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REDUCTION OF RADON WORKING LEVEL BY A ROOM AIR CLEANER

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ABSTRACT

A room air cleaner containing HEPA-type and activated carbon filters was exposed to a controlled chamber environment in which the concentrations of radon and condensation nuclei were capable of being selectively varied. Experiments were conducted using specified ranges of air cleaner flow rates (80-150 cfm), radon concentrations (13-33 pCi/l), and condensation nuclei concentration (3000-47500 cm-3). Preliminary reduction tests monitoring Working Level over time during air cleaner operation provided timing information for the subsequent steady-state protocol. Grab and semi-continuous monitoring of radon and filter sampling for determination of ^{218}Po(RaA), ^{214}Pb(RaB), and ^{214}Bi(RaC) were obtained at steady-state levels prior to and after operation of the air cleaner. Alpha-decay monitors and modified Tsivoglou counting techniques were employed for analysis of the Working Level. The chamber conditions: radon and condensation nuclei concentrations, infiltration rate, temperature, and dew point were monitored during all tests. A reduction in radon concentration was not observed. However, the total Working Level was reduced with an average removal of 86.5% over a variety of test conditions.

INTRODUCTION

Epidemiological studies associated with exposure to elevated levels of radon have shown an increased risk of developing lung cancer in humans (1,2,3). The Environmental Protection Agency (EPA) reports that about 5,000 to 20,000 lung cancer deaths a year in the United States may be attributed to indoor radon (3). It has been shown that the hazards of radon do not come from radon itself, but from the radioactive decay products formed in the natural breakdown of radon (1,2,3). These radon decay products are charged atoms of heavy metals that readily attach themselves to airborne particulates. The main health problems stem from inhaling the unattached radon decay products and dust particles carrying radon decay products (1,2,3). As one breathes, the radon decay products become trapped within the lung. As these decay products naturally decay, they release small bursts of energy in the form of alpha, beta and gamma radiation which can damage tissues in the lung and lead to lung cancer (1,2,3). An illustration of the radium decay series along with the total alpha energy associated with the natural decay of the individual radon decay products is presented in Figure 1.

The standard measure of concentration of radon decay products is Working Level (WL), and prolonged exposure to radon decay products over time is measured in Working Level Months (WLM). WL is a unit of measure of the concentration of radon decay products defined as the quantity of short-lived decay products [^{218}Po(RaA), ^{214}Pb(RaB), ^{214}Bi(RaC), ^{214}Po(RaC')] that will result in 1.3 x 10^5 MeV of potential alpha energy per liter of air (3). This is approximately the amount of alpha energy emitted by one WL of radon decay products when in secular equilibrium with 100 pCi/L of radon (^{222}Rn). Due to a variety of reasons, the EPA assumes an equilibrium factor of 0.5 between radon and radon decay products in typical home environments. Therefore, one WL of radon decay products is in equilibrium with 200 pCi/L of radon. WLM is defined as a unit of radon exposure equivalent to one WL of radon decay products for one working month, or 170 hours. This is historically derived from the typical duration of occupational exposure of miners in one month (3).

The EPA currently combines WL measurements with epidemiological studies of underground miners to estimate the risk of developing lung cancer from exposure to radon to the general population. These risk estimates are based on the effective cummulative lifetime exposure to radon in WLM adjusted for inhalation rates and duration of exposure by taking into account that miners have higher breathing rates and shorter exposure times than the general population (3). EPA's risk estimates assume a minimum induction period of ten years with a relative risk of 1% to 4% chance of developing lung cancer per WLM. It also estimates a linear dose/response relationship with no threshold level. Based on this assumption, a higher cumulative exposure to radon will result in a proportionally higher risk of developing lung cancer (3).

In this study, a room air cleaner was tested for its ability to reduce both radon gas and total WL of radon decay products in a test chamber held under conditions representative of home dwellings. The purpose of this study was to evaluate the potential role of utilizing a room air cleaner in reducing the concentration of radon decay products in rooms until primary mitigation of indoor radon occurs via EPA recommended guidelines.

