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RaMonA system for radon and thoron measurement

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Summary. — RaMonA is a homemade system for the measurements in air of the specific activity of ^{222}Rn (radon) and ^{220}Rn (thoron) based on the electrostatic collection of the alpha emissions of the ionized descendants of the two radioisotopes. The use of a semiconductor detector and of an appropriate signal processing apparatus allows to obtain alpha spectra with excellent energy resolution. The system has been used for many years for the continuous monitoring of the gas indoors, outdoors and in soil air. For several purposes, different geometries of the measurement chamber are realized and suitably calibrated, even in mixed atmospheres of ^{222}Rn and ^{220}Rn. In this paper, the different measurement systems and their potentialities are presented and the collection efficiencies of the different polonium isotopes are compared.

1. – Introduction

After the consolidation and standardization of radon (^{222}Rn) measurement techniques in the last decades through the use of several different devices (scintillation cells, nuclear track detectors, charcoal canisters, gamma spectrometry and electrostatic collection monitors) [1-5], the interest in the measurement of thoron (^{220}Rn) has increased in recent years, also because it has been shown that the dose due to the thoron (half-life equal to 55.3 s) can be higher than that of the radon (half-life equal to 3.82 d) in certain conditions and in particular environments such as mines, basements and tunnels [6-8]. Therefore, the contribution to the annual effective dose uptaken by the population and/or by workers cannot be negligible, so the scientific community has researched measurement methods and calibration procedure to provide the measurement of thoron distinct from that of radon.

In this context, the electrostatic collection devices are the most performing ones able to measure in air both ^{222}Rn and ^{220}Rn based on progeny detection of the two isotopes of the gas collected in a specific measuring chamber [9-13].

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2. – General features of the RaMona system

The homemade RaMonA (Radon Monitoring Acquisition) system is a fully adequate instrument that provides the specific activity (Bq/l) of radon and thoron in air [1, 14, 15]. The device was built in the laboratories of the Universities of Naples "Federico II" and of Campania "L. Vanvitelli" and provides an excellent energy resolution and a temporal fast response compared to the most used commercial ones. In addition, RaMonA also monitors temperature, pressure and relative humidity inside and outside the measuring chamber. The system (fig. 1) consists of:

1) a metallic cylindrical chamber (volume = 0.785 l) for the electrostatic collection of ionized radon and thoron decay products on a silicon detector that allows the alpha spectrometry; the chamber also holds the electronics of the climatic sensors and the detector preamplifier;

2) a control tool for the management and the storage of the signals, and also a power supply and an ethernet connection of the system;

3) a software for the management of the system locally and remotely;

4) the homemade FORTAS software for the complete analysis of the alpha spectra [15].

A typical complete alpha spectrum obtained from the measurement of mixed atmosphere of ^{222}Rn and ^{220}Rn has six peaks related to the ^{210}Po, ^{218}Po, ^{214}Po, ^{216}Po, ^{212}Bi, ^{212}Po emissions and the peak of the coincidence $\alpha + \beta$, having energies between 5 MeV and 10 MeV [14]. The peak at 5.3 MeV of the ^{210}Po, can be present in the spectrum as a consequence of the prolonged use of a detector, which causes the accumulation of an increasing amount of the radioisotope due to its half-life equal to 138.4 d. The next peak is due to the overlapping of the emissions of ^{218}Po at 6.003 MeV and of the ^{212}Bi at 6.09 MeV. The peaks at energies 6.7 MeV of ^{216}Po and 7.7 MeV of ^{214}Po, allow to determine, respectively, the activity of thoron and radon. The last peak is due to the superposition of alpha particles at 8.8 MeV of ^{212}Po and of beta particles of ^{208}Tl coming from the second branch of the decay of ^{212}Bi.

