ASSESSMENT OF RADON-DAUGHTER DEPOSITION IN THE RESPIRATORY TRACT

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ABSTRACT

Since some decades it is known, that most of the radiation dose to the lung is due to the inhalation of the short-lived decay products of ^{222}Rn. Their deposition in the respiratory tract strongly depends on the attachment rate to aerosol-particles present in the indoor air and their plate-out rate to the surfaces. Instead of measuring the activity size distribution of the airborne decay products, knowledge on the respiratory tract retention has been incorporated in the design of a measurement system, called bronchial dosemeter, to assess the lung dose directly. The simulation of the deposition characteristics of the short-lived radon daughters in the nasal cavity and the bronchial tree is based on the comparison of the model of the respiratory tract with results from screen penetration theory. A bronchial dosemeter consisting of three sampling heads has been built and calibrated. Additionally, an outline of future activities will be given.

INTRODUCTION

During the last decade the radon issue has become one of the major problems in radiation protection. Already 40 years ago it was found, that the lung dose in uranium miners is not due to radon (^{222}Rn) but to the inhalation of its short-lived decay products ^{218}Po, ^{214}Pb and ^{214}Bi (^{214}Po) [1,2,3]. The airborne decay products of radon deposit in the respiratory tract leading to a radiation dose to the lung. In the indoor environment this deposition strongly depends on the attachment rate of the freshly formed decay products to aerosol-particles and on the plate-out rate to indoor surfaces. Since it is known that the unattached fraction of the decay products is a major contributor to the radiation dose, several attempts have been made to measure the activity size distribution of the unattached fraction. These measurements on the basis of wire-screen methods were only partially successful, because there are intrinsic problems to separate the unattached fraction completely from the rest of the activity size distribution [4].

Therefore, it has been suggested to simulate the deposition characteristics of the short-lived radon daughters in the nasal and bronchial regions and measure the deposited activity directly. According to the theoretical concept of such a measurement system [5] a so-called bronchial dosemeter has been built at the Belgian Nuclear Research Center, SCK•CEN. In the following the design and the efficiency determination of this bronchial dosemeter will be reported.

CONCEPT OF THE BRONCHIAL DOSEMETER AND EFFICIENCY DETERMINATION

Basically, it is assumed that the deposition characteristics of the nasal cavity and the bronchial tree may be simulated by different numbers of screens [6,7]. Their respective sizes and numbers are determined by comparing models of the respiratory tract with results from the screen penetration theory. For an average nasal inspiration flow rate of 30 l/min, a 400 mesh screen operated at a face velocity of about 12 cm/s provides a rather good approximation to the nasal absorption characteristics [8]. Adding up four such screens provides a good approximation to the bronchial tree [9,10].

The bronchial dosemeter consists basically of two different units. The first unit is the sampling section, which is used to collect the airborne radon decay products. This part of the dosemeter consists of three different sampling channels:

1. The sampling head of the first channel consists of an open-faced polycarbonate membrane filter with a pore size of 0.4 µm, which collects the total airborne activity.
2. In the second head the filter is covered by a 400 mesh screen in order to collect the activity penetrating the nasal cavity. The activity deposited in the nasal cavity is then given by the difference between the activity collected on filter (1) and filter (2).

3. The filter of the third sampling head is covered by five 400 mesh screens to collect the difference between the airborne activity and what deposits in the nasal cavity plus bronchial tree. From the difference between the activity collected on filters (2) and (3) the activity absorbed in the bronchial tree is obtained.

