cleaner was used. The ionization air cleaner also costs less and has a lower power consumption than either electrostatic precipitator.

V. Conclusions and Recommendations

Conclusions

The purpose of this thesis was to characterize the effectiveness of three types of air cleaning devices in reducing the concentrations of radon progeny in indoor air. Evaluation of the air cleaning appliances was accomplished by first determining specific information about the chamber in which the appliances were to be tested, and then by conducting a variety of tests that involved operating the air treatment devices to actually reduce the radon progeny concentrations present in a radon test chamber. Based on the results of testing reviewed in the preceding material, the following conclusions are drawn concerning operation of the radon test chamber and the effectiveness of the air treatment appliances:

1. Radon progeny concentration can be determined effectively by a continuous monitor, thus providing a means to determine the equilibrium factor, which allows for better evaluation of radon progeny reduction, especially when radon gas concentration is non-constant.

2. All of the air treatment devices tested during this thesis are effective in reducing the concentrations of radon progeny in indoor air. Turbulent plate-out of attached radon progeny due to increased air flow is the

dominant removal mechanism and is enhanced by ionization caused by either electrostatic precipitation or unipolar space charging.

Recommendations

The following recommendations are suggested for further studies or work concerning radon progeny reduction testing at the AFIT radon test chamber:

1. Provisions for monitoring of temperature and humidity on a continuous basis should be added to the test chamber. This may provide insight into the reason for radon gas concentration fluctuations.

2. Installation of a venturi type air flow meter in the chamber exhaust duct will allow investigation of radon progeny reduction effectiveness over a wide range of initial equilibrium factors and may provide insight into the reason for radon gas concentration fluctuations.

3. Reducing the volume of the test chamber by installation of a lower ceiling and/or a room dividing wall should be considered. Although the smaller volume would allow a greater range of radon gas concentrations and would reduce the effect of the outside environment by further insulating the chamber, it would also mean that the ventilation system would be oversized and low air turnover rates typical of a residence could not be attained.

4. Installation of a ceiling fan would allow testing of the ionization air cleaner with an air-moving device that is typical of a residence.

Appendix A: Computer Program Listings

This appendix lists the computer programs used in performing calculations for this thesis. The first listing is the program used in calculating radon gas concentrations and the second listing is the program used in calculating radon progeny concentrations. Both programs are written in ZBASIC for use on the Zenith Z-100 computer system. These programs are saved under the filenames LUCAS2 and TSIVOG1 on the Winchester disk system of the Z-100 computer that is located in the AFIT Nuclear Physics Laboratory.

```

10 '      RADON CONCENTRATION BY INTEGRATED COUNT METHOD
20 '
30 ' This program finds the radon concentration of a filtered
40 ' air sample counted in a Lucas cell by application of the
50 ' integrated count method.
55 '
60 ' The integrated count method can be found in "Determination
70 ' of Radon-222 Concentrations By an Integrated Count Method"
80 ' Jonassen and Clements, Heath Physics , Vol. 27, pp.347-351,
90 ' (1974).
95 '
100 ' The following is required as input information:
110 '      (1) Radon free lucas cell background count
120 '      (2) Background count interval (min)
130 '      (3) Time between sample collection and start of
135 '           sample counting (min)
140 '      (4) Counting interval (min)
150 '      (5) Total counts
160 '      (6) Volume of the Lucas Cell
170 '      (7) Lucas cell efficiency and uncertainty
180 ' Variables:
190 '      BC : observed background counts
200 '      GC : gross counts from radon filled lucas cell
210 '      NC : net counts from count of lucas cell
220 '      E  : counting system efficiency
230 '      DE : uncertainty in efficiency (input value)
240 '      T1 : delay time, the time from sample collection
250 '           until the start of sample counting, (min)
260 '      TC : the counting interval length, (min)
270 '      TB : the background counting interval, (min)
280 '      T2 : time from sampling to end of count, (min)
290 '      F  : time dependent radon activity function, (min)
300 '      R1 : radon activity, (dpm)
310 '      R  : radon activity, (pCi)
320 '      C1 : radon concentration, (pCi/liter)
330 '      S  : deviation in radon concentration, pCi/liter
340 '      VOL : Lucas cell volume, (liters)