Therefore, the following objectives were established for this study in order to verify this concept: 1) to determine if a room air cleaner containing both activated carbon and HEPA-type filters could be used to reduce radon gas and the WL of radon decay products in a room under controlled steady-state conditions representative of home environments; 2) to determine what conditions would affect the removal of radon decay products in a room by an air cleaner (i.e., by varying the radon concentration, condensation nuclei concentration and air cleaner flow rate); 3) to determine the removal of each individual short-lived radon decay product (RaA, RaB, and RaC) by a room air cleaner under a variety of steady-state conditions; 4) to determine if a room air cleaner containing a HEPA-type filter could reduce the concentration of condensation nuclei in the size range typically found in home dwellings; 5) to establish the maximum size room in which an air cleaner could be used and still effectively reduce the WL of radon decay products; and 6) to determine the environmental limitations within the home and operational conditions of the air cleaner for optimum performance in reducing radon decay products.

PROCEDURE AND EQUIPMENT

A consumer product currently being marketed as a room air cleaner for the removal of airborne particulates was tested to determine if it could reduce the WL of radon decay products in a room. The room air cleaner as shown in Figure 2 is a portable stand-alone cabinet design which utilizes five separate filters: 1) a final filter containing activated carbon impregnated into non-woven polyester material; 2) a HEPA-type filter designed with over 41 square feet of HEPA-type material to remove particles down to and below 0.01 microns in size; 3) two activated carbon filters each covered with a layer of non-woven polyester containing 4 1/4 pounds of activated carbon held in place by a honeycomb matrix to prevent settling inside the filter; and 4) a prefilter made of open-cellular polyurethane foam material. The room air cleaner was capable of operating at four separate flow rates representing airflows of 40, 80, 120 and 150 cubic feet per minute, respectively. During this study, only the three highest air flow rates were tested.

The room air cleaner was tested by placing it into a chamber capable of representing conditions within home dwellings. The chamber utilized for this study is illustrated in Figure 3 and was the Radon/Radon Daughter Environmental Chamber at the Department of Energy Technical Measurements Center, Grand Junction, Colorado. This test chamber has the ability to vary radon concentration, condensation nuclei concentration, infiltrating airflow rate, temperature and dew point. The environmental parameters of the test chamber were held as constant as possible and were intended to represent a typical home environment (air exchange rate, 200 liters/minute or 0.5 air exchanges per hour; temperature 17-22°C; and dew point 1-15°C). The radon concentration was maintained at one of two experimentally selected ranges of 13-15 pCi/L or 29-33 pCi/L. The condensation nuclei concentration (CNC) was selectively varied between 3,000-47,500 particles/cm^3. Concentration of RaA, RaB, and RaC were obtained from the test chamber by measurement of the alpha-decay of particles on sample filters collected from air sampled during the steady-state conditions within the chamber. The testing protocol utilized a combination of standard radon and radon decay product sampling procedures (4,5). The concentration of RaA, RaB, RaC and total WL were calculated using a modified Tsivoglou counting procedure (5). This procedure takes measurements of alpha decay counts at intervals of 2-5, 6-20 and 21-30 minutes following the end of the five minute sampling period. The volume of air pulled through the filters during this five minute sampling period is recorded and used in the calculations.

Throughout the entire set of experiments, the temperature and air exchange rate within the chamber were held constant. The concentration of radon and condensation nuclei were adjusted to specific levels as designed for the individual experiments. The radon concentration within the chamber was adjusted by varying the ratio of the supply air through the radium 226 sources. The concentration of condensation nuclei within the test chamber was changed by adjusting the setting of a rotometer which controlled the uptake of the 0.2% (w/w) fluorescein solution. The solution was then aerosolized by means of a nebulizer into the infiltrating air to the test chamber.

During a given set of experiments, the room air cleaner was installed with a new set of filters and placed into the center of the test chamber and connected to an externally controlled power outlet. The room air cleaner was programmed to operate at a preset airflow rate when the remote power switch was activated. Once the initial steady-state condition has been reached, the conditions within the test chamber were monitored. The air cleaner was then activated until a new steady-state was established. In order to measure the time required to reach the air cleaner operating steady-state condition, preliminary tests were designed to measure the actual air cleaner reduction time period.

The concentration of radon decay products were measured utilizing a five minute, open-faced filter sampling technique for both initial and final steady-state conditions. When the air cleaner was turned on, several open-faced filters were utilized for the following 20-60 minutes in order to monitor the reduction of the WL of radon decay products in the test chamber.

