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# ANALYSIS OF THE PERFORMANCE OF A RADON MITIGATION SYSTEM BASED ON CHARCOAL BEDS

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## ABSTRACT

The performance of a radon mitigation system based on adsorption of radon onto charcoal beds (RAdsorb system) combined with an electronic air cleaner (EAC) installed in a single family house in Shrewsbury, MA was studied in a series of tests. Semi-continuous measurements were made of the radon gas concentration, potential alpha energy concentration (PAEC), particle concentration with size distribution and radon decay product activity-weighted size distribution with and without additional aerosol sources. The instruments used were a radon gas monitor (EBERLINE, RGM-3), WL-meter (Thomson & Nielsen), and a differential mobility particle sizer (DMPS) by TSI. For measurements of the activity size distribution, an Automated, Semi-continuous Graded Screen Array (ASC-GSA) developed at Clarkson University was utilized. During the time of tests, the conditions in the basement of the house, without the mitigation system in operation, were as follow: radon concentration up to 800 Bq $m^{-3}$, PAEC up to 650 nJ $m^{-3}$ (30 mWL), particle concentration below 1000 $cm^{-3}$, and the fraction of PAEC and $^{218}Po$ in the smallest size range 0.5- 1.58 nm was up to 0.6 and 0.9, respectively. The tests were designed to study the influence of the combined system as well as the separate components of the mitigation system: fan, charcoal bed and EAC on the all of the measured parameters. When all the components of the mitigation system were working, the achieved reductions were radon concentration below 150 Bq $m^{-3}$ (4 pCi $L^{-1}$) and PAEC below 100 nJ $m^{-3}$ (5 mWL) with the smallest sized fraction of PAEC (0.5-1.58 nm) of about 0.4. The tests proved that under certain conditions, the charcoal bed/EAC mitigation systems can be a potentially valuable technique for reducing a health risk due to indoor radon.

## INTRODUCTION

Inhalation of the short lived decay products of radon ($^{222}Rn$): $^{218}Po$, $^{214}Pb$, $^{214}Bi$ and $^{214}Po$, is thought to be the second largest cause of lung cancer after cigarettes smoking. To reduce this potential risk, it is presently recommended that the remedial measures should be taken when the level of radon gas in a home is found to exceed 150 Bq $m^{-3}$ (4 pCi $L^{-1}$) (1). Several mitigation methods have been tried in houses with elevated radon levels. These techniques might be divided into two main categories:

a) Ones based on the reduction of the radon entry rate into the house, that sometimes required changes in a house construction or house modification e.g." subslab ventilation", "crawl space ventilation",

b) Others based on the removal of radon from indoor air (ventilation, filtration, radon adsorption).

The RAdsorb system built by the RAd Systems Inc. is a carbon adsorption system. The system has been installed in a single family house in Shrewsbury, MA. The RAdsorb radon removal system is based on activated carbon adsorption of radon. A radon gas removal efficiency evaluation was performed by the producer yielding values up to 97% reduction in radon gas concentrations (2). In addition, for this study, an electronic air cleaner (EAC) (Honeywell Model F50E) has been added to the RAdsorb system. The influence of the operation of the RAdsorb system on the indoor radon and its decay products concentrations (PAEC) and activity weighted size distributions are important from the health risk point of view and were the objective of measurements made in this house during September 1990.

## HEALTH RISK DUE TO INDOOR RADON

The health risk associated with radon in indoor air is not from radon itself but rather from radon's short lived decay products. Radon as an inert gas with a half-life of more then 3 days may be inhaled and subsequently exhaled with little decay while in the human lung. The decay products of radon, however, are reactive and when inhaled, may deposit within the lung. Since they have short half-lives, further radioactive decay will occur prior to particle clearance from the respiratory tract. The alpha energy emitted during decay is therefore fully deposited in the lung tissue, possibly causing damage to the DNA within the target cells. If the DNA is damaged, the abnormal cell may reproduce and may result in a cancer. The deposition of the radon decay products within the lungs depends to a great extent on the attributes of the particles to which it is attached. The efficiency of deposition of particles in the lung varies with the particle size and hence, knowledge

of the particle size distribution and the activity size distributions are important in evaluating the risk attributed to radon progeny. The fraction of radon progeny atoms or ions possibly clustered with other molecules such as $H_2O$ is traditionally defined as the "unattached" fraction. The most recent studies strongly suggest that so-called "unattached" fraction is actually an ultrafine particle mode in the 0.5 - 3.0 to 5.0 nm size range (3). In the absence of active particle sources, the radon decay product activity size distribution may be thought of as bimodal, with a fairly sharp small-diameter mode near the molecular size corresponding to the "unattached" fraction and a broader large-diameter mode corresponding to the "attached" fraction (4). Two physical parameters used in all lung dosimetry models estimating radiation doses from inhaled radon decay products, are the activity median diameter of the "attached" radioactive aerosols and the "unattached" fraction of $^{218}Po$. The $^{218}Po$ is of particular interest because it is the first short-lived decay product in radon chain with a half-life of only 3.1 minutes.

The dosimetric calculations for evaluation of the absorb dose in lung tissue per unit exposure suggest that the dose per unit exposure from the "unattached" fraction could be up to 25 times higher then that for the "attached" fraction (5).

In the most recent dose estimates (6), particle size has been taken into consideration. The basal cell and the secretory cells in the bronchial epithelium were considered as target cells. The resulting dose conversion factors per unit exposure from monodisperse activity $D_i$, are presented in Figure 1 as a function of breathing rate.

