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ASSESSMENT OF THE ^{222}RN RADIOACTIVITY CONTENT IN DRINKING WATER BY USING LIQUID SCINTILLATION COUNTING (LSC)

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Abstract. In this article the evaluation of the radon content in drinking water samples from the province of Reggio Calabria (Calabria, Southern Italy), is reported. In particular, the ^{222}Rn activity concentration was measured by using the Liquid Scintillation Counting (LSC) PerkinElmer Tricarb 4910 TR setup, and it was compared with the parameter value (100 Bq L^{-1}) reported in the Italian Legislative Decree 28/2016. The annual effective dose for the population of the investigated areas, due to the ingestion of ^{222}Rn dissolved in water, was then evaluated only in those cases in which the parameter value was exceeded. Noteworthy, results reported in this paper represent a main reference for the investigated areas and constitute a baseline for future investigations regarding background radioactivity levels.

1. Introduction

Although the environmental aspects of the natural radioactivity have been widely discussed in the literature (Picciotto *et al.* 2006; Torrisi *et al.* 2006; Baeza, Salas, and Legarda 2008; Caridi *et al.* 2017a, 2021a,b), the presence of natural radioisotopes in drinking waters has not been sufficiently addressed up to now, despite water represents a critical component of the surrounding environment (Alabdula'aly and Maghrawy 2010; Caridi *et al.* 2016a; Mottese *et al.* 2020). In particular, among the naturally occurring radioisotopes, radon is one of the most remarkable since, as is well known, its ionizing radiation provides the major contribution of internal human exposure compared with other natural sources (Caridi *et al.* 2016b) and then it can lead, in the long term, to the development of diseases of internal organs, primarily stomach and gastrointestinal cancer (Trautmannsheimer, Schindlmeier, and Hübel 2002). Radon concentration in water is mainly due to porosity, permeability, soil exhalation rates and radium contents of the soil beneath water source or to the composition of rocks related to the source area (Caridi *et al.* 2016c).

In this paper, measurements of the radon specific activity in drinking water samples from springs of the Reggio Calabria district (Calabria, Southern Italy), were carried out by using a Liquid Scintillation Counting (LSC) setup with the aim to contribute to the collection of data on the presence of ^{222}Rn in drinking water in the area under investigation and to determine the associated health risk to the members of the population due to the radon ingestion (Caridi *et al.* 2017b; Caridi, Messina, and D'Agostino 2017).

2. Materials and methods

Four samples of drinking water (one for each season of the year), from springs, were collected for each of the five selected locations in the Reggio Calabria district (Calabria, Southern Italy), as indicated in Fig. 1 and reported in Table 1.

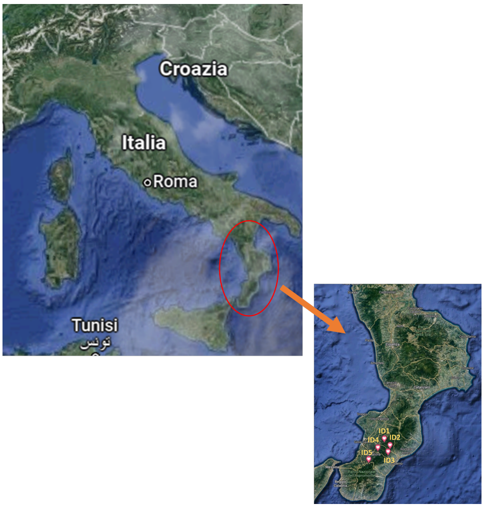

FIGURE 1. The investigated area, with the sampling sites, ID# (# = 1, 2,. . . , 5), indicated.

TABLE 1. The average value of the ^{222}Rn activity concentration in the analysed drinking water samples.

Site ID	Location	GPS coordinates	
		Latitude	Longitude
1	Giffone	38°26'21"N	16°09'06"E
2	Mammola	38°21'37"N	16°14'17"E
3	Canolo	38°19'26"N	16°11'33"E
4	Cittanova	38°21'41"N	16°04'35"E
5	S. Cristina d'Aspromonte	38°15'22"N	15°58'13"E

The samples collection was carried out according to the local weather conditions, that in some periods put severe limitations to the access to the monitoring stations (Caridi *et al.* 2016a). After the sampling, a label stating date, time and source of the water was applied. The specific activity of ^{222}Rn in the investigated samples was quantified through the following procedure: 10 mL of sample were inserted with a gas-tight syringe into the bottom of a 25 mL plastic vial previously filled with 10 mL of Perkin Elmer Opti-Fluor O scintillating cocktail immiscible in water, stored and, after a rest time of 5 hours, counted for 60 minutes together with a background (*Manuale della Rete RESORAD* 2016).

