THE KFK PASSIVE PERSONAL DOSEMETER FOR EXPOSURE TO RADON AND EXTERNAL GAMMA-RADIATION

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INTRODUCTION

The recognition of the role of radon and its decay products in the induction of lung cancer in uranium miners led to exposure limitation guides. The ICRP has recommended limits for the purpose of radiation protection in mines, expressed in terms of Annual Limits on Intake. The efforts required to maintain satisfactory control are quite variable, depending on the mining method, the geological formation, the concentration of uranium and thorium in hostrock and ore, climate etc.General principles of monitoring for radiation protection of workers have been established by the Commission in ICRP Publication 35. The main functions and the various forms of monitoring are analyzed with particular attention given to the design of a monitoring programme and the interpretation of results for external radiation, for surface, air, skin and internal contamination. The requirements for both ambient and staff monitoring in mines should conform with these general principles.

While for the dosimetry of the external γ-radiation the instrumentation is well approved to a high standard, the measurement of internal exposure by radon and its daughters is relative laborious and unprecise. There are several instruments available for grab sampling and continuous monitoring of radon and its daughters in mines and in the environment. Best estimation of exposure, however, can be achieved using continuous or integrating measuring equipment and integrating personal dosemeters. These especially exclude difficulties arising from well known short term variations of radon concentration which can be as much as one order of magnitude or more. There are mainly two techniques used today for radon measurements: active and passive systems. Active techniques need an external power supply for pumps and electronics, which passive devices avoid. They use thermoluminescence detectors or track etch detectors. Detailed information is available from literature.

DOSEMETER DESIGN

For environmental and personal monitoring a small size, integrating dosemeter for the determination of the radon as well as external γ-exposure has been developed at KfK (1). It uses a polycarbonate solid state nuclear track detector (MAKROFOL E) for the registration of α-particles from radon and its short lived decay products. γ-radiation is registered by TLD chips. The design of the dosemeter is shown in Fig. 1, the cross section in Fig. 2. Special attention was given to electrically conductive surfaces for all parts of the dosemeter. Different surface charges occuring on non conductive surfaces will result in inhomogeneous plate out effects of charged radon decay products. This will result in poor reproducibility of the measurement, especially for small size dosemeters, where the distance surface to detector is within the range of the α-particles. The KfK dosemeter is produced from carbon loaded thermoplast by pressure decasting.

CALIBRATION, REPRODUCIBILITY

The quantity measured by the dosemeter is the time integral of the actual radon concentration (2) i. e. the exposure. The radon exposure X is:

$$X_{Rn} = \int_0^T C(t)\ dt$$

where are
X = radon exposure in Bq/m3·d
C(t) = radon concentration at the time t,
T = exposure time

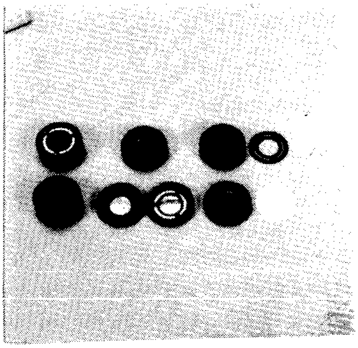

Fig. 1: Design and parts of the KfK Passive, Personal Radon Dosemeter, including TLD for external γ-radiation

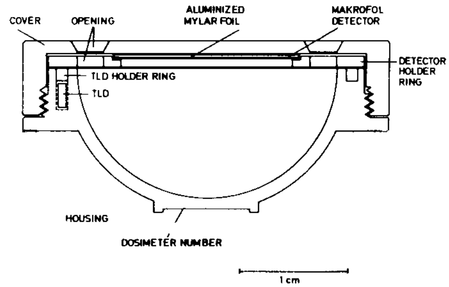

Fig. 2: Cross section of the KfK Passive, Personal Radon Dosemeter, including TLD for external exposure

Assuming linearity between radon exposure and the number of tracks counted with the sensitivity ε of the diffusion chamber:

$$\varepsilon = X_{Rn}^{-1}\left(\frac{N_1}{A_1} - \frac{N_0}{A_0}\right)$$

where are

ε = radon sensitivity in (tracks/cm2)/(kBqm-3d),
N, = number of tracks counted in the field A,
N0 = background tracks in the field A0,
A, = area counted in cm2 for the total number of tracks
A0 = and background tracks,

Several calibrations have been done in the past. Fig. 3 shows as an example the results of the CEC intercalibration test organized by the French CEA in the uranium mine of Lodève in 1985

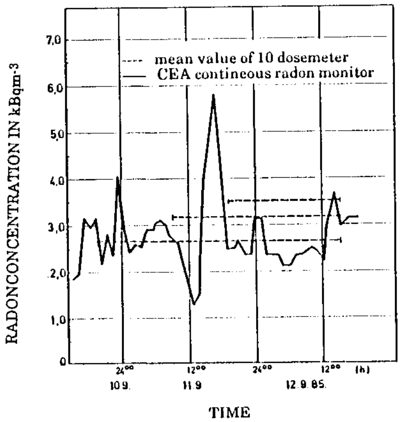

Fig. 3: Comparison of the reading of the CEA continuous radon monitor with the readings of the KfK Passive, Personal Radon Dosemeter

