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FEASIBILITY OF *IN SITU* RADON MONITORING USING COMMON GM COUNTERS

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Abstract. *Most of the detectors used for radon measurements rely on registering the alpha-rays coming from the* ^{222}Rn *decay itself and those from its daughters* ^{218}Po *and* ^{214}Po*, as well. Although active alpha-detectors have very low background and good efficiency, they are relatively expensive and are not well suited for field work due to their sensitivity to the ambient air humidity. In this work, an alternative possibility for in situ systematic measurements (monitoring) of radon concentration is investigated. It is suggested to use simple and wide spread detectors - Geiger-Mueller (GM) counters which are sensitive to beta/gamma radiation of* ^{222}Rn *daughters* ^{214}Pb *and* ^{214}Bi*. Long term measurements of the radiation background in uninhabited dwelling rooms were performed using simultaneously a classical radon alpha-particles detector (based on an ion chamber) and a beta/gamma detector (GM counter); the basic meteorological parameters at the site were also monitored. A very high correlation between the response of both detectors was found (*$r^2 \sim 0.9$*) which indicates that the radon monitoring can be successfully performed by means of cheap and moisture resistant GM counters. The drawbacks and the limitations of this method are also discussed.*

Keywords: *radon monitoring, GM counters*

1. INTRODUCTION

Radon (^{222}Rn) arises as an intermediate product in the ^{238}U decay chain:

$$\boxed{\begin{array}{l} \ldots \\ {}^{222}Rn \\ \quad\Downarrow\left(\dfrac{\alpha}{3.82d}\right) \\ {}^{218}Po \\ \quad\Downarrow\left(\dfrac{\alpha}{3.1m}\right) \\ {}^{214}Pb \\ \quad\downarrow\left(\dfrac{\beta}{26.8m}\right) \\ {}^{214}Bi \\ \quad\downarrow\left(\dfrac{\beta}{19.9m}\right) \\ {}^{214}Po \\ \quad\Downarrow\left(\dfrac{\alpha}{164.1\mu s}\right) \\ \ldots \end{array}} \qquad (1)$$

Being a noble gas, radon (together with its short-lived progeny, hereafter denoted by Rn+) is the main natural factor for dispersing radioactivity in the environment. Its large-scale monitoring is of scientific interest in two different fields: assessment of the human health radiation risk, and/or investigation of some natural phenomena related to radon exhalation and its propagation in the Earth's crust and atmosphere. Both areas are an object of extensive investigations (and a huge number of publications: a few of the recent reviews on different aspects of radon-related investigations are in [1-4]).

While the radiological effect of Rn+ on humans depends on the radiation dose accumulated for a long period of time (months and years) which can be conveniently evaluated by passive track detectors [5], the study of the radon transfer dynamics (by exhalation from ground, rainfall by-precipitation, atmospheric transfer, tectonic activity etc.) requires long term continuous observations at a fixed site on an hour or minute scale.

Most of the methods used so far for *in situ* Rn+ measurements rely on detecting the alpha-rays coming from the ^{222}Rn decay itself and those from its daughters ^{218}Po and ^{214}Po, as well. Either ionization chambers, scintillation detectors or semiconductor PIN diodes are usually used as active monitoring instruments [1]. (A notable work of Silverman [6], however, demonstrates a method for Rn in air measurements 'from first principles' by thin-window Geiger-Mueller (GM) counters sensitive to alpha-rays). All alpha-detectors have very low background and good intrinsic efficiency (the overall efficiency depends also on their active volume and/or contact surface). They can ensure enough dynamical range and precision; however, they are relatively expensive and are not well suited for field work (due to their sensitivity to ambient air humidity and to radon containing substances). Additional sample preparation work is often required

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when using alpha-detectors (radon de-emanation from waters, quantitative air dosage and drying procedures).

In this work, an alternative possibility for *in situ* systematic measurements (monitoring) of radon concentration is investigated. It is suggested to use simple, robust and wide spread standard GM counters which are sensitive to beta/gamma radiation of ^{222}Rn daughters ^{214}Pb and ^{214}Bi. Their performance as Rn+ detectors is evaluated by long term measurements of the background radiation in uninhabited dwelling rooms in parallel with a classical radon alpha-particles detector.