```

```

350 ' Input initial data
360 PRINT ".....LUCAS CELL DATA INPUT....."
370 INPUT"Lucas background counts = ",BC
380 INPUT"Lucas background count interval = ",TB
390 INPUT"Lucas cell efficiency = ",E
400 INPUT"Efficiency uncertainty=",DE
410 INPUT"Time from sample collection to start of count",T1
420 INPUT " Counting interval length,(min) = ",TC
430 INPUT "Total counts =",GC
440 INPUT "lucas cell volume,(liters) = ",VOL
450 T2 = T1 + TC
460 NC = GC - BC*TC/TB
470 TM1 = EXP(-1.259E-04*T1) -EXP(-1.259E-04*T2)
480 TM2 = EXP(-.22726*T1) - EXP(-.22726*T2)
490 TM3 = EXP(-.025864*T1) - EXP(-.025864*T2)
500 TM4 = EXP(-.035185*T1) - EXP(-.035185*T2)
510 F = 23906.063**TM1-4.5063*TM2-165.5**TM3+93.6453*TM4
520 R1 = NC/(E*F)
530 R = R1/2.22
540 C1 = R/VOL
550 S = C1 * ((1/NC) + (DE/E)^2)^.5
560 PRINT ".....LUCAS CELL DATA INPUT....."
570 PRINT"Lucas background counts = ",BC
580 PRINT"Lucas background count interval = ",TB
590 PRINT "Lucas cell efficiency = ",E
600 PRINT "Delay time = ",T1
610 PRINT " Counting interval length,(min) = ",TC
620 PRINT "Total counts =",GC
630 PRINT "lucas cell volume,(liters) = ",VOL
640 PRINT
650 PRINT ".....LUCAS CELL output....."
660 PRINT "t1 = ";T1;" T2 = ";T2;" T2 - T1 = ";TC
670 PRINT"Bkgd count rate =";BC/TB;" +/- ";SQR(BC)/TB;"cpm"
680 PRINT
690 PRINT "Radon conc = "; C1 ; " +/- ";S;"pCi/liter"
700 END

```

```

10 ' RADON PROGENY CONCENTRATIONS BY MODIFIED TSIVOGLOU METHOD
20 '
30 ' This program finds the concentrations of radon daughters
40 ' in an air sample from the gross alpha counting of a filter
50 ' in accordance with the modified Tsivoglou method.
60 '
70 ' The modified Tsivoglou method may be found in " Measurement
80 ' of Radon Daughters in Air," Health Physics, 23, : pp783-789
90 ' (1972).
95 '
100 ' The following is required as input information :
110 ' (1) Air sampler flow rate and uncertainty, in liters/min
120 ' (2) Counting system efficiency and % uncertainty, cpm/dpm
130 ' (3) Gross alpha counts for time intervals 2-5, 6-20, 21-30
140 '     minutes after sampling
150 ' (4) Background counts
160 ' (5) Background count time interval, minutes
170 '
180 ' Variables:
190 '     C2 : Radium A concentration, pCi/liter
200 '     C3 : Radium B concentration, pCi/liter
210 '     C4 : Radium C concentration, pCi/liter
220 '     SIGC2 : Uncertainty in C2
230 '     SIGC3 : Uncertainty in C3
240 '     SIGC4 : Uncertainty in C4
250 '     E : Counting system efficiency
260 '     DE : Deviation in E
270 '     V : Volumetric sampling rate, liters/min
280 '     DV : Uncertainty in V
290 '     G1 : Gross alpha counts, 2-5 min after sampling
300 '     G2 : Gross alpha counts, 6-20 min after sampling
310 '     G3 : Gross alpha counts, 21-30 min after sampling
320 '     R : Background count rate, cpm
330 '     TB : Background count interval, min
340 '     SW : Uncertainty in Working Level

