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The Effects of Home Ventilation Systems on Indoor Radon-Radon Daughter Levels

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FOREWORD

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Technical reports allow comprehensive and rapid publishing of the results of Office of Radiation Programs' intramural and contract projects. The reports are distributed to State and local radiological health offices, Office of Radiation Programs' technical and advisory committees, universities, laboratories, schools, the press, and other interested groups and individuals. These reports are also included in the collections of the Library of Congress and the National Technical Information Service.

I encourage readers of these reports to inform the Office of Radiation Programs of any omissions or errors. Your additional comments or requests for further information are also solicited.

W. D. Rowe, Ph.D.
Deputy Assistant Administrator
for Radiation Programs

PREFACE

The Eastern Environmental Radiation Facility (EERF) participates in the identification of solutions to problem areas as defined by the Office of Radiation Programs. The Facility provides analytical capability for evaluation and assessment of radiation sources through environmental studies and surveillance and analysis. The EERF provides technical assistance to the State and local health departments in their radiological health programs and provides special analytical support for Environmental Protection Agency Regional Offices and other federal government agencies as requested.

This study is one of several current projects which the EERF is conducting to assess environmental radiation contributions from naturally occurring radioactivity.

Charles R. Porter
Director
Eastern Environmental Radiation Facility

ABSTRACT

A study was conducted in a house in Polk County, Florida, to determine the effects of normal home ventilation methods on radon, radon progeny, and working levels. Three ventilation conditions were studied which approximate those found during normal occupancy. The effects of the central air conditioner, the central blower without air conditioning and outside air ventilation were studied, with radon, radon progeny, and working level measurements made sequentially until significant changes ceased to be observed.

In all three experiments, radon, radon progeny, and working levels decreased, with the decreases corresponding to estimated increases in house ventilation rate.

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I. Introduction

The U.S. Environmental Protection Agency's Office of Radiation Programs is conducting a multifaceted study of the radiological implications of the phosphate mining and milling industry in the United States. The study began in June 1974 and has concentrated mainly on facilities located in Florida, North Carolina, and Idaho. The purpose of this study is to evaluate the radiological impact of this industry on the environment and develop appropriate radiation protection guidelines in areas where existing controls are determined to be inadequate.

Phosphate deposits throughout the world are known to contain elevated concentrations of natural radioactivity. This radioactivity originates from the decay of naturally occurring uranium and thorium present in the phosphate ores. Through mining and processing, the radioactive materials are redistributed in the products, by-products, and wastes of the industry. Levels of radioactivity in these media are described by Guimond and Windham (1).

Mining of phosphate ores in the United States began in 1867. Mining at that time entailed the removal of overburden using horse-drawn pans and screening to remove only the pebble phosphate material. Mining was conducted principally on phosphate deposits covered only with shallow overburden and little reclamation was performed on the land. This mining technique, removing only the larger pebble phosphate, resulted in redistributing much of the previously buried radioactive materials on or near the surface. In later years some of the mined areas were reclaimed and returned to uses as any other unmined land. As an indication of the large amount of phosphatic material (and associated radioactivity) not removed by these coarse mining techniques, some of this previously mined but not reclaimed land has been remined in recent years using modern flotation techniques to remove this remaining phosphate matrix.

Modern mining and benefication techniques are much more efficient in the removal of phosphate matrix from the ground. Large electric powered draglines often remove 15.2 - 21.3 meters of overburden which is set aside to fill the mined-out pits. The phosphate matrix is removed by the dragline and dropped into a sluice pit where it is slurried with water and pumped to the washer plant. In the washer plant the slurry is separated into three parts: the phosphate rock, sand tailings, and slime. The radioactivity in these three products is associated principally with the phosphate rock (42%) and the slimes (48%), with a lesser amount (10%) in the sand (1). The sand tailings and slimes (a very fine clay in water suspension) are waste products. The slimes are very slow to dewater and must be maintained in storage ponds for extended periods of time. Modern reclamation techniques make use of the mined-out areas as disposal sites for the sand tailings, slimes, and the overburden which may be used in various combinations for reclamation.

Reclamation techniques vary widely depending on how recently the land was mined, the availability of adequate materials for use in the project, the use for which the land is being reclaimed, etc. Radioactivity in the reclaimed land varies considerably based on the radioactivity in the materials used in reclamation and the proximity of the radioactivity to the surface. For example, if the top 3 - 6 meters of material applied on the reclaimed surface is clean overburden which was removed prior to mining, the reclaimed land will be similar in surface radioactivity levels to the original unmined land. We found this overburden in Florida typically contains radium-226 concentrations of 1-2 pCi per gram. The phosphate matrix material which is mined typically contains 40-50 pCi per gram of radium-226. Therefore, depending on the completeness of removal of the phosphate matrix, the materials used in reclaiming, and the degree of mixing of the materials during reclamation, the reclaimed land could have radium-226 levels ranging from 1 pCi per gram to 50 pCi per gram. It was found in sampling some of the reclaimed land that radium concentration varied widely both horizontally and vertically within small areas such as single building lots.

Vast reclamation projects have been initiated in recent years. An estimated 1.3×10^8 m^2 to 1.4×10^8 m^2 of phosphate mined land has been reclaimed in Florida. The Polk County Health Department estimates that about 1.0×10^8 m^2 have been reclaimed in Polk County and is used as follows:

Use	*Percentage*
Residential	29
Commercial or Industrial	8
Farming	16
Grazing	41
Miscellaneous	6

Presently in Florida about 5.3×10^8 m^2 of land have been mined, and the industry is currently mining about 2.2×10^7 m^2 per year, about half of which is not committed to slime ponds and is thus reclaimable. Consequently, vast amounts of reclaimed land are expected to be made available in Florida for general use.

The radioactivity associated with reclaimed land usage results primarily from radium-226 and its daughter products. Radium-226 is a member of the chain produced by the decay of uranium-238 (figure 1). As the radium decays in the soil it produces radon-222, a noble gas, part of which is free to migrate through the soil to the surface. Radon-222 is radioactive and decays through several daughters to stable lead. Radon reaching the ground surface is normally diluted in the atmosphere and dispersed. However, if a structure is built on the land, the radon diffuses through the slab or floor into the structure and may accumulate. Whether or not the radon and daughters become hazardous depends on the quantity of radon entering the structure and the degree to which it accumulates or remains in the structure. This accumulation rate for radon and its decay products depends mainly on the influx rate and the ventilation or leakage rate from the structure. Under theoretical conditions where no leakage from a structure existed, the radon and its decay products would reach transient equilibrium after some finite period of time. However, the natural infiltration or leakage from structures precludes equilibrium from being attained. In fact, radioactive decay as a removal process is generally small when compared to losses via ventilation effects. The radon/radon daughter composition in structures varies temporally to a degree which makes characterization through repetitive measurements extremely difficult. "Working level" is the unit used to describe radon daughter product concentrations in air. It is defined as any combination of short-lived radon daughters in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy (2).