2. EXPERIMENTAL

The experimental setup was designed to ensure long-term measurements of Rn+ by using two detectors in parallel under possibly equal conditions. It included:

- detector A: a commercial radon monitor RD200M [7] based on pulse ion chamber with active volume 200 cm^3 and factory calibrated in radon volume concentration within 10% uncertainty;
- detector B: a standard cylindrical GM counter SBM-20 [8] with wall thickness of 50μm stainless steel;
- additional sensors for monitoring the basic microclimate parameters (temperature, atmospheric pressure and relative humidity).

Registered data was reported every 10min via a *wi-fi* module to the Internet based open data platform meter.ac [9].

The two detectors were placed near to each other 10cm above the (concrete) floor and at more than 2m distance to all other (brick) walls in an uninhabited basement room in Sarnegor village, Bulgaria (N42.45836, E24.93712, 400m a.s.l.), a site with previously identified elevated radon concentration. Data was acquired for three months in the winter.

The radiation background at the site consists of the following components:

- Rn+ (three alpha- and two beta-emitters);
- beta/gamma radiation of the long-lived natural radionuclides of ^{238}U, ^{235}U, ^{232}Th decay chains and ^{40}K. They appear in the surrounding environment and in the detectors materials, as well;
- secondary cosmic radiation (mainly muons).

The detectors have quite different efficiency for the background components:

- detector A: RD200M has practically 100% efficiency for α-emitters (^{222}Rn, ^{218}Po, ^{214}Po) and no efficiency for β- and γ-rays (their interactions in the ion chamber result in small amplitude pulses which are electronically discriminated);
- detector B: SBM-20 has zero efficiency for α-particles, high efficiency for β-rays and low efficiency (under 2%) for gammas. Its corpus passes β-rays with energy above 150keV, so most of the ^{214}Pb radiation is stopped, but, vice versa, the main part of ^{214}Bi enters into GM counter.

Thus, the GM counter measures mainly beta-component of the background, while the RD200M ion chamber registers only the alpha-component.

3. RESULTS AND DISCUSSION

Time series of the registered events in both detectors are illustrated in Fig. 1 together with the meteorological parameters. The temperature and humidity variations inside the room are much smaller than those outside, since the room is rather well isolated (although not hermetic). The radon levels, however, depend on both the inside and outside microclimate, so their diurnal variations are clearly emphasized.

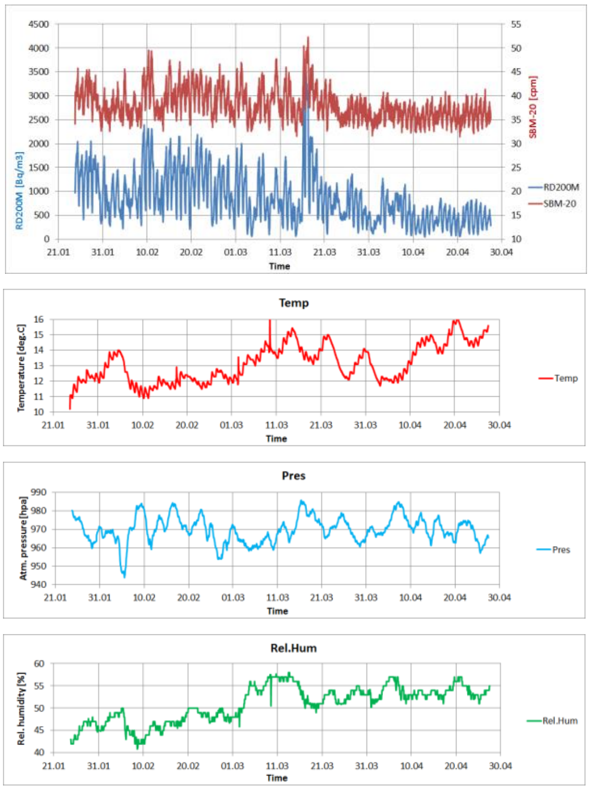

Figure 1. Data from RD200M [Bq/m^3], SBM-20 [cpm] and meteosensors for the observation period

The following data analysis is based on a general assumption: *the temporal variations of the background radiation are due entirely to ones of the Rn levels, for the given experimental conditions (isolated room, fixed detectors and surrounding).*