```

```

350 ' A11 thru A34 are constants for 5 minute sample time
360 '      and count intervals 2-5, 6-20, 21-30
370 A11 = .1689: A12 = -.082 : A13 = .0775 : A14 = -.0566
380 A21 = .0012 : A22 = -.0206 : A23 = .0491 : A24 = -.1575
390 A31 = -.0225 : A32 = .0332 : A33 = -.0377 : A34 = -.0576
400 E = .42: SE = .033
410 INPUT V
420 SV = V*.05
430 INPUT R : TB = 5
440 INPUT G1
450 INPUT G2
460 INPUT G3
470 C2 = (A11*G1 + A12*G2 + A13*G3 + A14*R)/(V*E)
480 C3 = (A21*G1 + A22*G2 + A23*G3 + A24*R)/(V*E)
490 C4 = (A31*G1 + A32*G2 + A33*G3 + A34*R)/(V*E)
500 SIGC2 = 100* SQR((SV/V)^2+(SE/E)^2 +
      (A11^2*G1+A12^2*G2+A13^2*G3+A14^2*R/TB)/((V*E*C2)^2))
510 SIGC3 = 100* SQR((SV/V)^2+(SE/E)^2 +
      (A21^2*G1+A22^2*G2+A23^2*G3+A24^2*R/TB)/((V*E*C3)^2))
520 SIGC4 = 100* SQR((SV/V)^2+(SE/E)^2 +
      (A31^2*G1+A32^2*G2+A33^2*G3+A34^2*R/TB)/((V*E*C4)^2))
530 PRINT "***** input data *****":LPRINT
540 PRINT "G(2,5) =";G1;" G(6,20) = ";G2;" G(21,30) = ";G3
550 PRINT "background..... ";R;" cpm for ";TB;"minutes"
560 PRINT "flow rate..... ";V;" +/- ";SV;" liters/min"
570 PRINT "counter efficiency ";E;" +/- ";SE;" cpm/dpm"
580 PRINT
590 PRINT "***** results *****":LPRINT
600 PRINT "Ra A = ";C2;" +/- ";SIGC2*C2 ;"pCi/liter"
610 PRINT "Ra B = ";C3;" +/- ";SIGC3*C3;"pCi/liter "
620 PRINT "Ra C = ";C4;" +/- ";SIGC4*C4 ;"pCi/liter"
630 PRINT "daughter ratio wrt Ra-A is 1 -";C3/C2;" -";C4/C2
640 SW = ((.00103*SIGC2/100)^2 + (.00507*SIGC3*C3/100)^2 +
      (.003738*SIGC4*C4/100)^2)^.5
650 PRINT:PRINT "WL =";.00103*C2 +.00507*C3+.00373*C4;" +/- ";SW
660 END

```

Appendix B: Tabulated Data and Results of Individual
Radon Progeny Reduction Tests

This appendix consists of tables that list the results of sampling during radon progeny reduction testing. The tables are arranged by test type and include the following information for each sample taken during the test:

1. date and time radon progeny sample was taken
2. working level
3. uncertainty in working level (Δ WL)
4. output from continuous monitor at time of sample
5. radon concentration, from continuous monitor reading, for samples taken after 20 November 1985, the date flow was shifted to 8 l/min
6. equilibrium working level, corresponding to radon concentration from the continuous monitor
7. equilibrium factor, when radon concentration is known

Additional information in the remarks section of each table includes the times air cleaning equipment was started and stopped and the average working level values used to determine the reduction percentages.

TABLE IV
DATA AND RESULTS FOR TEST #1, RADON PROGENY
REDUCTION BY FORCED VENTILATION

Time	Measured WL	Delta WL
28 Oct		
0900	0.0439	0.0035
1012	0.0394	0.0031
1047	0.0417	0.0033
1129	0.0123	0.0014
1205	0.0089	0.0011
1240	0.0067	0.0009
1326	0.0051	0.0008
1401	0.0053	0.0008
1500	0.0180	0.0017

Remarks

1058 Blower on
1435 Blower off

Average Working Level before air treatment = .041

Average Working Level after air treatment = .005

% reduction in WL achieved = 88

TABLE V
DATA AND RESULTS FROM TEST #2, RADON PROGENY
REDUCTION BY FORCED VENTILATION

Time	Measured WL	Delta WL
30 Oct		
0920	0.0304	0.0026
0955	0.0328	0.0028
1045	0.0209	0.0020
1115	0.0185	0.0018
1210	0.0067	0.0010
1245	0.0061	0.0009
1400	0.0054	0.0008
1455	0.0049	0.0008

