Technical note

ACCURACY AND PRECISION OF RAD7 AND RAD H_2O ACCESSORIES RADON DETECTOR IN WATER MEASUREMENT BASED ON COUNTING STATISTICS FOR SNIFF AND NORMAL MODES

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Abstract. Many biological risks may occur due to radioactive elements through drinking water, reason for which it is very important to investigate the precision and accuracy of radon measurements in such sources. The concentrations of radon were measured in commercially available drinking waters sourced from water wells in the Arar city (Saudi Arabia) in winter season of 2017. Two methods of measurement were used for this study: NORMAL mode and SNIFF mode, for both using RAD7 and RAD H_2O accessories. The uncertainty value (2σ) of the mean activity concentration of radon for SNIFF mode was decreased from 32% for one-hour cycle to 8% for 72 hours cycle, while for NORMAL mode measurement the 2σ decreased from 25% for 1 hour cycle to 6% for 72 hours. The results showed that the average values of radon concentrations of studied water sources were more accurate and precise using NORMAL mode than using SNIFF mode, due to the decrease of 2σ when switched from the SNIFF mode to NORMAL mode. Therefore, further studies are recommended in order to investigate in more detail the standardization and calibration processes of RAD7 in radon measurements using different techniques.

Key words: Radon, uncertainty budget, RAD7, drinking water.

INTRODUCTION

The main concern of environmental monitoring is the measurement of the natural radiation arising from naturally radioactive materials and their progenies [19]. Radon (^{222}Rn) is one of the most important causes for lung cancer [4]. Uncertainty in measurement means doubt about the validity of the result of a measurement [7]. Certainty in radon measurements reflect the good equipment as well as advantage of the used measurement procedure [2]. There are several detection techniques for measuring radon concentration levels, active detectors depending on continuous radon sampling requiring an electric power [1], such as

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the RAD7® [7] and AalphaGuard® [9]. RAD7 detector is used currently to measure radon concentration in water. Studies of the distribution of radon ^{222}Rn concentration in groundwater samples and their annual effective dose exposure in some areas were acquired using Durridge RAD7 radon-in-air monitor [9, 11,17], through RAD H_2O technique with closed loop aeration concept [6]. RAD7 detector was also used for measuring the radon concentration in drinking water supplies in Palestine [3, 8].

Short-term (RAD7) measurements are useful in identifying elevated radon levels, but may not always accurately estimate the long-term average radon level [1]. RAD7 was also involved in measurements of radon in surface, underground water and oil-produced water separated from oil in Basra Governorate in Iraq [12]. RAD7 was used for measuring the concentration of radon in drinking water supplies in Palestine [3]. Radon studies and measurements are also an important topic in the applied nuclear and environmental field [18].

Therefore, health hazards due to the exposure of population to radon for long periods of time are the most important reason of this scientific pursuit.

The present study is based on comparative measurements of water radon concentration using an active detector RAD7 in NORMAL mode and SNIFF mode, which assess the specific accuracy of RAD7 and RAD H_2O accessories.

Measurements for this study were performed on commercially available drinking waters sourced from selected water wells in the Arar city (Saudi Arabia) in winter season of 2017.

The comparison of these two different modes of data acquirement is mainly related to the evaluation of measurement precision in different operational conditions, such as of atmospheric conditions [5].

Accuracy and precision of the values reported in this study are considered as a baseline for RAD7 in radon level measurements in underground drinking water in Arar city, since no such similar radon study has been carried out in this area before.