The preliminary procedures on raw data include the following steps:

a) The RD200M communication protocol reports data as 10-minutes values obtained by a moving average of the last 6 values (i.e. the last hour). The same moving average procedure was applied to all other values (SBM-20 events and meteoparameters) in order all data to be compared correctly;

b) The beta/gamma signal *B(t)* measured by the GM counter delays in time relative to the alpha-pulses detected by the ion chamber *A(t)* due to the particular decay scheme of ^{222}Rn (see Eq.(1)). According to the basic assumption mentioned above, the dynamics of the SBM-20 data follows that of the RD200M data with a certain effective time delay (which magnitude, by the way, depends also on the relative part of the registered ^{214}Pb betas with respect to their successors ^{214}Bi betas, i.e. from the wall thickness of the counter):

$$B(t+t_d) \Leftrightarrow A(t) \qquad (2)$$

The effective delay time t_d was determined from the maximum of the correlation coefficient between SBM-20 and RD200M time series by shifting the first data series consecutively by one step (10 min) portions related to the second one. The result is presented in Fig. 2.

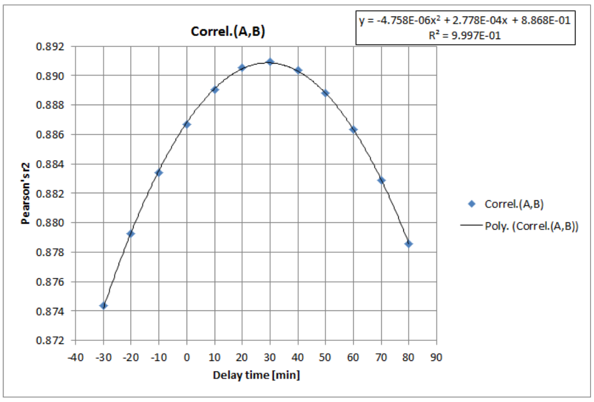

Figure 2. Correlation coefficient between SBM-20 (*B*) and RD200M (*A*) events *vs* delay time *B-A*

The correlation coefficient *vs* delay time has a well pronounced maximum whose vicinity is approximated with a quadratic function to assess the effective *B-A* time delay; in this case $t_d = 29.2m$. This value is very close to three report steps (30 min), so it is sufficient to shift the SBM-20 series 3 steps backwards in order the GM data to be correctly related to the corresponding RD200M values. In a general case the intermediate values can be obtained by interpolation.

The essential data analysis consists in an attempt to build an adequate model of the stochastic dependency *A(B)*. If our basic assumption is true then the Rn volume concentration reported by detector *A* at the moment t_i has to be a linear function $F(t_i)$ of the registered beta/gamma count rate in detector *B* at the moment t_{i+3}:

$$A(t_i) \cong F(t_i) = BG + b * B(t_{i+3}) . \qquad (3)$$

The coefficient b depends on the SBM-20 sensitivity (in units [cpm/Bq.m^{-3}]) and $BG = const(t)$ is a measure for the non-radon background component in the two detectors.

This is a classical linear regression problem. The least-squares solution yields the 'best' values of the parameters (Table 1):

Table 1. Optimal values of the parameters in Eq. (3)

parameter	value	σ
BG	-4694.82	0.67
b	143.95	0.02

The correlation coefficient after optimization is $r^2(A,F) = 0.895$. This very high correlation between both time series supports the validity of the basic assumption for the persistency of the non-Rn+ background throughout the observation period. Of course, this correlation is not perfect because of (at least) the stochastic nature of nuclear radiation.

The parallel measurements and their analysis can be regarded as a calibration procedure for a GM counter for detecting Rn+. In order to check the real performance of this calibration, the least-squares approximation using Eq. (3) was reapplied to observations in the first two months only and the resulting coefficients (*BG, b*) were then used to extrapolate the model (Eq.(3)) forward to the next observations. The results are shown on Fig. 3 together with the reference measurements from RD200M.

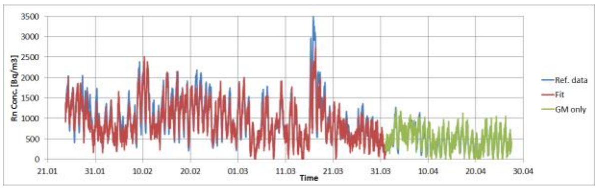

Figure 3.a) Reference data for the whole period (Ref.data), its approximation for the first two months (Fit) and evaluated data (GM only) for the third month

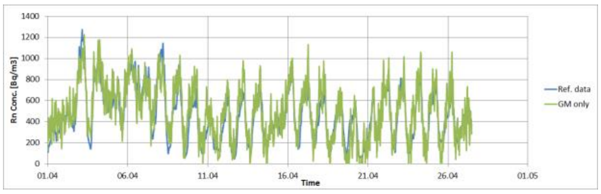

Figure 3.b) Reference and evaluated data for the third month in a larger scale

The correlation coefficients between the time series on Fig. 3 are as follows: *r^2(Ref.data,Fit)=0.876*, *r^2(Ref.data,GM)=0.831*. A certain decrease of the correlation is to be expected; nevertheless it remains rather high which confirms the adequacy of the linear model used here (Eq.(3)).

