Retrospective radon dosimetry (*)

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Summary. — Knowledge of the precise life-time radon history in houses is essential for epidemiologists, mitigation professionals and house-owners. For radon dosimetry and to make a reasonable health-risk study similar information about the indoor aerosol environment is necessary. For this purpose a combined data analysis from measurements of the ^{210}Po activity implanted in glass-surfaces as well as trapped in spongy materials is proposed. This analysis technique provides a characterization of the average indoor aerosol-particle environment. As a consequence, a radon dose estimation improves by a factor of about 3 compared to the commonly applied single surface-activity analysis.

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1. – Introduction

The strategies to assess the apparent health risk due to radon in the indoor environment rely principally on different types of information. In the first instance the activity concentration of radon gas and of the short-lived radon daughters may be measured with the existing techniques rather precisely. On the contrary the assessment of dose relevant parameters, *i.e.* the fractional deposition of individual radon daughters across the respiratory tract, is difficult. Since these parameters are strongly affected by the present aerosol-particle environment, the conclusions are today quite model dependent, and only a few experimental techniques exist, see, *e.g.*, ref. [1]. Anyway, all radon and radon-daughter measurements available act on a medium or even short term scale ranging from at best one year down to one day. Due to strong daily and seasonal fluctuations in the indoor environment any evaluated risk factor carries an uncertainty easily exceeding a factor of two. Therefore, retrospective assessment strategies on life-time scale have to be considered. Nowadays the analysis

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of the ^{210}Po activity implanted in glass surfaces (a_s) is commonly used to obtain information on the integrated radon exposure [2]. Since deposition and implantation is strongly affected by the present aerosol particles, the uncertainty on the radon exposure easily exceeds a factor of two [3, 4]. However, this degradation of the ^{210}Po signal may be used as a measure for the aerosol-particle environment in the past. The recently introduced analysis of the ^{210}Po activity deposited in volume traps (a_v), *e.g.*, spongy materials used for mattresses and cushions, provides a clear relationship between the measured volume activity a_v and the radon exposure E_{Rn}, *i.e.* a very accurate information about the radon history [5] completely unaffected by the indoor air-quality. Therefore, a combination of both methods is compelling.

With a combined surface + volume analysis it is possible to assess the radon history as well as the dose-related parameters as the average value of the attachment rate (X), of the equilibrium factor (F) as well as of the unattached fraction of the short-lived radon progeny (f_u), retrospectively.

2. – Description of the method

The basic idea is the following. With the surface technique we obtain the surface activity a_s and with the volume technique we measure the volume activity a_v, which clearly relates to the exposure $E_{Rn} = \overline{c_{Rn}}\ t_{ex}$. Assuming an aerosol-free environment we can calculate from a_v for a given surface-to-volume ratio S/V an equivalent surface activity $a_{s,0}$. The following relation between $a_{s,0}$ and the measured a_s may then be considered:

$$a_s = \mathscr{F}(X, \lambda_u, \lambda_a, \lambda_v, S/V)\, a_{s,0}, \tag{1}$$

with $\mathscr{F} < 1$, where λ_u, λ_a are the deposition velocities of the unattached and attached radon decay-products, and λ_v denotes the ventilation rate.

Next it is sufficient to assume λ_v and S/V as constants, which are characteristic values for the particular dwelling or even room being under investigation. Also, λ_u and λ_a are assumed to be log-normally distributed with ranges obtained from the

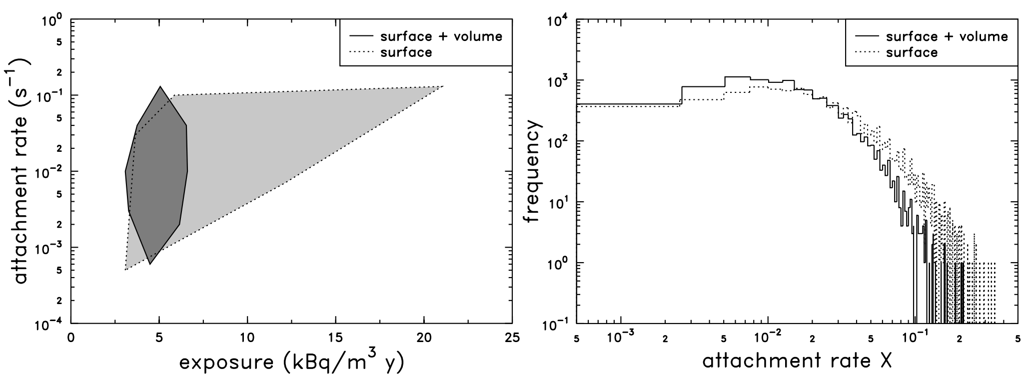

Fig. 1. – Comparison of the results obtained with the standard surface analysis and with the new combined surface + volume analysis. Left part: all possible combinations of the attachment rate *vs.* radon exposure which reproduce a given a_s. Right part: distribution of the attachment rate X.

literature [6, 7]. By entering $\overline{c_{\mathrm{Rn}}}$ and X the dose-relevant parameters f_{u}, f_{a} and F for a given surface activity a_{s} may be obtained using the room-model equations [6, 8, 9]. This is an iterative procedure for the attachment rate X. Starting with the single surface technique it is clear from published experimental data [4, 10] that the measured surface activity a_{s} may not clearly be correlated with a particular radon concentration, but $\overline{c_{\mathrm{Rn}}}$ must also be drawn randomly from a log-normal distribution. In consequence a large uncertainty is added to the average attachment rate and so to the dose-related parameters. A simulation of a single surface-activity analysis has been performed assuming a surface activity $a_{\mathrm{s}} = 10\,\mathrm{Bq/m^2}$ and an exposure period $t_{\mathrm{ex}} = 10\,\mathrm{y}$. The distributions for $X(E_{\mathrm{Rn}})$, F, f_{u} and the annual dose D_{a} based on 10000 entries are presented in figs. 1 and 2.