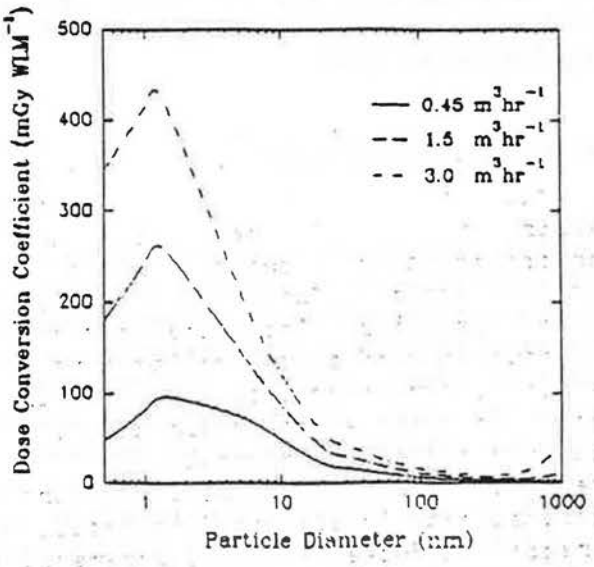



Figure 1. Dose to bronchial secretory cells as a function of the size of radon decay products for an adult male (6)

The graph shows the dose to secretory cells for three different breathing rates equivalent to resting, light activity and heavy work and that for all cases the conversion factor is strongly dependent on the activity median diameter especially for particles smaller then 10 nm. Therefore, to calculate the dose per unit exposure to secretory cells, the following formula applied:

$$\frac{D_s}{E_p} = \sum_{i=1}^{i=n} f_i D_{si} \qquad (1)$$

where,
$E_p$ - exposure to PAEC [WLM]
$D_s$ - total dose to secretory cells [Gy],
$D_{si}$ - dose to secretory cells per unit exposure to PAEC with size i [Gy/WLM],
$f_i$ - fraction of activity with size i,
n - number of size ranges considered.

A similar expression applies for the basal cells. Thus, any action influencing the physical parameters of indoor aerosols should be considered very carefully from the point of view of possible health risk. Because the major effect of any air cleaning system on the radon decay products in indoor air is the alteration of the activity size distribution by reducing the particle concentration, the evaluation of such systems is desirable.

## DESCRIPTION OF THE RAdsorb/EAC SYSTEM

In general, air cleaning systems can reduce the concentration of radon decay products and PAEC by three mechanisms. The first is the direct collection of "unattached" and "attached" radon decay products by the air cleaning systems. The second is the enhancement of deposition of the radon progeny to the room surfaces created by the air cleaning system's air circulation. The final mechanism is the shift in average size to smaller particles. The plateout rate then increases because of the higher diffusivity of these smaller particles.

Preventing radon entry into the house is the technique advised by the EPA, but in some cases, the radon must be removed from indoor air. The adsorbing properties of charcoal have been utilize in a unit design by RAd System Inc. The theoretical background for the adsorption of radon in charcoal beds is presented in detail by Abrams and Rudnick (7) and by Bocanegra and Hopke (8). The schematic diagram of the RAd Systems Inc.'s RAdsorb/EAC unit is presented in Figure 2.

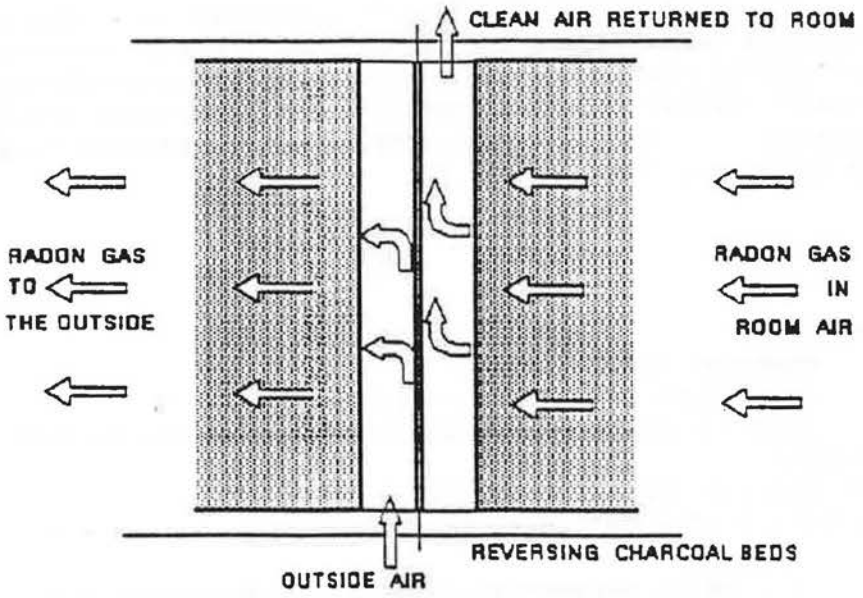



Figure 2. Schematic diagram of the RAdsorb system

The unit contains a cylindrical radon bed 0.9 m high and 0.6 m in outside diameter. It is divided vertically by a solid baffle into two sections; one for adsorption, the other for regeneration. Room air flows into the unit through the EAC. The radon-laden air then flows from the outside of the front bed into the core, while outside air (essentially radon free) flows through the other bed from the core through the bed to the outside and to the outdoors by a duct. The regeneration flow through the bed is at 4 to 10 $m^3$ $min^{-1}$ and forced by a fan, which is an integral part of the removal unit. When the one bed's adsorptive capacity is expended, the bed rotates 180° and repositions the expended bed in the regeneration zone and the freshly regenerated bed in the adsorption zone. The cycle of adsorption of radon in one half of the charcoal bed and desorption in the second half is repeated continuously on a fixed time cycle. The flow of indoor air is forced by 6 $m^3$ $min^{-1}$ fan. The unit incorporates the bed, drive, filters and both the room air and outside air blowers in the 0.7 m x 0.7 m x 1.6 m cabinet. The unit also is equipped with an outside air temperature sensor to vary the speed of the outside air blower inversely with temperature for the best desorption of radon. The prototype system was tested under laboratory conditions (2) with very good results yielding up to 97% radon gas removal efficiency. The investigated unit was installed in the basement of the house in Shrewsbury, MA in May 1989 and had been in continuous operation since then.

