

RADON LEVELS AND GAMMA RADIONUCLIDES IN GROUNDWATER SOIL, AND AIR IN THE ARCHEOLOGICAL SITE OF CUMAE (PHLEGRAEAN FIELDS, SOUTHERN ITALY)



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1. Introduction

²²²Rn originates from the decay of radium ²²⁶Ra a member of the uranium (²³⁸U) decay series. Although radium occurs in virtually all type of rocks and soil, its concentration varies with the specific site [1]. Radon concentrations were measured in soil, air and groundwater in the Cumae archaeological site, which is located in the coastal north-western sector of the active volcanic district of Phlegraean Fields (Southern Italy)[2].

Fig.1. Three radionuclide chains: uranium, thorium, and actinium decay series.

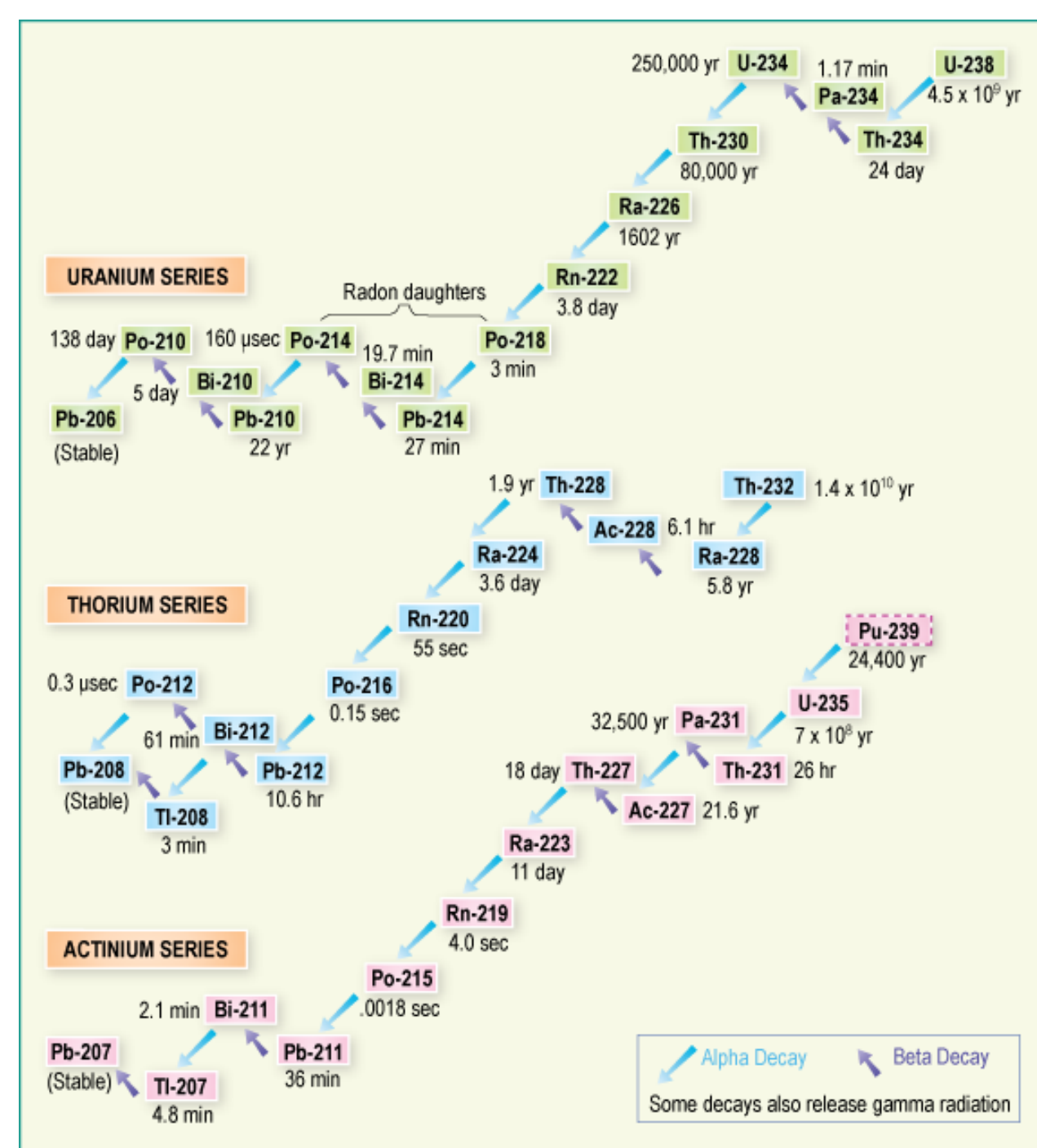
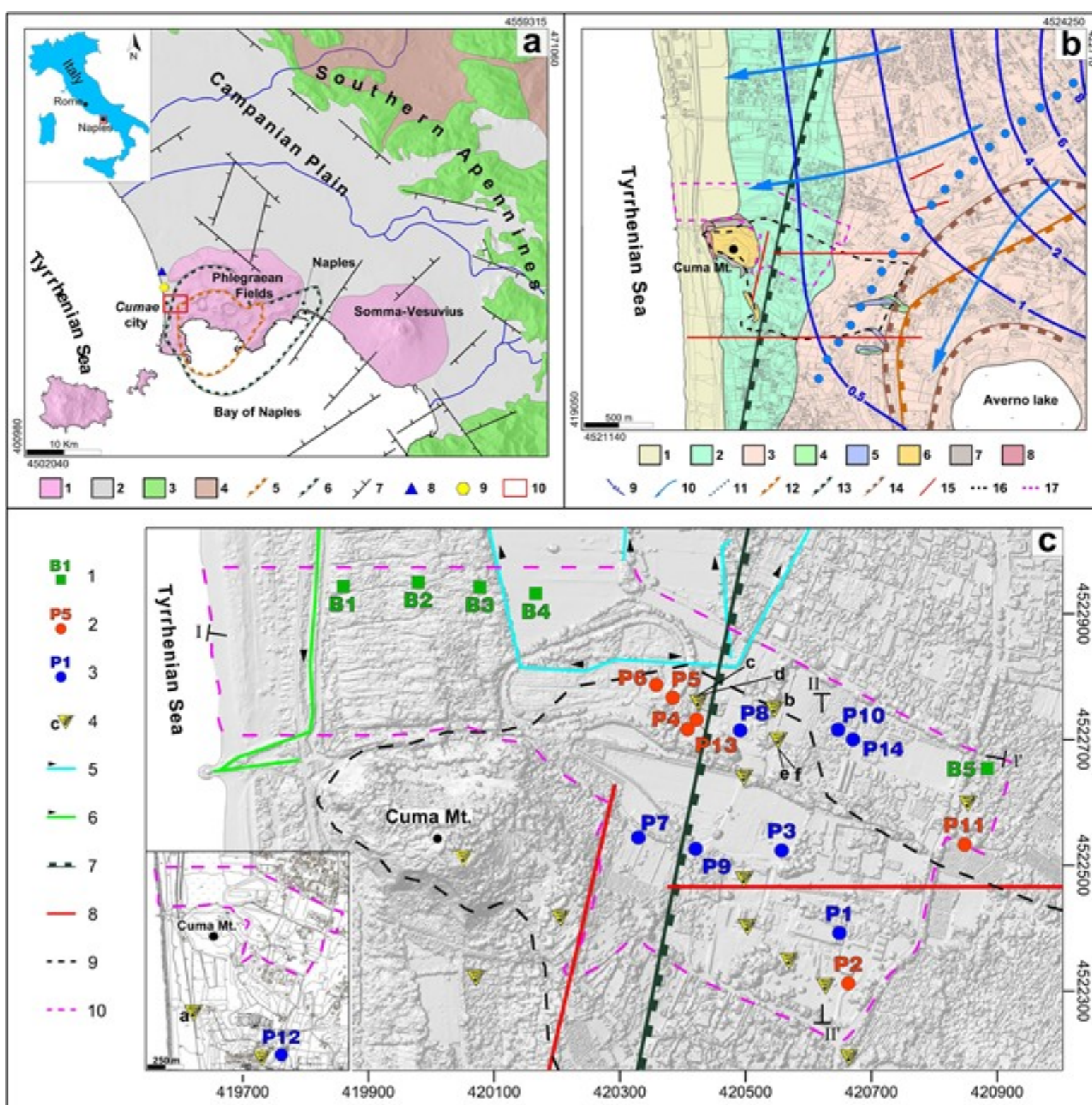