The reduction of condensation nuclei within the test chamber was also monitored as an indicator of when steady-state conditions were obtained. Steady-state conditions were considered to be achieved when no significant change in the concentration of condensation nuclei occurred over time. In addition to the observed steady-state condition of condensation nuclei, the time between the initial steady-state and air cleaner steady-state conditions were determined based on the theoretical CN removal curve as determined by a mass balance equation (6). The time to achieve 98% theoretical reduction in CN is given in Table 1. For the purposes of this study, the minimum time used to measure the radon decay products was one hour after air cleaner operation at 150 cfm. During May 1987, experiments were conducted utilizing a room air cleaner to determine the timing protocol for the steady-state procedure. In order to obtain additional data on the room air cleaner, performance studies from July to August 1987 employed two air cleaners which were used in successive experiments within the same testing day. The use of the second air cleaner occurred immediately after measurements of the first air cleaner operating steady-state. The first air cleaner was turned off and the second air cleaner was activated. The necessary equilibration time had to elapse prior to measurement of the second air cleaner steady-state condition. An illustration of the single and successive room air cleaner steady-state procedure is given in Figure 4.

Actual data obtained during the initial steady-state and air cleaner operating steady-state is shown in Figure 5. Results indicate that when the air cleaner is activated, it takes 30-35 minutes to remove about 90% of the WL of radon decay products. This is in good agreement with the theoretical predictions based on the mass balance equations for CN removal. Furthermore, Figure 6 indicates that only 58.6% of RaA is removed while 94.0% of RaB and 97.8% of RaC is removed by the room air cleaner once steady-state conditions have been reached. These studies also found that the room air cleaner did not reduce the radon concentration in the test chamber under any conditions. Since radon is not removed, it will always produce RaA before the air cleaner can remove it completely. Determination of the size distribution of CNC within the test chamber was found to have the majority of CN in the range of 0.04222-0.2371 um based on midpoint diameter. This size range has been found to be within the typical size range of CN in home environments (7).

RESULTS AND DISCUSSION

The reduction in WL of radon decay products by the room air cleaner operating in a test chamber under steady-state conditions is presented in Tables 2 and 3. Results indicate that the air cleaner can significantly reduce the WL by an average of 86.5%. These results were obtained under a variety of test conditions and involved a total of 27 studies. The airflow rate of the air cleaner was shown to have the greatest impact on reducing the WL as would be expected since a lower airflow rate of the air cleaner will not process as much filtered air in a given time period under steady-state conditions. Test results indicate that the air cleaner reduced the WL by an average of 86.9% at 150 cfm, and 82.7% at 80 cfm. Table 3 demonstrates the accuracy and precision of the test procedure under a variety of steady-state conditions. The comparison of performance at 150 cfm and 80 cfm can be utilized for determining the air cleaners performance in various size rooms. A reduction in airflow from 150 cfm to 80 cfm in an 850 ft^3 chamber would yield a modeled condition of a chamber volume of approximately 1,600 ft^3 with the air cleaner operating at 150 cfm. Although these assumptions do not take into account surface to volume ratios and mixing factors within the chamber, it still allows one to estimate the largest size room for which the air cleaner would be effective in reducing the WL. In addition to these assumptions, theoretical calculations were performed using the results obtained when the air cleaner was operating at 80 cfm by using a mass balance equation which takes into account the steady-state conditions of the test chamber (6). These calculations indicate that the air cleaner would be effective in removing radon decay products in rooms at least 1,600 ft^3 while operating at 150 cfm.

Test results showing the reduction of condensation nuclei concentration (CNC) by the air cleaner as monitored by a TSI Model 3020 Condensation Nuclei Counter are shown in Tables 4 and 5. The initial steady-state conditions for CNC ranged from 3,000-47,500 particles/cm^3 which has been found to be within the typical range of CNC in home dwellings (7). Results indicate that the air cleaner reduced the CNC by an average of 82.8% for 27 studies under a variety of steady-state conditions. The airflow rate of the air cleaner was also found to have the greatest impact on the reduction of CNC within the test chamber. Results indicate that the air cleaner reduced the CNC by an average of 84.1% at 150 cfm, 83.9% at 120 cfm and 75.9% at 80 cfm. Table 5 demonstrates the accuracy and precision of the test procedure for monitoring the reduction of CNC by the air cleaner within the test chamber. Results displayed in Tables 2-5 indicate that a strong correlation between reduction of the WL of radon decay products and the removal of CN even at low CN levels where the fraction of unattached radon decay products is high (7). This supports the possibility that both attached and unattached radon decay products maybe removed by the air cleaner since the reduction in WL is approximately the same at higher CN levels. The increase in plate out of unattached radon decay products on the surface of the chamber as the air cleaner is removing the CN within the chamber may also help in the reduction of WL.