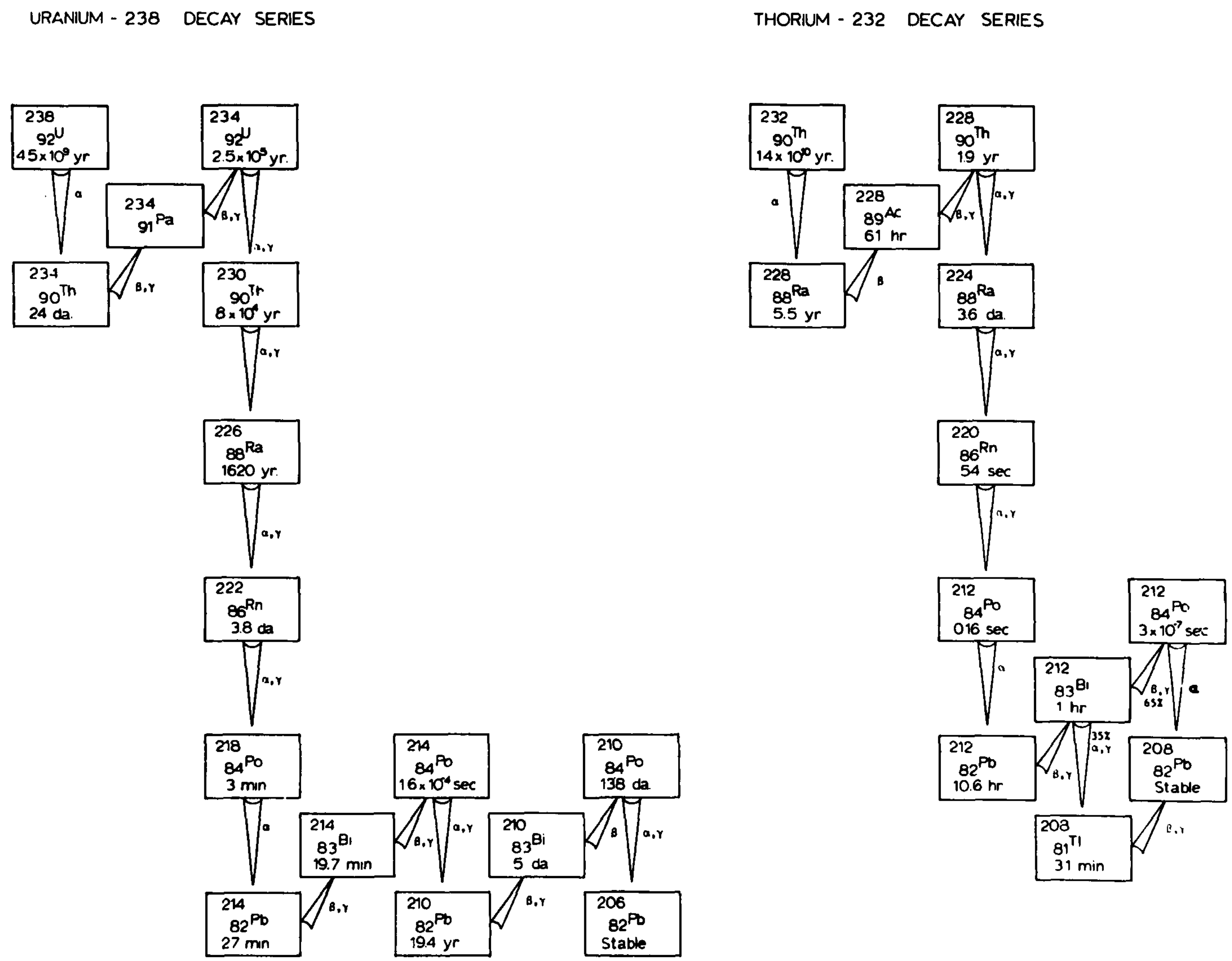

Figure 1. Uranium and Thorium Decay Series

To determine the radiological significance of radon and radon daughters in structures built on phosphate reclaimed land in central Florida, a limited study was begun in 1975. Monitoring devices to determine working level were placed in 125 structures, two-thirds of the structures being on reclaimed land and one-third on land believed to be normal soil. In retrospect, some of the "control sites" were found to be on land in which unmined phosphate formations were present or where phosphate slag or other phosphate material was nearby. The data collected over several weeks indicated that some structures built on reclaimed land had indoor radon daughter levels significantly greater than structures not built on reclaimed land (3). Because of these findings, additional work was begun to evaluate the many parameters which affect the working levels found in structures built on phosphate reclaimed land. The purpose of the work described in this report is to quantify effects of typical home ventilating systems on radon and radon daughter concentrations in homes built on reclaimed land.

II. The Study Site

In July 1976 an unoccupied single family house located in Polk County, Florida, was studied extensively over a period of 17 days and nights to characterize ventilation effects on radon and radon daughter levels. The house studied was located in a subdivision constructed almost totally on reclaimed land.

The house was typical of most houses in the development and of most houses built in that area. It was built on a concrete slab-on-grade and was of concrete block construction. The area of the house was approximately 186.5 m^2 (heated and cooled) with an attached carport. Figure 2 shows the floor plan and salient features of the house. At the time of the study the house had drapes and carpets, but no furniture.

The house was equipped with central heating and cooling, with the furnace and cooling coil located in the attic and ducts delivering the conditioned air to the various parts of the house via ceiling vents. There were two ducts to return air to the central system. One intake grill was located on an interior living room wall near the floor and the other in the ceiling of the hall. The central system was designed to totally recirculate the air with no provision for introduction of outside makeup air. This is typical of most home heating and cooling systems designed for use in this area. A single thermostat located in the central hall controlled the operation of the unit. The house had aluminum cased and framed windows which could be opened for natural ventilation as weather permitted.

III. Methodology

In the course of the study, many parameters were measured in and around the study house. These included radon and radon daughter concentrations, working level, condensation nuclei, temperature, relative humidity, and outside meteorological conditions.