Fig. 2

a) Geological map of the Campanian Plain. 1) Quaternary epiclastic deposits; 2) Quaternary volcanic deposits; 3) Apennine platform carbonates; 4) Miocene deposits; 5) NYT caldera boundary; 6) CI caldera boundary; 7) Normal fault; 8) Licola pluviometric station; 9) Licola draining station; 10) Study area.

b) Hydrogeological map of the western sector of Phlegraean Fields volcanic system. 1) Eolic deposits; 2) Pyroclastic-fluvio-palustrine deposits; 3) Pyroclastic deposits; 4) Baia's tuffs; 5) Gauro's eruption deposits; 6) Neapolitan Yellow Tuff; 7) Museum Breccia; 8) Mt Cuma's lavas; 9) Groundwater contour line (m a.s.l.); 10) Groundwater flow direction; 11) Groundwater divide; 12) NYT caldera boundary; 13) CI caldera boundary; 14) Buried caldera boundary; 15) Normal fault; 16) Cumae archaeological park; 17) Study area.

c) Groundwater, soil, and air sampling network. 1) Borehole; 2) Sampling point of shallow groundwater, soil, and air; 3) Sampling point of deep groundwater, soil, and air; 4) Archaeological site; 5) Groundwater draining channel; 6) Wastewater channel; 7) CI caldera boundary; 8) Normal fault; 9) Cumae archaeological park; 10) Study area.



2. ²²²Rn concentration in groundwater, air (outdoor) and soil

The activity of radon shows a marked increase in the groundwater with the depth of the wells, confirming its origin from the deep layers of the volcanic aquifer.

