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Radon Entry Dynamics with Alpha Track Monitors
or
Just How Does the Radon Get In ?

Robert W. Pollock and Bruno E. Sabels
Radon Environmental Monitoring Inc., Northbrook IL 60062

ABSTRACT

As long as most common alpha track detectors or monitors featured "designated entry ports" for the radon in their caps, the radon world appeared to be in order. But since solid caps and housings have appeared, both clients and professionals have been asking: Just how does the radon get in ? Did you not forget something ?

It is shown in the paper that holes, ports and filter papers are rather unnecessary for the operation of ATDs. Even though it appears that the joint or gap between the two monitor halves and its length, equal to the circumference, is critical for admitting radon into the monitor - even that is not so.

Critical for the sensitivity of an ATD is its geometry, coupled with an entry way whose nature will affect the rate of ramping up of the monitor until equilibrium of radon levels is reached inside and out. Diffusion through airways into monitors such as the AT-100 as well as permeation (entry through the body) can be stopped completely by sealing the joint or gap. Inferior housings will admit a minor percentage of radon through permeation through their bodies, even if the joint or gap is cemented with epoxy.

The rate of permeation through layers of plastic is discussed, and it is shown that 40 mils of plastic layers shield an uncapped ATD with a 40 mil wall thickness as well as if it were closed and its gap cemented shut.
Confusion between "unfiltered" detectors and "filtered" detectors without filters should be reduced by RMP nomenclature modification.

INTRODUCTION

One of the great radon technicians of our time is supposed to have said: "If you want to understand radon, you have to think like one". But despite this good advice, there is much humanization in working with radon monitors.
For example, there are the "designated entry ports" in the caps of most radon monitors, underlain by filter paper. They appear to attract and entice the radon similar to a gateway leading into a shopping mall. But just as there are ways for the consumer to find his merchandise without visiting shopping malls, so there are ways for the radon to get inside monitors without gateways.

But ever since the days of the Canadian pill vial and the solid-capped AT-100 which appeared early in 1990 people have wondered about the performance, and some even insist that it cannot work.

The work reported here goes back several years, and we recently summarized it and performed some concluding tests so as to satisfy ourselves and to answer the many inquiries received with a degree of certainty.

BACKGROUND

Alpha track detectors can be classified into two types:
1) open faced (called "unfiltered" in the EPA Radon Measurement Program
2) closed (called "filtered" in the EPA RMP). The terminology should be modified to prevent confusion between "unfiltered" detectors and "filtered" detectors which do not contain any filters. Solid-capped closed detectors have a fixed geometry and a means to keep radon progeny from reaching the track registration foil inside the housing. The filtration is built into the design of the detector.

In addition to the open faced detectors, Tommasino (1) mentions two broad categories of passive gas-monitoring devices used for radon monitoring - diffusion samplers and permeation samplers.

A diffusion sampler typically consists of a tube with a detector located at one end of the diffusion zone formed by the tube. The other end of the tube is generally open to the atmosphere.
A permeation sampler differs from the former in that the sample must pass through a permeable membrane.
The two mechanisms are not exclusive and can exist in the same detector.

THE CONTRIBUTION FROM DIFFUSION

The rate of diffusion of radon into a detector, dQ/dt, is proportional to the difference between the outside and inside concentrations, ΔC, the diffusion length L, the cross section area A and the diffusion constant D (2):

$$\frac{dQ}{dt} = \frac{D\ A\ \Delta C}{L}$$

Thus a small cross section and/or a long diffusion length will allow for both thoron decay and daughter plateout along the path. In a monitor design with filter paper, the paper acts as a "compressed column" with a long, torturous (!) diffusion path.

With a solid cap on the AT-100, the diffusion path for the radon become the gap between the cap and the base. This friction fit appears tight, but actually contains gaps that are thousands of times larger than the 1.5 angstrom radon atom.

To confirm the validity of this design, chamber exposures were made with both filtered caps and solid caps. The inside geometry was of course identical. The following Table 1 shows no significant difference in sensitivity between filtered and solid caps. The wrap label which covers the radon entry gap has no effect on sensitivity.

Table 1
Comparison of filtered and solid-capped ATDs

cap type	tracks per square millimeter
holes and filter paper	60.6 +/- 4.2
solid with wrap label	63.8 +/- 7.6
solid without label	63.3 +/- 3.2

To further investigate the diffusion design, several solid cap detectors were drilled through the housing (bottom part) with either 1, 2 or 3 holes. Each hole had a diameter of 0.35mm and a length through the housing wall of 1.65 mm, which gives a ratio of length to area of 17 to 1. (As long as the length of the hole outweighs the cross section, diffusion persists, no filter paper is needed, and no effect on sensitivity results).

Chamber exposures demonstrated the absence of significant differences between groups (see Table 2). The chamber contained a flask of water for water vapor, so that an equilibrium factor of 0.3 could be maintained through present condensation nuclei.

Table 2

Significance of Number of (unfiltered) Openings

detector type	tracks per square millimeter
cap with filter paper	168 +/- 8
solid cap, no side holes	162 +/- 18
solid cap, 1 side hole	172 +/- 14
solid cap, 2 side holes	171 +/- 6
solid cap, 3 side holes	179 +/- 18

THE CONTRIBUTION FROM PERMEATION

In addition to diffusing through the gap between cap and base, radon may enter through the solid housing of the detector itself. To examine the amount of radon entering by this route, another chamber exposure was conducted with three different detector designs.