Introducing the volume-technique the simulation has been repeated entering a much more precise value for c_{Rn} obtained from the measured volume activity a_{v}. In fact, c_{Rn} is now drawn randomly from a normal distribution with a standard deviation corresponding to the experimental uncertainty of the volume-trap technique of typically 10%. The mean value was chosen at $600\,\mathrm{Bq/m^3}$ according to the data from ref. [4]. The results for the same values of a_{s} and t_{ex} are shown together with the previous results in figs. 1 and 2.

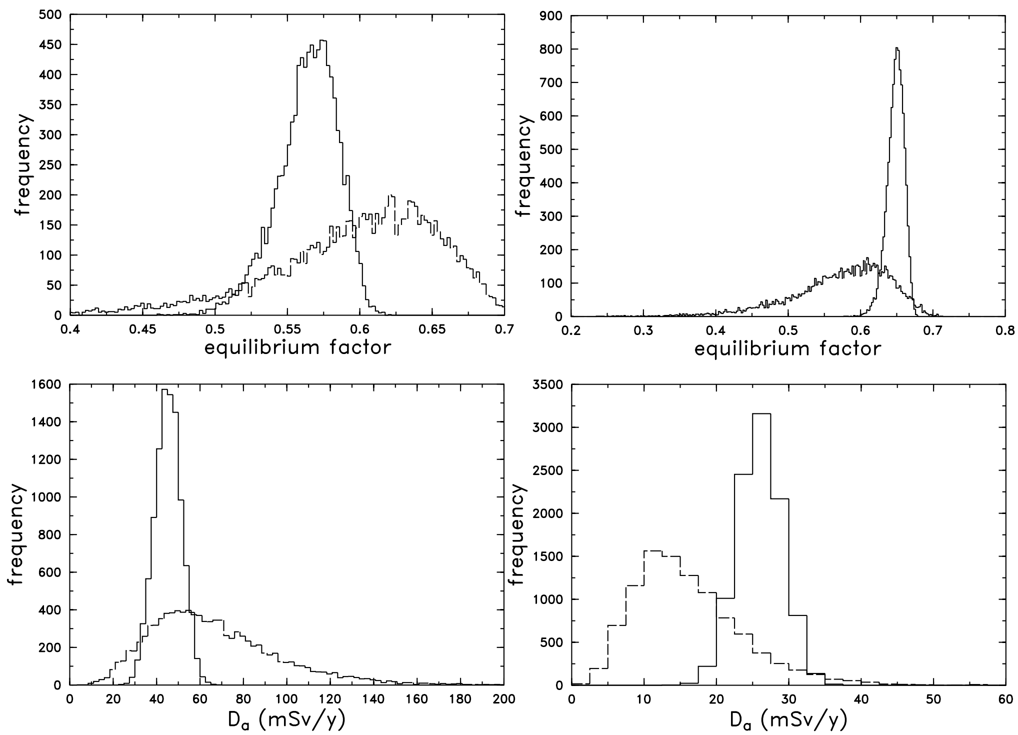

Fig. 2. – Comparison of the results obtained with the standard surface analysis (broken line) and with the new combined surface + volume analysis (full line). The upper row shows the distribution of the equilibrium factor F and the lower row gives the corresponding distributions of the average annual dose D_{a}. Left part: $t_{\mathrm{ex}} = 10\,\mathrm{y}$, $a_{\mathrm{s}} = 10\,\mathrm{Bq/m^2}$, $E_{\mathrm{Rn}} = 6\,\mathrm{kBq/m^3\,y}$; right part: $t_{\mathrm{ex}} = 20\,\mathrm{y}$, $a_{\mathrm{s}} = 5\,\mathrm{Bq/m^2}$, $E_{\mathrm{Rn}} = 6\,\mathrm{kBq/m^3\,y}$.

The corresponding annual dose D_a has been calculated according to

$$D_a(\text{mSv/y}) = 0.8 \frac{1 \text{ mSv/y}}{6 \text{ Bq/m}^3 |_{EEC}} F \overline{c_{\text{Rn}}}, \tag{2}$$

with a conversion factor estimated from refs. [11, 12]. The factor 0.8 takes into account the residential probability at home.

As is obvious from both figures, the distributions for F and X obtained with the combined surface + volume analysis are much narrower. The relative uncertainty for D_a obtained from the surface analysis is 44% and from the combined analysis only 12%. A similar result has been obtained for $a_s = 5$ Bq/m^2 and a similar exposure scenario, $t_{ex} = 20$ y and $\overline{c_{\text{Rn}}} = 300$ Bq/m^3. Here, the corresponding uncertainties were 45% and 14%.

3. – Conclusion

For both surface activities evaluated, 5 Bq/m^2 and 10 Bq/m^2, the combined surface + volume analysis shows up an annual dose estimation being roughly a factor of 3 more precise than the usually applied surface technique. This is clearly due to the precise knowledge of the average radon concentration provided by the volume technique. In conclusion a combined sampling of glass material and volume-trap material during forthcoming epidemiologies is highly recommended.

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