After, the LSC Perkin-Elmer Tricarb 4910 TR setup, with an energy range of 0-2 MeV (β particles) and 0-10 MeV (α particles), minimum acceptable efficiency of 60% for 3H (0-18.6 keV) and 95% for 14C (0-156 keV) and average Background of 17 CPM for 3H and 26 CPM for 14C was employed for the measurements. It works in Normal Count Mode/Low activity-High Sensitivity Mode, with the external standard ^{133}Ba to take into account chemical and optical quenches and to determine the counting efficiency through the tSIE/AEC (Caridi *et al.* 2016d). The calibration was performed by using a reference source of ^{222}Rn, according to what reported in *Manuale della Rete RESORAD* (2016). A photo of the experimental setup is reported in Fig. 2.

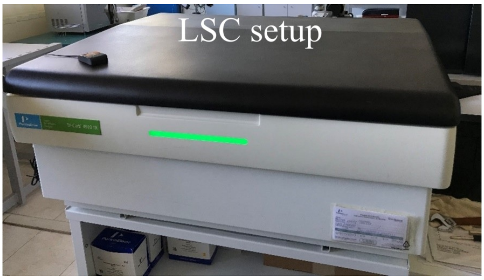

FIGURE 2. A photo of the experimental setup.

Moreover, to manage the unintended decrease in radon activity concentration due to its radioactive decay and partly to the degassing phenomenon (Sabatino *et al.* 2019) occurring during the radon-in-water analysis or in the case when a water sample is taken and analysed sometime later, the resulting activity concentration was decay-corrected back from the time of sampling to the time of analysis through the following equation:

$$C_{Rn-222}\,(\mathrm{BqL^{-1}}) = \mathrm{C_{0,Rn-222}e^{-\lambda t}} \tag{1}$$

where C_{Rn-222} (Bq L^{-1}) is the measured ^{222}Rn specific activity, $C_{0,Rn-222}$ (Bq L^{-1}) is the initial concentration, *i.e.* at the sampling time, λ is the decay constant of ^{222}Rn (s^{-1}) and t is the time elapsed since collection (s). All the activity concentrations measured in the laboratory were corrected according to Eqn. (1). In particular, the C_{Rn-222} value is given by:

$$C_{Rn-222}\,(\mathrm{BqL^{-1}}) = \frac{\lambda \mathrm{C_N}}{(1-\mathrm{e}^{-\lambda \Delta \mathrm{t}})\varepsilon \mathrm{V}} \tag{2}$$

where C_N are the total net counts, Δt is the analysis duration (3600 s), ε is the method efficiency (4.55) and V is the sample volume (*Manuale della Rete RESORAD* 2016).

In order to control radiation exposure to the public, the estimation of the total annual effective dose due to ingestion of ^{222}Rn in water samples was carried out:

$$H_{ing}(Sv \times y^{-1}) = DCF_{ing} \times C_{0,Rn-222} \times I_w \times 365 \tag{3}$$

where DCF_{ing} is the dose conversion factor by ingestion of ^{222}Rn in water samples (23, 5.9 and 3.5 nSv Bq^{-1} for infants, children and adults, respectively) and I_w is the average daily water consumption rate (UNSCEAR 2000). In this article, a pro capita consumption of 150, 350 and 730 L per year for infants, children and adults, respectively, was considered.[1]

3. Results and discussion

The average values of ^{222}Rn activity concentration in the investigated drinking water samples, for each sampling site, are reported in Table 2.

TABLE 2. The average value of the ^{222}Rn activity concentration in the analyzed drinking water samples

Site ID	**C**$_{0,Rn-222}$ (Bq L^{-1})
1	13 ± 2
2	164 ± 46
3	39 ± 8
4	77 ± 19
5	32 ± 7