Exposed were six each of the AT-100, polypropylene loaded with carbon, o.o6" thick, the REM "school monitor" of natural polyethylene, 0.04" thick, and the amber Canadian pill vial made of polystyrene, o.o4" thick.None of these designs has filter paper. All the detectors were totally sealed for diffusion entry by having the joint between the cap and the base cemented shut with epoxy. In addition to the sealed monitors, standard monitors were also exposed, and the results used to determine the permeation entry. As can be seen, essentially none of the radon signal with the AT-100 is due to permeation through the detector housing (Table 3 on p.5)

Table 3

Permeation of Radon through Housing in ATDs

detector design	Share of Permeation (total equal 1)
AT-100 sealed with epoxy	0.02 +/- 0.02
"school monitor" with epoxy	0.12 +/- 0.02
pill vial monitor sealed with epoxy	0.11 +/- 0.02
pill vial mon. (no cap) inside 0.04"plas.	0.12 +/- 0.02

However, over 10% of the signal produced by the other two detector designs resulted from radon entering the detector through the housing. This would be in close agreement with other reports in the literature. Using the experimental results for radon permeability in plastics by Hafez and Somogyi (3), 0.04" of polyethylene should produce an attenuation factor of 0.13.

In order to test the results of the latter authors, we took an uncapped and unsealed pill vial and put it inside 20 layers of 0.002" of polyethylene. The radon admitted to the detector foil was identical in concentration to the radon observed in the epoxy sealed pill vial. This test also showed that the epoxy seal used in the test reported in Table 3 was an effective seal.

RADON ENTRY DYNAMICS

So far we have looked at the relative contributions of diffusion and permeation in different monitor designs. As we were testing three different detectors, it was obvious that we would compare the performance of the three, to see to what extent they differed and if we could understand why.

In the following Table 4, we are compiling several parameters and results for each of the three monitor types.

Table 4

Monitor Size and Performance

monitor type	diameter	admitted radon	circumference	ratio $\frac{\text{radon}}{\text{circ}}$
AT-100 monitor	3.6 cm	605 pCi/l	11.3 cm	53.5
school monitor	3.8 "	552 "	11.3 "	48.8
pill vial mon.	2.3 "	360 "	7.22 "	49.9

On first glance, there appears to be an indication of dependence of radon sensitivity on the diameter of the detector housing. Since we have shown that most or even all of the radon enters the three monitor models tested by way of the housing gap, it would be understandable that the more radon would enter the monitor, the longer the circumference of the housing. Table 4 appears to bear out such a relationship, as it shows the ratio of radon concentration and monitor circumference to be constant, within the limits of the test.

A further case in point for this argument would be the comparison of the amber pill vial with its 2½" length with the shortened, 1" long, black alpha track monitor introduced out of Golden, CO in 1989. Both detectors had the same sensitivities, though one was 2½ times larger in volume. But the diameter and circumference were the same.

Unfortunately, the argument for the significance of the circumference of a detector is a mute one.

The length of the gap will help establishing equilibrium during the ramping-up period. The more openings, filtered or not, the more rapidly will the freshly opened detector adjust to the sampling environment. But once the equilibrium is reached, a large circumference/ long gap detector will simply allow more radon to diffuse in both directions, both in and out. But the concentrations inside will be the same.
Picture a double carburetor, high-power automobile. It corresponds to the large diameter detector. It will accelerate rapidly and allow large volumes of sample to pass through rapidly. But once at cruising speed, it will throttle down, and the extra horsepower will not be needed.

The Nuclear Research Center in Karlsruhe used to work with a large, about 3" (8cm) diameter radon monitor. They carefully changed the design and brought it down to a diameter of about 3 cm. They claim that they were able to actually increase the sensitivity of their monitor despite reducing its size.

Drs. Urban and Schmitz were fortunate. They worked in a diameter region where the penetration distance of alpha particles in air is less than the critical distances of detector geometry. On the other hand, the pill vial happens to be below the critical dimensions. It is less sensitive, not because of a shorter circumference, but because its geometry is too small for optimal conversion of alpha disintegration into tracks per square millimeter.

There is one test which we have not as yet carried out, but which we will now as a "thought-experiment".

Picture us cementing the circumference of an AT-100 not completely, but for 90^{o}, 180^{o}, 270^{o} and, maybe 345^{o} - almost shut.
If we leave the detectors in the chamber long enough, all will come out with the same result. The most significant difference between monitors will be the ramp-up time. It will take longer to reach equilibrium with the sampling environment, the shorter the uncemented gap is that is available for diffusion. If we keep the monitors stored for a while after the end of exposure, then the slow ramp-up monitors will also be slow in ramping down, and they will keep on collecting alpha tracks while the quicker monitors have finished holding their radon.

Alpha track monitor design is based on a few important parameters dictated by the behavior of the radon alpha particle and those of the daughters in air. But it does not require filtered openings as long as it is provided that the atmosphere inside the monitor and out can come to equilibrium. What we generally assume to determine the workability of a monitor, its filtered holes, will only affect the ramping-up speed in the short term. We have attempted to show that, other than that - within certain limits, almost any two-part housing will perform as an alpha track detector !

REFERENCES

(1) Tommasino L., et al., A Plastic-Bag Sampler for Passive Radon Monitoring, Nuclear Tracks, Vol. 12, p. 681 (1986).

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(3) Hafez A. and Somogyi G., Determination of Radon and Thoron Permeability Through some Plastics by Track Technique, Nuclear Tracks, Vol 12, p. 697 (1986).