SARAD GmbH
Wiesbadener Straße 10
01159 Dresden
Germany

Phone: +49 351 6580712
FAX: +49 351 6580718
e-mail: support@sarad.de
web: www.sarad.de

APPLICATION NOTE AN-005_EN

Quantifying of Radon Concentration in Soil Gas

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This application paper describes how to simply and quickly quantify Radon activity concentration in soil gas using a packer probe and a Radon- or Radon-Thoron-Monitor.

Physical and Geo-Physical Basics

The quantifying of Radon activity concentration in soil gas is based on a continuous or clocked taking of soil gas samples via a packer probe located in a suitably sized bore-hole and sealed with respect to ambient air (for instance SARAD soil gas sampling system).

For continuous sampling, the internal pump of the chosen Radon monitor is used mostly. Frequently, well-defined gas volumes have to be investigated and a clocked taking of soil gas samples is necessary. In many of these cases, an external pump is used, possibly a special hand operated one. The risk to suck water out of the soil into the device will be minimised by this procedure.

The Radon activity concentration C [Bq/m³] in soil gas (more generally in aerosols) denotes the ratio (Radon-) activity A [Bq] to the (gas-) volume V [m³]. The unit Bq/m³ reads „Becquerel per cubic meter“, where 1 Bq means that that there is 1 radioactive decay (here with respect to the radioactive inert gas Radon-222) per second.

The Radon activity concentration in soil gas (in a depth of about 1 m) covers normally a range between circa 1.000 and more than 1.000.000 Bq/m³, depending upon where the samples are taken. But also at the same measurement location, the results may differ remarkably, especially in dependence of several parameters as temperature, air pressure, precipitation, moon phases (tides of the earth's crust) and others. These parameters influence the velocity of soil gas flow and others. The larger the resting time of the gas in soil and the lower the replenishment of Radon from the source, the smaller the Radon activity concentrations that will be measured in the soil near surface (in depth of 1-2 m), since the half-life period of Radon-222 amounts only 3,8 days.

Relevant tasks (for instance of civil engineers) frequently require the assessment of the risk caused by Radon in soil gas. As described above, the permeability k of soil has a great influence on the Radon risk. This will be paid attention to by considering the parameter of the so-called Radon availability R which allows – together with the Radon activity concentration C – to compare different Radon situations. Due to papers of TANNER and SURBECK from the nineties, the Radon availability can be defined as product of Radon activity concentration and permeability of soil:

$R = C * k$ [Bq/m], (1)

For the soil's permeability k [m²], a good approximate kn can be calculated by using falling time data of the plunger piston of a smooth-running hand operated plunger pump:

$kn = pk / (T1 – T0)$ [m²] (2)

The parameter pk [s * m²] denotes a device-specific pump constant and T1 and T0 [s] are averages of falling times measured in the following way: By free fall, the heavy plunger piston will press the ambient air (sucked in before) through the measurement system "pump pipe, connection tube, packer probe" into the sealed bore-hole (T1) and later into the ambient air (T0) after extracting probe from the hole. This procedure should be carried out after the radon measurement because (otherwise) the ambient air pressed into the soil gas would lead to incorrect values of the Radon activity concentration (measurement errors).

Example: The soil gas delivered via a packer probe may have a Radon activity concentration of 90.000 Bq/m³, the averages T1 and T0 obtained by 5 falling time measurements of each type are 18.8 and 10.8 s, respectively. The pump constant for this pump may be given as $4 * 10^{-12}$ sm².
For the permeability k, one obtains the approximate kn = (4/8) * 10^{-12} sm² / s = 5 * 10^{-13} m².
The Radon availability R amounts R = (90.000 Bq/m³) * (5 * 10^{-13} m²) = 4.5 * 10^{-7} Bq/m.

Procedure of Measurement

By the use of a (extendable) hand-operated drilling system (for instance Eijkelkamp) for silty/sandy natural grounds or by machine rams or drills otherwise, bore holes of 1–2 m depth with a diameter of 7 cm are produced. The lifted ground material gives essential additional information concerning permeability or Radon sources below ground near surface (for instance ashes or slags in earth deposits)
Attention ! An official permission (on private properties at least a map with information concerning supply of water, electricity etc.) should be available in order to avoid troubles or accidents (for instance with live wires below ground).