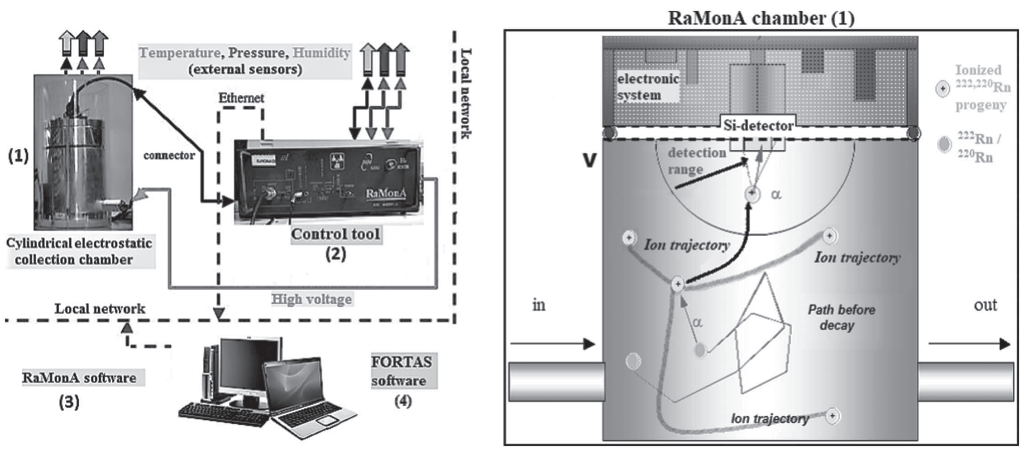

Fig. 1. – General setup of the RaMonA system (left), and schematic functioning of electrostatic deposition of ionized radon and thoron decay products inside the chamber (right).

The developed FORTAS software (Fit Of Radon-Thoron Alpha Spectra) performs the complete, detailed, automated and fast analysis of a such alpha spectrum: it identifies each peak in the spectrum, according to its energy, and determines its area and associated uncertainty. The software provides the best fit of the alpha peaks, taking into account the background due to all the other peaks; it makes the deconvolution of the overlapping peaks in the case of ^{218}Po + ^{212}Bi and of $\alpha + \beta$ coincidences; it analyzes different spectra obtained in non-standard condition characterized by: partial presence of the six peaks, few counts, accidental background noise [15]. The effectiveness of this analysis is highlighted in the case of the simultaneous presence of ^{218}Po and ^{212}Bi, whose deconvolution allows to use the peak of ^{218}Po for the determination of the activity of radon using the best response speed of the measurement system.

3. – Different RaMonA versions

The first version of the RaMonA system, improved and enhanced over time, is mainly used in air flow for continuous monitoring indoors, outdoors and in soils [16, 17]. It is currently used as continuous monitor in the two sites of the interesting seismic area of Phlegrean Fields (Naples-Italy), where the device analyzes the soil gas to a depth of 0.80 m by 1 l/min pumping.

Modified versions of the system have been realized, and differently renamed, by changing the geometry of the measurement chambers and the measurement methods, in order to be used for different purposes.

3˙1. *Ramonello*. – The measurement chamber is a metallic grid half-spherical shell, with a volume of 0.301 l, covered with a 380 μm thick sheet of white Tyvek® filter that has the function to stop the diffusion of ^{222}Rn and ^{220}Rn daughters, already present outside the chamber, in the active volume of the monitor. The system is portable. It is used in diffusion for indoor and outdoor measurements. For this reason the chamber is encased in a black cubic grid made of Teflon®, which also avoids light interference on the silicon detector and isolates the applied high voltage (fig. 2). A prototype of Ramonello is currently used at the National Institute of Ionizing Radiation Metrology (INMRI) of the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA-Roma, Italy).

3˙2. *Ramonino*. – The measurement chamber has the same geometry of Ramonello chamber, with slightly smaller dimensions and a volume of 0.26 l, only covered with a 380 μm thick sheet of white Tyvek® filter. The system is used in diffusion and is designed to be used in an environment protected from light as a reference monitor. It is permanently installed in the radon exposure chamber of the Radioactivity Laboratory of the University of Naples "Federico II" [18, 19] (fig. 2).

3˙3. *Emanatore*. – It consists of two cylindrical metallic superimposed chambers of equal volume (0.8 l) separated by a metallic grid. The below chamber contains the sample emanating radon and thoron, which diffuse in the above chamber where they are measured. The system is used for measurements of emanation from materials or soils (fig. 3).

3˙4. *Esalatore*. – The measurement chamber is that of the first RaMonA, with a larger volume equal to 1.0 l, and the bottom basis is replaced by a metallic grid resting on the measuring ground. The electric field is obtained by the metallic grid covered with a 380 μm thick sheet of white Tyvek® filter to reduce the humidity inside the chamber.