Measurements of radon concentration in the house were made using scintillation counting cells. The cells have a nominal 125 cc volume and are coated on the inner surface with activated zinc sulfide. The ends of the cells are fitted with a quartz window which is optically coupled to a photomultiplier tube for counting. Decaying radon and daughters in a cell produce scintillation in the zinc sulfide coating which are counted by

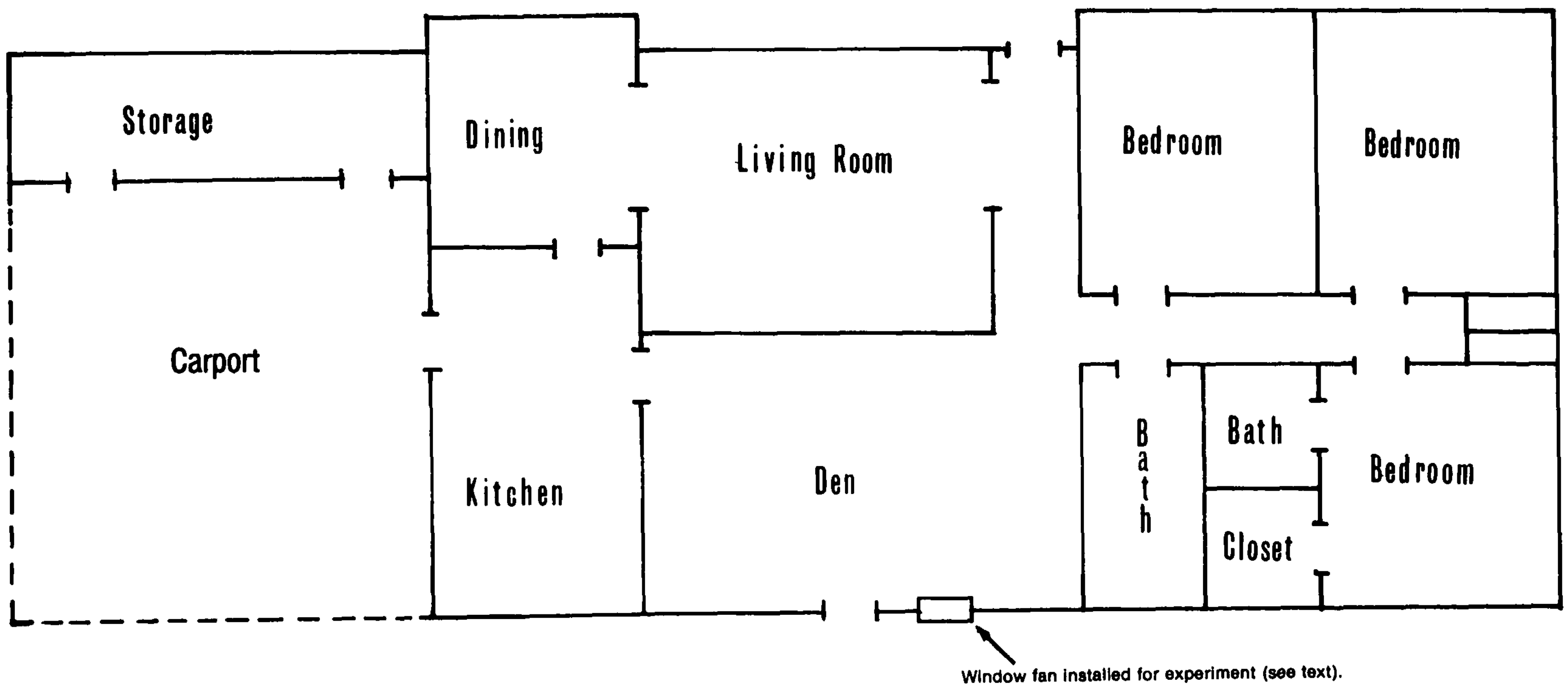

Figure 2. Floor Plan of Study House

the photomultiplier detector. An air sample to be counted for radon is drawn into an evacuated cell through a drying column to remove water vapor and radon daughters. The sample is counted after an appropriate time for radon daughter ingrowth is allowed.

Measurements of radon daughter concentration and working level were performed in several ways. In one method, depending on the daughter levels expected, 50 to 300 liters of air were drawn through an 0.8 micrometer pore size filter which was then counted on an alpha spectroscopy system utilizing a surface barrier detector. Data was accumulated in a 1024 channel analyzer and computer-reduced using the methods described by Martz, et al. (4) for determining the working level and radon daughter values. Methods of data reduction described by Harley and Pasternack (5) were also used in some cases to obtain immediate results at the study site.

Measurements of working level and radon daughters were also made using a prototype instant working level meter (IWLM) developed by Groer, et al. (6) at Argonne National Laboratory. This instrument draws approximately 20 liters of air through a 1.2 micrometer pore size filter, then counts the filter for 3 minutes using both alpha and beta detectors. Data is reduced in the instrument and the working level and daughter concentrations are displayed digitally. From sampling to readout of data requires only 6 minutes. This ability to sample and obtain data rapidly was very useful in the ventilation experiments performed in the house. Working level determinations shown in the remainder of this report were made using the IWLM. Comparisons of data were made between those produced by the alpha spectroscopy methods described previously and by the IWLM (7). Comparison of these two measurement techniques showed that the data produced agreed satisfactorily. The radon daughter concentrations used to estimate ventilation rates and equilibrium ratios were determined by alpha spectroscopy.

Because of the importance in making projected dose calculations from the indoor radioactivity measurements, concentrations of airborne submicron particles were determined. An Environment One Condensation Nuclei Monitor Model Rich 100 was used to monitor the real-time concentration of nuclei in air. The instrument detects particles with diameters of 0.0025 micrometer and larger in concentrations from 50 particles per cubic centimeter up to 10^6 particles per cubic centimeter of air. A recording hygrothermograph was used inside the house to measure relative humidity and temperature. Outdoor meteorological data were obtained from a National Weather Service facility located approximately 9.7 kilometers from the house.

Air velocities through windows or through the ducts and grills of the central heating/cooling system were measured using an Alnor Instrument Company Thermo-Anemometer Type 8500.

IV. Results

Baseline Conditions

At the beginning of the study, the house had been unoccupied and closed for about 10 days. The central heating and air conditioning system had been off for this period and all the windows had been closed. The only air exchange with outside air was due to leakage around or through window and door cracks, flaws in the weather stripping, etc. It was felt that the working level in the house at this time would be at a maximum for the particular set of environmental parameters which affect radon influx into the structure. Several measurements of the working level for the closed structure ranged from .17 to .20 working levels. Outside ambient radon levels (0.5 - 1.5

pCi/l, .003 - .005 WL) determined prior to experiments were sufficiently lower than unventilated levels found in the house (.17 .20 WL) to preclude interference from diurnal variation. Measurements showed the relative radon daughter equilibrium (WLX100/Rn) to range from .41 to .44 for this set of conditions. Only once during the study at this house did the working level rise significantly above these values. Following a very heavy rain late one afternoon the working level rose to a value of .25. At the same time the radon emanation rate from the soil outside the house dropped sharply. It is speculated that the heavy rainfall saturated the soil surrounding the house and in effect "capped" the radon in the ground. The relatively dry soil underneath the slab of the house remains uncapped and allows the radon emanation rate into the house to increase, thus the increase in working level. This hypothesis, along with data on other outside the house measurements, will be examined in a later report.

The degree of radioactive equilibrium between radon and its daughters in a dwelling is dependent on the ventilation rate. These relations have been described by Haque and Collinson (8). If the daughter ratios are known, the ventilation rate may be calculated from the above-mentioned relationship. Due to the short half-life of Ra A, in relation to the time between removal of the filter and counting and the relative low concentrations of daughters involved, the equilibrium between ^{214}Pb (Ra B) and ^{214}Bi (Ra C) is used to estimate ventilation rates. Since the ventilating air contains negligible daughter concentrations in comparison with room air, the relationship between Ra C and Ra B can be solved for the fractional ventilation rate V (min^{-1}).

$$V = \lambda_c \, [(C_B/C_C) - 1]$$

where C_B and C_C are the concentrations of Ra B and Ra C, respectively, and λ_C is the decay constant for Ra C (.035 min^{-1}).