Remarks

1105 Blower on
Blower runs through night

Average Working Level before air treatment = .028

Average Working Level after air treatment = .005

% reduction achieved in WL = 82

TABLE VI
DATA AND RESULTS FROM TEST #3, RADON PROGENY
REDUCTION BY FORCED VENTILATION

Time	Measured WL	Delta WL	Flow Cell Counts/ 1000 Sec
5 Nov			
0806	0.0134	0.0015	406
0840	0.0162	0.0016	423
0915	0.0150	0.0016	410
0957	0.0238	0.0032	450
1100	0.0224	0.0032	442
1145	0.0227	0.0032	409
1240	0.0101	0.0021	403
1318	0.0116	0.0020	396
1634	0.0127	0.0021	460

Remarks

1206 Blower on
1639 Blower off

Average Working Level before air treatment = .023

Average Working Level after air treatment = .012

% reduction achieved in working level = 48

TABLE VII

DATA AND RESULTS FROM TEST #4, RADON PROGENY
REDUCTION BY FORCED VENTILATION

Time	Measured WL	Delta WL	Flow Cell Counts/ 1000 Sec
12 Nov			
1015	0.0697	0.0065	429
1055	0.0778	0.0069	448
1135	0.0860	0.0076	435
1245	0.0915	0.0080	449
1330	0.0969	0.0081	429
1405	0.0556	0.0055	401
1555	0.0348	0.0039	437
1635	0.0323	0.0038	467
1905	0.0240	0.0033	356

Remarks

1335 Blower on
Blower runs through night

Average Working Level before air treatment = .084

Average Working Level after air treatment = .024

% reduction achieved in WL = 71

TABLE VIII

DATA AND RESULTS FROM TEST #5, RADON PROGENY
REDUCTION BY FORCED VENTILATION

Time	Measured WL	Delta WL	Flow Cell Counts/ 1000 Sec	Radon Conc. (pCi/l)	Equil WL	F
25 Nov						
0910	0.0756	0.0068	934	18.9	0.1853	.41
1005	0.0715	0.0065	912	18.3	0.1799	.40
1055	0.0592	0.0056	857	16.9	0.1664	.36
1200	0.0443	0.0047	831	16.3	0.1600	.28
1250	0.0415	0.0044	858	17.0	0.1666	.25
1345	0.0402	0.0044	836	16.4	0.1612	.25
1615	0.0417	0.0045	824	16.1	0.1583	.26
26 Nov						
0940	0.0383	0.0042	827	16.2	0.1590	.24
1035	0.0392	0.0044	908	18.2	0.1789	.22

Remarks

1143 Blower on

Test #5a

Average Working Level before air treatment = .069

Average Working Level after 4 hours of air treatment = .042

% reduction in WL achieved = 39

Test #5b

Average Working Level before air treatment = .069

Average Working Level after 23 hours of air treatment = .039

% reduction in WL achieved = 43

TABLE IX
DATA AND RESULTS FROM TEST #6, RADON PROGENY
REDUCTION BY PERMANENTLY-INSTALLED
ELECTROSTATIC PRECIPITATOR

Time	Measured WL	Delta WL
31 Oct		
0805	0.0089	0.0011
0845	0.0085	0.0011
0930	0.0081	0.0010
1025	0.0025	0.0006
1100	0.0028	0.0006
1135	0.0025	0.0006
1255	0.0025	0.0005
1410	0.0034	0.0006
1700	0.0329	0.0028

Remarks

1013 ESP on
1352 ESP off

Average Working Level before air treatment = .028
(from 30 Oct, Test #2)

Average Working Level after air treatment = .003

% reduction achieved in WL = 89

TABLE X
DATA AND RESULTS FROM TEST #7, RADON PROGENY
REDUCTION BY PERMANENTLY-INSTALLED
ELECTROSTATIC PRECIPITATOR

Time	Measured WL	Delta WL	Flow Cell Counts/ 1000 Sec
6 Nov			
0842	0.0278	0.0036	434
0922	0.0307	0.0037	427
1015	0.0343	0.0040	440
1050	0.0222	0.0031	450
1130	0.0152	0.0025	482
1210	0.0133	0.0023	463
1310	0.0154	0.0025	470
1345	0.0103	0.0019	408
1445	0.0080	0.0019	420
1650	0.0111	0.0020	366
1730	0.0117	0.0021	368

