DETECTION OF RADON AND RADON DAUGHTERS BY MEANS OF AN ELECTRET IONIZATION CHAMBER COMBINED WITH SOLID STATE NUCLEAR TRACK DETECTORS

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ABSTRACT

For measuring radon concentrations in air an electret ionization chamber of the diffusion type was developed. The change of the charge density on the electret surface is a measure of the radon concentration from which the concentration of radon daughters can be estimated assuming an equilibrium factor. This factor, however, varies strongly dependent on environmental and other conditions. In order to determine the equilibrium factor more precisely, a combination of three solid state nuclear track detectors was studied which allows the selective detection of alpha particles in defined energy intervals.

INTRODUCTION

The radiation exposure of the human respiratory tract is mainly determined by the concentration of short-lived radon decay products in the inhaled air. Using passive detectors inside diffusion chambers the radon concentration in air can be measured from which the concentration of radon daughters is calculated presuming an appropriate equilibrium factor[1,2]. Because the equilibrium factor is not known with the required precision, the uncertainty of the estimated radiation exposure is relatively high[3]. The use of a multi-detector system is, therefore, proposed which allows to measure the radon concentration using an electret ionization chamber and separately the equilibrium factor using three solid state nuclear track detectors.

RADON DETECTION BY MEANS OF AN ELECTRET IONIZATION CHAMBER

The principle of an electret ionization chamber (EIC) of the diffusion type is shown in Figure 1. On the top of the diffusion chamber aerosols and radon daughters are retained on the diffusion filter whereas the radon gas diffuses into the chamber volume. Radon decay products generated within the EIC are almost completely plated-out on the inner surface of the chamber walls. The electret made of PTFE or FEP is characterized by a quasi-permanent electrical charge which generates a surface potential, the electret voltage U_E. Within the chamber alpha particles emitted by radon and its daughters result in an ionization of the air and thus in a degradation of the electrical charge of the electret surface.

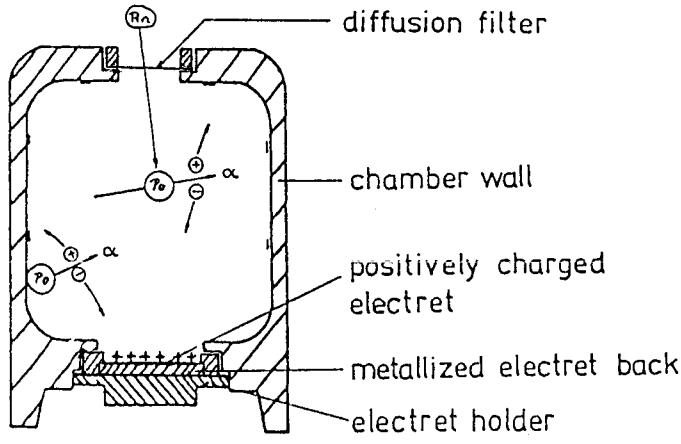

Figure 1 Scheme of the electret ionization chamber for radon measurements[4]

The response of the EIC is given by

$$m_{Rn} = \frac{\Delta U_E}{c_{Rn}\ \Delta t} \qquad (1)$$

where ΔU_E is the radiation induced change of the electret voltage, whereas c_{Rn} and Δt are the concentration of ^{222}Rn and the exposure period, respectively. The response m_{Rn} was calculated by means of a Monte Carlo program[5] resulting in $m_{Rn,calc}$ = 0.065 V/Bq·m^{-3}·d. By exposing the EIC in different well-defined radon atmospheres, the experimental estimation resulted in a value of (0.060 ± 0.004) V/Bq·m^{-3}·d. The lower detection limit was found to be 40 Bq·m^{-3} (with Δt = 7d) and the upper limit 5 kBq·m^{-3} (with Δt = 1d).

DETECTION OF RADON AND RADON DAUGHTERS USING A SYSTEM OF NUCLEAR TRACK DETECTORS

It is the common technique to measure the radon concentration using, for instance, EIC or other types of diffusion chambers. For the estimation of the lung exposure by radon decay products, however, the equilibrium factor is needed. Because this factor varies strongly with a number of environmental and other conditions, a consistent system of three nuclear track detectors has been studied with the aim of a separate detection of radon and its daughters under free air conditions. Thus, the equilibrium factor can be determined as average value also for longer exposure periods.