Based on the concentrations of Ra B and Ra C measured in the house during the closed conition, it was estimated that the house had an inherent ventilation or leakage rate of approximately 0.4 - 0.6 air changes per hour. This is consistent with commonly accepted values of .5 to 1.5 air changes per hour for occupied homes (9,10). An unoccupied home such as this one was would be expected to have a slightly lower ventilation rate.

Air Conditioning Operation

Previous unpublished work by this facility and others indicated that operation of a central heating or air conditioning system would reduce the radon and working level inside a home. This was reportedly true even in houses equipped with a system which did not introduce "fresh or makeup" air into the central system. The reduction in working level might be explained by the increased "plate-out" of radon daughters caused by the circulation of house air in the duct system. However, plate-out would not explain the concurrent reduction in radon levels which had been observed. This more likely had resulted from dilution with outside air caused by increased ventilation.

A study was conducted in the house to quantitatively determine the reduction in radon and working level caused by operation of the central air conditioning system. The house had been closed and the air conditioning system off for at least 12 hours prior to the beginning of the study. Measurements of radon and radon daughters were made prior to and at selected intervals for approximately 700 minutes after the air conditioning system was turned on (figure 3, table 1).

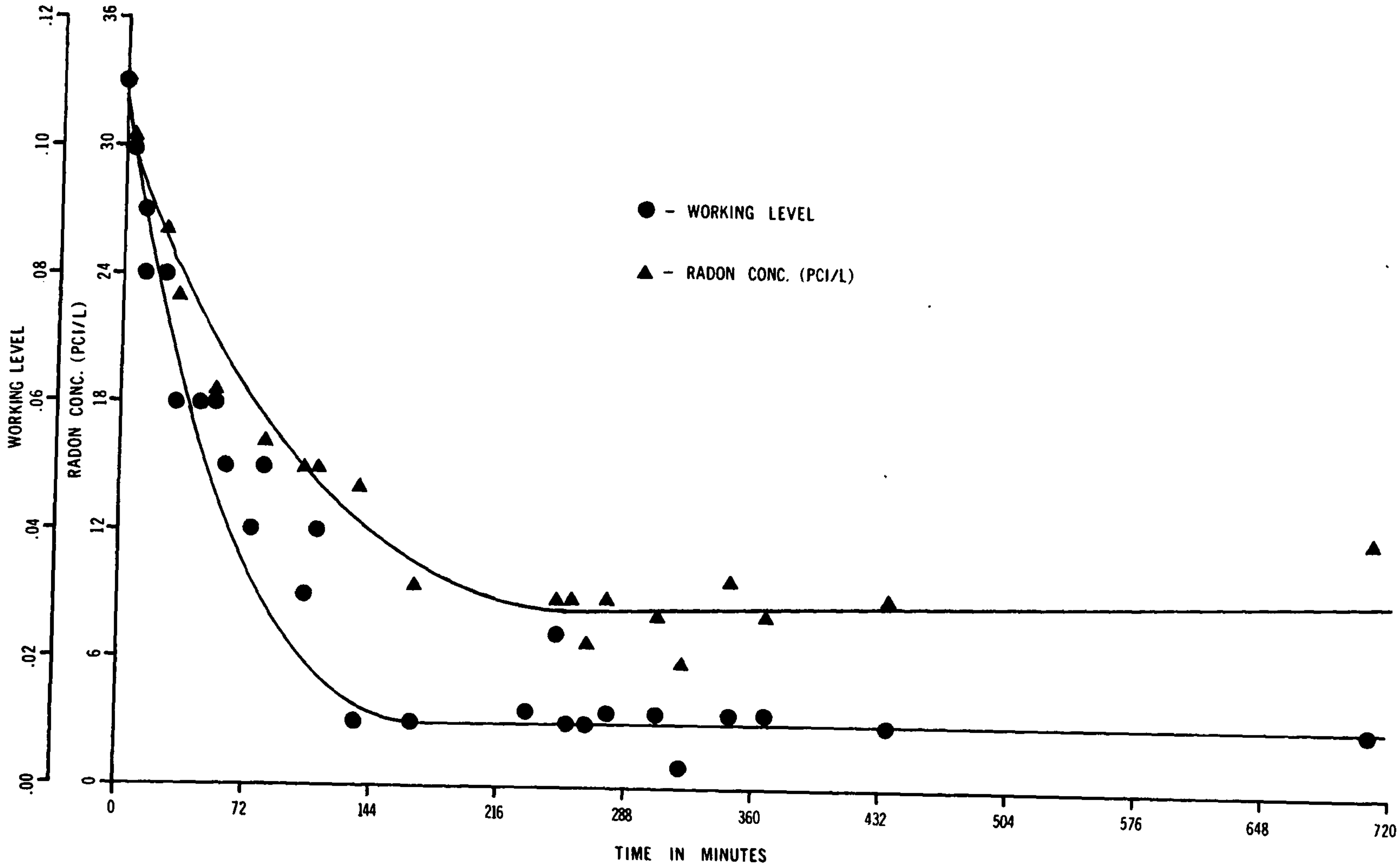

Figure 3. Air Conditioner Depletion

Table 1

Air Conditioning Experiment Data

	Rn (pCi/l)	WL	Equilibrium (WLx100/ Rn)	Condensation Nuclei (Nuclei per cm^3)	Ventilation Rate (Air changes per hr)
Baseline	34	.11	.35	$6x10^3$	.50
Steady State	7	.01	.10	$3x10^3$	2.5

Data presented in figure 3 are an average of two separate but duplicate experiments. After approximately 180 minutes of continuous running, the working level had been reduced by a factor of approximately 10 (from .11 to .01 working level). Radon levels were reduced by a factor of approximately 5.

This reduction in radon concentration would indicate an increase in the effective ventilation rate from .5 air changes per hour up to approximately 2.5 per hour caused by the central air moving system. Since no makeup air is intentionally introduced into the system, it is assumed the increased ventilation rate results from leaks in the duct system and alteration of the relative indoor/outdoor pressures. The radon daughter equilibrium at the onset of the test was .35 and fell to a value of .10 at 300 minutes of operation, where it remained.

At the time the air conditioner was turned on the indoor temperature was 30° C.. The system thermostat was set at 24° C and the system ran continuously for approximately 180 minutes to lower the temperature sufficiently for the unit to cycle. After reaching this point, the unit continued to cycle with approximately 10 minutes off-time and 20 minutes on-time. Outdoor temperatures varied between 28° C and 32° C during the experiment. This setting of the thermostat and resultant operating cycle are as might be expected in a typical occupied home.

