Determination and calculation of dose from the specific activity of radon and radon daughter products

The element Radon-222 is a noble gas which has the following characteristics: gaseous, inert, colourless and odourless. Radon-222 has a short half-life of T = 3.8 days, but it is again and again formed from the long-lived radium-226 with T = 1600 years and this in turn results from the uranium-238 with a large Rn-222 is one of the three natural isotopes of Radon. Radon-220 with a half-life of T = 56 s, also called thoron, comes from the decay of radium-224 in the Thorium-232 series. The radon-219, also called Actinon, with a half-life of T = 4s, originates from radium-223 decay in the uranium-235 series.

The causes of increased measured radon concentrations in residential areas are:

- geological underground with increased uranium/radium content,
- the construction of the house without sealing base plate,
- the air pressure difference between the floor and the house,
- the lack of ventilation in the energy saving house
- the building materials that release radon.

The aim is not only to measure radon concentrations in the premises to be measured but also to determine the dose from the specific activity of radon and radon daughter products. The aim is therefore to estimate harmful effects of inhaled radon subsidiary products. Radon is the risk factor No. 2 for lung cancer after smoking. The majority of the exposure of the lungs is not due to the inhalation of radon, but to the inhalation of short-lived radontochternuclides (^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po).

High radon concentrations cannot be found in the free atmosphere, as the gas dilutes widely. Under certain conditions and conditions high concentrations can be observed in closed premises.

Assumption: there is no Plate Out -. Radioactive balance of Radon + daughter nuclids.

For a mixture of a long-lived mother nuclide and its short-lived decay products (after about 5 half-lives of the longest-lived daughter), the concentration of the daughters builds up to such an extent that as many atoms decay for each daughter as were newly formed from the mother or the previous member of the decay series will. Thus the radionuclides have the same concentration. This applies to radon and its decay products only if fresh air or deposits of aerosol particles do not reduce the concentration of the decay products. This condition is never “fulfilled”. This means that the daughters are always present in a lower concentration than radon.

The equilibrium is not always ideal, because when the radon and its daughter products decay, their nuclei in the air lose their electrons as a result of the recoil and become positively charged. The positive charge causes the ions formed in this way to adhere to dust particles (aerosols), but also to deposit on electrically charged plastic surfaces (plate-out effect). The process is also dependent on the humidity. This means that not all daughter nuclei are recorded during the measurement and the equilibrium required for determining radon is changed. The deviation is indicated by the equilibrium factor F and indicates how many follow-up cores are still available for the metrological acquisition. In other words, at F = 0 only radon is present, while at F = 1 a radioactive equilibrium is completely established.

Equivalent dose determination from radon concentration $C(\mathrm{Radon})$

The relationship between the equilibrium and non-equilibrium state of the radon concentration is determined by the formula

$$C(\mathrm{Radon}) \cdot F = EEC$$

described. The $C(\mathrm{Radon})$ the real radon concentration in non-balance of the atmosphere, while EEC the equilibrium equivalent of the decay products of radon in relation to radon concentration. The balance factor F characterizes the ratio or imbalance or the degree of dilution of short-lived derived products compared to the radon in ambient air. The size becomes F in the range between 0 and 1. Typical figures are:

- Room with normal ventilation between 0,3 and 0,6
- large room with dusty air at 0.8
- out door air 0,7

The equivalent dose H is determined from the equilibrium equivalent concentration (EEC) using a dosing rate coefficient D'_{EEC}

$$H = EEC \cdot t \cdot D'_{EEC} = C_{Rn} \cdot F \cdot t \cdot D'_{EEC}$$

The following dosing coefficient of the reference person shall be used.

Reference person	Dose conversion coefficients D'_{EEC} innSv·m^3 · (Bq·h)$^{-1}$
Population	6,1[1]
Radon at work place for professionals	7,8**Fehler! Textmarke nicht definiert.**
Thoron at work place for professionals	81,7[2]

[1] *BfS: Calculation bases for the determination of radiation exposure due to mining-based environmental radioactivity, Salzgitter, March 2010*

[2] L. Bi, Frauo Li, J. Tschiersch, JL. Li : Age and sex, inhalation doses to members of the public from indoor thoron progeny, Journal of Radiological Protection, Volume 30, Number 4, December 2010

Example of equivalence dose determination from radon concentration

For the estimation of the radiation exposure of the lungs, equilibrium factor of $F = 0{,}4$of course. Exposure is called the product of concentration [Bq·m^{-3}] and length of stay [h]. A measured radon concentration in a living room with e.g.$C_{Rn} = 100$ Bq·m^{-3} corresponds to an equilibrium equivalent radon concentration of $EEC = 40$ Bq·m^{-3}.

