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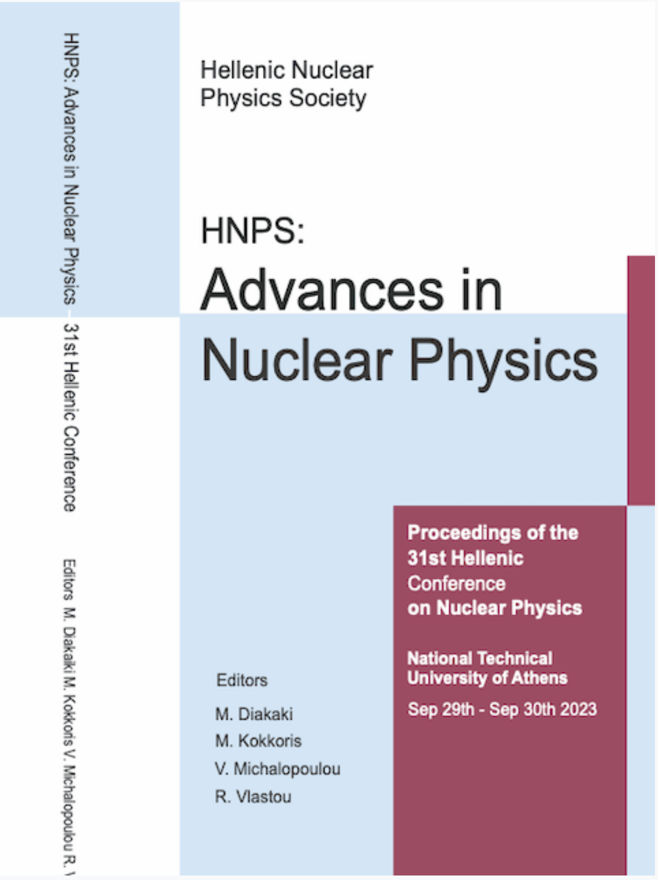

An Improved Technique for Monitoring Radon Progeny in Ambient Air

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An Improved Technique for Monitoring Radon Progeny in Ambient Air

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Abstract Radon progeny fluctuation outdoors has been widely studied for decades, with increasing interest in the last few years towards the investigation of possible correlation with atmospheric parameters and various environmental processes. Within this context, ^{214}Bi activity in ambient air has been systematically monitored at the Nuclear Engineering Laboratory of NTUA for several decades. However, the measuring technique and data analysis demonstrated various shortcomings. Currently, the measuring system has been upgraded and a new approach has been implemented for signal analysis. Measures were also taken to reduce background radiation and enhance the signal. Analysis of the collected data deemed challenging because of the effect of precipitation to the detected ^{214}Bi; efforts were made to monitor and interpret this effect. Analysis of experimental data over a period of ~6 months together with data for rain events confirmed that precipitation led to elevated signals. Furthermore, the results pointed towards a possible correlation between rain rate and ^{214}Bi count rate, indicating the need for further work on the subject. When concluded, this study will hopefully contribute to the ongoing investigation of radon progeny fluctuations in atmospheric air.

Keywords radon progeny, environmental monitoring, rain effect, earthquake precursory signal

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INTRODUCTION

Radon progeny fluctuation outdoors –especially that of the short-lived ^{214}Pb and ^{214}Bi– has been widely studied around the world for decades with the use of different methods [1-3]. The interest in this field of research is recently focused on the investigation of possible correlations between radon progeny concentration and various atmospheric parameters such as air stability and atmospheric dispersion conditions [4,5], as well as the potential association of radon and radon progeny fluctuations with environmental phenomena, e.g. precipitation events [6-9]. Within this context, the Nuclear Engineering Laboratory of the National Technical University of Athens (NEL-NTUA) has been systematically monitoring ^{214}Bi activity in ambient air for almost 40 years [10]. During that research, attention was paid towards the possible use of elevated ^{214}Bi activity concentration as an earthquake precursory signal [11], since an increase in soil gas emissions and particularly radon exhalation is widely associated with seismic activity [12-14]. However, the measuring techniques utilized were subject to shortcomings, such as low signal-to-noise ratio, calibration challenges due to the temperature drift of the detector system and data analysis. In this ongoing work, new approaches and methodologies are tested, aiming to the improvement of the monitoring system capabilities as well as the signal analysis and evaluation methods.

MATERIALS AND METHODS

The original experimental setup consisted of a 2”x2” ^{241}Am doped NaI detector mounted on the outside of the building wall and the associated nuclear electronics (Fig. 1), including an Analog Spectrum Stabilizer used for real time signal stabilization. For signal recording two Single Channel Analyzers were used, one counting the gross area corresponding to the 609 keV ^{214}Bi photopeak and

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the other one recording the total spectrum area.