Measurements of condensation nuclei concentrations inside the house were made prior to starting and throughout the air conditioning experiment. The initial concentration of nuclei was $6x10^3/cm^3$. During the first 60 minutes of operation of the air conditioning system the concentration rose steadily to a high of $15x10^3/cm^3$ at which time the level began to decline. At approximately 300 minutes after startup the concentration had fallen to $3x10^3/cm^3$ where it remained for the duration of the experiment. The initial rise in the concentration of nuclei was due to resuspension of small particles by the increased air movement. Continued operation of the air conditioning system tended to "clean" the air in the house by circulating it through the filter system.

Air-flow through the air conditioning duct system was measured using a thermoanemometer at the return air ducts. The measured value was approximately 0.47 m^3/s entering the return plenum. Literature for this particular air conditioning system lists desirable air flows between 0.56 - 0.66 m^3/s.

Central Fan Operation

It is believed that the reductions in working level and radon as measured during the air conditioning experiment resulted from the movement of air and not as a result of cooling the air. If this were the case, then the central heating system or simply the operation of the central fan or blower would have the same effect.

Measurements of radon concentration and working level were made prior to and at selected intervals for 600 minutes after the central blower was started (figure 4, table 2).

Table 2

Central Fan Experiment Data

	Rn (pCi/l)	WL	Equilibrium (WLx100/ Rn)	Condensation Nuclei (Nuclei per cm^3)	Ventilation Rate (Air changes per hr)
Baseline	25	.09	.33	5x10^3	.57
Steady State	5	.01	.15	3x10^3	2.1

Data presented in figure 4 are an average of two separate but duplicate experiments. After approximately 180 minutes of operation the working level had been reduced from .09 to .01, a reduction of 9. Radon levels had been reduced by a factor of 5. These reductions are consistent in magnitude and time with those achieved in the air conditioning experiment. The radon daughter equilibrium was .33 at the onset and fell to a value of .1-.2 after 300 minutes of operation.

Estimated ventilation rates increased from .57 air changes per hour at the beginning of the experiment to 2.1 air changes per hour after 300 minutes.

The central fan system ran continuously during the experiment with no cycling. Air flow in the duct system was the same as in the air conditioning experiment. Inside temperatures ranged from 28. - 35° C during the experiment. Outdoor temperatures ranged from 28° C to approximately 34° C. Indoor temperatures were higher than outdoor because of the air being circulated through the hot duct system in the attic.

Condensation nuclei concentrations varied much the same as in the air conditioning experiment. At the start of the experiment the concentration was 5x10^3/cm^3, rose to 12x10^3/cm^3, then declined to approximately 3x10^3/cm^3 where it remained.

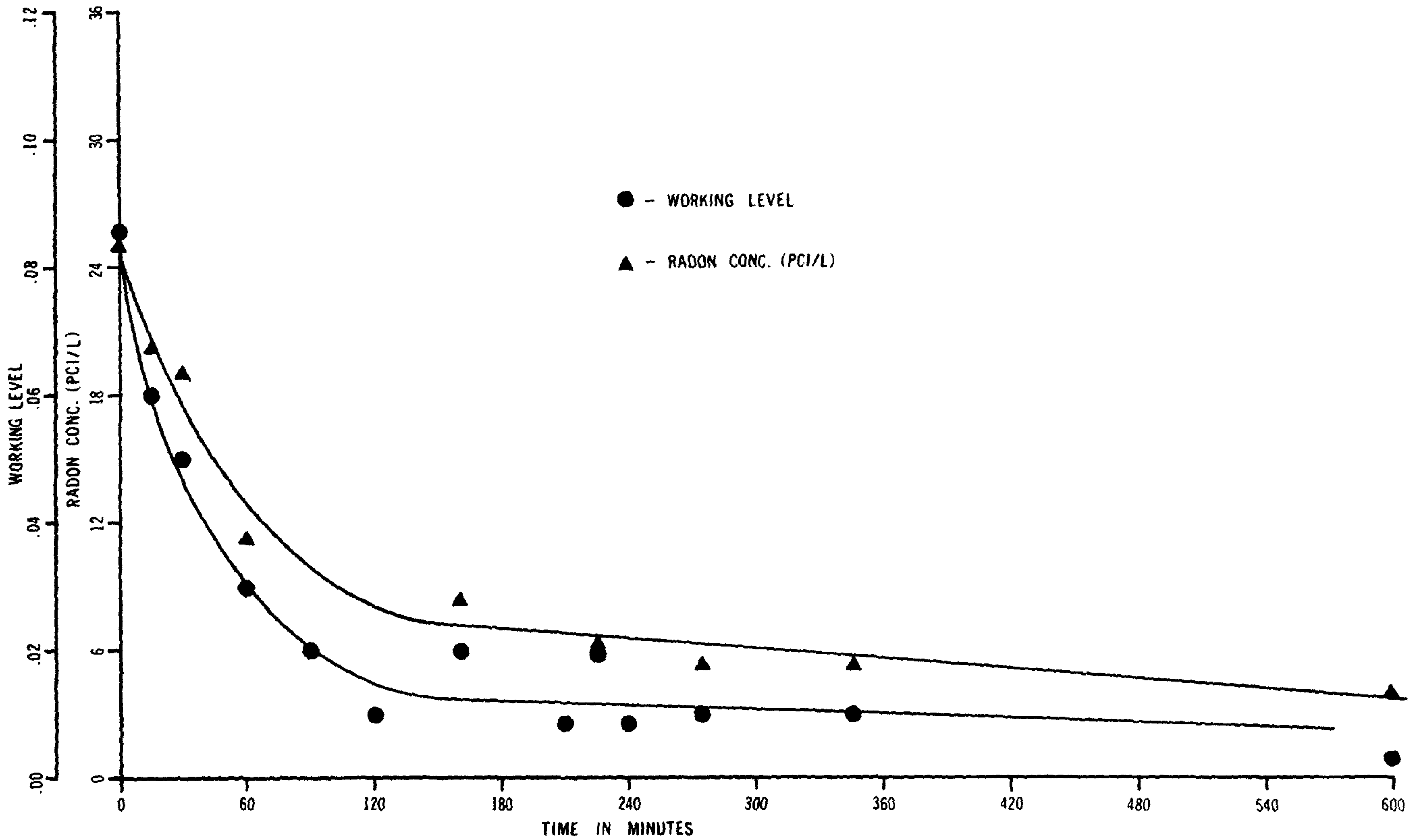

Figure 4. Central Fan Depletion

All reductions in working level and radon, changes in equilibrium, increases in ventilation rate, and condensation nuclei concentrations were consistent with those measured in the air conditioning experiment. This indicates that the reduction in radon and daughters was the result of increased ventilation rate due to air movement in the central duct system, not the cooling of air.

Outside Air Ventilation

Another ventilation condition commonly encountered in most homes is when windows are opened and outside air is purposefully allowed to circulate through the house. The outside air at the time of this study had radon concentrations between 0.5 and 1.5 pCi/l and working levels between .003 and .005. While both the radon and working level values are slightly high for normal outside air, it is believed that the large amount of radon entering the atmosphere from nearby large phosphate land tracts may cause somewhat elevated levels in this area. It was expected that these levels would quickly dilute the indoor levels when ventilation was initiated.