MATERIALS AND METHODS

THE RAD7

The RAD7 (manufactured by Durridge Company [8]) with RAD H_2O accessory was used to measure radon in water within the concentration range of 10 pCi/L up to 400 000 pCi/L (Fig. 1). With the RAD H_2O accessory, in order to dry the air stream before it enters the RAD7, a desiccant should be used, which has blue color, if it is good. If it changes to pink color, it needs to heat in the oven for 2 hours with 200 °C – 225 °C before a next measurement. For water sample analysis, it should be avoided a large drying tube to prevent dilution of the radon. So, small drying tubes were used instead. Humidity for RAD7 should remain below 10% and must be free of radon and dry before starting the measurement. Drying unit during the initial process is necessary in order to save the small drying tubes for the actual measurement in water. The Modes of Operation are SNIFF rapid response, which detects the 3-minute alpha decay of a radon daughter, without interference from other radiations. It also detects the instantaneous alpha decay of a thoron daughter for rapid thoron measurements, and continuous radon monitor, called NORMAL high sensitivity [8]. At the end of each run, the detector prints out a complete report.

Technically, the principle of operation is based on electrostatic collection of alpha-emitters with spectral analysis passivated ion-implanted planar silicon detector. SNIFF mode counts polonium-218 decays but NORMAL mode counts both polonium 218 and polonium 214 decays with every RAD7 cycle. According to nominal sensitivity the following data was obtained: in SNIFF mode 0.25 cpm/(pCi/L), while in NORMAL mode 0.5 cpm/(pCi/L) [8].

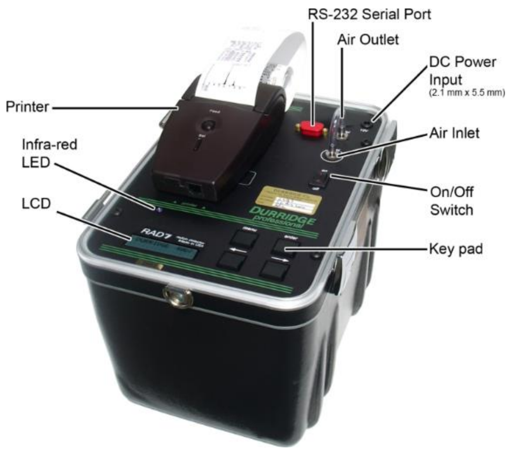

Fig. 1. The RAD7 professional electronic radon detector [8].

RAD7 SETUP PROTOCOL

The setup group of commands allow the RAD7 to perform tests according to experimental needs. They include commands to form the most frequently used parameters (Cycle time, Recycle number, Mode setting, Pump setting) according to preset protocols. These standard preset protocols include SNIFF and NORMAL modes. Selecting Setup Protocol automatically loads in a group of setup parameters under one of the standardized protocols, or the user protocol.

Indicate the values of these parameters you used, not only the possibilities of RAD7.

The cycle time can be adjusted anywhere from two minutes to 24 hours. For continuous monitoring, the cycle time is usually 30 minutes or longer. For radon sniffing, the cycle time is usually 5 or 10 minutes. It should be remembered that a run includes many cycles in sequence and that the total duration of the radon test is determined by the cycle time multiplied by the number of cycles. The length of the test is determined by choosing both the length and number of cycles. My setup was made for reading every 60 minutes, so 24 cycles are needed for a 24-hour test. In this case, 24 is the recycle number. After that the reading was taken every 2 hours, 6 hours, 24, 48, 72 hours and the corresponding cycles were calculated.

RAD7 SETUP MODE

Setup mode must be selected to change the RAD7 mode of operation. The available modes are SNIFF and NORMAL. SNIFF mode is used while following rapid changes of radon concentration. Also, in this mode the RAD7 achieves rapid response to changing radon levels by focusing on the 3-minute polonium 218 alpha peak, calculating the radon concentration on the basis of this peak alone.

In NORMAL mode, RAD7 achieves higher statistical precision by counting both polonium 218 and polonium 214 alpha peaks. This allows time for the equilibrium of the longer-lived radon daughter isotopes. The earliest part of the run will have the benefit of the SNIFF mode’s quick response, while the latter parts of the run will benefit from the NORMAL mode’s superior statistical precision.