CONCLUSIONS

Based on the results of this study, the following conclusions can be stated: 1) Test results indicate that radon gas was not removed by the room air cleaner under any of the test conditions. 2) The room air cleaner was found to effectively reduce the WL of radon decay products by an average of 86.5% over a variety of test conditions. The change in airflow rate was found to be the biggest factor in removing the WL within the test chamber as would be expected. Results show an average reduction in WL of 86.9% at 150 cfm, 88.7% at 120 cfm, and 82.7% at 80 cfm under steady-state conditions. 3) While the room air cleaner was in operation, it was found to reduce the individual short-lived radon decay products by approximately 58.6% for RaA, 94.0% for RaB, and 97.8% for RaC within the test chamber. Since the air cleaner could not remove radon gas, the level of RaA was not reduced as much as the other decay products because of the equilibrium that exists between radon and its decay products. 4) The room air cleaner effectively reduced the concentration of condensation nuclei within the test chamber by an average of 82.8% over a variety of test conditions. The change in airflow of the room air cleaner was found to have the biggest impact on reducing the CNC within the test chamber under steady-state conditions. Results indicate an average removal of 84.1% at 150 cfm, 83.9% at 120 cfm, and 75.9% at 80 cfm. 5) The size distribution of CN within the test chamber was primarily between 0.0237 and 0.7499 um with the majority of the CN around 0.04220 to 0.2371 um based on midpoint diameter. This is within the typical size range of CN found within a home dwelling assuring that the air cleaner will work under normal use conditions. 6) Test results obtained on the air cleaner operating at an airflow rate of 80 cfm in this test chamber (850 ft^3) indicate that the air cleaner could reduce the WL of radon decay products by 82.7% in a room the size of approximately 1,600 ft^3 while operating at 150 cfm under steady-state conditions. 7) The room air cleaner may have utility when used in rooms with radon levels between 4-20 pCi/L or 0.02-0.1 WL as an interim mitigation measure for reducing radon decay products to below the action level of 4 pCi/L or 0.02 WL in rooms up to at least 1,600 ft^3 until primary mitigation occurs within the time frame recommended by EPA. 8) The air cleaner should be operated at the highest airflow rate of 150 cfm for optimum performance in rooms up to at least 1,600 ft^3 for reducing the WL of radon decay products.

SUMMARY

Results obtained under a variety of controlled laboratory test conditions suggest that the room air cleaner incorporating a HEPA-type filter may have utility when used to effectively reduce the level of radon decay products in rooms up to at least 1,600 ft^3 and reduce the hazards associated with indoor radon based on WL measurements.

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				Alpha Energy (MeV/pCi)
	α	^{226}Ra	$T_{1/2}$ = 1620 years	
	α	^{222}Rn	$T_{1/2}$ = 3.82 days	
Radon Decay Products	α	^{218}Po	$T_{1/2}$ = 3.11 minutes	137
Radon Decay Products	β	^{214}Pb	$T_{1/2}$ = 26.8 minutes	660
Radon Decay Products	β	^{214}Bi	$T_{1/2}$ = 19.7 minutes	484
Radon Decay Products	α	^{214}Po	$T_{1/2}$ = 1×10^{-6} minutes	6×10^{-5}
				1281 MeV/pCi/L = 0.01 WL
		^{210}Pb	$T_{1/2}$ = 22.3 years	