To obtain an accurate measurement of the quantity of outside air entering through the open windows, a window fan was used to exhaust a measured amount of inside air. Measurements showed that the influx rate of outside air equaled the exhaust rate of the fan. The fan was installed in a den window (see figure 2) and used to exhaust indoor air from this location. Windows in the other rooms of the house were opened different amounts to assure approximately equal air-flow through each room. The fan exhausted 0.68 m^3/s with approximately equal movement of air throughout the various areas of the house. The interior of the house had a volume of approximately 453 m^3, thus the flow of 0.68 m^3/s represents an air turnover rate of 5.4 changes per hour. Though many houses don't use window fans, it was felt that the relatively low flow rate through the house caused by the fan would be typical of what may be encountered with all windows opened fully and a slight breeze outdoors. As an example, assuming two open windows (.61 x .45 m openings) on the upwind side of the house, adequate outlet windows open on the downwind side, and a 4.8 - 8.0 kilometer per hour outside breeze, the ventilation rate was calculated to be between 0.41 and .69 m^3/s (11). Thus the condition established by operation of the window fan is typical of what might be seen if house windows remained open on a typical day with light winds.

All measurements of radon and working level in the house were made in the central hall to avoid sampling in a direct flow of incoming outside air. Measurements of radon and daughters were made prior to and at selected intervals for 160 minutes after the windows were opened and the window fan started (figure 5, table 3).

Data presented in figure 5 are an average of two separate but duplicate experiments. Working level values dropped from .11 to background (approx. .01) in 20 minutes. Radon concentrations also fell in 20 minutes from 25 pCi/l to 1.5 pCi/l which also is background. Based on the volume of air being moved by the fan, this reduction occurred after 1.8 air changes in the house.The radon daughter equilibrium also fell rapidly from .30 down to .08 at 26 minutes.

Condensation nuclei concentrations prior to starting the fan were $1.7x10^3/cm^3$. At 18 minutes after the windows were opened and fan started the nuclei concentration had risen to $36x10^3/cm^3$ and began to decline slightly. This was caused by the influx of dusty outside air (and/or the pickup of indoor dust).

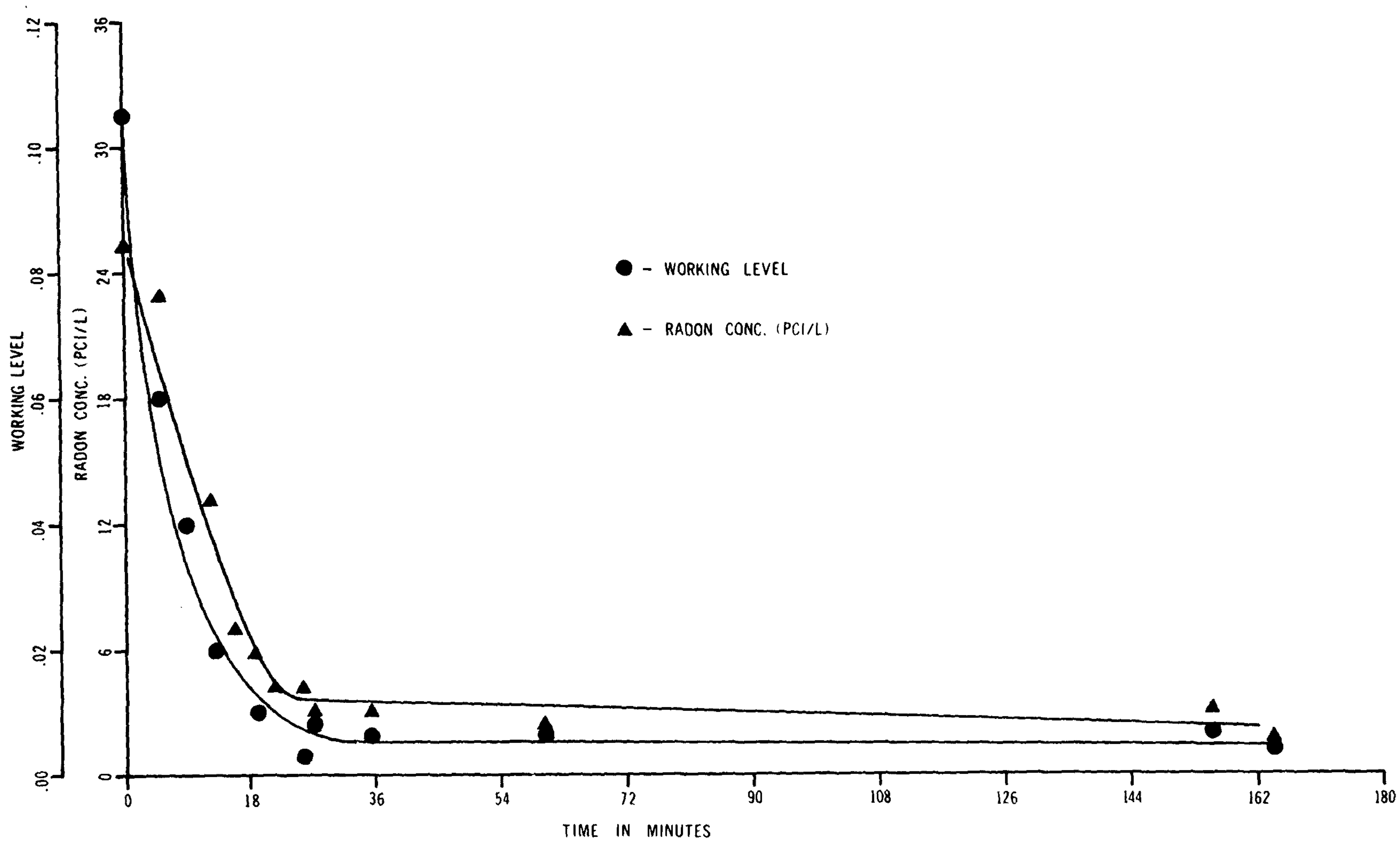

Figure 5. Window Fan Depletion

Table 3

Outside Air Ventilation Data

	Rn (pCi/l)	WL	Equilibrium (WLx100/ Rn)	Condensation Nuclei (Nuclei per cm^3)	Ventilation Rate (Air changes per hr)
Baseline	25	.11	.30	$1.7x10^3$	.50
Steady State	1.5	.01	.08	$20\text{-}36x10^3$	5.4

Ingrowth from Background

The rate of ingrowth or buildup of radon and daughters depends primarily on the input rate of the radon and the leakage rate from the house. As mentioned previously, the input rate is dependent also on soil moisture and atmospheric conditions such as barometric pressure. For this given house and its leakage rates and a given set of influx conditions, the ingrowth rate was determined. The house had been opened and completely ventilated prior to start of the experiment. Working level and radon concentration in the house were at background or outdoor levels. The ingrowth was measured through approximately 750 minutes after the house was closed (figure 6). Data presented in figure 6 are an average of three separate but identical experiments. It is interesting to note that after 80 minutes of ingrowth the working level only reached approximately 5 percent of the final baseline or equilibrium value of 0.2 working level which was found in the house after being closed for 2 weeks. During normal operating cycles of the air conditioning and heating units in which the house would normally be closed, an "off" cycle of 80 minutes or longer would be unusual. Therefore, under these conditions for this house the working level would not be expected to approach the "closed house" equilibrium value. After approximately 10 - 12 hours the ingrowth rate declines but continues to increase toward the equilibrium level.