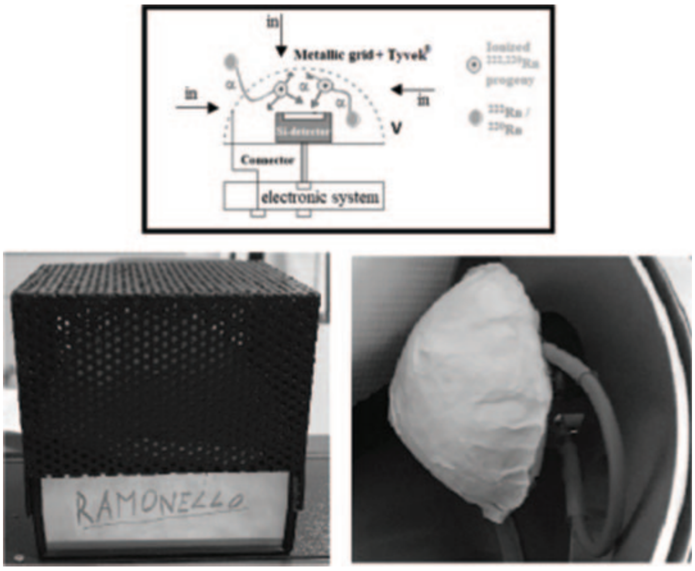

Fig. 2. – Schematic functioning of electrostatic deposition of ionized radon and thoron decay products (top) inside the Ramonello (left) and Ramonino (right) chambers.

This system follows the variations in the gas activity concentration in the soil by direct measurements of radon exhalation (fig. 3).

4. – Applications and results

The different versions of the RaMonA system have been calibrated for ^{222}Rn and ^{220}Rn, through the creation of mixed atmospheres of properly characterized radon and thoron sources. The activity of each source has been measured by gamma-ray

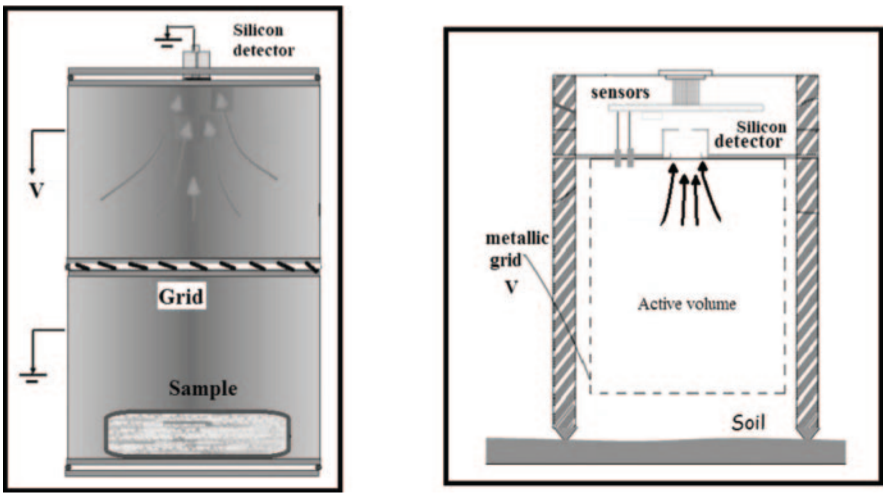

Fig. 3. – Schematic functioning of Emanatore (left) and Esalatore (right) chambers.

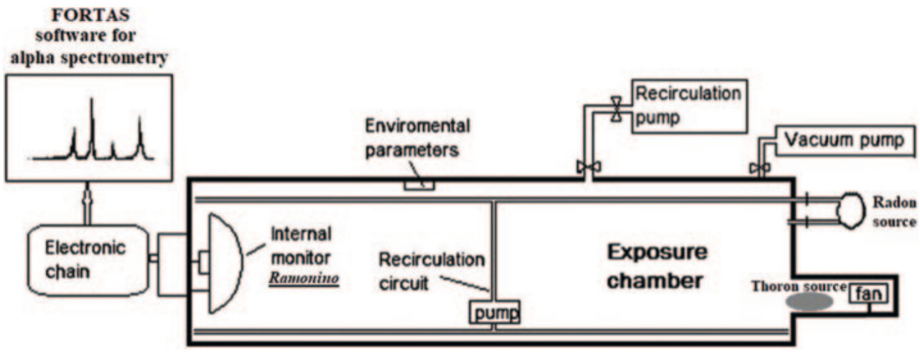

Fig. 4. – Schematic outline of the radon exposure chamber for the calibration procedure in mixed atmosphere of radon and thoron.

spectrometry using a shielded 49% efficiency, 2 keV energy resolution at 1.33 MeV hyperpure germanium detector.