Remarks

1030 Blower on
1330 ESP on

Average Working Level before air treatment = .031

Average Working Level after air treatment = .012

% reduction achieved in WL = 61

TABLE XI
DATA AND RESULTS FROM TEST #8, RADON PROGENY
REDUCTION BY PERMANENTLY-INSTALLED
ELECTROSTATIC PRECIPITATOR

Time	Measured WL	Delta WL	Flow Cell Counts/ 1000 Sec
13 Nov			
0925	0.0838	0.0075	345
1030	0.0927	0.0080	324
1120	0.0990	0.0083	317
1220	0.0122	0.0022	320
1315	0.0153	0.0024	327
1400	0.0148	0.0023	351
1535	0.0164	0.0024	380
1625	0.0127	0.0022	368

Remarks

1132 Blower and ESP on
1630 Blower and ESP off

Average Working Level before air treatment = .092

Average Working Level after air treatment = .015

% reduction achieved in WL = 84

TABLE XII

DATA AND RESULTS FROM TEST #9, RADON PROGENY
REDUCTION BY PERMANENTLY-INSTALLED
ELECTROSTATIC PRECIPITATOR

Time	Measured WL	Delta WL	Flow Cell Counts/ 1000 Sec	Radon Conc. (pCi/l)	Equil WL	F
25 Nov						
0910	0.0756	0.0068	934	18.9	0.1853	.41
1005	0.0715	0.0065	912	18.3	0.1799	.40
1055	0.0592	0.0056	857	16.9	0.1664	.36
1200	0.0443	0.0047	831	16.3	0.1600	.28
1250	0.0415	0.0044	858	17.0	0.1666	.25
1345	0.0402	0.0044	836	16.4	0.1612	.25
1615	0.0417	0.0045	824	16.1	0.1583	.26
26 Nov						
0940	0.0383	0.0042	827	16.2	0.1590	.24
1035	0.0392	0.0044	908	18.2	0.1789	.22
1135	0.0362	0.0041	902	18.0	0.1774	.20
1300	0.0280	0.0035	902	18.0	0.1774	.16
1405	0.0284	0.0034	933	18.8	0.1851	.15
1515	0.0267	0.0033	997	20.4	0.2008	.13
1850	0.0268	0.0033	744	14.2	0.1397	.19

Remarks

1026 25 Nov Blower on
1118 26 Nov Perm ESP on

Average Working Level before air treatment = .074

Average Working Level after air treatment = .027

% reduction achieved in WL = 64

TABLE XIII
DATA AND RESULTS FROM TEST #10, RADON PROGENY
REDUCTION BY PORTABLE
ELECTROSTATIC PRECIPITATOR

Time	Measured WL	Delta WL	Flow Cell Counts/ 1000 Sec
7 Nov			
0755	0.0461	0.0049	350
0840	0.0512	0.0052	338
0915	0.0543	0.0054	330
0955	0.0615	0.0059	367
1030	0.0460	0.0049	367
1120	0.0241	0.0033	386
1155	0.0206	0.0029	392
1255	0.0165	0.0026	420
1325	0.0149	0.0024	428
1400	0.0129	0.0023	408
1530	0.0110	0.0021	488
1820	0.0132	0.0022	448
1905	0.0132	0.0022	448

Remarks

1015 Blower on
1325 Portable ESP energized

Average Working Level before air treatment = .053

Average Working Level after air treatment = .013

% reduction achieved in WL = 75

TABLE XIV

DATA AND RESULTS FROM TEST #11, RADON PROGENY
REDUCTION BY PORTABLE
ELECTROSTATIC PRECIPITATOR

Time	Measured WL	Delta WL	Flow Cell Counts/ 1000 Sec	Radon Conc. (pCi/l)	Equil WL	F
3 Dec						
1015	0.0502	0.0052	642	11.9	0.1167	.43
1115	0.0525	0.0053	651	12.1	0.1186	.44
1200	0.0413	0.0045	731	13.9	0.1367	.30
1300	0.0315	0.0038	784	15.1	0.1487	.21
1400	0.0328	0.0038	787	15.2	0.1494	.22
1700	0.0294	0.0036	820	16.0	0.1573	.19
4 Dec						
0935	0.0242	0.0032	740	14.2	0.1388	.17
1340	0.0330	0.0038	784	15.1	0.1487	.22