Prior to closing the house when the indoor levels were at outside or background levels, the radon daughter equilibrium was .03. After approximately 500 minutes the equilibrium had risen steadily to .32. Baseline equilibria were reported earlier and were measured at .41 to .44 for this particular house.

V. Discussion

The study house located in the central Florida phosphate area was built using construction materials and methods typical to many if not most other houses built in that area in the past several years. Other than the normal weatherstripping which is built into aluminum windows and pre-hung door units, no steps had been taken to reduce the natural infiltration of outside air into the house. The estimated turnover rate of .5 air changes per hour is what might be expected from an unoccupied house of this design. The best available data suggests that the average turnover rate for an occupied single family house may be as high as 1.5 changes per hour

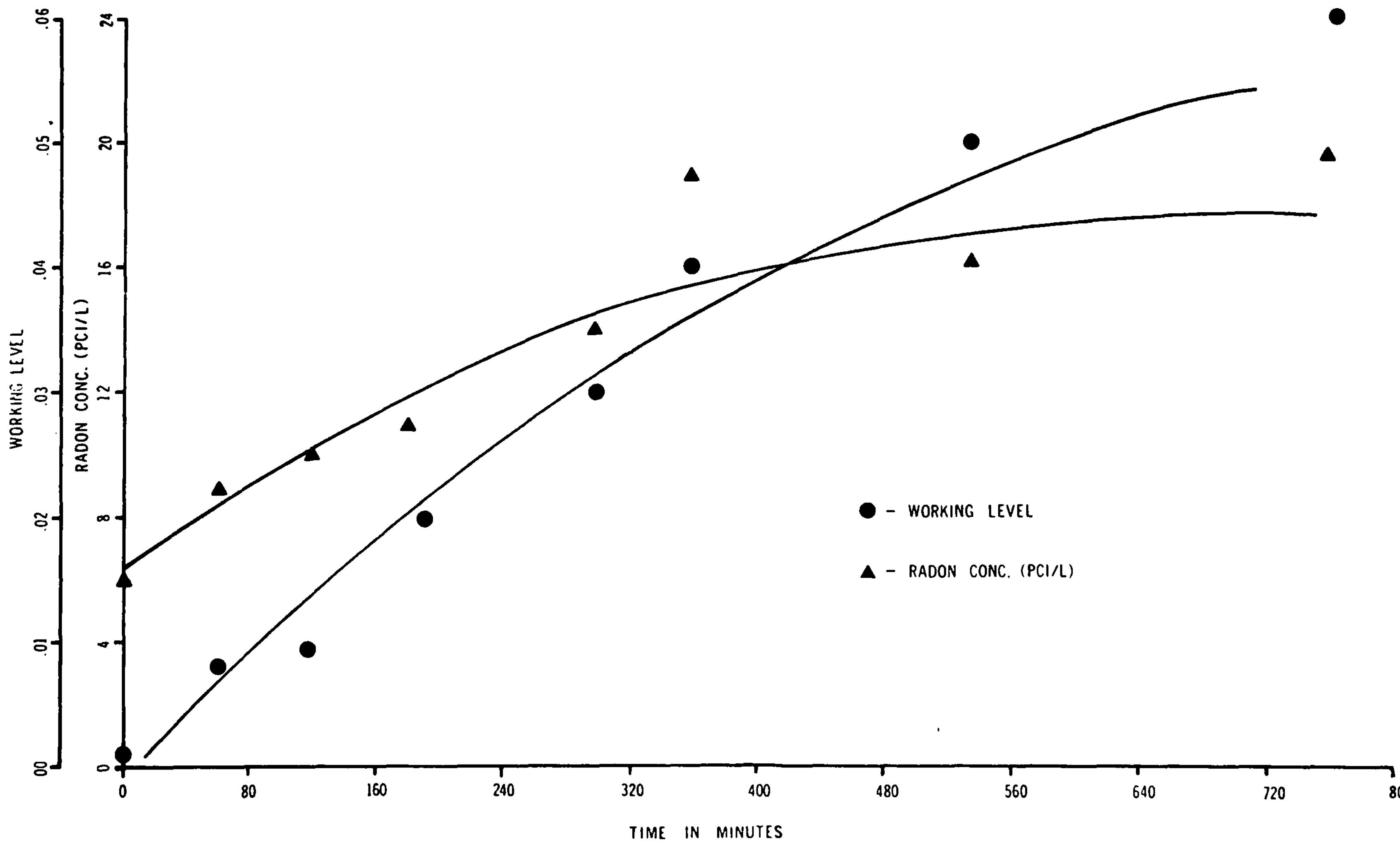

Figure 6. Ingrowth

(9,10). Therefore, it is felt that data obtained in the study house would be generally applicable to other structures of similar design if the different radon influx rates are factored in. This has been confirmed to a degree by a similar set of experiments, though less extensive, conducted in 3 other houses in the area. The reductions in working level and radon were very similar in time and magnitude to those measured in this study house.

Some structures which differ appreciably in natural infiltration or ventilation rate would produce depletion and ingrowth rates different from those described above. In an old or poorly built new structure in which the natural leakage rate was high, the working level buildup would not be as great for the same radon influx. Likewise, the operation of a central air movement system would produce a more rapid reduction in radon and working level. In a newly built house which incorporated extensive measures toward being an "energy efficient" structure the natural infiltration or leakage would be low and thus depletions would occur less rapidly and buildups more rapidly for a given radon influx. It has been reported (10) that the greatest percent WL reduction occurs where the initial ventilation rate is lowest, with the percent WL reduction gradually decreasing until little further reduction is seen. For these reasons, in conducting surveys of homes in which working level is to be measured, it may be necessary in some cases to have an indication of the natural leakage rate. This can be obtained by actual measurement or through estimation. Measurement of this parameter is more accurate but requires greater time and equipment. Several techniques have been reported which employ the measurement of the depletion rate of gases such as sulfur hexafluoride or helium which had been introduced into the structure. The method used in our study and described earlier in this report employs the ratios of the daughters of radon to estimate the ventilation rate. The American Society of Heating, Refrigeration, and Air-Conditioning Engineers Handbook (11) describes methods for estimating leakage based on numbers and sizes of windows and doors plus other factors. For houses which are suspected of falling outside of the normal leakage rate of .5 to 1.5 air changes per hour, one of these methods should be used to find the actual ventilation rate.