Figure 1. *Left: The 2”x2” NaI detector mounted on the building wall. Center: The original setup electronic configuration. Right: The signal processing and storage units currently in use.*

The improved and currently used experimental setup consists of a 3”x3” NaI detector, placed outdoors on the NEL-NTUA building roof (~12 m above ground, ~1 m away from any building surface), a signal processing unit, a Multi-Channel Analyzer (MCA) and a PC for the sequential data storage (Figs. 1 and 2). For spectrum stabilization a ^{40}K source is positioned close to the detector. Outdoor temperature and humidity are also being continuously recorded.

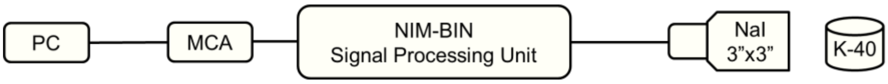

Figure 2. *Schematic diagram of the experimental setup*

As a result of the new configuration the continuum background is significantly reduced, the full spectrum is collected for 1 hour and the net peak area corresponding to the 609 keV ^{214}Bi photopeak is recorded. Measurements are conducted on a continuous basis and the collected spectra are regularly analyzed with a mathematical algorithm (Fig. 3), developed in MATLAB environment. In particular, with the use of simple mathematical techniques each spectrum is calibrated for energy *a posteriori* and the net count rate of ^{214}Bi photopeak along with its uncertainty are calculated and stored as a time series for subsequent analysis.

Identification of the ^{40}K 1460 keV photopeak in the spectrum and determination of peak centroid.

↓

Fitting of the ^{40}K peak to a Gaussian, calculation of peak centroid, net area and uncertainty and estimation of peak drift.

↓

Determination of the ^{214}Bi 609 keV photopeak position by applying the required peak drift correction.

↓

Fitting of the ^{214}Bi peak to a Gaussian, calculation of peak centroid, net peak area and uncertainty. Storage of the ^{214}Bi net count rate (signal) and uncertainty as a timeseries.

Figure 3. *Simplified scheme of the spectrum analysis algorithm*

RESULTS AND DISCUSSION

Even though the currently used technique yielded stronger signal and more reliable data, significant challenges were met during the analysis of the collected timeseries. Therefore, the investigation of the effect of rain events on the detected signals was prioritized. Comparing the collected signals over a period of ~6 months represented by the average value over a 3h period and the daily rain intensity in the neighboring (600 m) residence area Papagou as provided online by the meteorological network Meteo of the National Observatory of Athens, it is confirmed that the elevated ^{214}Bi signals were significantly affected by rain events (Fig. 4), as anticipated from findings of other studies [9]. Nevertheless, no correlation between the normalized signal values and rain intensity seem to emerge. Contrariwise, the daily highest signal obtained and the daily highest rain rate from data provided online by Openmeteo meteorological network from sensors located at NTUA campus –close to NEL-NTUA– appear to be in greater accordance (Fig. 5), which agrees with results from recent studies that correlate the increment in detected radon progeny activity during precipitation events with the rain rate [8]. Thus, future efforts ought to focus on methods to quantify the effect of precipitation as well as other meteorological parameters on the ^{214}Bi signal.

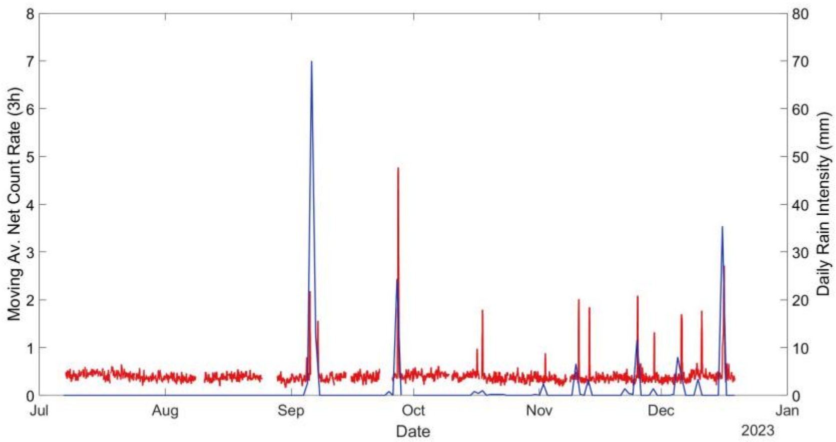

Figure 4. *Detected ^{214}Bi signal (red line), averaged over 3 h, and daily rain intensity (blue line) provided by Meteo (https://penteli.meteo.gr/stations/papagou/)*