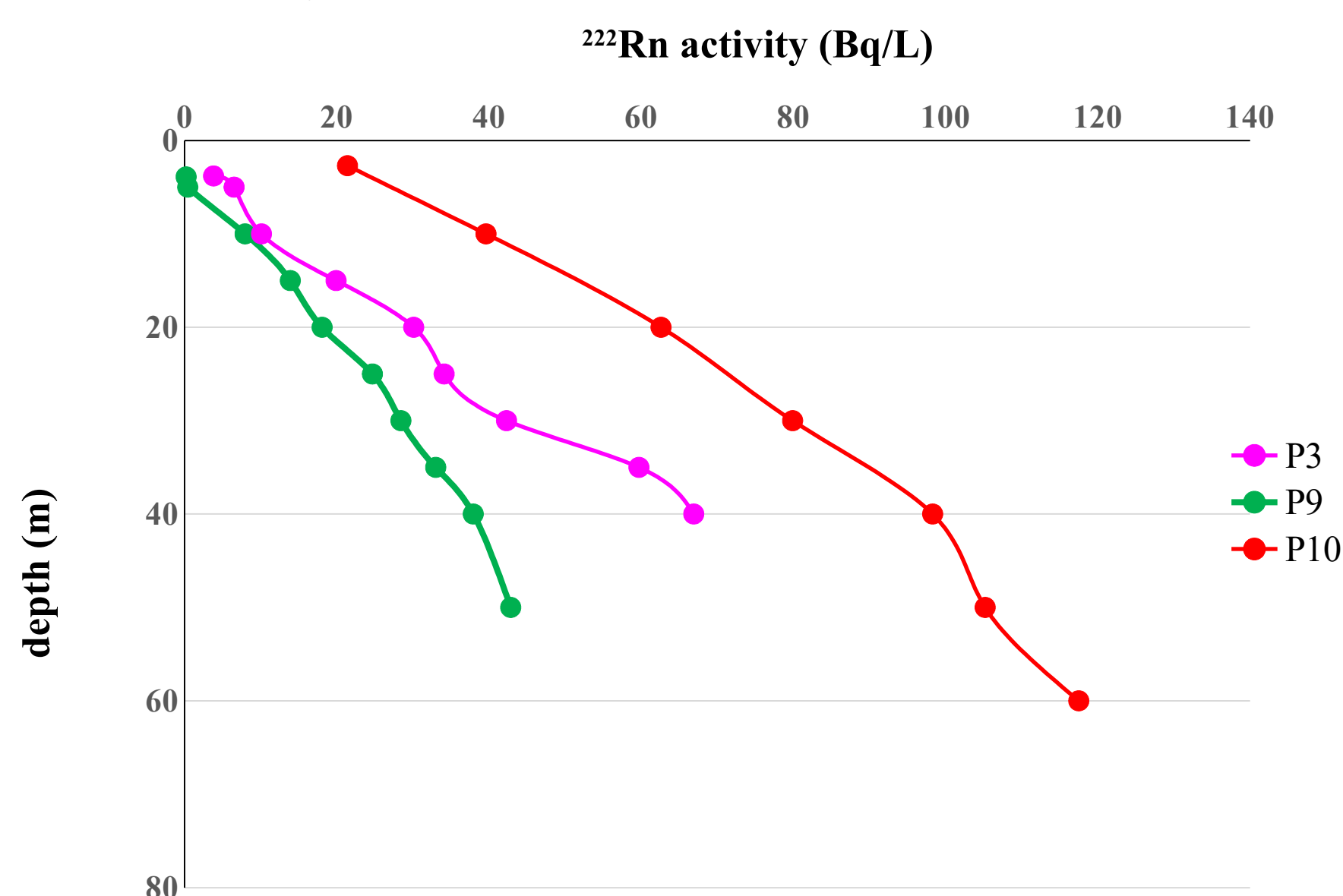


Fig.3. ²²²Rn activity (Bq/L) in groundwaters, in function of depth (meter) in P3, P9, P10 sites.

Table 1. ²²²Rn activity in air (outdoor) and soil in P1-P14 sites.

Sample	²²² Rn activity													
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
Air ^a	20	40	40	20	20	20	20	40	20	40	20	20	20	20
Soil ^b	15.6	12.7	21.9	1.3	15.1	12.9	6.4	24.7	13.5	24.8	22.4	8.7	1.3	5.3

(a) Bq/m³ ±15; (b) kBq/m³ ±0.5

3. Activity of gamma emitting radionuclides in groundwater

Table 2. Activity of some gamma emitting radionuclides in groundwater (P1-P14 sites)

Sample	Activity of gamma emitting radionuclides													
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
⁴⁰ K ^a	1.68	2.49	0.34	0.18	1.98	2.22	0.091	1.29	2.37	0.12	0.075	0.070	0.29	0.12
²²⁶ Ra ^b	0.54	0.45	0.46	0.25	0.25	0.35	0.058	0.13	0.058	0.25	0.051	0.055	0.324	0.354
²³⁴ Th ^c	0.19	0.19	0.20	0.14	0.19	0.12	0.067	0.12	0.062	0.10	0.056	0.054	0.205	0.091

(a) (Bq/L) ±0.5; (b) (Bq/L) ±0.5; (c) (Bq/L) ±0.5.