Remarks

1143 3 Dec ESP on
1345 4 Dec ESP off

Test 11a

Average Working Level before air treatment = .051

Average Working Level after 5 hours of air treatment = .024

% reduction achieved in WL = 53

Test 11b

Average Working Level after 26 hours of air treatment = .029

% reduction achieved in WL = 43

TABLE XV

DATA AND RESULTS FROM TEST #12, RADON PROGENY
REDUCTION BY IONIZATION AIR CLEANER

Time	Measured WL	Delta WL	Flow Cell Counts/ 1000 sec
19 Nov			
0920	0.0743	0.0067	322
1010	0.0802	0.0072	348
1115	0.0818	0.0073	347
1200	0.0830	0.0074	373
1320	0.0771	0.0071	378
1420	0.0807	0.0072	415
1820	0.0787	0.0072	456
1915	0.0782	0.0070	451

Remarks

1143 Ionization air cleaner on
1930 Ionization air cleaner off

Average Working Level before air treatment = .080

Average Working Level after air treatment = .078

% reduction achieved in WL = 2

TABLE XVI

DATA AND RESULTS FROM TEST #13, RADON PROGENY
REDUCTION BY IONIZATION AIR CLEANER AND RADON
PROGENY REDUCTION BY IONIZATION AIR CLEANER
WITH FORCED VENTILATION

Time	Measured WL	Delta WL	Flow Cell Counts/ 1000 Sec	Radon Conc. (pCi/l)	Equil WL	F
27 Nov						
0921	0.0507	0.0052	695	13.1	.1286	.39
1018	0.0563	0.0055	760	14.6	.1433	.39
1110	0.0631	0.0060	777	13.4	.1315	.48
1155	0.0685	0.0063	828	16.2	.1592	.43
1310	0.0726	0.0066	906	18.2	.1784	.41
1404	0.0717	0.0065	939	19.0	.1865	.38
1623	0.0623	0.0058	908	18.2	.1789	.34
28 Nov						
0942	0.0402	0.0044	809	15.7	.1544	.26
1044	0.0319	0.0038	800	15.5	.1524	.21
1828	0.0304	0.0036	796	15.4	.1515	.20
29 Nov						
1004	0.0236	0.0031	853	16.8	.1654	.14
1055	0.0229	0.0031	863	17.1	.1678	.14
1948	0.0670	0.0063	911	18.3	.1796	.37
2040	0.0679	0.0064	970	19.8	.1941	.35
30 Nov						
1207	0.0881	0.0076	1005	20.8	.2038	.43
1445	0.0913	0.0076	884	17.6	.1730	.53
1535	0.0965	0.0082	924	18.6	.1828	.53

Remarks

1120 27 Nov Ionization air cleaner on
1015 28 Nov Blower on, air throughput = 2.5 ACH
1100 29 Nov Blower off
1345 30 Nov Start injection of cigar smoke for one hour
1545 30 Nov Ionization air cleaner off

Test 13a

Average Working Level before air treatment = .056

Average Working Level after 5 hours of air treatment = .060

% reduction in WL achieved = 0

Test 13b

Average Working Level after 23 hours of air treatment = .042

% reduction in WL achieved = 25

Test 13c (Blower on after 23 hours without)

Average Working Level before air treatment = .056

Average Working Level after air treatment = .023

% reduction in WL achieved = 59

TABLE XVII

DATA AND RESULTS FROM TEST #14, RADON PROGENY
REDUCTION BY FORCED VENTILATION AND
IONIZATION AIR CLEANER

Time	Measured WL	Delta WL	Flow Cell Counts/ 1000 Sec
15 Nov			
0915	0.0396	0.0045	320
1020	0.0424	0.0046	330
1130	0.0505	0.0051	315
1225	0.0197	0.0029	290
1325	0.0171	0.0025	310
1415	0.0166	0.0025	311
1625	0.0146	0.0024	300
1725	0.0378	0.0042	300

Remarks

1150 Blower and ion air cleaner on
1643 Blower and ion air cleaner off

Average Working Level before air treatment = .044

Average Working Level after air treatment = .016

% reduction achieved in WL = 67

Appendix C: Commercial Names of the
Air Cleaning Appliances

The permanently-installed electrostatic precipitator is a Honeywell Electronic Air Cleaner, Model F50, size 20 by 25 inches. The portable electrostatic precipitator is a Comfort Glow Electronic Whole House Air Cleaner, Model AC 2025, and is manufactured by AMCA International, Bowling Green, Kentucky. The ionization air cleaner is a Pulsair ionization air cleaner and is manufactured by Ion Systems, Inc., Berkeley, California.