Looking forward to practical applications of the method, it is necessary to note that the non-Rn+ background is specific for both the particular site and the detector position and, moreover, it includes also the inherent background of the GM counter used.

Therefore, a calibration procedure like the described above has to be performed for any site and detector geometry separately, which makes the problem for reducing the calibration time rather important.

In order to evaluate the minimum reasonable calibration time, the calibration adequacy was investigated as a function of the calibration time T in the following way: a 'calibration interval' $[t_0, t_0+T]$ is defined and only a part of the data series lying within that interval is used for solving the regression problem (Eq.(3)); then the resulting values of the parameters (BG_T, b_T) are applied to the entire data series using the model function $F(t)$ from Eq.(3). Several different values of t_0 were used for each T to get statistically representative evaluation and to reduce the influence of the initial calibration moment's t_0 choice.

The calibration quality is measured by the root mean square deviation between the reference data (detector A) and the estimated values $F(t)$ normalized to the mean value of $A(t)$:

$$NRMSD = \frac{\sqrt{\dfrac{\sum_{i=0}^{n-1}[F(t_i)-A(t_i)]^2}{n}}}{\bar{A}} . \qquad (4)$$

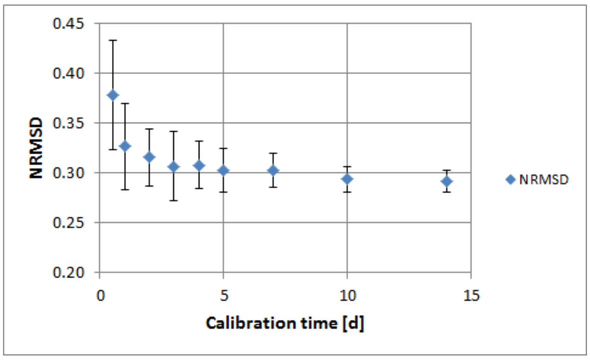

Figure 4. NRMSD *vs* calibration period length

Fig. 4 illustrates the results. It is seen that three days calibration time ensures accuracy which is comparable to the asymptotic one (i.e. when parallel measurements are available for the whole period of observation). A few days side by side calibration time seems reasonable if the radon monitoring is planned for months or years. It should be taken into account also that a calibration procedure is not mandatory in some studies (e.g. in geophysical research) wherein the main interest is focused on the variations of the radon concentration and not on its absolute value.

The applicability of the proposed method is limited by the statistical uncertainties of the data and the high noise level of SBM-20 due to non-Rn+ background. Using results from Table 1 and Eq.(3), the sensitivity of SBM-20 to Rn+ is evaluated by the parameter b: $Sens_{SBM-20} = 144\ Bq/m^3/cpm$. This value is only twice worse than the sensitivity of RD200M as declared by its manufacturer ($Sens_{RD200M} = 74\ Bq/m^3/cpm$) [2]. However, the non-Rn background of SBM-20 (it approaches $-BG$ at very low radon concentrations) is equivalent to about 4700Bq/m^3 in the studied case and this is the main restriction factor to use GM counters for low level radon monitoring.

If the non-Rn+ contribution from the detector surrounding is not steadily constant then a GM counter could not be used as a radon-only monitor. So, the applicability of GM for radon monitoring is limited to long-term observations at a fixed position in a non-disturbed site with high radon levels.

4. CONCLUSION

The feasibility of radon concentration monitoring using standard GM counters is evaluated in this work. The main advantage of GM based radiation detectors is their low cost (at least one order of magnitude lower than the active alpha-rays detectors) which greatly facilitates the development of dense networks for radon monitoring. An additional advantage of the GM counters is their robustness and especially their humidity resistance. The main drawback of the GM counters is their sensitivity to non-Rn+ components of the local radiation field which deteriorates their signal-to-nose ratio. The results obtained in the present work suggest that GM counters can be successfully used for long-term Rn+ monitoring in a stationary ambience (e.g. elevated indoor Rn levels, underground, in soil gas or in waters).

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