MEASUREMENT OF THE POTENTIAL ALPHA ENERGY CONCENTRATION IN AIR BY SEPARATE REGISTRATION OF THE RADON DECAY PRODUCT 214-Po USING NUCLEAR TRACK ETCHED DETECTORS

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INTRODUCTION

Long-term measurements of the activity concentration of ^{222}Rn in air can be easily performed using a solid state nuclear track detector within a diffusion chamber. The radiation exposure of the human respiratory tract is, however, mainly characterised by the potential alpha energy concentration W_p of the radon daughters. The measurement of this quantity over the same period of time is very difficult. Some authors applied the double chamber method, using one detector within a chamber closed by a diffusion filter and another detector within an analogeous chamber, but without the filter (1,2). The results found from the relationship between W_p and the activity concentration of both alpha active decay products (^{218}Po and ^{214}Po) depend strongly on the exposure conditions, e.g. on the equilibrium factor and the fraction of unattached radon daughters. The aim of our studies was to find a new approach to estimating the potential alpha energy concentration on the basis of its relation to the activity concentration of ^{214}Po only.

CONCEPT OF MEASUREMENT

The actual radon daughter concentration in air is affected by the dilution as the result of ventilation as well as the deposition on wall surfaces. The latter effect is different for radon daughters attached on aerosols and unattached daughters, resp. Taking into account realistic values for the attached fraction and the deposition rates the radon daughter concentrations c_1 (^{218}Po), c_2 (^{214}Pb), c_3 (^{214}Bi), c_4 (^{214}Po) can be calculated from the ^{222}Rn concentration c_0 by means of a recursion formula. Inserting the results into the definition equation for the potential alpha energy concentration W_p, the functions

$$\frac{W_p}{c_0} = f\left(\frac{c_1 + c_4}{c_0}\right) \tag{1}$$

and

$$\frac{W_p}{c_0} = f\left(\frac{c_4}{c_0}\right) \tag{2}$$

can be calculated (3). The results are shown in Fig. 1. Determining the activity concentration of radon on the one hand, and that of ^{218}Po and ^{214}Po or of ^{214}Po only on the other hand, the potential alpha energy concentration can be derived from these curves.

Measurements of ^{222}Rn and the total activity concentration of both alpha active decay products are frequently performed by means of the double chamber method. However, because of the marked steepness of the corresponding curve (I) in Fig. 1 a very high uncertainty of W_p results. Therefore, we proposed a new concept detecting ^{214}Po only. Then curve (II) in Fig. 1 is relevant which is much more flat. Therefore, more precise results for W_p can be expected. The superiority of this new method has been theoretically shown in our recent studies, especially in such cases where the unattached fraction of the radon daughters is relatively high (3-5). It needs, however, a method for the separate long-term measurement of the activity concentration of ^{214}Po.

For this purpose, the application of nuclear track detectors with a suitable energy response function is useful. From the alpha energy spectrum in air followed that such a detector should be sensitive only to alpha particles slowed down to energies within a window between 6.1 MeV and 7.4 MeV. This limitation is needed in order to avoid tracks from radon daughters plated out on the detectór surface. The aim of our studies was to optimize the energy response of a Makrofol DE detector for that purpose.

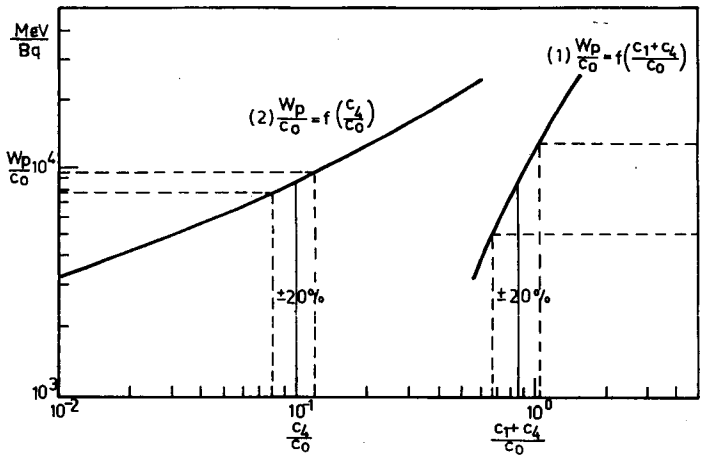

Figure 1. Potential alpha energy concentration as a function of the radon daughter concentrations after eq. (1) and (2)

EXPERIMENTAL AND THEORETICAL BASIS

The detector material used was Makrofol DE with a thickness of 475 µm. During the irradiations the detectors were covered by a protecting Mylar foil with a thickness of about 2 µm.

For irradiations with high energy alpha particles a source has been prepared by electrodeposition of thoron daughters. The alpha particles with an initial energy of 8.8 MeV have been slowed down in the irradiation chamber by variation of the air pressure to fall into the interesting energy interval between 5.8 MeV and 7.7 MeV.

The main task was to investigate whether the energy window characterised by two thresholds can be generated. For that some theoretical considerations were performed. Etchable tracks are formed only when the restricted energy loss REL_{350} of the alpha particles along their paths exceeds the critical energy loss for the detector material. The REL_{350} value depends strongly on the alpha energy and varies, therefore, considerably along the alpha particle trajectories (see Fig. 2).