In addition to the effects of the leakage rates, the living habits of the occupants have a great influence on the working level which may be measured. For example, a home which has several children who frequently exit and enter the house will have a greater turnover rate than a home which has no children and the adult occupants work during the day. The preference of the occupants for running the air conditioning system versus that for fresh air and opening windows must also be taken into account. Seasonal changes in the natural climatic conditions will also have an influence on the extent to which the occupant depends on outside air or the air conditioning/heating system.

As a result of the factors discussed, it follows that a "grab sample" or short duration measurement of working level will generally not represent the average or typical condition for a structure. It was shown that for a given radon input rate for a particular house, the working level as measured at any one period in time would be dependent on where the heating or cooling system was in its operating cycle or the number of windows and/or doors open. If the central heating/cooling system was operating on a relatively short cycle (3 - 6 cycles per hour) then the working level as measured could vary by a factor of 10. For this reason we believe that a single measurement of working level with no regard for these other factors could be very misleading in estimating an average value. To circumvent these problems, it would be necessary either to account for these variables at the time of measurement or take an integrated measurement over a sufficient time period to find the average working level. For purposes of expediency it may be necessary in some houses to take a grab sample and factor in these variables. In such a case it would be desirable to know the maximum working level which could be expected at equilibrium and the average working level. Because of the many parameters which affect the working level and all of the factors which would have to be accounted for a separate report is being prepared which deals with this problem. Mathematical models are being prepared which can be used in conjunction with limited measurement data in a structure to estimate a maximum and average working level for the structure taking into account these variables.

One method of working level determination which minimizes many of these measurement problems employs techniques that integrate the measurement over an extended period. One method used extensively in the reclaimed phosphate land evaluation is the track etch film dosimeter (3). This is a passive measurement device left in a structure for a 6 to 18-month period to measure the average working level. Alpha energy released by the airborne radioactive daughters causes ionization tracks on the film surface. Upon development or etching the tracks can be counted and the density of the tracks related through calibration factors to the working level in the house. For the house employed in this study a track etch film was in place for 9863 hours during which time the house was occupied and recorded an average of .077 working levels for the period. As noted in the previous discussion, an instantaneous measurement could have fallen anywhere between 0.2 and .005 working levels.

Another integrating measurement technique which has been used in this house is the thermoluminescent dosimeter (TLD) air pump (3). With this device air inside the house is pumped through a filter system which collects the radon daughters. Alpha energy from the daughters exposes a TLD chip which is evaluated in a reader to indicate the total alpha energy absorbed by the chip. A TLD chip is normally exposed for a 1-week period. To determine average working level and to average seasonal effects, at least four separate pumpings should be conducted over a 1-year period. Because of logistics problems, only three pumping periods were obtained in the study house during normal occupancy. These produced an average working level value of .067 for the three periods. The total sampling time for the three periods was 74 hours, somewhat short of the desirable time of 600-700 hours for four pumpings in 1 year.

The Office of Radiation Programs publication, "A Preliminary Evaluation of the Control of Indoor Radon Daughter Levels in New Structures," describes technology for control of radiation levels in new structures(10). Of the technologies described for the control of indoor radon daughters, several are not easily applicable to structures which have already been built. For instance, the removal of reclaimed material, or pouring an extra thick concrete slab, or the use of a sealant could not easily be applied to existing structures. One method described in the report, improved effective ventilation, is more easily applied to existing structures. Methods of increasing effective ventilation require either introducing controlled amounts of relatively radon free air for dilution or physical removal of daughter products on a filter or electronic air cleaner.

Data presented earlier in this report substantiate the usefulness of outside air as makeup air for dilution and reduction of working level. From our evaluation of the natural infiltration rate for the study house (approximately .5 air changes per hour, unoccupied), it appears that this volume of dilution plus the increased dilution gained by operation of the central blower is adequate to reduce the indoor working level a considerable amount. In the case of the study house, should it be deemed necessary based on any applicable guidance to lower the indoor working level, it may be sufficient to assure periodic operation of the central blower system. This could be accomplished with a timer used in conjunction with the central blower control to cause periodic operation of the blower, regardless of the normal demand placed on the blower by the heating/cooling thermostat. This system should be cheaper to install, operate, and maintain than a combination of intentionally introduced makeup air and daughter product removal. In addition to the reduction in working level obtained, there would be the added benefit of air being circulated in the house which helps maintain more comfortable living conditions throughout.

In some cases it may be desirable to assess the effectiveness of a blower system prior to the purchase and installation of control timing devices. This assessment is easily accomplished by closing the structure without operating any ventilation system for a time sufficient for ingrowth (12 - 14 hours), and measuring the working level. The blower is then operated for several hours and the working level measured again. If the percent reduction is adequate, then an appropriate timer can be selected and installed to operate the blower as required to maintain the working level within acceptable guidelines. If the central blower system alone did not acceptably reduce the level, then other methods of control may be considered.

VI. Summary and Conclusions

Data are presented in this report as to the effect of natural ventilation and operation of central heating/cooling systems on radon concentration and working level in a house built on reclaimed phosphate land. The effects of these systems on condensation nuclei concentrations, radon daughter equilibrium states, and air turnover rates are also discussed. From the data presented in the report the following conclusions are reached:

1. *The influx of outside air through open windows is very effective in reducing indoor working level.*

With airflows through the house which are typical of that expected during a day with a 4.8-8.0 kilometer per hour outside breeze and windows open, the working level is reduced by a factor of 10 or more in 20 minutes.

2. *Operation of the central blower system, through forcing increased ventilation, is effective in reducing indoor working level.*

The increased ventilation rate resulting from operation of the central blower system causes a reduction by a factor of 10 in the indoor working level after approximately 180 minutes of operation. More limited measurements in three other houses produced similar results.

3. *Ingrowth or radon daughters and resultant working level occurs at a rate dependent on several factors.*

The influx rate of radon into the structure and the effective ventilation rate of the structure primarily determine the working level ingrowth rate. Factors such as recent heavy rainfall were seen to greatly influence the radon influx rate and thus working level in the structure.

4. *A single grab sample or short term measurement of working level could vary significantly from the average working level.*

Trying to estimate an average working level for a structure based on a short term sampling method will in all probability produce results which are in error, possibly by as much as a factor of 10. The central heating/cooling system in its normal operating cycle can produce widely varying results. For an accurate determination of average working level either the many influencing parameters must be accounted for or an integrated type measurement must be made.

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16. ABSTRACT

A study was conducted in a house in Polk County, Florida, to determine the effects of normal home ventilation methods on radon, radon progeny, and working levels. Three ventilation conditions were studied which approximate those found during normal occupancy. The effects of the central air conditioner, the central blower without air conditioning and outside air ventilation were studied, with radon, radon progeny, and working level measurements made sequentially until significant changes ceased to be observed.

In all three experiments, radon, radon progeny, and working levels decreased, with the decreases corresponding to estimated increases in house ventilation rate.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Radon Isotopes	Radon Progeny	1802
Environmental Radioactivity	Radiation Surveys	1806
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