The radon activity concentration was found to vary from a minimum of (13 ± 2) Bq L^{-1} for the site ID1, to a maximum of (164 ± 46) Bq L^{-1} for the site ID2, thus indicating that the origin of these drinking waters is not the same and that they come from different depths and pass through different geological layers. Specifically, the highest value was recorded for a site situated within the geological context of the "Calabrian-Peloritan arc" (Atzori *et al.* 1983). This particular geological setting is known for its abundance of uranium-rich rocks, resulting in elevated levels of radon gas. Moreover, in all cases with the only exception of site ID2, the activity concentration values were found to be always lower than 100 Bq L^{-1}, *i.e.* the parameter value according to the Italian Legislation (2016). Consequently, the assessment of the annual effective dose H_{ing}, resulting from the intake of ^{222}Rn by infants, children, and adult individuals from the population, was exclusively conducted for site ID2. As a result, this radiological parameter turned out to be 0.56 mSv y^{-1}, 0.34 mSv y^{-1} and 0.42 mSv y^{-1}, respectively. Notably, the obtained values appear to be in good agreement with those found in the literature, since they fall within the acceptable range of 0.2 mSv y^{-1} – 1.8 mSv y^{-1} reported in the "Commission recommendation of 20 December 2001 on the protection of the public against exposure to radon in drinking water supplies (notified under document number C(2001) 4580)". As a consequence, any radiological hazards for the

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population living in the investigated area, related to the radon ingestion, can be reasonably excluded.

4. Conclusions

In this article, the assessment of the radon concentration in drinking water samples coming from five selected locations of the Reggio Calabria district (Calabria, Southern Italy), is reported.

Measurements were performed by means of a LSC setup. Obtained results revealed that the specific activity of radon is below the parameter value indicated by the current Italian legislation, except in the case of site ID2. In this latter case, the annual effective dose by ingestion for infants, children and adult members of the population was assessed, and it turned out to be within the range of acceptability between 0.2 mSv y^{-1} and 1.8 mSv y^{-1} reported in the Recommendation 2001/928/Euratom. Then, the safety of the analysed samples for drinking purposes can be reasonably ensured, and no remedial actions are demanded.

Finally, it must be put in evidence that periodical screening could be necessary in order to guarantee the safety of drinking water and for this reason data reported in this article will be implemented in the next future by increasing the sampling points and the number of analysed samples.

References

Alabdula'aly, A. I. and Maghrawy, H. B. (2010). "Radon emanation from radium specific adsorbents". *Water Research* **44**(1), 177–184. DOI: 10.1016/j.watres.2009.09.031.

Atzori, P., Ferla, P., Paglionico, A., Piccarreta, G., and Rottura, A. (1983). "Remnants of the Hercynian orogen along the 'Calabrian- Peloritan arc', southern Italy: a review." *Journal of the Geological Society*. DOI: 10.1144/gsjgs.141.1.0137.

Baeza, A., Salas, A., and Legarda, F. (2008). "Determining factors in the elimination of uranium and radium from groundwaters during a standard potabilization process". *Science of The Total Environment* **406**(1-2), 24–34. DOI: 10.1016/j.scitotenv.2008.07.050.

Caridi, F., Acri, G., Belvedere, A., Crupi, V., D'Agostino, M., Marguccio, S., Messina, M., Paladini, G., Venuti, V., and Majolino, D. (2021a). "Evaluation of the radiological and chemical risk for public health from flour sample investigation". *Applied Sciences* **11**(8), 3646. DOI: 10.3390/app11083646.

Caridi, F., D'Agostino, M., Belvedere, A., Marguccio, S., and Belmusto, G. (2016a). "Radon radioactivity in groundwater from the Calabria region, south of Italy". *Journal of Instrumentation* **11**(05), P05012. DOI: 10.1088/1748-0221/11/05/P05012.

Caridi, F., D'Agostino, M., Belvedere, A., Marguccio, S., Belmusto, G., and Gatto, M. (2016b). "Diagnostics techniques and dosimetric evaluations for environmental radioactivity investigations". *Journal of Instrumentation* **11**(10), C10012. DOI: 10.1088/1748-0221/11/10/C10012.

Caridi, F., D'Agostino, M., Messina, M., Marcianò, G., Grioli, L., Belvedere, A., Marguccio, S., and Belmusto, G. (2017a). "Lichens as environmental risk detectors". *The European Physical Journal Plus* **132**(4), 189. DOI: 10.1140/epjp/i2017-11459-y.

Caridi, F., Di Bella, M., Sabatino, G., Belmusto, G., Fede, M. R., Romano, D., Italiano, F., and Mottese, A. F. (2021b). "Assessment of natural radioactivity and radiological risks in river sediments from Calabria (Southern Italy)". *Applied Sciences* **11**(4), 1729. DOI: 10.3390/app11041729.