We recommend that the same mode be used for all screening tests and any tests to measure the average concentration over a period of time. With the NORMAL mode there is no need to throw away the first three hours of data, or to calculate adjustments to correct for disequilibrium. The mean concentration reported in the run summary should accurately reflect the actual mean. SNIFF mode should be used where the goal is to follow, and measure, rapid changes in the radon concentration.

RAD7 ACCESSORIES: TESTING FOR RADON IN WATER

Rad H_2O accessory

The RAD H_2O (Fig. 2) is an accessory for the RAD7 that enables to collect water samples to detect the radon level with high accuracy over a wide range of concentrations, obtaining the reading within an hour of taking the sample. It is particularly suited for well water testing, where immediate results are often required.

The RAD H_2O uses a standard, pre-calibrated degassing system and pre-set protocols, built into the RAD7, which give a direct reading of the radon concentration in the water sample itself. The most widely supported sample sizes are 40 mL and 250 mL, as these correspond to the RAD7’s built-in Wat-40 and Wat-250 protocols. Large water samples of up to 2.5 L may be sampled using the big bottle RAD H_2O system.

Fig. 2. The RAD H_2O accessory [8].

Drinking water samples selected from drinking wells were chosen because there is the common water used for drinking in Arar city. The sample is taken from one station, Alshark. 250 mL of water sample was used in the study. A larger sample size was chosen for improving the sensitivity and precision of measurements at low radon concentrations. Then, the bottles were closed rapidly and tight to avoid radon leakage [14]. The samples were analyzed in the Radiation Physics Laboratory, Northern Border University, Arar, Kingdom of Saudi Arabia.

CALCULATION OF RADON DOSE

RAD7 calculates the sample water concentration by multiplying the air loop concentration by a fixed conversion coefficient which depends on the sample size.

The results were corrected from the time the sample was drawn to the time it was counted. Decay correction can be used for samples counted up to 10 days after sampling, though analytical precision will decline as the sample gets weaker and weaker. The decay correction factor (*DCF*) is:

$$DCF = \exp(T/132.4), \tag{1}$$

T being the decay time in hours [5].

Based on decay correction factor's table [9], decay times of less than 3 hours require very small correction. The decay correction factor can be neglected for the samples counted quickly. Thus, the actual radon concentration for each sample was calculated as below:

$$\textit{Concentration in water} = \textit{Measured radon concentration} \times DCF \qquad (2)$$

No correction is needed for the temperature of the water sample [3].

The background of RAD7 is less than 1 count per hour [13]. So, there is no need for measuring the background of RAD7 because it is very low. For stabilization, the RAD7 was purged for 30 minutes to remove the old radon from the machine and purged again for 15 minutes between a measurement and the next one [14].

The loop consists of the RAD7, a small laboratory drying unit, a filter, the piece of tubing and the printer [8].

STARTING A SNIFF TEST

Sniffing means quick, qualitative surveys of radon and thoron levels. There are some advantages in sniffing for both thoron and radon at the same time. A small drying tube was used. For portability, the external power from the RAD7 was removed and RAD7 runs on its batteries [6].

Active detectors are designed to be used in measurements for safety purposes. For measurements of radon in water samples, simple extra accessories are needed as shown in Figure 2, such as plastic hose connected with rubber valves, glass bottle, stainless steel outstanding holder associated with probe. For both tests, SNIFF and NORMAL mode, RAD7 is calibrated by the manufacturer against a master instrument, which, in turn, is calibrated against a standard maintained by the British National Radiological Protection Board (NRPB), known as HPA (Health Protection Agency) since 2004. The overall calibration accuracy is estimated to be about ±5% [10].