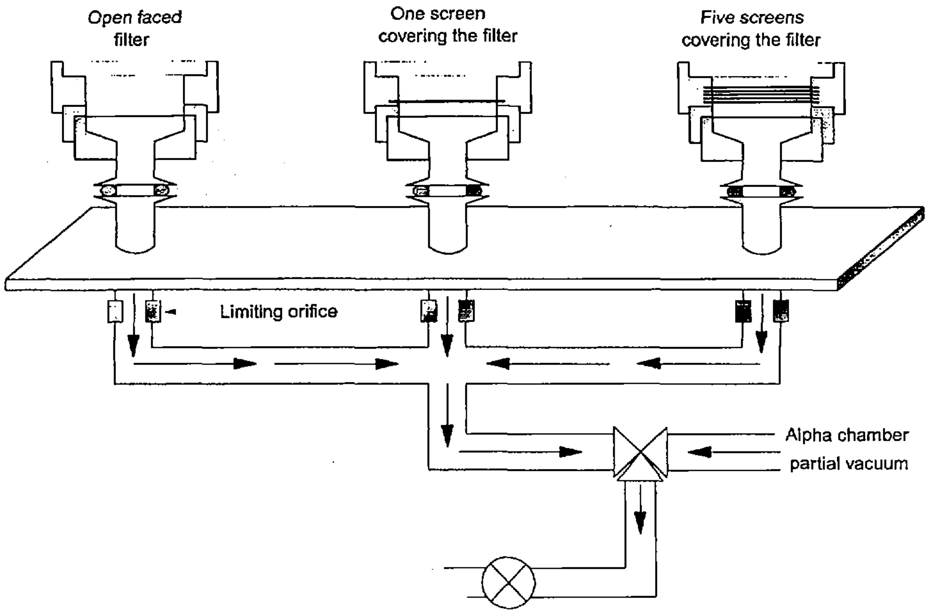

Fig. 1: Sampling section of the bronchial dosemeter. The open diameter of one sampling channel is 4 cm. The flow rate at standard atmospheric conditions is 9.1 l/min leading to a face velocity of 12 cm/s.

The sampling section of the bronchial dosemeter is shown in Fig.1. For further details it is referred to ref. [11].

The second unit of the bronchial dosemeter is the alpha-spectrometer section which consists of three separate α-detectors. After sampling the filters remain mounted on their sampling heads in order to keep the counting geometry reproducible. The sampling heads are put into the vacuum chambers, where the filter activities due to the α-decay of ^{218}Po and ^{214}Po are measured. From the peak areas obtained in two subsequent measurements the decay product concentrations of ^{218}Po, ^{214}Pb, and ^{214}Bi (^{214}Po) collected on the filters can be calculated.

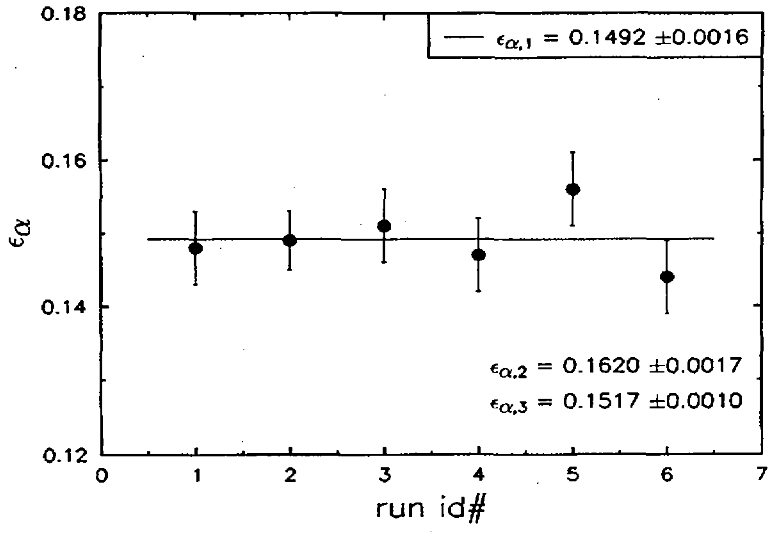

Fig. 2: Efficiency of sampling channel (1) obtained at a distance of 0.7 cm from the detector. The full line indicates the weighted average of the data.

The efficiency of the bronchial dosemeter is determined by the efficiency of one sampling channel and the intercomparison of all three channels. The efficiency of one sampling channel is determined by measuring the α-activity from ^{218}Po and ^{214}Po and the γ-activity following the β-decay of ^{214}Bi.