Figure 1. Radium Decay Series

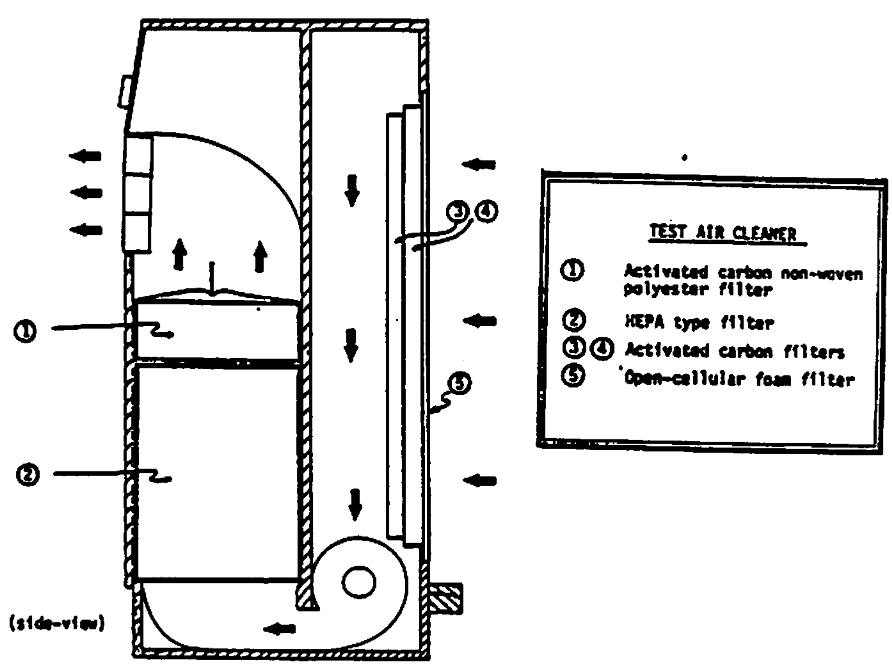
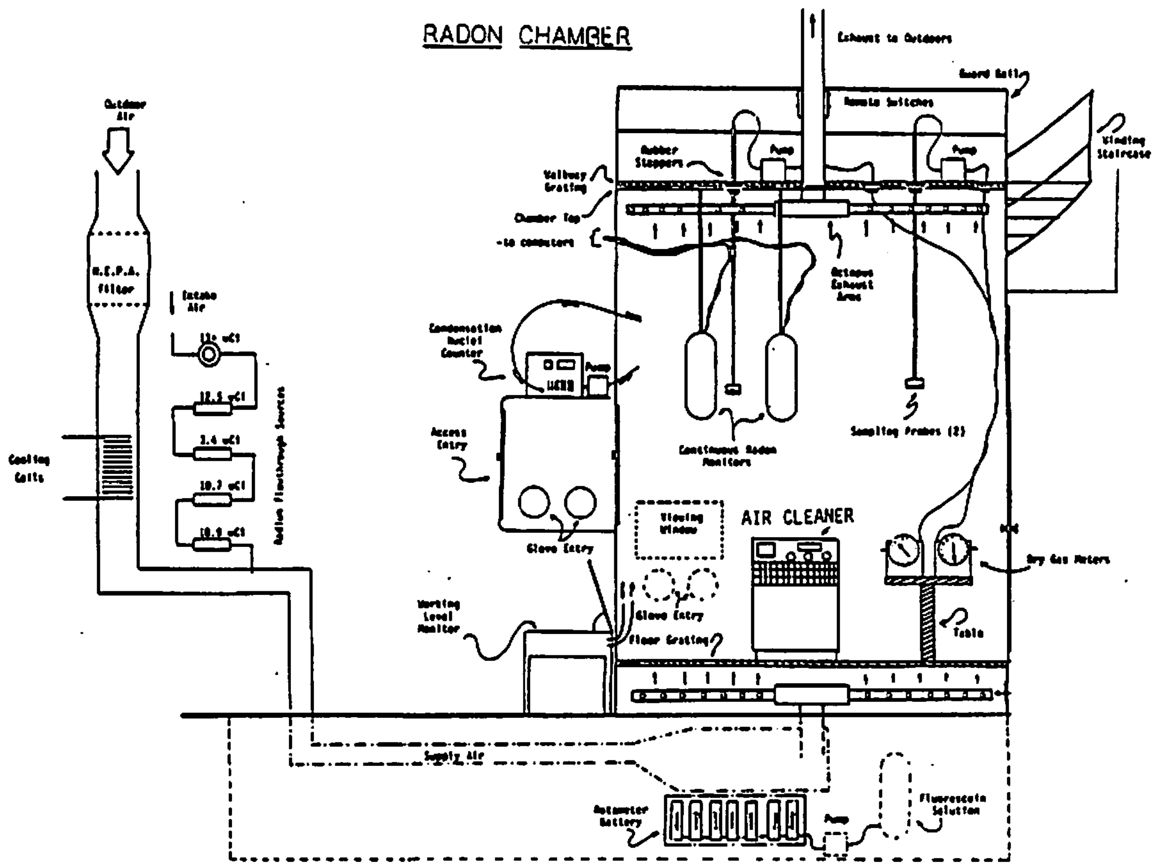


Figure 2. Room Air Cleaner



Chamber Environment Specifications

Volume	24,000 l
Air Flow Rate	0 - 4000 l/min
Radon	1 - 1000 pCi/l
Temperature	0-45 C
Dew Point	-10 C to saturation
Condensation Nuclei	10-100,000 /cc

Figure 3. Test Chamber and Environmental Specifications.