Caridi, F., Marguccio, S., Belvedere, A., Belmusto, G., Marcianò, G., Sabatino, G., and Mottese, A. (2016c). "Natural radioactivity and elemental composition of beach sands in the Calabria region, south of Italy". *Environmental Earth Sciences* **75**(7), 629. DOI: 10.1007/s12665-016-5393-z.

Caridi, F., Marguccio, S., D'Agostino, M., Belvedere, A., and Belmusto, G. (2016d). "Natural radioactivity and metal contamination of river sediments in the Calabria region, south of Italy". *The European Physical Journal Plus* **131**(5), 155. DOI: 10.1140/epjp/i2016-16155-x.

Caridi, F., Marguccio, S., Durante, G., Trozzo, R., Fullone, F., Belvedere, A., D'Agostino, M., and Belmusto, G. (2017b). "Natural radioactivity measurements and dosimetric evaluations in soil samples with a high content of NORM". *The European Physical Journal Plus* **132**(1), 56. DOI: 10.1140/epjp/i2017-11343-x.

Caridi, F., Messina, M., and D'Agostino, M. (2017). "An investigation about natural radioactivity, hydrochemistry, and metal pollution in groundwater from Calabrian selected areas, southern Italy". *Environmental Earth Sciences* **76**(19), 668. DOI: 10.1007/s12665-017-7031-9.

Italian Legislation (2016). "Decreto Legislativo 15 Febbraio 2016, n. 28". *Gazzetta Ufficiale della Repubblica Italiana*. (GU Serie Generale n. 55 del 07-03-2016). URL: https://www.gazzettaufficiale.it/eli/id/2016/03/07/16G00036/sg.

Manuale della Rete RESORAD (2016). Version 2. Istituto Superiore per la Protezione e la Ricerca Ambientale. URL: https://www.isprambiente.gov.it/files/sicurezza-nucleare-radioattivita/ManualeReteRESORAD_rev2.pdf.

Mottese, A. F., Fede, M. R., Caridi, F., Sabatino, G., Marcianò, G., Calabrese, G., Albergamo, A., and Dugo, G. (2020). "Chemometrics and innovative multidimensional data analysis (MDA) based on multi-element screening to protect the Italian porcino (Boletus sect. Boletus) from fraud". *Food Control* **110**, 107004. DOI: 10.1016/j.foodcont.2019.107004.

Picciotto, A., Krása, J., Láska, L., Rohlena, K., Torrisi, L., Gammino, S., Mezzasalma, A. M., and Caridi, F. (2006). "Plasma temperature and ion current analysis of gold ablation at different laser power rates". *Nuclear Instruments and Methods in Physics Research. Section B: Beam Interactions with Materials and Atoms* **247**(2), 261–267. DOI: 10.1016/j.nimb.2006.01.066.

Sabatino, G., Bella, M. D., Caridi, F., Italiano, F., Romano, D., Magazù, S., Gnisci, A., Faggio, G., Messina, G., Santangelo, S., Leonetti, F., and Tripodo, A. (2019). "Radiological assessment, mineralogy and geochemistry of the heavy-mineral placers from the Calabrian coast (South Italy)". *Journal of Instrumentation* **14**(05), P05015. DOI: 10.1088/1748-0221/14/05/P05015.

The Commission of the European Communities (2001). "Commission recommendation of 20 December 2001 on the protection of the public against exposure to radon in drinking water supplies (notified under document number C(2001) 4580)". (2001/928/Euratom). *Official Journal of the European Communities*, L 344/85 –L 344/88. URL: https://faolex.fao.org/docs/pdf/eur37638.pdf.

Torrisi, L., Caridi, F., Picciotto, A., Margarone, D., and Borrielli, A. (2006). "Particle emission from tantalum plasma produced by 532nm laser pulse ablation". *Journal of Applied Physics* **100**(9), 093306. DOI: 10.1063/1.2358400.

Trautmannsheimer, M., Schindlmeier, W., and Hübel, K. (2002). "Radon exposure levels of the staff in the drinking water supply facilities in Bavaria, Germany". *International Congress Series* **1225**, 81–86. DOI: 10.1016/S0531-5131(01)00517-9.

United Nations Scientific Committee on the Effects of Atomic Radiation (2000). *Sources and Effects of Ionizing Radiation*. Annex B: Exposures from Natural Radiation Sources. Tech. rep. New York, NY, USA: United Nations. URL: https://www.unscear.org/unscear/en/publications/2000_1.html.

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