Bibliography

1. Bigu, J. "On the Effect of a Negative Ion Generator and Mixing Fan on the Plateout of Radon Decay Progeny in a Radon Box," Health Physics, 44: 259 (March 1983).
2. Busigin, Anthony and Colin R. Phillips. "Uncertainties in the Measurement of Airborne Radon Daughters," Health Physics, 39: 943-955 (December 1980).
3. Busigin, Anthony and others. "Collection of Radon Daughters on Filter Media," Environmental Science and Technology, 14 (6): 533-536 (May 1980).
4. Cohen, B. L. "Large Scintillation Cells for High Sensitivity Radon Concentration Measurements," Nuclear Instruments and Methods, 212: 403-412 (July 1983).
5. Cross, F. T. and others. "Health Effects and Risks from 222-Rn in Drinking Water," Health Physics, 48: 649-670 (May 1985).
6. Evans, Robley D. The Atomic Nucleus. New York: McGraw-Hill Book Company, 1955.
7. Hinds, William C. and others. "Control of Indoor Radon Decay Products by Air Treatment Devices," Journal of the Air Pollution Control Association, 33: 134-136 (February 1983).
8. Jacobi, W. and K. Eisfeld. "Internal Dosimetry of Radon-222. Radon-220 and Their Short-Lived Daughters," Natural Radiation Environment, edited by K. G. Vahra and others. New York: John Wiley and Sons, 1981.
9. James, A. C. "Dosimetric Approaches to Risk Assessment for Indoor Exposure to Radon Daughters," Radiation Protection Dosimetry, 7 (1-4): 353-366 (1983).
10. Jonassen, Niels and William E. Clements. "Determination of Radon-222 Concentration by an Integrated Count Method," Health Physics, 27: 347-351 (October 1974).
11. Knoll, Glenn F. Radiation Detection and Measurement. New York: John Wiley and Sons, 1979.

12. Little, David R. Analysis of Radon and Radon Progeny in Residences: Factors that Affect Their Amounts and Methods of Reduction. MS thesis, AFIT/GNE/ENP/85M-14. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, March 1985.
13. Lucas, Henry F. "Improved Low-Level Alpha Scintillation Counter for Radon," The Review of Scientific Instruments, 28 (9): 680-685 (September 1958).
14. Moeller, D. W. and K. Fujimoto. "Cost Evaluation of Control Measures for Indoor Radon Progeny," Health Physics, 46: 1181-1193 (June 1984).
15. Nero, A. V. "Indoor Radiation Exposures from 222 Rn and its Daughters: A View of the Issue," Health Physics, 45: 277-288 (August 1983).
16. O'Riordan, M. C. and others. "Some Aspects of Human Exposure to 222-Rn Decay Products," Radiation Protection Dosimetry, 3: (1/2): 75-82 (1982).
17. Rudnick, S. N. and others. "Effect of Plateout, Air Motion and Dust Removal on Radon Decay Product Concentration in a Simulated Residence," Health Physics, 45: 463-470 (August 1983).
18. Thomas, Jess W. "Measurement of Radon Daughters in Air," Health Physics, 23: 783-789 (December 1972).
19. Walker, F. William and others. Chart of the Nuclides (Thirteenth Edition). San Jose CA: General Electric Company, 1984.
20. Wicke, Andreas and Justin Postendoerfer. "Radon Equilibrium in Dwellings," Natural Radiation Environment, edited by K. G. Vohra and others. New York: John Wiley and Sons, 1981.