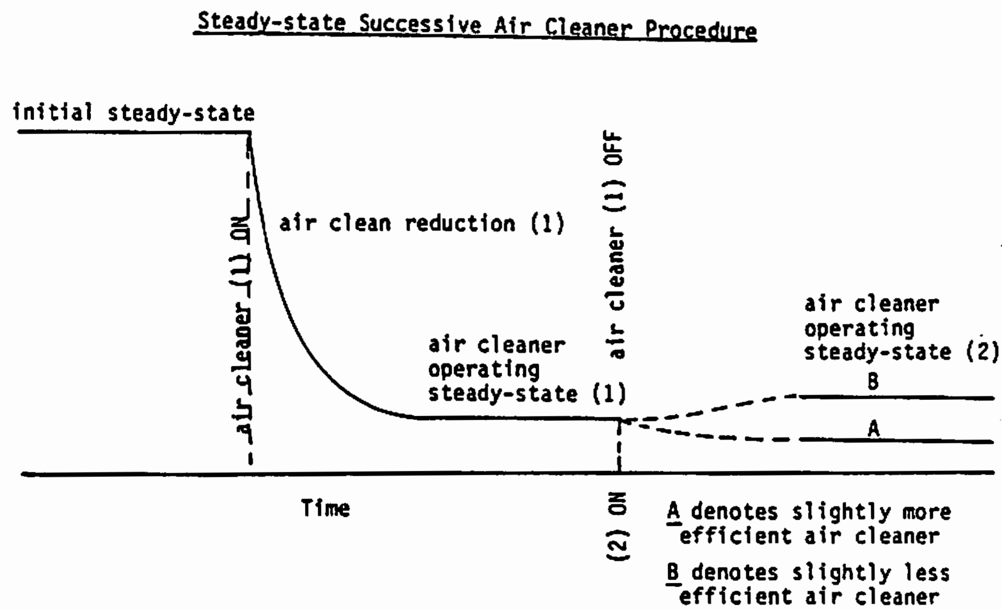


Figure 4. Single and Successive Room Air Cleaner Steady State Procedure.

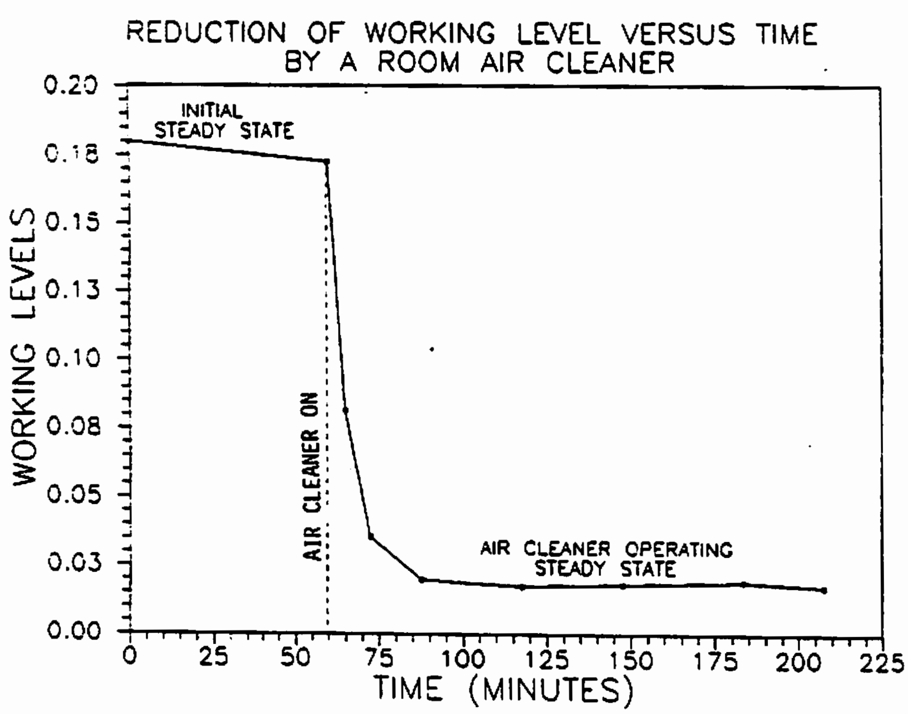


Figure 5. Reduction of WL Versus Time by a Room Air Cleaner.