In the living rooms is a stay of $t = 7000$ hin year. To convert exposure to the effective dose, the dosing factor of 6,1 nSv·m^{3}·(Bq·h)$^{-1}$ used for radon equivalent concentration. The following calculations are made:

$$100\ \text{Bq·m}^{-3} \cdot 0{,}4 \cdot 7000\ \text{h} \cdot 6{,}1\ \text{nSv·m}^{3} \cdot (\text{Bq·h})^{-1} = 1708000\ \text{nSv} = 1{,}708\ \text{mSv}$$

Based on this sample calculation, it is a dose of 1,71 mSv.

Equivalent dose determination from radon succession products ($PAEC$orEEC)

The more precise method for determining the equivalent dose is the calculation directly from the inhaled radon daughter products.

For this purpose, the potential alpha-energy concentration for a daughter-nuclide mixture from the radon incidence series is considered in the air and is described as the level of harmful effects of a gas mixture.

$$PAEC = \frac{\sum_i PAE_i}{V_{\text{Luft}}}$$

With i as an appropriate radon daughter nuclide.

For radon(Rn-222) in balance, the $PAEC\ \ EEC$ and vice versa with the help of unit conversion

$$1\ \text{Bq·m}^{-3} = 5{,}56\ \text{nJ·m}^{-3}$$

for Thoron (Rn-220) the unit conversion is

$$1\ \text{Bq·m}^{-3} = 75{,}6\ \text{nJ·m}^{-3}.$$ [3]

The next step is to determine the potential alpha energy exposure (PAEE). Exposure is the time integral of the concentration of short-lived Rn-222 follow-up products over exposure time. It should be noted that the PAEE does not look at the individual decay processes in the lungs. The quantity of inhaled and deposited radon daughters depends on

- the potential alpha energy concentration in inhaled air; and
- the time period $t$in which persons are exposed to a particular PAEC.

This connection can be discribed by the formula

$$PAEE = PAEC \cdot t$$

Ultimately, the equivalent dose can be determined

$$H = PAEE \cdot D'_{pot} = PAEC \cdot t \cdot D'_{pot}$$

[3]ICRP Publication 115: Lung Cancer Risk from Radon and Progeny and Statement on Radon, M. Tirmarche, J.D. Harrison, D. Laurier, F. Paquet, E. Blanchardon, J.W. Marsh, Ann. ICRP 40(1), 2010

from the Potential Alpha Energy Exposure (PAEE) using a dose-conversion coefficient D'_{pot}.

For radon-progeny products and thoron-progeny products, the following dosing rate coefficients apply – effective dose per potential alpha energy exposure:

Place of exposition	Dose conversion coefficients D'_{pot} in Sv·m^3 · (J·h)$^{-1}$
Radon in the domestic area (population)	1,1*
Radon at work place for professionals	1,4*
Thoron at work place for professionals	0,5**

Source:
**BfS: Calculation bases for determining radiation exposure due to mining-based environmental radioactivity, Salzgitter, March 2010*
** BfS: radiation exposure due to mining related environmental radioactivity, explanatory notes on the calculation of mining, Salzgitter, April 2012

Example of equivalent dose determination from the $PAEC$

From an average PAEC 1029 nJ·m^{-3} can be achieved at a complete measuring time of $t = 18$ h the exposure

$$PAEE = 1029 \text{ nJ·m}^{-3} \cdot 18 \text{ h} = 18530 \text{ nJ·h·m}^{-3}$$

An equivalence dose is obtained for employed persons $H = 25{,}94$ µSv from the calculation:

$$H = 18530 \text{ nJ·h·m}^{-3} \cdot 1{,}4 \cdot 10^{-9} \frac{\text{Sv·m}^3}{\text{nJ·h}} = 0{,}000025942 \text{ Sv} = 25{,}94 \text{ µSv}.$$