A microcomputer controls the system, collects the raw data, performs the data inversion to obtain the particle concentration as a function of particle diameter. The diameter range measured in these experiments is 0.01 $\mu$m to 0.4 $\mu$m with a concentration in the range of $10^3$ to $10^5$ particles per $cm^3$.

Activity-Weighted Size Distributions

The activity weighted size distribution was measured with the automated, semi-continuous graded screen array (ASC-GSA) described by Ramamurthi (9) and Ramamurthi and Hopke (10). The ASC-GSA measurement system involves the use of combination of six sampler-detector units (see Figure 3) operated in parallel.

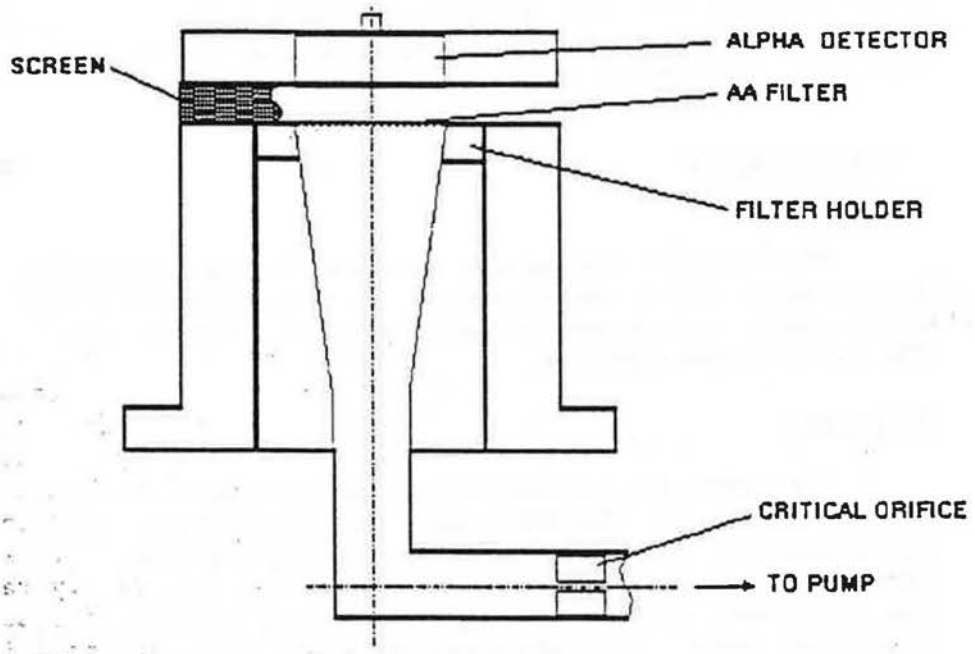



Figure 3. The cross-section of the sampler unit

Each sampler-detector unit couple wire screen penetration, filter collection and activity detection with a solid state detector in a way as to minimize depositional losses. The system samples air simultaneously in all of the units, with a flow of about 15 lpm through the sampler slit between the detector and filter holder section in each unit. The sampled air is drawn through a Millipore filter (0.8 $\mu$m, Type AA). The combination of wire screens wrapped around the samplers are presented in Table 1.

## HOUSE CHARACTERISTIC

The house consists of a living room and kitchen on the first floor and three bedrooms on a second floor. The initial concentration of radon in house basement before mitigation ranged up to 1100 Bq $m^{-3}$ (30 pCi $L^{-1}$). The RAdsorb system was chosen by house owners as the easiest way of reducing radon levels without significant construction work and changes in a house operation. The dimensions of the basement were 8 m x 7.5 m x 2.3 m, with a volume of about 138 $m^3$. Standard doors connected the basement with the kitchen and with the outdoors. The sampling location was in the basement close to the RAdsorb/EAC system outlet and near to the outside door. This location was necessary because of the use of the basement as a workshop and storage room by the house owner. The radon concentration on the day of arrival to the house was about 660 Bq $m^{-3}$ (18 pCi $L^{-1}$) with particle concentration of 10000 $cm^{-3}$. The average temperature in the basement during the measurements was up 30° C with very high humidity.

## INSTRUMENTATION

The physical parameters measured during testing the RAdsorb/EAC system were: radon concentration, particle concentration, potential alpha energy concentration, and activity-weighted size distribution of the radon decay products.

### Radon gas

For radon gas concentration measurements, an EBERLINE RGM-3 radon monitor was used. The RGM-3 is a portable, microcomputer-based radon gas measuring instrument which utilizes a 3.3 liter, scintillation cell detector and microcomputer controlled 8 lpm pump to sample radon gas. The instrument allows the operation in the grab sampling mode and a continuous mode. That provides the radon gas concentration at one hour intervals. The microcomputer predicts decay products plateout as a function of time during the first hours of operation and compensates for it. The sensitivity of the device was 0.12 cps/pCi $L^{-1}$.

### Particle Concentration

To measure the airborne particle concentration and size distribution, a TSI Model 3932 Differential Mobility Particle Sizer (DMPS) was used. The DMPS measures the size distribution of submicrometer aerosols by the electrical mobility detection technique. The aerosols are classified with Model 3071 Electrostatic Classifier and their concentration measured with Model 3086 Electrometer.

TABLE 1. THE PARAMETERS OF THE SIX SAMPLERS OF THE ASC-GSA SYSTEM

| Unit | Sampler Slit Width [cm] | Sampler Diameter [cm] | Screen Mesh | $Dp_{50}$ (0.5-350 nm) [nm] |
|---|---|---|---|---|
| 1 | 0.5 | 5.3 | - | - |
| 2 | 0.5 | 5.3 | 145 | 1.0 |
| 3 | 0.5 | 5.3 | 145x3 | 3.5 |
| 4 | 0.5 | 5.3 | 400x12 | 13.5 |
| 5 | 1.0 | 12.5 | 635x7 | 40.0 |
| 6 | 1.0 | 12.5 | 635x20 | 98.0 |

One of the sampler-detector units is operated with an uncovered sampler slit, thus providing information on the total radon decay product concentrations. To detect alpha particles emitted by $^{218}Po$ and $^{214}Po$ atoms collected or formed on the filters, ORTEC Model DIAD II, 450 $mm^2$ surface barrier alpha detectors are used. The signals from the detectors are amplified and routed through a multiplexer to PC-based multichannel analyzer (ORTEC-MAESTRO) installed in an IBM-compatibile laptop computer. The collected spectra are saved on the hard disk of the PC for further analysis. The block diagram of the ASC-GSA system is presented in Figure 4.