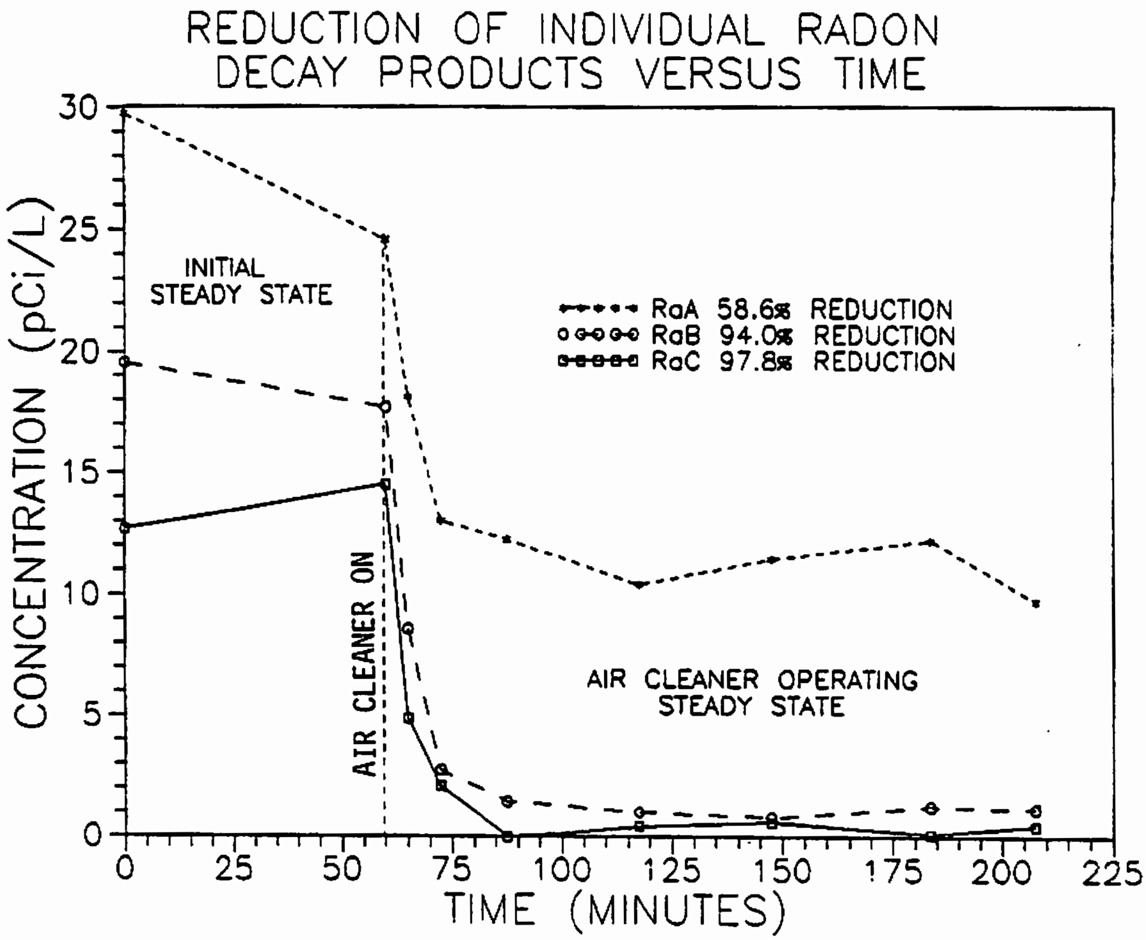


Figure 6. Reduction of Individual Radon Decay Products Versus Time by a Room Air Cleaner.

