Applied Radiation and Isotopes ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Study of parameters relevant for a better prediction of the radon potential

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HIGHLIGHTS

- Special application of measurement techniques for ^{222}Rn and permeability in soil.
- High correlation between local dose rate above ground and ^{222}Rn in soil gas.
- Testing time trend analysis to improve the applicability of single ^{222}Rn values.

ARTICLE INFO

Article history:
Received 14 April 2015
Accepted 25 November 2015

ABSTRACT

In 2012 and 2013 measurements of parameters relevant for a better prediction of the radon potential were carried out in Austria at 100 sites. The parameters were the ^{222}Rn activity concentration in soil gas, the soil's permeability, the ambient equivalent dose rate above the ground and the soil's massic activity by gamma spectrometry. The uncertainties of sampling and measurements are discussed as well as the correlations between these parameters.

1. Introduction

Radon-222 is a radioactive noble gas, which is produced by the decay of ^{226}Ra and therefore part of the uranium–radium decay chain. As ^{238}U occurs almost everywhere in the Earth's crust, the same applies for radium and radon. After radon is produced in the ground it can escape into the air consequently also into houses, whereby the properties of the basement of a house influence the magnitude of this process. ^{222}Rn has a half-life of 3.8 days and the half-life of its four direct daughter radionuclides are less than half an hour each. Thus with the decay of ^{222}Rn five decays take place in a relatively short period of time. According to the WHO, radon is the greatest cause of lung cancer, after smoking, and there is no threshold under which there is no contribution to the risk (WHO – World Health Organization, 2009). In Austria the mean effective dose to a citizen is 4.61 mSv per year. About 54% of this dose is caused by the inhalation of ^{222}Rn (Maringer et al., 2012). The new EU Basic Safety Standards (BSS) (European Union, 2013) have introduced a limit (reference value) for the yearly mean radon activity concentration in indoor air to 300 Bq/m^3 at both work places and in private accommodations. The member states are advised to identify areas where these values are expected to be exceeded in a significant number of buildings, this is facilitated by establishing radon potential maps. The radon potential gives the estimated mean value of radon activity concentrations in houses. Such a map is a tool for finding areas where high concentrations are expected and corrective actions are indicated. Even before the new BSS was approved, an Austrian project to improve such a map, the ÖNRAP (Österreichisches nationales Radonprojekt), was carried out (Friedmann et al., 2007). Within this project indoor ^{222}Rn measurements were taken over the whole country to get a first look over the national area. The results were used as basis for compiling the Austrian radon potential map, which gets continuously updated (BMLVUW, 2010). For these updates, indoor ^{222}Rn measurements need to be taken over the period of half a year and are complicated to distribute. Consequently other ways to evaluate the radon potential are of great interest and are being investigated. In earlier work the ^{222}Rn activity concentration in soil gas was measured over an area in upper Austria (Ringer, n.d.). In a later project, soil gas ^{222}Rn measurements were taken in a geologically-diverse region in Austria to look for correlations between the measured ^{222}Rn values and specific geological characteristics. The results have already been published (Kabrt et al., 2014). Now attention is given to identifying correlations between the ^{222}Rn activity concentration in soil gas and other parameters like: the soil's

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http://dx.doi.org/10.1016/j.apradiso.2015.11.096
0969-8043/

permeability, the local radiation dose rate, and the massic activity of ^{238}U and ^{226}Ra in the soil. The aim of this investigation is to improve the measuring methods for evaluating a region's radon potential, which is necessary for establishing a qualitative radon potential map.

2. Material and methods

Two measurement series were carried out in autumn 2012 at 40 measuring sites and in spring 2013 at another 60 measuring sites. Four municipalities in Styria, Austria, were chosen as the investigation area, due to their geological diversity.

At every site three probes (1.6 m long and 12 mm diameter), to which ends pointy tips have been attached, were hammered up to 1.4 m into the ground. Then a rod was stuck into them to lower the pointy tips and to create a 5-cm-deep gap below the end of each probe. Afterwards the rod was removed and soil gas was extracted from the probes by a 200 mL syringe. The first charge was discarded, because it contained the fresh air, which filled the probe before hammering into the ground. The volume of that air is calculated by adding the volume of the probe (181 mL) (which is an overestimation, because the outer diameter was used for calculation), the volume of the gap below (6 mL), and the volume of the adapter (12 mL). Given that a 200 mL syringe contains more volume than 200 mL (it is only the biggest marker) the underestimated volume of the discarded air is bigger than the overestimated volume of the whole probe volume. After discarding that probe's air, from each probe 100 mL of unfiltered soil gas was extracted and injected into an AlphaGUARD (produced by Saphymo GmbH) measuring device, one for each probe. The AlphaGUARD was set in flow mode with a 10 min measuring cycle with the diffusion filter and gas inlet sealed. That mode was chosen, because it is the measuring mode with gas inside the device in contrast to the diffusion mode, where the unsealed diffusion filter is in contact with ambient air. After flushing the AlphaGUARD chamber with fresh air between the measurements, the displayed ^{222}Rn activity concentration value shown during the injection was taken as blank value. The first actualized value was discarded, because the gas was not in the device over the whole measuring cycle. Then the mean of the second and third displayed values was used as measuring value of one probe, thus measuring the activity concentration of the soil gas inside the chamber during 20 min.