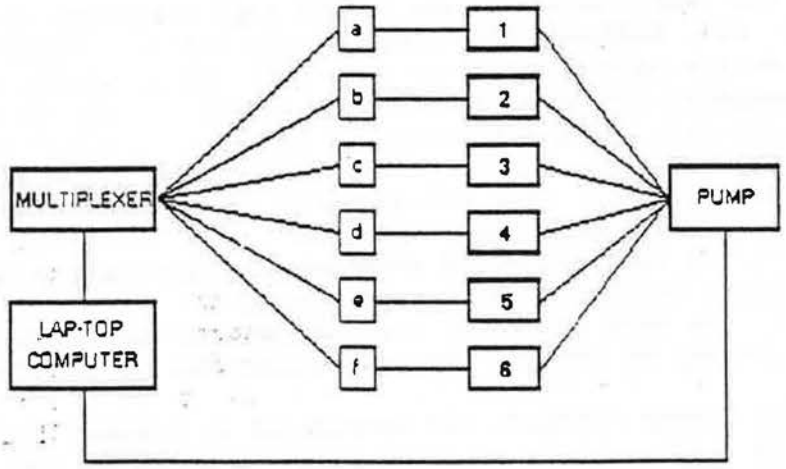



Figure 4. The block diagram of the ASC-GSA system

The computer control of sampling, counting and analysis permits automated, semi-continuous operation of the system with a sampling

frequency between 1.5 to 3 hours. The activities of each radon progeny are estimated from alpha spectra collected during two counting intervals: the first one during sampling and the second 20 minutes after end of sampling. The observed concentrations of $^{218}Po$, $^{214}Pb$ and $^{214}Bi$ are used to reconstruct the corresponding activity-weighted size distributions using the Expectation-Maximization algorithms (11).

The ASC-GSA system allows the determination of the activity weighted size distributions in six inferred size intervals in geometric progression within the 0.5 - 500 nm size range. The performance of the ASC-GSA system was tested during laboratory (9) and field (12) intercomparison measurements showing very good agreement with systems from other leading laboratories.

## RESULTS

To study the performance of the RAdsorb/EAC radon mitigation system on radon and radon decay products the experiments were designed to:

a) Test the effectiveness of RAdsorb/EAC in removal of Rn gas and progeny.

b) Determine the changes in the size distributions of Rn-d caused by the RAdsorb/EAC system.

The design approach was to run each component of the RAdsorb/EAC system: Fan, RAdsorb, EAC independently and in combination, establishing the baseline before and after each run. As a control parameter to test the potential health effects of the action during the tests, the dose to secretory cell for a resting adult male was calculated by the method described earlier. The reference levels (the "background" values) of $^{222}Rn$ concentration, PAEC and activity fractions to which the comparisons were made, were taken as:

1) The mean values of measurements after assuming that the steady-state conditions were established,

2) The mean values of the "background" measurements performed on the day of arrival and on the last day of tests (see Table 4).

The second approach was considered to present the changes in measured quantities in relation to the conditions when no devices were operated and which could be treated as a true "background".

The exposure to PAEC was calculated as follow:

$$E_p = PAEC\frac{8760}{170}n \qquad (2)$$

where,

$E_p$ - exposure to PAEC [WLM],
PAEC - potential alpha energy concentration [WL],
8760 - numbers of hours per year,
170 - number of hours per working month,
n - occupancy factor (n=0.8 was assumed).

"Background" Conditions

To establish the "background" conditions and the operational parameters of the instruments, the first measurement was performed on the day of arrival with the RAdsorb/EAC system turned off 40 hours earlier.
The measured "background" conditions are presented in Table 2.

TABLE 2. THE "BACKGROUND" CONDITIONS IN THE SHREWSBURY HOUSE ON THE DAY OF ARRIVAL

| | |
|---|---|
| Particle concentration [$cm^{-3}$] | 10000 |
| $^{222}Rn$ concentration [Bq $m^{-3}$] | 659 |
| $^{218}Po$ concentration [Bq $m^{-3}$] | 307 |
| $^{214}Pb$ concentration [Bq $m^{-3}$] | 122 |
| $^{214}Bi$ concentration [Bq $m^{-3}$] | 78 |
| PAEC [mWL] | 33.1 |
| Equilibrium factor | 0.19 |
| "Unattached" fraction of $^{218}Po$ | 0.65 |
| "Unattached" fraction of PAEC | 0.35 |

The "background" conditions were tested again, after the RAdsorb/EAC system had been turned off for 15 hours during the last day of measurements. The measured variables are presented in Table 3.

TABLE 3. THE "BACKGROUND" CONDITIONS IN THE LAST DAY OF MEASUREMENTS

| | |
|---|---|
| Particle concentration [$cm^{-3}$] | 4000 |
| $^{222}Rn$ concentration [Bq $m^{-3}$] | 599 |
| $^{218}Po$ concentration [Bq $m^{-3}$] | 377 |
| $^{214}Pb$ concentration [Bq $m^{-3}$] | 93 |
| $^{214}Bi$ concentration [Bq $m^{-3}$] | 52 |
| PAEC [mWL] | 28.4 |
| Equilibrium factor | 0.18 |
| "Unattached" fraction of $^{218}Po$ | 0.87 |
| "Unattached" fraction of PAEC | 0.61 |

The size distributions of radon decay products and PAEC without RAdsorb/EAC system working are presented in Figure 5. The low particle concentration in the basement for the two background samples resulted in 65% and 87% of the $^{218}Po$ activity in the smallest inferred size interval with a mid-point diameter of 0.9 nm. The corresponding $^{214}Pb$ and $^{214}Bi$ distributions showed activity in the 0.5 to 1.6 nm range below 20% and 50%, respectively. The resulting PAEC distribution followed a standard bimodal distribution with maximums in the range 0.5 to 1.6 nm and 160 to 500 nm. The estimated doses to secretory cells and mean values of PAEC and $^{222}Rn$ concentrations in "background" conditions are presented in Table 4.