CORRECTIONS

The indications of the company should be verified for every concentration measurement made as follows:

Humidity correction

The presence of a precipitation process with large collecting volume of measurement chamber means that humidity inside the measurement chamber will harm the sensitivity of the RAD7. This is a function of the absolute humidity; technically, in the presence of water vapors, ions will attract water molecules, until a group of 6–10 water molecules gathers around each of them [13]. These group of molecules move slowly in the electrostatic field and thus the ^{218}Po atoms have enough time to become neutralized to the detector surface, and therefore lost. So, the sensitivity of the instrument drops at high humidity due to the difficulties to maintain the required high insulation resistance. At normal room temperature and with good drying in the air sample path, the humidity in the measurement chamber at the start of a measurement will quickly be downed below 6% [20]. So, it doesn't need to make a correction of the humidity due to the good drying of the chamber. When the operating temperature rises well above normal room temperature, the absolute humidity may become significant and a humidity correction may be required to compensate for the drop-in sensitivity. While high humidity reduces the sensitivity of a RAD7, leading to an automatic correction of the data, bringing readings back close to dry values. So, we don't need to make any humidity correction.

Concentration uncertainties

Long cycle times are necessary to obtain accurate readings of low radon concentrations, because, at low radon concentration, the statistical uncertainty is relatively high. At low count the reduction of uncertainty occurred when increasing the cycle time. In SNIFF mode, ^{218}Po (3.05 min half-life) takes more than 10 minutes to reach equilibrium with the radon concentration in the RAD7 chamber [13]. It must be noted that in SNIFF protocol, which uses 5-minute cycles, it is not possible to reduce uncertainty only after the first two cycles. So, we measured the radon activity by a spectrum of long cycles, which start with 1 hour up to 72 hours. Typical RAD7 precision based on counting statistics only, *i.e.* repeatability measurements of type A uncertainty. The two pathways studied comparative modes consisting of SNIFF mode, based on a sensitivity of 0.250 cpm/pCi/L, and NORMAL mode, based on a sensitivity of 0.50 cpm/pCi/L. The values are two-sigma uncertainty (or 95% confidence interval) in units of pCi/L.

Dusty environment

To prevent dusty environment, a dust filter was attached to the tubing at the sampling point, because dust may contaminate the desiccant substance that induces a state of dryness in its vicinity. So, radon background elevated due to radon emitted by trace amounts of radium deposited in the desiccant substance by the contaminating dust.

STATISTICS

The statistics was made directly by RAD7.

RESULTS AND DISCUSSION

DRY OPERATION

Precision represents the degree of mutual agreement among a series of individual measurements, values, or results. Accuracy represents the quality of being exact and free from error, how close a measurement is to the true value. An accurate instrument requires precision, but the precise instrument may be inaccurate due to lack of calibration process. When the operator obeys fixed procedures, counting statistics will give the RAD7's precision. The most important factor in RAD7 accuracy is calibration.

Durridge calibrates the RAD7 active detector to a set of four master instrument with a calibration precision of about 1% [6]. The master instruments have been calibrated through inter-comparison with secondary standard radon chambers designed by the U.S. EPA. The accuracy of the master instrument was found by Durridge to be within 4%, based on inter-comparison results. The target of overall calibration accuracy of RAD7 is about 5%. We look forward to new developments in calibration standardization and traceability, which we expect that it will help improve calibration accuracy.

Table 1 summarizes the precision obtained by using RAD7 in SNIFF mode, according to counting statistics, which depend on sensitivity (calibration factor) and background count rate which are applied before counting the net results.

The RAD7's fixed background count rate is a negligible contributor to precision, due to its very small value for the range of radon concentrations covered by the table. Environmental and other factors may affect precision by 2% [15]. The uncertainty values (2σ) reported by the RAD7 are estimates of precision based on counting statistics as shown in Table 1.