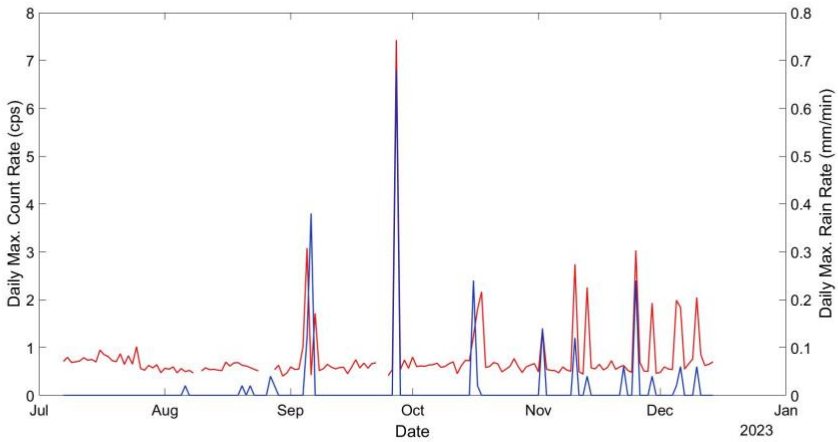

Figure 5. *Daily highest detected ^{214}Bi activity (red line) and daily highest rain rate (blue line) provided by Openmeteo (https://openmeteo.org/stations/1334/)*

Additionally, in the context of the present work a preliminary retrospective analysis of the data collected with the previous setup in 2020 during a 10-month period was conducted. From the results of this analysis, presented in Fig. 6, it is made clear that high signals are also in accordance with precipitation events. The elevated signals were less than 1.0 cps above a mean background (noise) of 2.9±0.3 cps (1σ). When compared to the signals acquired with the new technique, which were about 0.9–7.1 cps above a background of 0.4±0.1 cps (1σ), it becomes evident that the signal-to-noise ratio has been significantly improved with the technique currently in use. Furthermore, it is interesting to note that the highest signal during the sampling period (Fig. 6) was recorded 8 days before a 4.9R earthquake, 120 km south of Athens. Clearly, correlation of any recorded signals to earthquake precursory phenomena is a very challenging task as there are other parameters drastically affecting radon progeny concentration in ambient air, such as humidity, wind speed and direction etc., apart from the case-specific seismic activity characteristics (e.g. distance, depth, magnitude etc.). Nevertheless, there have been cases in the past where it was possible to distinguish precursory signals of seismic activity, e.g. in the case of the Athens 5.9R earthquake which occurred in September 1999 [11].

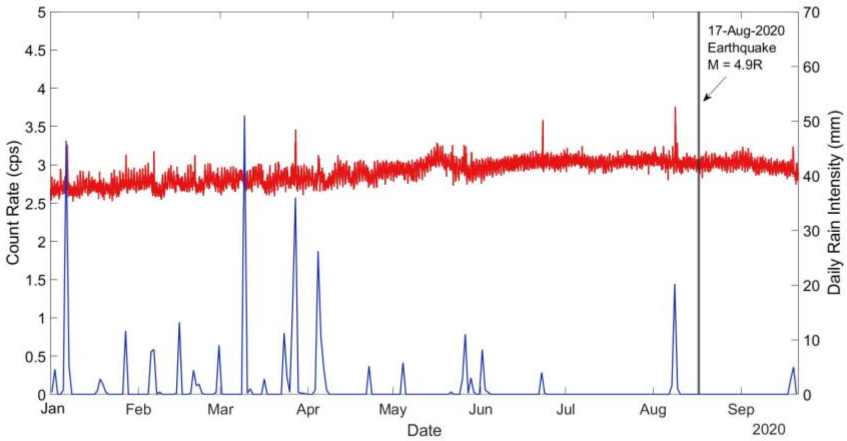

Figure 6. *Detected ^{214}Bi signals as recorded with the previous set-up (red line) and rain intensity (blue line) provided by Openmeteo (https://openmeteo.org/stations/1334/), during a 10-month period in 2020. The August 2020 4.9R earthquake event is also noted.*

CONCLUSIONS

The new methodology for data collection and signal analysis presented in this work demonstrates certain advantages over the previous one, significantly improving signal quality. With the spectrum analysis algorithm used, each spectrum is retrospectively corrected for drift with simple mathematical techniques using the ^{40}K photopeak, while ^{214}Bi net count rate time-series are subsequently yielded for further analysis. At the same time, humidity and temperature outdoors are continuously recorded, providing useful information for possible signal filtering.

The apparent effect of precipitation –and probably other environmental parameters– on the collected signals imposes great challenges on the analysis and exploitation of the data collected. Therefore, efforts to monitor and break down the effect of various parameters are a priority for signal filtering in the future. Nevertheless, any investigation on the use of radon progeny fluctuations as earthquake precursory signals requires additional methodologies for signal collection, data analysis and treatment to be developed, while long-term measurements need to take place as well.

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