TABLE 4. AVERAGE VALUES OF SOME PARAMETERS IN "BACKGROUND" CONDITIONS

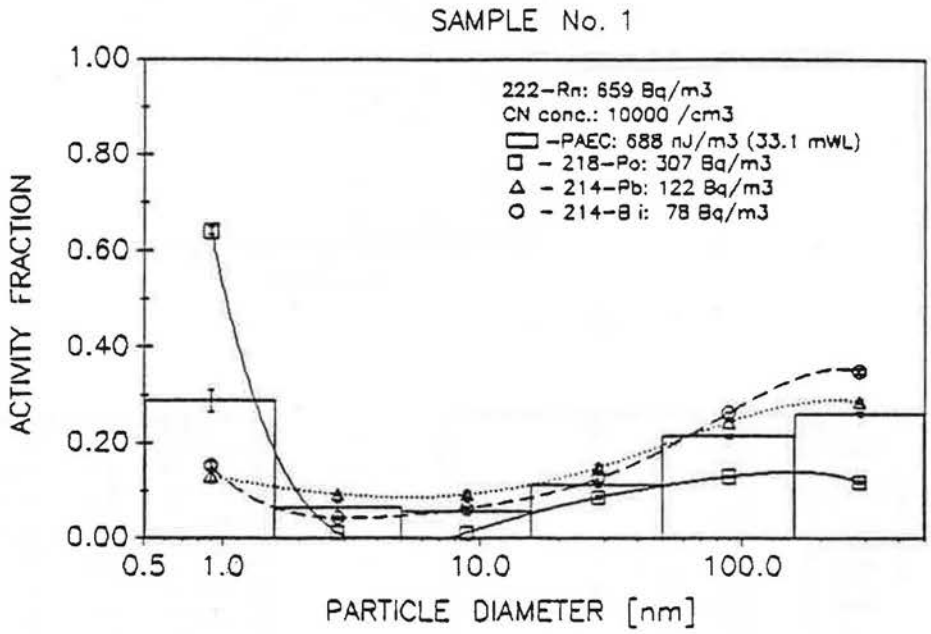
| $^{222}Rn$ [Bq $m^{-3}$] | PAEC [mWL] | 0.5-1.58 nm PAEC fraction | Secretory Cell Dose [mGy $y^{-1}$] |
|---|---|---|---|
| 630 | 30.8 | 0.428 | 55.8 |

Fan

To investigate the influence of the operation of the RAdsorb system's fan, the charcoal canister was blocked allowing free circulation of the air through the device. According to some studies, a fan itself can act as a removal unit by increasing the plateout rate of radon decay products (13). This effect was observed as well during operation of the RAdsorb's fan operating. The results of the experimental runs with fan ON and OFF are presented in Figure 6. As expected, radon gas concentration (Figure 6 a) was not effected by turning on the fan. The fan caused a decrease both in the PAEC and $^{218}Po$ concentrations (Figure 6 b) and d). This result is due to better mixing of indoor air and an increase in the deposition rate of the progeny on room surfaces. The activity size distributions of PAEC and $^{218}Po$ were not affected by the fan in any significant way.

Fan/EAC

To study the effect of the combined operation of the RAdsorb unit fan together with its attached EAC, the EAC was turned on while the fan was operating. The results are also presented in Figure 6. The concentrations of $^{222}Rn$ and $^{218}Po$ did not show any drastic changes that could be attributed to operating the fan/EAC. PAEC has shown a reduction of a factor of 2 from about 40 mWL to 22 mWL (mean values from four measurements under steady-state conditions before and after turning the device on). For the reference values from the "background" measurements (see Table 4), the reduction of PAEC was about 29%. A much



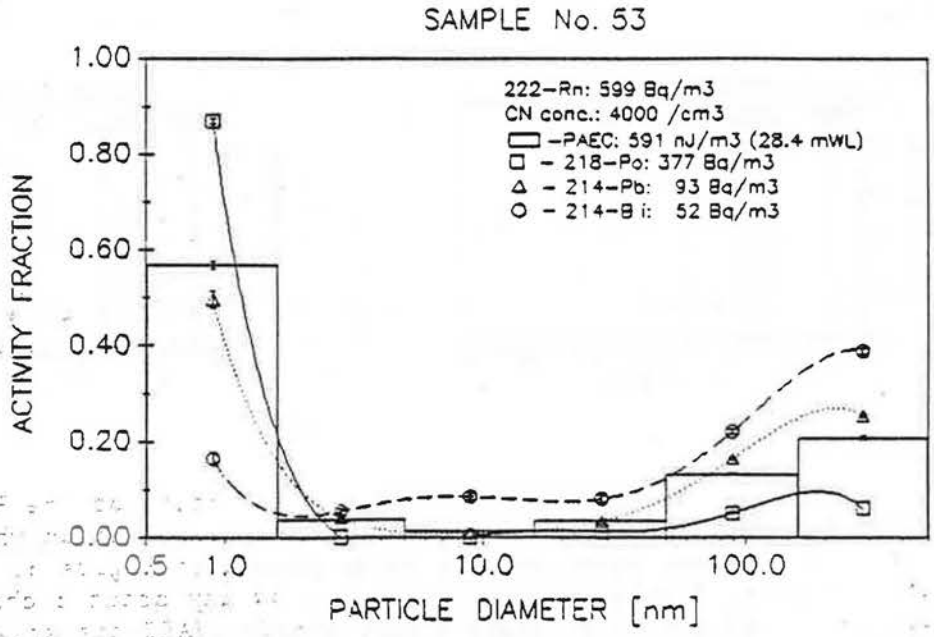
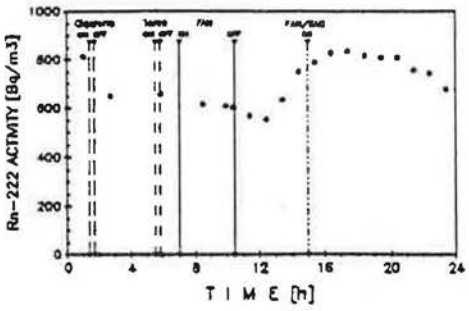
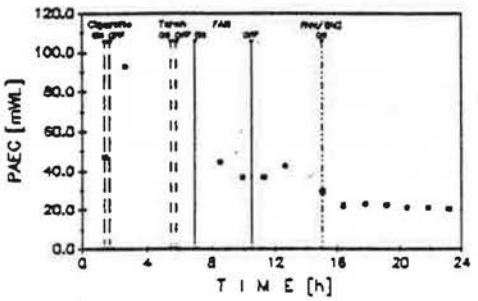