During the efficiency determination the sampling section of the bronchial dosemeter was placed in a chamber with a volume of about 6 m^3. The radon activity concentration c_{Rn} varied between 26 kBq/m^3 and 10 kBq/m^3. The sampling time was 10 min. After sampling the filters were transferred to the vacuum chambers within 1 min. The α-activity of all sampling heads were measured for 5 min and then for 15 min. Afterwards, the sampling head of channel (1) was transferred to a germanium detector. The γ-activity of filter (1) and the α-activities of filter (2) and (3) were measured for 30 min. From the area under the γ-peak at $E\gamma$ = 609.3 keV, the photon branching ratio and the γ-detection efficiency the expected number of α-particles $N_\alpha^{(e)}$ from ^{214}Po is determined. The detection efficiency for α-particles ϵ_α of this sampling channel is then the ratio between the number of α-particles extrapolated from the α-measurements, $N_\alpha^{(m)}$, and $N_\alpha^{(e)}$.

The efficiency of sampling channel (1), $\epsilon_{\alpha,1}$, obtained from six measurements is indicated in Fig. 2 together with the respective data. From these data the efficiency of the other two sampling channels, $\epsilon_{\alpha,2}$ and $\epsilon_{\alpha,3}$, were determined by intercomparing the equilibrium equivalent radon concentrations (EEC). The results are also given in Fig. 2. Their relative uncertainty on the mean value is less than 1.1 % at one standard deviation.

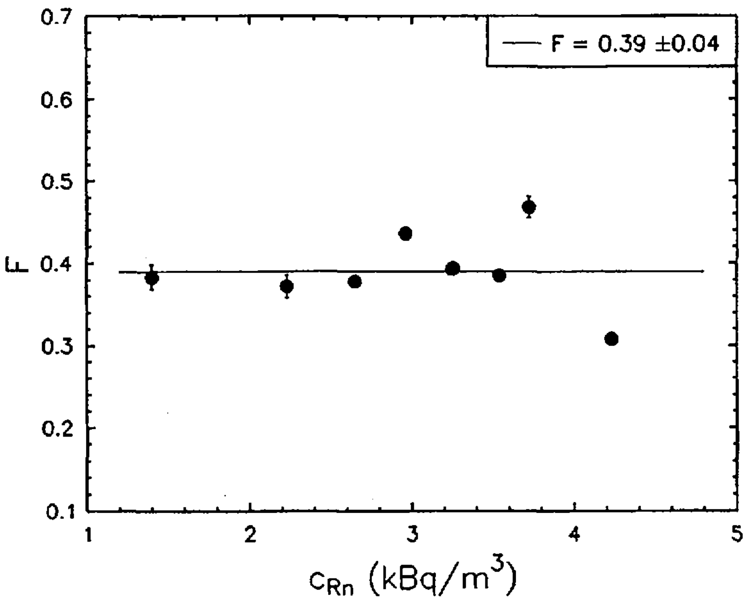

Fig. 3: Equilibrium factor F as a function of the radon concentration c_{Rn}. The average value for F = 0.39 with a relative standard deviation less than 11 %.

FIRST EXPERIMENTAL EXPERIENCE

Under laboratory conditions test measurements with the complete system were performed. In the beginning the radon concentration was about 4.5 kBq/m^3 and drops to about 1.5 kBq/m^3 at the end of the test period. The sampling period was 5, 6 or 7 min. The filter activities were measured during two periods for 10 min and 35 min, respectively.

From the open-faced filter of sampling channel (1) the EEC in air was obtained. Division of an EEC-value by its corresponding radon activity concentration c_{Rn} gives the equilibrium factor F, which gives a characterization of the aerosol-concentration present (see e.g. ref. [12]). In Fig. 3 F is shown as a function of c_{Rn}. The average equilibrium factor throughout the test measurements was 0.39 with a relative uncertainty less than 11 % at one standard deviation, which indicates rather stable atmospheric conditions during the measurement campaign.

The obtained fractional deposition of the short-lived decay products in the nasal cavity (f_n) as well as in the bronchial tree (f_b) is shown as a function of F in Fig. 4 for each nuclei separately. Although the data show some fluctuations, it is still valid to define average fractional depositions for the different decay products. Average values $\overline{f_n}$ and $\overline{f_b}$ taken from the data of ten measurements are summarized in Tab. 1.