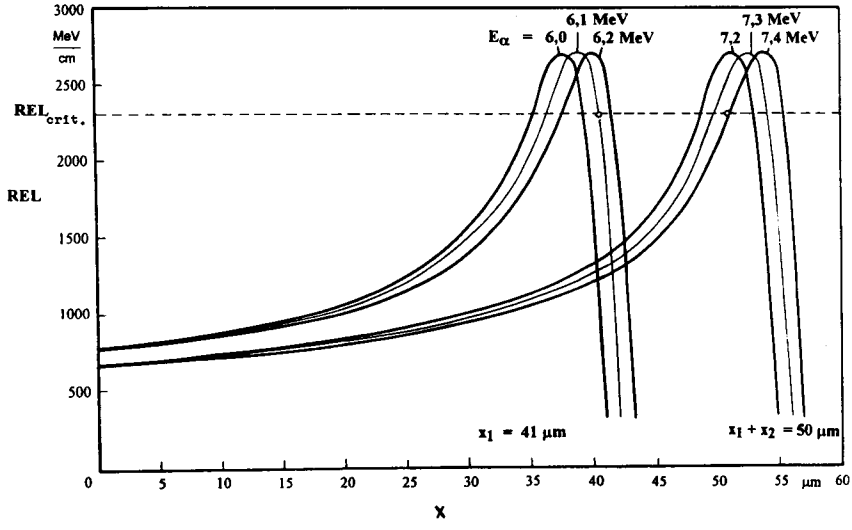

Figure 2. Restricted energy loss REL as a function of the depth x within the detector (including 2µm Mylar) (Parameter: Initial alpha energy E_α; Calculation using the program STOPOW 2000 (6))

The critical REL_{350} value has been found to be about 2300 MeV/cm in separate experiments. To avoid a formation of etchable tracks by alpha particles with energies lower than 6.1 MeV a detector layer (below the Mylar foil) of about 39 µm has to be removed by a chemical etching process. Over-etched tracks caused by lower energy alpha particles may not contribute to the detector reading during a further processing of the detector by electrochemical etching. The treeing process with strong enlargement of the tracks takes place only

if a sharp tip is formed at the end of the chemical etching, i.e. not for over-etched tracks. Figure 2 shows that at a depth x_1 of 41 μm the 6.1 MeV alpha particles are just ready to produce electrochemically etchable tracks. On the other hand, the energy loss of alpha particles with initial energies above 7.4 MeV may not exceed the critical value for track formation at a depth of $x_1 + x_2 = 50$ μm. That means, the detector layer removed during the electrochemical etching must be about 9 μm up to the end of this etching step. Because the formation of electrochemically etched tracks is influenced by the applied field strength it has been expected that the exact thresholds and the shape of the alpha energy window depend on the field strength, too.

RESULTS

The etching was carried out using a mixture of 80% ethanol and 20% KOH at 40°C. During the chemical pre-etching a detector layer of 39 μm was removed. The electrochemical etching was performed at an electric field strength of 51 kV/cm and a frequency of the high voltage of 3 kHz for 1 hour. After that a chemical post-etching followed for 0.5 hours. During this process the tracks are enlarged without changing the energy response of the detector. This last step makes, however, the detector evaluation easier. The total detector layer removed during the electrochemical etching and chemical post-etching was about 14 μm. The maximum track diameter amounted to 200 μm. The resulting energy response of the detector is shown in Fig. 3.

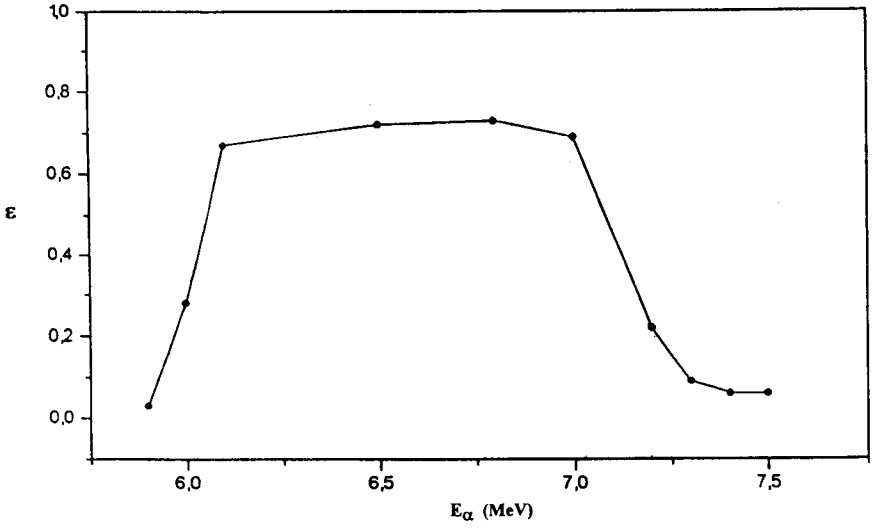

Figure 3. Registration efficiency ε as a function of alpha energy E_α

CONCLUSIONS

The results of our studies confirmed that, using Makrofol-DE detectors treated by a combined chemical and electrochemical etching, the energy window needed for a separate detection of ^{214}Po can be generated. The activity concentration c_4 of ^{214}Po results from the detector reading, i.e. the track density within a defined period of exposure. The calibration factor which links both quantites can be found by an experimental calibration using a reference measuring device for ^{214}Po. On the other hand, the calibration factor can also be calculated. The corresponding relationship was derived in a former paper (3). The most important quantity needed for the calculation is the critical angle of track detection as a function of the alpha energy. The precise determination of this function will be the objectives of our next work. Using the c_4 value and the radon concentration c_0 determined by means of a traditional method, e.g. using the diffusion chamber, the potential alpha energy concentration W_p can be determined..

A test of the method under practical conditions is planned, e.g. in living rooms or at special working places.

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