VITA

John A. Weidner was born on 15 July 1956 in Columbus, Ohio. He graduated from Bishop Hartley High School in Columbus, Ohio in 1974 and attended the United States Naval Academy at Annapolis, Maryland, from which he received the degree of Bachelor of Science in Systems Engineering in June 1978. Upon graduation he was commissioned an ensign in the United States Navy. He completed the course of instruction at the Navy Nuclear Propulsion School in Orlando, Florida and entered the United States Submarine Force in 1979. While serving onboard USS STONEWALL JACKSON (SSBN634) (BLUE) from 1980 to 1982, he was designated "Qualified in Submarines" and completed qualification as a Naval Nuclear Engineer Officer. He served as Radiological Controls Officer onboard the submarine tender USS HOLLAND (AS-32) at Charleston, South Carolina, until entering the School of Engineering, Air Force Institute of Technology, in August 1984.

Permanent address: 3354 Roswell Drive
Columbus, Ohio 43227

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE				
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFIT/GNE/ENP/86M-13			5. MONITORING ORGANIZATION REPORT NUMBER(S)	
6a. NAME OF PERFORMING ORGANIZATION School of Engineering		6b. OFFICE SYMBOL (If applicable) AFIT/ENP	7a. NAME OF MONITORING ORGANIZATION	
6c. ADDRESS (City, State and ZIP Code) Air Force Institute of Technology Wright-Patterson AFB OH 45433			7b. ADDRESS (City, State and ZIP Code)	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION		8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8c. ADDRESS (City, State and ZIP Code)			10. SOURCE OF FUNDING NOS.	
			PROGRAM ELEMENT NO.	PROJECT NO.
11. TITLE (Include Security Classification) See Block 19				
12. PERSONAL AUTHOR(S) John A. Weidner, B.S.S.E., Lt, USN				
13a. TYPE OF REPORT MS Thesis		13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Yr., Mo., Day) 1986 March	
15. PAGE COUNT 82				
16. SUPPLEMENTARY NOTATION				
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB. GR.	Rare Gases, Radon, Radium Radioactivity (1) Natural Radiation, Radiation (1), Ionizing Radiation (2), Alpha Particles	
18	04			
18	08			
19. ABSTRACT (Continue on reverse if necessary and identify by block number)				
Title: Reduction of Radon Progeny in Indoor Air Thesis Chairman: George John Associate Professor of Nuclear Physics				
Approved for public release: 1AW AFR 1984 BY E. WOLAVER 9 May 86 Dean for Research and Professional Development Air Force Institute of Technology (AFIT) Wright-Patterson AFB OH 45433				
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐			21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL Dr. George John			22b. TELEPHONE NUMBER (Include Area Code) 513-255-2012	22c. OFFICE SYMBOL AFIT/ENP

DD FORM 1473, 83 APR

EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

The effectiveness of using three different types of air treatment methods to reduce the concentrations of radon progeny in a residence was evaluated. The air treatment devices were two types of electrostatic precipitators that were designed for use with a whole house heating and cooling system and an ionization air cleaner that was designed for table-top use in a single room.

The air treatment devices were tested in a 100 cubic meter chamber at typical radon gas concentrations of 12.5 to 20.5 picocuries per liter. The modified Tsivoglou method was used to determine radon progeny concentrations and a continuous monitor for radon concentration was in operation, allowing calculation of the equilibrium factor under non-constant radon conditions.

Reduction in average working level measurements and reduction in equilibrium factor were used to evaluate the effectiveness of the air treatments. Radon progeny reductions of greater than 50 percent were observed for all three devices tested at air treatment rates that were comparable to those that would be used in a residence.

The effectiveness of using three different types of air treatment methods to reduce the concentrations of radon progeny in a residence was evaluated. The air treatment devices were two types of electrostatic precipitators that were designed for use with a whole house heating and cooling system and an ionization air cleaner that was designed for table-top use in a single room.

The air treatment devices were tested in a 100 cubic meter chamber at typical radon gas concentrations of 12.5 to 20.5 picocuries per liter. The modified Tsiivoglou method was used to determine radon progeny concentrations and a continuous monitor for radon concentration was in operation, allowing calculation of the equilibrium factor under non-constant radon conditions.

Reduction in average working level measurements and reduction in equilibrium factor were used to evaluate the effectiveness of the air treatments. Radon progeny reductions of greater than 50 percent were observed for all three devices tested at air treatment rates that were comparable to those that would be used in a residence.

END

1/1-S6

DTIC