For the final results the measured values were multiplied by the calibration factor 8, as the AlphaGUARD chamber volume contains 620 mL and is therefore not completely filled by the soil gas sample. The value has been obtained in former studies by injecting 100 mL of gas with known ^{222}Rn activity concentration (Gruber, 2004). The measured values for probes which were not inserted into the ground to the full 1.4 m depth were multiplied with a correction factor. The distribution of the ^{222}Rn activity concentration depending on the depth of the ground is given by $a_z = a_{const}(1-e^{-\frac{d}{l}})$, where d is the depth and l is the diffusion width according to $l=\sqrt{D^{*}*\lambda^{-1}}$ (D^* is the mass diffusivity and λ the decay rate of radon). The mass diffusivity is $5*10^{-2}$ cm^2/s, which covers humid loam and dry sand. The correction factor is $\frac{a_{1.4}}{a_d}$. The mean value of the three corrected probe values was taken as final result for a site.

In the experimental procedure there is a risk that the soil gas gets mixed with the atmospheric gas which would lead to a lower value. Therefore, we assumed that values significantly (<1 s) lower than the mean were affected in that fashion. Such values were therefore discarded for the calculation of the mean value, which was then calculated only by two values. When the extraction of the soil gas was considered too difficult (for example due to a low permeability), so that the probability of getting atmospheric air into the syringe was too high, a new site was searched. Furthermore, care was taken to assure that the same syringe and adapter were always used with the same AlphaGUARD, which would e.g. enable us to detect potential systematic errors or defective devices easier. For the investigation of the correlation between the parameters, the maximum of the ^{222}Rn activity concentration at one site is taken into account too.

For evaluating the soil's permeability the formula of Damkjaer and Korsbech (1992) was used. A geometry factor, which is given by the 5 cm hole under the probes, and the soil gas viscosity is used in the calculation. The soil gas is assumed to be homogenous. At each site the pressure and the simultaneous flow rate were measured while pumping gas from a probe.

For measuring the ambient equivalent dose rate a dosemeter 6150 AD 6/E and a connected scintillator 6150AD-b by Automess were used. The mean value over five minutes was taken while holding the measuring device 1 m above the ground.

At each site, soil samples from up to 1 m depth were taken. They were measured in the laboratory using gamma-ray spectrometry to determine the activity per unit dry mass of ^{226}Ra and ^{238}U.

The geographic coordinates were taken at each site to determine its geological characteristics by the Styrian geographical information system afterwards (GIS Styria).

During the period of time in which the measurements were taken, one system in autumn and two systems in spring were set up to evaluate the time trend of the soil gas ^{222}Rn activity concentration at a single site. At this site a pump sucked the soil gas continuously with 0.1 L/min from a probe into an AlphaGUARD device. The length of the tube between the probe and the AlphaGUARD was chosen to be long enough so that 0.52% of the initial activity concentration of thoron (^{220}Rn) was calculated to remain when the gas reaches the AlphaGUARD and therefore the influence of thoron can be disregarded. To protect the measuring devices from the weather, they were set up indoors.

3. Results

To find possible correlations, the ratio between various pairs of parameters were calculated for each site. For each parameter pair, the mean value of the ratio, the standard deviation of the ratio, and the correlation coefficient was calculated. A correlation coefficient value around zero means no correlation, whilst a value near to 1 or -1 means a strong positive or negative correlation, respectively. The comparisons of the different parameters are shown

Table 1
The results of the analysis of the different parameters regarding possible correlations.

	Mean value of the quotient	Relative uncertainty (%)	Correlation between the two parameters
$c_A(^{222}\text{Rn})$, kBq/m^3/$a(^{238}\text{U})$, Bq/kg	2.4	71	0.09
$c_A(^{222}\text{Rn})$, kBq/m^3/$a(^{226}\text{Ra})$, Bq/kg	1.8	61	0.35
$c_A(^{222}\text{Rn})$, kBq/m^3/permeability, m^2	$8.3 \cdot 10^{13}$	157	−0.03
$u_r(c_A(^{222}\text{Rn}))$, %/permeability, m^2			−0.13
$c_A(^{222}\text{Rn})$, kBq/m^3/$\dot{H}^*(10)$, μSv/h	655.8	63	0.49
$\dot{H}^*(10)$, μSv/$a(^{226}\text{Ra})$, Bq/kg	0.0029	29	0.5
$a(^{238}\text{U})$, Bq/kg/$a(^{226}\text{Ra})$, Bq/kg	0.86	31	0.67
Maximum $c_A(^{222}\text{Rn})$, kBq/m^3/$a(^{226}\text{Ra})$, Bq/kg	2.21	62	0.43
Adapted $c_A(^{222}\text{Rn})$, kBq/m^3/$a(^{226}\text{Ra})$, Bq/kg	3.09	69	0.26

Please cite this article as: Kabrt, F., et al., Study of parameters relevant for a better prediction of the radon potential. Appl. Radiat. Isotopes (2015), http://dx.doi.org/10.1016/j.apradiso.2015.11.096