The physical basis of such a detector system is formed by the creation of different energy response functions for the three detectors as the result of a suitable combination of the detector and absorber material and/or an optimization of the etching procedure. For this purpose the electrochemical etching technique of polycarbonate detectors (MAKROFOL DE, Bayer Leverkusen, FRG) and CR-39 detectors (PATRAS, Optische Werke Rathenow, FRG) have been studied.

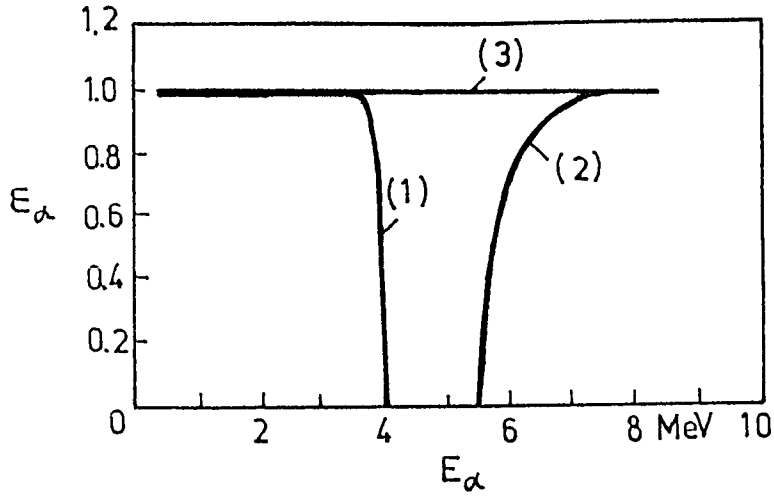

Figure 2 Qualitative presentation of the track detection efficiency ε_α of the nuclear track detector system as a function of alpha energy E_α
(1) MAKROFOL (electrochemically etched: 80 vol% 6N KOH + 20 vol% ethanol, 35°C, 5h 100Hz and 1h 2kHz, 26.7kV/cm)
(2) CR-39/PATRAS (chemically pre-etched: 6N KOH, 60°C, 10h; electrochemically etched: 6N KOH, 60°C, 2h 2kHz, 15kV/cm)
(3) CR-39/PATRAS (electrochemically etched: 6N KOH, 60°C, 5h 2kHz, 15kV/cm)

From Figure 2 follows that the MAKROFOL DE detector (1) has an upper energy threshold of about 4 MeV[6]. Using this etching condition, the detector registers only alpha particles from ^{222}Rn and its decay products incident from an air layer in a certain distance of the detector. On the other hand, decay products plated-out on the detector surface do not contribute to the track density because the corresponding alpha particle energies of about 6 MeV exceed the upper energy threshold. The resulting track density of the detector (1) is thus given by

$$\rho_1 = m_1^{Rn} \cdot c_{Rn} + m_1^{DA} \cdot c_{DA} \qquad (2)$$

where m_1^{Rn} and m_1^{DA} are the detector responses to ^{222}Rn and radon daughters in air, respectively, and c_{Rn} and c_{DA} the corresponding activity concentrations in air.

The second detector of the system should have a lower energy threshold at about 5.5 MeV, in order to detect only decay products from a certain air layer in front of the detector as well as decay products plated-out on the detector surface, whereas alpha particles from ^{222}Rn are not registered. The track density of the detector (2) follows from

$$\rho_2 = m_2^{DA} \cdot c_{DA} + m_2^{DD} \cdot c_{DD} \qquad (3)$$

Here, m_2^{DD} is the detector response to daughters deposited on the detector surface and c_{DD} the corresponding activity concentration. The lower energy threshold of 5.5 MeV could be created by means of a suitable dimensioned absorber in front of the detector. Using CR-39/PATRAS, however, this threshold has been obtained by chemical pre-etching of the detectors for 10 hours (see Figure 2).

Finally, a third detector (3) without an energy threshold is needed. Then its track density follows from

$$\rho_3 = m_3^{Rn} \cdot c_{Rn} + m_3^{DA} \cdot c_{DA} + m_3^{DD} \cdot c_{DD} \qquad (4)$$

Studies with CR-39/PATRAS detectors showed that without applying a chemical pre-etching this non-threshold behaviour exists (see Figure 2).

Thus, from equations (2), (3) and (4) the concentration of ^{222}Rn and its daughters in air can be determined separately whereas the plate-out effect on the detector surface is eliminated.

CONCLUSIONS

Using the track etched detector system described here, an energy-selective detection of alpha particles emitted by radon and its daughters is possible. From these results a mean equilibrium factor follows which can be used for the interpretation of the results of radon measurements using EIC or other types of passive radon diffusion chambers.

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