Figure 5. Typical activity size distributions in "background" conditions (no mitigation devices in operation) in the Shrewsbury house.




a)

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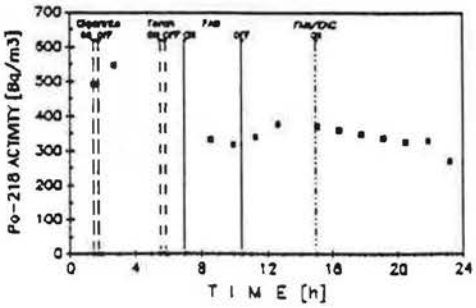
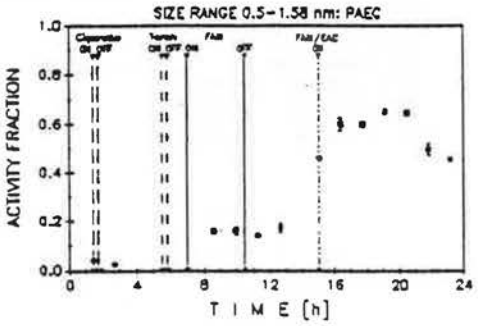
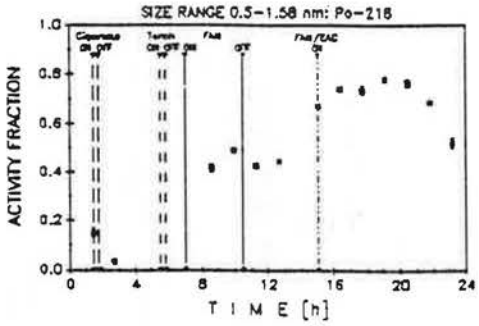



d)




c)




e)

Figure 6. The influence of a fan and electronic air cleaner (EAC) on indoor radon and its decay products:
a) $^{222}Rn$ concentration,
b) potential alpha energy concentration (PAEC),
c) activity fraction of PAEC in the size range 0.5-1.58 nm,
d) $^{218}Po$ concentration,
e) activity fraction of $^{218}Po$ in the size range 0.5-1.58 nm