Table 1

Typical RAD7 precision based on counting statistics. SNIFF mode with a sensitivity of 0.250 cpm/pCi/L. Table values are two-sigma uncertainty (or 95% confidence interval) in units of pCi/L and coefficient of variation (%)

Time/Activity	1 pCi/L	5 pCi/L	20 pCi/L	50 pCi/L
1 h	0.57 (32%)	0.88 (30%)	1.66 (11%)	2.4 (2.6%)
2 h	0.44 (25%)	0.75 (22%)	1.48 (8.2%)	1.8 (1.5%)
6 h	0.38 (23%)	0.63 (19%)	1.24 (6.4%)	1.6 (0.58%)
24 h	0.29 (16%)	0.56 (16%)	0.88 (4.3%)	1.3 (0.57%)
48 h	0.15 (12%)	0.42 (9%)	0.77 (3.2%)	1.1 (0.4%)
72 h	0.09 (8%)	0.31 (6%)	0.66 (2.1%)	0.9 (0.3%)

Our results indicate that for 1 pCi/L, as the cycle time increases, the percent of 2σ decreases, which lowering the error and acquires the corrected precise value for concentration measurements. It is in accordance with [14]. Also, for other activities (5, 20, 50 pCi/L), the results varied in the same manner as for 1 pCi/L. As cycles time increased, the sigma value decreased, and results forwarded to the corrected precise measured value.

Table 2 summarizes the precision obtained by using RAD7 in NORMAL mode, according to the counting statistics. Counting statistics depend also on sensitivity (calibration factor) and background count rate which are applied before counting the net results. The RAD7's fixed background count rate is a negligible contributor to precision due to its very small value for the range of radon concentrations covered by the table. Environmental and other factors may affect precision by 2% [15]. The uncertainty values (2σ) reported by the RAD7 are estimates of precision based on counting statistics as shown in Table 2.

Table 2

Typical RAD7 precision based on counting statistics only. NORMAL mode with a sensitivity of 0.50 cpm/pCi/L. Table values are two-sigma uncertainty (or 95% confidence interval) in units of pCi/L and coefficient of variation (%)

Time/Activity	**1 pCi/L**	**5p Ci/L**	**20p Ci/L**	**50p Ci/L**
1 h	0.49 (25%)	0.79 (24%)	1.39 (9%)	2.1 (2.2%)
2 h	0.38 (21%)	0.71 (20%)	1.33 (7.6%)	1.3 (1.7%)
6 h	0.31 (19%)	0.59 (13%)	1.18 (5.2%)	1.1 (0.47%)
24 h	0.28 (13%)	0.44 (11%)	0.66 (3.8%)	0.8 (0.37%)
48 h	0.12 (10%)	0.33 (9%)	0.54 (2.8%)	0.63 (0.33%)
72 h	0.07 (6%)	0.26 (5%)	0.48 (1.9%)	0.59 (0.2%)

From Table 2, it results that the same trend of sigma values occurred as in SNIFF mode, but in NORMAL mode the values of sigma decreased much more than in the SNIFF mode. This result suggests using it rather than SNIFF mode. This correlation may be attributed to the integration value of concentration which tend to be integrated as true value as the number of cycles increased, and this is clearer in NORMAL mode than in SNIFF mode.

CONCLUSION

This work measured accuracy and precision of two modes of RAD7 in radon measurements: NORMAL mode and SNIFF mode. No one was concerned with the comparative study of accuracy and precision based on the different pathway methods of measuring contamination of radon. The main conclusion was as follows: while spot measurements of radon using RAD7 in SNIFF mode are useful for the quick recognition of high emission sites to be later monitored for ^{222}Rn variations in time, NORMAL mode allows temporal monitoring of a relatively large number of areas or locations, but cannot distinguish short-term changes, due to their long integration times. The uncertainty value (2σ) of the mean activity concentration of radon for SNIFF mode was decreased from 32% for one-hour cycle to 8% for 72 hours cycle, while for NORMAL mode measurement the 2σ decreased from 25% for 1 hour cycle to 6% for 72 hours. The results showed that the average values of radon concentrations of studied water sources were more accurate and precise using NORMAL mode than using SNIFF mode, due to the decreased of 2σ when switched from the SNIFF mode to NORMAL mode.

We recommend that environmental protection measures designed for non-radiological hazards in the environment are sufficient to protect against any future natural radiological hazard that may arise in the area. However, further study may be important to estimate the calibration of RAD7 for controlling external and internal doses from other radiological natural sources.

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