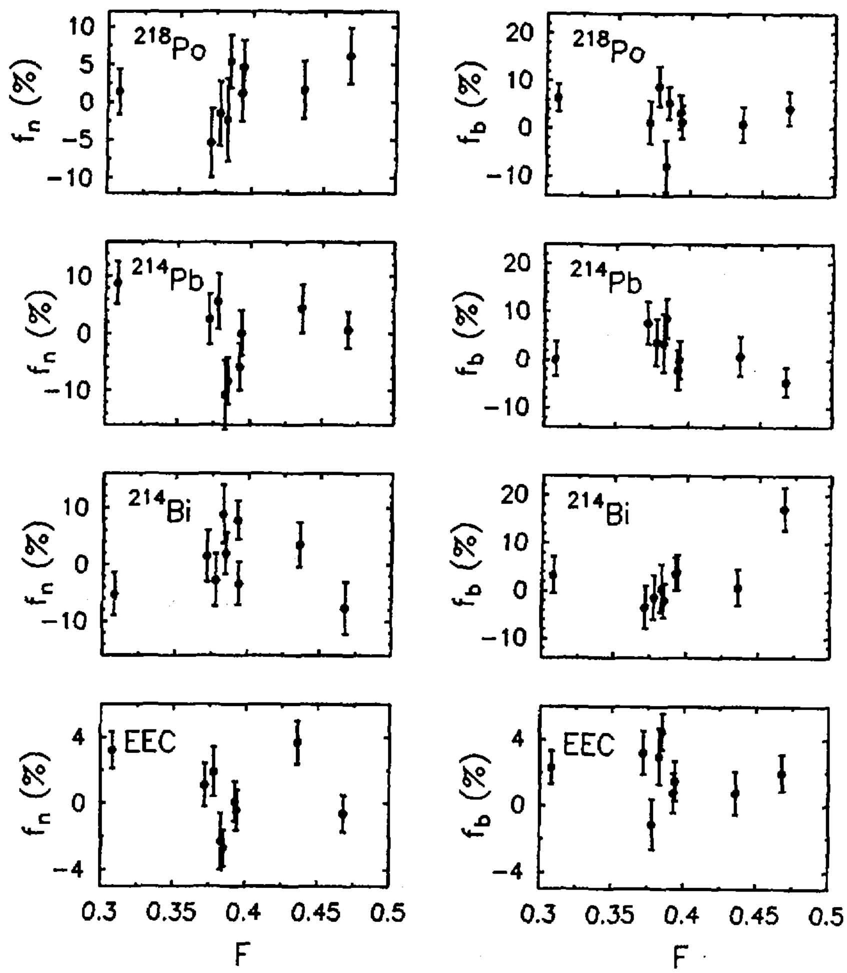

Fig. 4: Fractional deposition of the short-lived radon decay products ^{218}Po, ^{214}Pb, ^{214}Bi and the equivalent radon concentration (EEC) as a function of the equilibrium factor F. The left part shows the fraction of decay products deposited in the nasal cavity (f_n), and the right part shows the fractional deposition in the bronchial tree (f_b).

Avarage fractional deposition	^{218}Po 10^{-2}	^{214}Pb 10^{-2}	^{214}Bi 10^{-2}	EEC 10^{-2}
Nasal cavity $\overline{f_n}$	1.3 ± 1.3	-0.3 ± 2.2	0.5 ± 1.9	0.4 ± 0.7
Bronchial tree $\overline{f_b}$	4.4 ± 1.0	1.1 ± 1.6	2.5 ± 2.0	1.9 ± 0.5

Table 1: Average fractional deposition of the short-lived radon decay products in the nasal cavity $\overline{f_n}$ and the bronchial tree $\overline{f_b}$. The values are averaged over nine measurements with equilibrium factors F = 0.39 ± 0.04.

CONCLUSION

According to the conceptual design of a multiple wire screen sampler in ref. [5] a bronchial dosemeter has been built. First test measurements were performed under laboratory conditions. It turned out, that the bronchial dosemeter is a suitable facility to individually assess deposition characteristics of the different short-lived radon decay products in the nasal cavity as well as in the bronchial tree. However, the interpretation of the data strongly depends on the underlying model of the respiratory tract, which influences the choice of the mesh size as well as the number of screens used for the sampling heads. For instance, according to recent model calculations [14] the nasal absorption might be better simulated by a screen with a 100 mesh grid.

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