The packer probe (if necessary extended by additional tubes) will be carefully inserted into the bore-hole and located as deep as possible and necessary whereas the connecting flexible PVC-tube for inflating the rubber sleeve of the packer probr has to be tautened. In order to take soil gas samples, the packer probe's metallic main tube is connected to the special hand operated pump or directly to the Radon-monitor (possessing an internal pump) by a flexible PVC-tube. By the help of a pump customary in the trade for camping purposes, the rubber sleeve for sealing with respect to ambient air is inflated gradually until an non-movable position of the packer probe signalises a perfect fit to the inner wall of the bore-hole (checking of air over-pressure by a possibly available manometer and/or carefully trying to swivel the packer probe).
Caution !
Because of small damages having been without consequences so far or by sharp-edged stones in the sealing area of the bore-hole, the inflated rubber sleeve may suddenly be disrupted. Depending upon the air over-pressure chosen, a "rocket-like" ejection of the packer probe may occur. Therefore, any position of the user's head or body directly over the packer probe should be avoided.

By use of the special hand operated pump connected with the packer probe via a flexible PVC-tube, two or three samples of soil gas are taken and released in order to "clean" the soil gas sampling system from ambient air. By a further flexible PVC-tube connection (between

pump and monitor), the measuring chamber of the Radon monitor can be filled with soil gas according to the given schedule of measurements.

Attention ! If the used Radon monitor is equipped with an internal pump, it should be switched on and off synchronously to the phases when the cylinder of the special smooth-running hand operated plunger pump is emptied. Otherwise, damages of the internal pump may occur. If necessary by hand operation, the velocity of emptying should be made suitable to the capacity of the device's internal pump.

Durance of sampling and measurement toe to the type of characteristic statements to be established on the one hand and to general rules of Radon measurement on the other hand (see also AN 002 Measurement Principals).

In case of grounds containing a very large number of stones, hand-operated drilling systems may sometimes fail to produce sufficiently deep bore-holes. If the use of machine rams or drills is not intended or possible, so-called punch probes can be utilised: A circa 1 m long small diameter (about 1 cm) hollow probe with a „lost" (can be ejected) cone-shaped sharp tip is punched into the ground. A drive-in head on the top is used to protect the steel tube probe since a heavy weighted hammer should be taken by the user for punching. A circa 1,15 m punch wire inserted into the probe by hammer will replace the tip and form a small sampling volume in the ground. The soil gas can be sampled using a 150 ml syringe or by a hand operated pump or by the internal pump of a Radon monitor. The two different diameter types of flexible PVC tube (probe size and device size) are connected by a diameter reducing interface.
All measurement procedures described above may analogously be carried out with the punch probe system, too. The advantage of this system lies in its easy handling and the possibility to sample reliable soil air volumes in a definite depth, whereas the probe is sealed to the soil automatically.

Appropriate Radon Monitors

For the measurement method described, there are some requirements concerning the used Radon monitor which have to be taken in account. The monitor has to provide an internal pressure tight air loop (sealed chamber and tube connectors for inlet and outlet). An internal pump is an advantage. Membrane pumps are more suitable than rotary pumps because membrane pumps offer a much lower leakage rate.

To get a short sample period, a spectroscopic (Alpha spectroscopy) monitor is required. The internal volume of the monitor should be as small as possible since this volume and the sensitivity of the instrument are the parameters which are defining the detection limits of the sampling method.

For Radon soil gas measurements, the RTM1688-2 is the most recommended solution. The unit offers a high sensitivity of more than 3 cpm/(kBq/m³) (fast mode) obtained from a very small internal volume of only 130 ml. Although the sensitivity of the RTM2200 is lower (1.5 cpm/(kBq/m³) at possibly occurring high humidity levels) and its internal volume is nearly three times higher (370 ml), also this instrument is suitable for Radon soil gas measurements.
Both units are working with Alpha spectroscopy and both are equipped with membrane pumps.

Detection Limits

The detection limit depends on the used sampling configuration (volumes) and on the sensitivity of the Radon monitor on the one hand and on the sampling period used for the Radon measurement in the air loop, on the other hand. Since the detection limit as well as the statistical error of the measurement corresponds only with the number of detected decays within the sampling period, the configuration can be optimised by the following rules:

- use a Radon monitor with a high sensitivity
- choose a sampling interval as long as possible

Standard Operating Procedure

- Produce a bore hole.
- Place and carefully seal the packer probe in the bore hole.
- Connect the probe with pump and Radon monitor. Release the first 2-3 soil gas samples.
- Determine the maximal Radon concentration of the soil gas by taking several samples.
- Determine falling times T0 and T1.
- Calculate permeability and Radon availability according to formulae (1) and (2).

IMPORTANT HINT: The stated procedure should be performed only under visual control. No water must enter the Radon monitor. This can cause the damage of the pump and the detectors/sensors. Work, if possible, with a protection flask.

Final Remarks

Because of the various objective factors affecting the results - and - taking into account that placing the soil gas sampling equipment is always a subjective procedure, a reliable measurement is only possible if the conditions are repeatable. This should be less or more not a problem inside a laboratory but keep in mind that “in situ” measurements with varying conditions will definitely result in a higher uncertainty.