TABLE 1. TIME TO ACHIEVE 98% THEORETICAL REDUCTION

AIR CLEANER SPEED	AIR FLOW (CFM)	TIME TO 98% REDUCTION	MINIMUM TIME USED TO MEASUREMENT
4	150	35 min	60 min
3	120	45 min	60 min
2	80	64 min	75 min
1	40	120 min	not tested

TABLE 2. SUMMARY OF WORKING LEVEL MEASUREMENTS

DATE	AIR CLEANER SPEED	RADON (pCi/l)	WORKING LEVEL MEAN INITIAL	WORKING LEVEL MEAN FINAL	% REDUCTION IN WORKING LEVEL
5/4/87	4	33.0	0.1761	0.0183	89.6
5/5/87	4	32.5	0.1743	0.0173	90.1
5/6/87	4	31.5	0.1339	0.0130	90.3
5/7/87	4	32.5	0.1380	0.0124	89.9
7/22/87	4	31.0	0.1757	0.0260	85.2
7/23/87	4	30.5	0.1221	0.0154	87.4
7/24/87	4	19.0	0.0900	0.0120	86.7
8/17/87	4	29.0	0.1757	0.0231	86.9
			0.1757	0.0268	84.7
8/18/87	4	29.0	0.0640	0.0116	81.9
			0.0640	0.0132	79.4
8/19/87	4	29.0	0.1369	0.0148	89.2
			0.1369	0.0154	88.8
8/20/87	2	33.5	0.1486	0.0311	79.1
			0.1486	0.0244	83.6
8/21/87	3	30.0	0.1678	0.0196	88.3
			0.1678	0.0177	89.5
8/24/87	4	13.0	0.0726	0.0066	90.9
			0.0726	0.0071	90.2
8/25/87	3	15.0	0.0759	0.0083	89.1
			0.0759	0.0091	88.0
8/26/87	2	14.0	0.0692	0.0117	83.1
			0.0692	0.0104	85.0
8/27/87	4	13.5	0.0440	0.0068	84.5
			0.0440	0.0063	85.7
8/28/87	4	13.0	0.0762	0.0114	85.0
			0.0762	0.0116	84.8

TABLE 3. SUMMARY OF WORKING LEVEL REDUCTION

AIR FLOW (CFM)	STUDIES	MEAN	STD.DEV.	REL.STD.DEV.	RANGE
150,120,80	27	86.5%	3.28	3.79%	79.1%-90.9%
150	19	86.9%	3.15	3.62%	79.4%-90.9%
120	4	88.7%	0.70	0.78%	88.0%-89.5%
80	4	82.7%	2.53	3.06%	79.1%-85.0%

TABLE 4. SUMMARY OF CONDENSATION NUCLEI MEASUREMENTS

DATE	AIR CLEANER SPEED	RADON (pCi/l)	CONDENSATION NUCLEI CONCENTRATION MEAN (particles/cc) INITIAL	MEAN FINAL	% REDUCTION OF CONDENSATION NUCLEI
5/4/87	4	33.0	37000	5500	85.2
5/5/87	4	32.5	30000	4000	86.7
5/6/87	4	31.5	3000	150	95.0
5/7/87	4	32.5	3000	150	95.0
7/22/87	4	31.0	37000	7000	81.1
7/23/87	4	30.5	4200	1200	71.4
7/24/87	4	19.0	47500	11000	76.8
8/17/87	4	29.0	45500	9150	80.0
				9150	80.0
8/18/87	4	29.0	3000	475	84.2
				200	93.3
8/19/87	4	29.0	10500	2150	79.5
				1600	84.8
8/20/87	2	33.5	10000	2600	74.0
				2600	74.0
8/21/87	3	30.0	10000	1600	84.0
				1450	86.5
8/24/87	4	13.0	10000	1350	86.5
				1350	86.5
8/25/87	3	15.0	11500	2400	79.1
				1600	86.1
8/26/87	2	14.0	9500	2400	74.7
				1800	81.1
8/27/87	4	13.5	3750	400	89.3
				400	89.3
8/28/87	4	13.0	37800	9000	76.2
				9000	76.2

TABLE 5. SUMMARY OF CONDENSATION NUCLEI CONCENTRATION REDUCTION

AIR FLOW (CFM)	STUDIES	MEAN	STD.DEV.	REL.STD.DEV.	RANGE
150,120,80	27	82.8%	6.48	7.83%	71.4%-95.0%
150	19	84.1%	6.66	7.93%	71.4%-95.0%
120	4	83.9%	3.40	4.05%	79.1%-86.1%
80	4	75.9%	3.45	4.54%	74.0%-81.1%