The RaMonA, Ramonello and Ramonino chambers have been calibrated with a procedure based on the introduction of a known activity concentration of gas in the measurement chamber. The ^{222}Rn is obtained from a standard reference source of ^{226}Ra within a glass ampoule by diffusion in the radon exposure chamber (fig. 4) where it decays according to its lifetime. The ^{220}Rn is obtained directly in the radon exposure chamber by exhalation of the gas from ^{232}Th salts, ensuring a constant rate of exhalation in constant climatic conditions provided by an appropriate ventilation system [19, 20]. Using this methodology [10], a series of mixed atmospheres characterized by different activities

Table I. – *Efficiencies of the electrostatic collection of* ^{218}*Po,* ^{214}*Po and* ^{216}*Po in the different versions of the RaMonA system.*

	RaMonA	Ramonello	Ramonino
Efficiency (cps/Bq/l)			
^{218}Po (^{222}Rn)	0.041 ± 0.001	0.0275 ± 0.0008	0.0108 ± 0.0003
^{214}Po (^{222}Rn)	0.037 ± 0.001	0.0232 ± 0.0010	0.0106 ± 0.0003
^{216}Po (^{220}Rn)	0.047 ± 0.005	0.0149 ± 0.0011	0.0108 ± 0.0003
HV chamber (V)	3500	1500	1500
Volume chamber (l)	0.785	0.301	0.26

	Emanatore	Esalatore
Efficiency (cps/Bq/l)		
^{218}Po (^{222}Rn)	0.25 ± 0.02	0.010 ± 0.003
^{214}Po (^{222}Rn)	0.26 ± 0.02	0.011 ± 0.002
^{216}Po (^{220}Rn)	0.0054 ± 0.0005	0.017 ± 0.013
HV chamber (V)	3000	2500
Volume chamber (l)	0.83	1.0

has been produced. The Ramonello and Ramonino measurement chambers have been positioned inside the radon exposure chamber, while that of RaMonA outside with the use of an external circuit.

In the calibration procedure of the Emanatore and Esalatore chambers, a sample of soil from Mount Olibano in the Phlegrean Fields in the district of Naples was used. It has been reduced to 2 mm grains, in order to help the emission of the gas from the interstitial spaces of the sample. In this procedure it is important to take into account the percentage of emitted radon that can be reabsorbed by the sample from the volume of the chamber. This phenomenon, called back-diffusion, is negligible in the initial phases of emission when the available volume of gas expansion is maximum, while when the sample saturation condition is reached, this probability is estimated to be inversely proportional to the volume of the chamber [21].

The values of the efficiencies (expressed in cps/Bq/l) of the electrostatic collection of the main radon and thoron progeny (^{218}Po, ^{214}Po, ^{216}Po) in the different versions of the RaMonA system have been calculated (table I). The results from the present study show that the efficiencies of ^{218}Po and ^{214}Po are always in good agreement under standard conditions of temperature, pressure and relative humidity, while the ^{216}Po efficiency in some cases is in agreement with those of the other two, because of the different geometric characteristics of the chambers [14, 15].

5. – Conclusions

RaMonA system is a homemade device based on the electrostatic collection of the ionized alpha descendants of ^{222}Rn and ^{220}Rn on a silicon detector in a metallic cylindrical chamber. The various versions of the RaMonA system, obtained by changing only the measurement chamber, and their applications are presented. Thanks to the alpha spectrometry obtained by silicon detector, a software for the analysis of spectra and an appropriate calibration performed in a mixed radon and thoron atmosphere, the individual instruments have been characterized to measure the activity concentration of both isotopes of the gas for different purposes.

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