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TECHNICAL NOTE

Fast measurement of radon concentration in water with Lucas cell

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Abstract Fast method of measurement of radon concentration in water based on flushing (bubbling) water sample with air in closed loop with Lucas cell is presented. The main feature of the method is washing radon from large sample of water to small volume of air including the volume of Lucas cell, thanks to which high radon concentration in the air and considerable sensitivity of measurement is achieved. Estimated measuring sensitivity is $S = 8.5$ cpm/(Bq/dm^3). Random error due to statistical fluctuations of count rate at radon concentration 1, 100, 10 000 Bq/dm^3 is: 11, 1.1, 0.1% correspondingly at counting (measuring) time 10 min. Minimum detectable radon concentration in water for such counting time is 0.11 Bq/dm^3.

Key words radon in water • measurement • concentration

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Block diagram and basic relations

Radon concentration in water is measured since a long time employing different methods and detectors [2, 5–8, 10, 11]. Block diagram, of a gauge for fast measurement of radon concentration in water with Lucas cell, is shown in Fig. 1. If water sample containing radon is flushed (bubbled) with air in closed loop with Lucas cell in such a manner that radon equilibrium is achieved between radon dissolved in water and radon flushed into the air the following relation can be written:

$$Q = q_p kV_w + qV_p \tag{1}$$

$$q_p = \frac{Q}{kV_w + qV_p} \quad (\text{Bq}/\text{dm}^3) \tag{2}$$

where: q_p – radon concentration in air per unit volume; Q – total radon activity in water before flushing; k – coefficient of radon solubility in water; V_w – volume of water sample; V_p – volume of air including Lucas cell, air pump and connections. High radon concentration in air is achieved when volume of air is smaller than the volume of water sample. This is illustrated in Fig. 2 showing radon concentration changes with variation of air volume at constant water volume (0.75 dm^3).

The solubility coefficient, k, of radon in water (Ostwald coefficient), defined as the ratio of radon concentration in water to radon concentration in air, measured and published in 1911 by Boyle [1] is $k = 0.51$; 0.25; 0.16 for water temperature T = 0°C, 20°C and 39.1°C. The solubility coefficient can also be found in [3, 9, 12] for water temperature up to 100°C. Weigel [12] gives mathematics formula for compu-

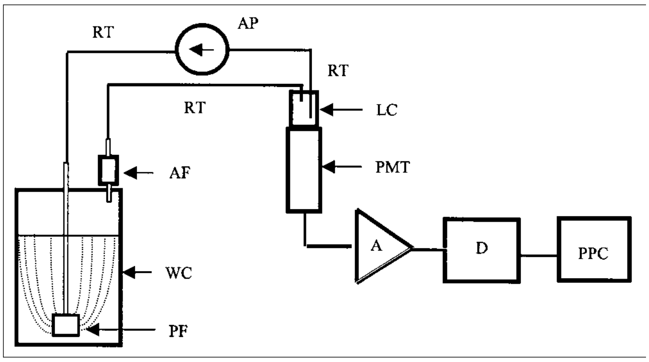

Fig. 1. Block diagram of gauge model for measurement of radon concentration in water. WC – water container; AP – air pump; AF – air filter, cylinder ∅ 15 × 55 mm filled with cotton; LC – Lucas cell 0.17 dm^3; PMT – photomultiplier tube; A – pulse amplifier; D – pulse discriminator; PPC – programmable pulse counter; RT – rubber tubes (black) ∅ 5 mm; PF – porous membrane filter.

tation of the coefficient $k = 0.105 + 0.405^* \exp(-0.0502\,T)$ where T – water temperature, °C. The differences between the data given by different authors do not exceed 4%.

Noting that radon activity flushed into air is $Q_p = q_p \cdot V_p$ and that the radon activity in air is given by

$$Q_p = \frac{n}{60\,v}\frac{V_p}{3k_t\varepsilon} \tag{3}$$

after substitution and rearrangements the expression for radon concentration q_w in water is achieved:

$$q_w = \frac{n}{180\,v\,k_t\varepsilon}\left(k + \frac{V_p}{V_w}\right) \quad (\mathrm{Bq/dm^3}) \tag{4}$$

where: n – mean count rate corrected by background count rate, cpm; v – volume of Lucas cell, dm^3; ε – detection efficiency of alpha radiation; k_t – coefficient taking into account no equilibrium between radon and radon daughters in Lucas cell at the time of pulse counting as illustrated in Fig. 3. For counting time equal to 10 min the k_t coefficient is defined as the ratio of mean count rate in the period 0–10 min to the mean count rate in the period 181–200 min multiplied by constant value 0.977 (decrease of activity of radon after 3 hrs).