The estimation of the total measuring uncertainty of the radon exposure is done as follows: Taking into account the statistic uncertainty of track counting for the total tracks ($N + N_0$) the relative measuring uncertainty is given for low track numbers by the standard deviation of the background reading S_0 and for the high track numbers by the relative standard deviation s of the exposed set:

$$s(N) = \frac{100}{N} (N + N_0 + S_0^2 + s_0^2 \cdot \; N^2)^{1/2}$$

where are N, N_0 = number of radiation induced or background tracks,
S_0 = standard deviation of the background reading N_0,
s_i = relative standard deviation caused by systematic uncertainties

The relative standard deviation s(N) vs. number of tracks can be calculated on the basis of the formula and the experimental values S_0 and s_r of an unexposed and an exposed set. The relative standard deviation s_i is given by the measured standard deviation s_r of the exposed set with the number of tracks N_r:

$$s_r^2 = s_i^2 + N_r^{-1}$$

S_i is the total systematic uncertainty resulting mainly from the scatter of the individual detector sensitivity within the set as well as from the etching and counting technique. With the radon sensitivity of the track detector in the diffusion chamber the lowest detectable radon exposure X_L can be calculated

$$X_L = N_L \cdot \; \varepsilon_{Rn}^{-1}$$

where N_L is the lowest detectable number of tracks at a relative standard deviation of 50%. These calculations have been confirmed by various series of measurements (3).

PERSONAL DOSEMETER FOR MINERS

In rough environments with dust and high moisture loads, active dosemeters are prone to failure. For instance, variations in air flow through the filter can falsify the readings in an unpredictable ways. In addition, the equipment requires a more or less high amount of maintenance.

The passive dosimeters has none of these drawbacks. It is integrated into miner's helmets (Fig. 4) in such a way, that the dosimeter opening, through which gases and aerosols are exchanged, faces the interior of the helmet. This protects the dosimeter mechanically and from direct impacts by dust and water sprays. In environments with mud, high dust or moisture loads, the dosemeter can be covered with a hydrophobic fiberglass filter, which prevents wetting of the dosimeter inside as well as the penetration of dust. This ensures that the measurements are reliable also under rough operation conditions.

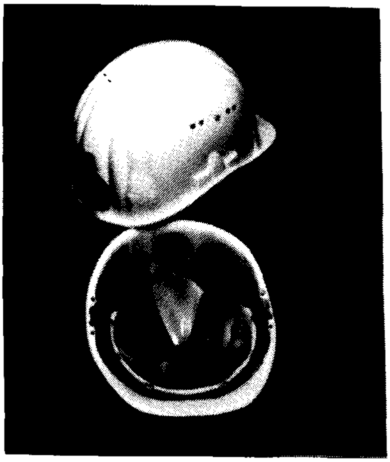

Fig.: 4 KfK Passive Personal Radon Dosemeter integrated in miners helmets

The main disadvantage associated with the use of a filter is, that only the radon gas and not the dose effective short-lived decay products are measured. Therefore, a mean equilibrium factor has to be applied, which is estimated from grab sample measurements. However, these measurements are still necessary also where personal dosimeters are used, i. e. for clearing workstations after changes in ventilation patterns or after a breakdown of the fans. Personal dosimeters only integrate, indicating the monthly exposure received. The working place measurements prescribed by the mining authorities are carried out routinely in uranium mining, and their statistical evaluation results in the necessary accuracy for converting radon concentrations into lung exposures. Another negative characteristic is, that the passive detectors register radiation all the time and not only during working hours. This however can easily be corrected by using some additional dosimeters for the background in the pithead. The time, where the miner was working, is recorded as Ts. The total exposure time of the dosemeter is T. The individual miners exposure $X_{Rn,\,ind}$ then can be calculated as follows:

$$X_{Rn,ind} = X_{Rn,Pers.dos.} - X_{Rn,controls} \cdot \left(1 - \frac{T_s}{T}\right)$$

where are $X_{Rn,pers.dos}$: radon exposure of the personal dosemeter
$X_{Rn,controlls}$: radon exposure of the control dosemeter

The KfK Personal Dosemeter for miners is used for official exposure measurements in a German uranium mine. Extensive tests side by side with the CEA dosemeter have been performed in German and French mines together with the CEA. In addition the dosimeter is used in Brasilian and Argentinian mines. The main advantage of this dosimeter is, that the individual exposure measurement can be done with ruggedized cheep dosemeters having no moving parts to fail under extreme environmental conditions. Also no power supply and in consequence recharging stations are necessary. An advantage also is, that the dosemeter can be used as it is without any modifications for en vironmental monitoring of mining sites and houses.

References:

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