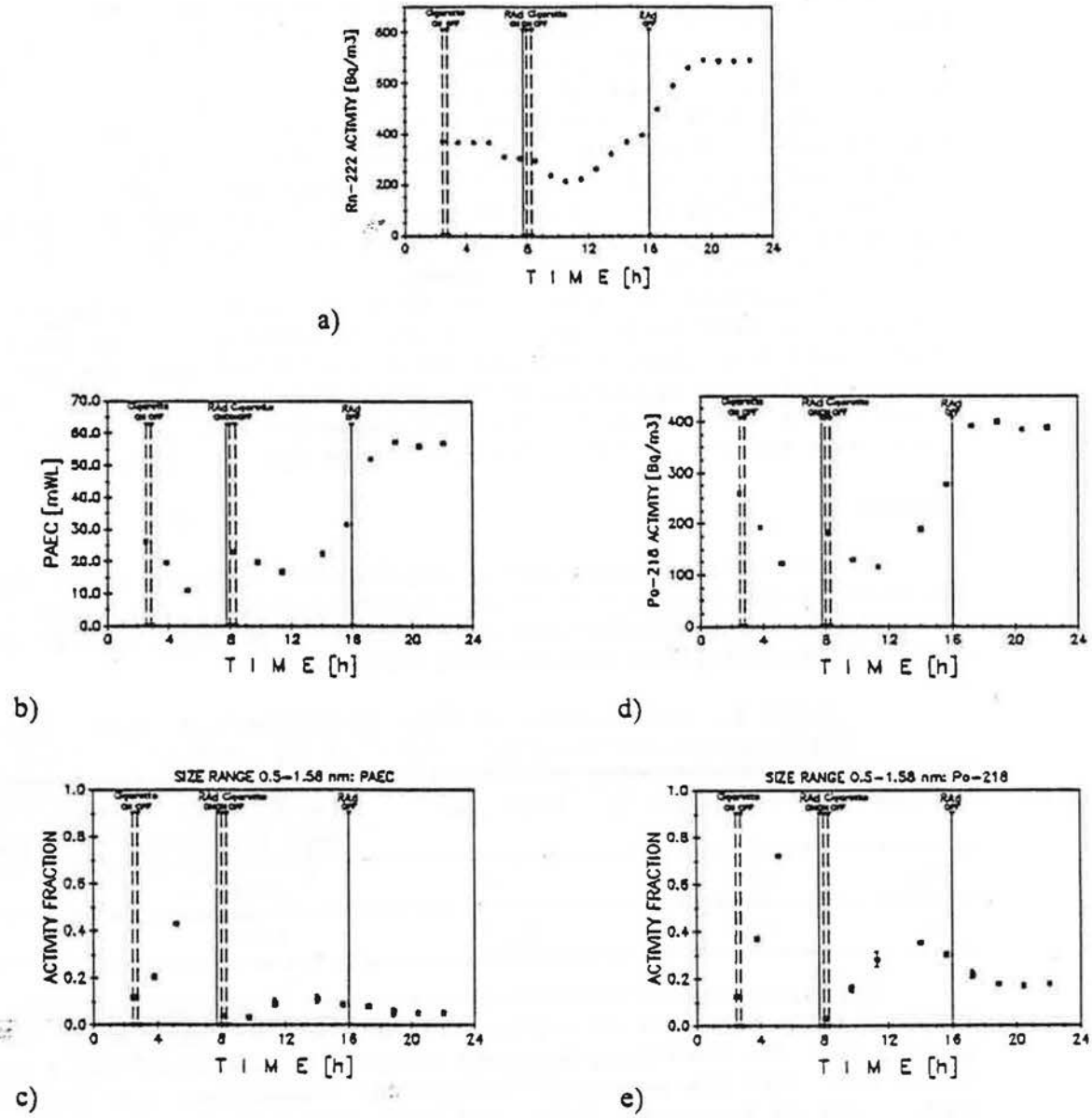



Figure 7: The influence of the RAdsorb system on indoor radon and its decay products:
a) $^{222}Rn$ concentration,
b) potential alpha energy concentration (PAEC),
c) activity fraction of PAEC in the size range 0.5-1.58 nm,
d) $^{218}Po$ concentration,
e) activity fraction of $^{218}Po$ in the size range 0.5-1.58 nm

larger effect was observed in the size distributions both of $^{218}Po$ and PAEC. The combined operation of the fan/EAC caused an increase in the fraction 0.5-1.6 nm of $^{218}Po$ from 0.445 to 0.754 (1.7 times increase) and for PAEC from 0.158 to 0.626 (4 times increase).

Using the values obtained in the investigated house (decrease in PAEC of about 50% and the changes in size distributions), the estimated dose to secretory cells was 53 mGy $y^{-1}$ before and 51 mGy $y^{-1}$ after turning the EAC/fan on. For the measured "background" parameters, the estimated dose was 56 mGy $y^{-1}$ (see Table 4). Therefore, no benefit in reducing the health risk was observed.

The increase in "unattached" fraction without substantial reduction in PAEC could lead to an actual increase in the radiation dose, especially considering the relationship between dose per unit exposure and size of particles described earlier (Figure 1). These observations agree with the EPA recommendation not to used air cleaners alone as a device for controlling the risk due to indoor radon.

RAdsorb

The results of operation of the RAdsorb system without the EAC attached to the room air inlet are summarized in Figure 7 and Table 5. The data included in table are mean values of measurements performed after establishing the steady-state conditions.

TABLE 5. THE CHANGES OF $^{222}Rn$ CONCENTRATION, PAEC, SIZE DISTRIBUTION AND RESULTING DOSE DUE TO OPERATION OF RAdsorb

| RAdsorb | $^{222}Rn$ [Bq $m^{-3}$] | PAEC [mWL] | 0.5-1.58 nm PAEC fraction | Secretory Cells Dose [mGy $y^{-1}$] |
|---|---|---|---|---|
| OFF | 670 | 55.6 | 0.061 | 37.5 |
| ON | 289 | 22.7 | 0.074 | 15.5 |

The operation of RAdsorb system caused a decrease in radon gas and PAEC of about 60%, and an increase in 0.5-1.6 nm fraction of PAEC of about 21%. The resulting decrease in dose to secretory cells was also about 60%. For the measured "background" conditions (see Table 4), the reductions in radon gas, PAEC, and dose were 54%, 26% and 72%, respectively.

RAdsorb/EAC

The fully assembled RAdsorb system with the EAC unit attached to the room air intake was operated continuously for 12 hours. After about three to four hours, a new steady-state was established. The influence of the device on Rn, PAEC, size distribution and dose are presented in Figure 8 and Table 6.

TABLE 6. THE CHANGES OF $^{222}Rn$ CONCENTRATION, PAEC, SIZE DISTRIBUTION AND RESULTING DOSE DUE TO OPERATION OF of RAdsorb/EAC

| RAdsorb/EAC | $^{222}Rn$ [Bq $m^{-3}$] | PAEC [mWL] | 0.5-1.58 nm PAEC fraction | Secretory Cell Dose [mGy $y^{-1}$] |
|---|---|---|---|---|
| OFF | 666 | 55.6 | 0.061 | 37.5 |
| ON | 163 | 8.0 | 0.339 | 10.5 |

The operation of the combined RAdsorb unit with the EAC yielded a substantial reduction in the radon gas concentration of about 76% and PAEC of about 86%. This improved removal efficiency was enough to compensate for the potential increase in the health effect due to changes in the radon decay products size distribution (5 times increase in the 0.5-1.6 nm fraction of the PAEC). The estimated dose to secretory cells of 10.5 mGy $y^{-1}$ was 72% lower then the initial value. The estimation of the changes because of the operation of the combined RAdsorb/EAC system was performed using the measured "background" values (see Table 4). In relation to those values, the radon gas was reduced by 76%, the PAEC by 74% and the dose to the secretory cells by 81%. The results suggest that the combined use of the RAdsorb and electronic air cleaner (EAC) provided greater dose reduction than either operating alone. The data suggests that the EAC is more effective in reducing the dose from radon decay products when radon concentrations are lower (e.g. less than 200 Bq $m^{-3}$). It was only when the RAdsorb lowered the concentrations that the EAC provided some dose reduction. Since the EAC are often installed to provide removal of pollen and other irritants, the possible ancillary benefit of a reduction in radon progeny dose at low radon concentrations warrants further investigation. Figure 8 a) presents the hourly measurements of radon gas. The data shows a first sharp decrease in the radon concentration reaching the lowest point of about 111 Bq $m^{-3}$ in about 6 hours. Later, the radon level increased and fluctuated around 150-200 Bq $m^{-3}$. This pattern was observed during all of the experiments with the RAdsorb unit.