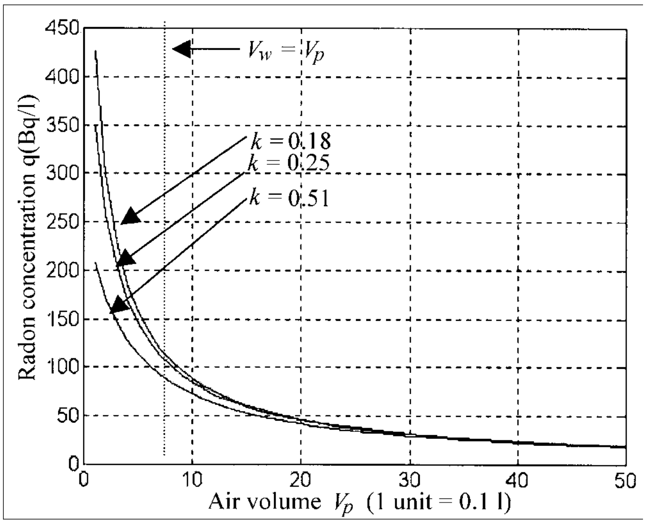

Fig. 2. Radon concentration in air per unit volume $q_p = 100/(kV_w + V_p)$ flushed out from water. Water sample V_w = 0.75 dm^3, at variable air volume, and water temperature 0÷30°C.

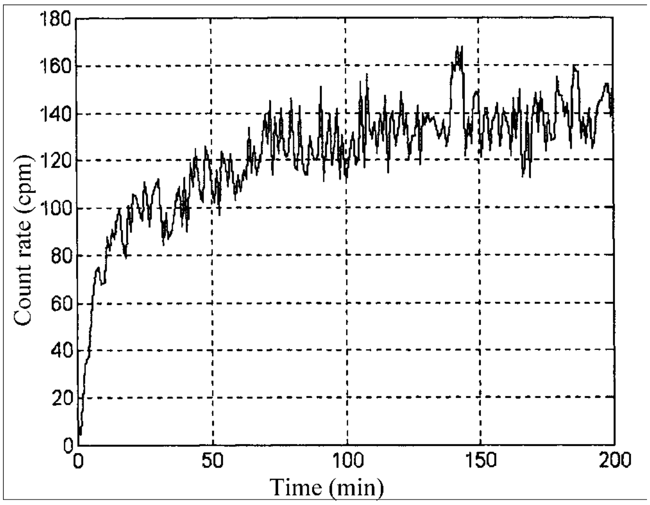

Fig. 3. Example count rate registered by Lucas cell against time since the moment flushing of water sample started. Radon concentration in water sample was 5.9 Bq/dm^3. Flushing time 5 min.

Performance

Measurements of gauge model in Fig. 1, were carried out. Water sample 0.75 dm^3 was placed in glass container ∅ 90 × 150 mm. At the end of air outlet pipe in water a porous membrane filter with dimensions 15 × 15 × 20 mm was fixed dividing air stream 0.4 dm^3/min into several tiny streams of air bubbles. Air volume including Lucas cell, air pump and connections was 0.485 dm^3. Cotton wool air filter was used to protect Lucas cell against droplets of water that are produced during flushing water sample. Lucas cell detection efficiency of alpha radiation was determined by measuring radon concentration in radon chamber of Central Laboratory for Radiological Protection and comparing with indications of Alphaguard radon concentration gauge as reference. The detection efficiency was found to be $\varepsilon = 0.66$. It was found that 5 min flushing time is adequate to obtain equilibrium between radon dissolved in water and radon flushed into air [4]. Mean value of no equilibrium coefficient k_t was determined from several curves of count rate against time, see Fig. 3, and was found to be 0.38 for 5 min flushing period and the Lucas cell used. Water enriched with radon and ground water from Warsaw wells were measured. Prior to measurements water temperature was measured. At switching flushing on (air pump) counting of pulses from Lucas cell was initiated too. After 5 min flushing was switched off, but measurements of counts were continued for the period of 10 min. Radon concentration in water was computed from Eq. (4).

Measurements showed that sensitivity of the presented model, for measurement of radon concentration in water, defined as the ratio of count rate variation to radon concentration variation is 8.5 cpm/(Bq/dm^3) at counting time 10 min. Such sensitivity permits for measurement of radon concentration starting from 0.11 Bq/dm^3. Random error due to count rate fluctuations is equal to: 11; 1.1; 0.1% at radon in water concentration 1, 100, 10 000 Bq/dm^3 correspondingly. The model requires that water temperature sensor is installed that enables computation of proper value of solubility coefficient *k*. The model is useful for portable radon concentration gauges for fast measurements of radon concentration in water.

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