## SUMMARY

The influence of the RAdsorb/EAC radon mitigation system installed in a single family house in Shrewsbury MA, was studied in a series of tests. The radon gas concentration, PAEC and radon decay products activity-weighted size distributions were measured on semi-continuous bases.
The results obtained confirmed the theoretical predictions:

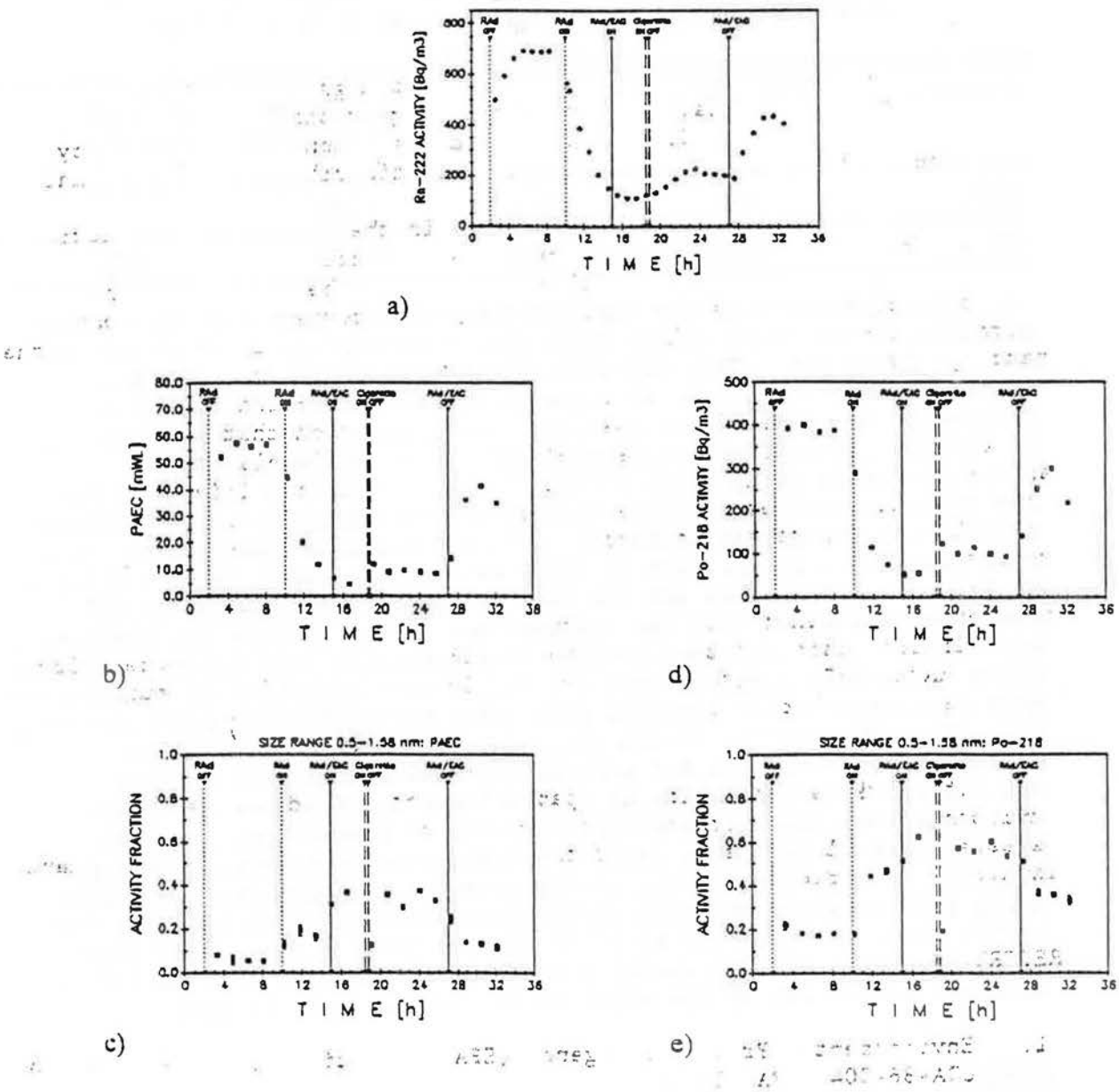



Figure 8. The performance of the RAdsorb system (RAd) alone and combined with a electronic air cleaner (EAC):
a) $^{222}Rn$ concentration,
b) potential alpha energy concentration (PAEC),
c) activity fraction of PAEC in the size range 0.5-1.58 nm,
d) $^{218}Po$ concentration,
e) activity fraction of $^{218}Po$ in the size range 0.5-1.58 nm

1) No substantial changes in measured parameters were observed during only the operation of the fan,
2) The EAC caused a shift of the size distribution towards smaller particles,
3) The RAdsorb system decreased the radon gas concentrations without substantial changes in the progeny size distributions,
4) The combined RAdsorb/EAC reduced the radon concentration by about 76%, with the shift in the size distribution towards smaller particles.

To study the effect of the increase in the "unattached" fraction (0.5 - 3 nm), the doses to bronchial secretory cells of adult male resting were evaluated. The estimation of doses before and during the operation of the EAC gave similar results. By comparison, the combined operation of the RAdsorb/EAC system not only substantially decreased the radon gas concentration to a value around the EPA recommended limit of 150 $Bq\ m^{-3}$ (4 $pCi\ L^{-1}$), but also yielded an 86% reduction in the PAEC. The resulting dose reduction was 76% with assumption that the new steady-state conditions were established. If the levels of $^{222}Rn$, PAEC and activity fraction measured in the "background" conditions were taken as the point of reference, the dose reduction was about 81%.

The dose estimates presented in the study, are based on the most recent dosimetric calculations. However, it is possible that the conversion factors applied in this study may change in the future due to new development in dosimetric calculations.

In conclusion, the overall performance of the combined operation of the RAdsorb/EAC system was very good in reducing both exposures to and dose from indoor radon and its decay products.

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