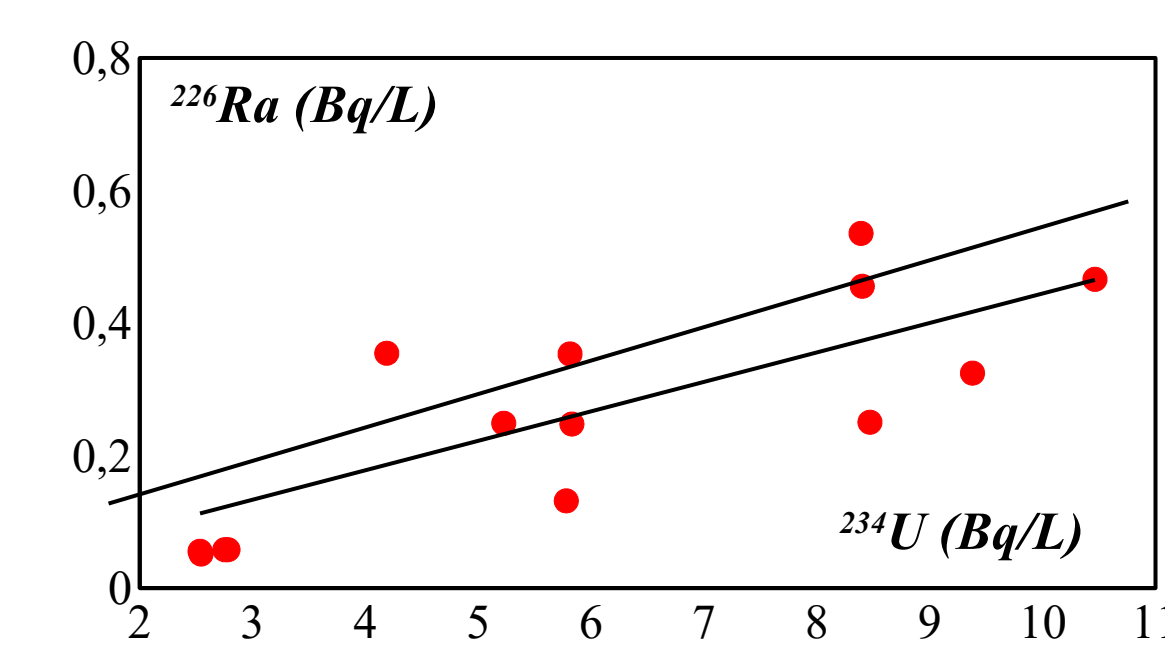


Fig.4. ²²⁶Ra activity (Bq/L) as function of ²³⁴U activity (Bq/L) in groundwaters ($y=0.0445x$, $r^2=0.901$) (uranium series).

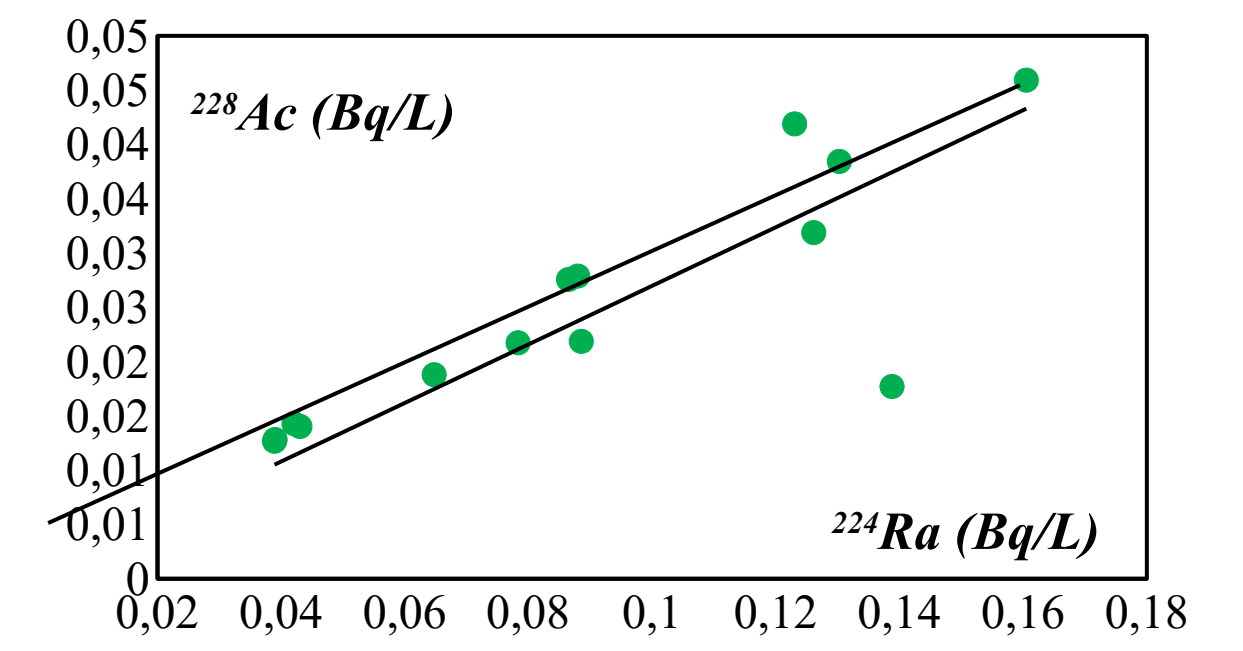


Fig.5. ²²⁸Ac activity (Bq/L) as function of ²²⁴Ra activity (Bq/L) in groundwaters ($y=0.270x$, $r^2=0.946$) (thorium series).

4. Activity of gamma emitting radionuclides in soil

Table 3. Activity of some gamma emitting radionuclides in soil (P1-P14 sites)

Sample	Some activity of gamma emitting radionuclides													
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
Gamma dose ratio ^a	0.29	0.27	0.21	0.23	0.21	0.20	0.21	0.23	0.25	0.22	0.25	0.28	0.22	0.20
⁴⁰ K ^b	1.68	1.65	0.14	0.54	1.78	1.50	1.64	1.05	1.53	1.43	0.44	0.45	0.50	0.25
²²⁶ Ra ^c	65.1	100.2	36.5	51.7	69.5	54.9	38.4	67.5	60.6	84.7	76.1	124.1	121.6	84.3
²³⁴ Th ^d	116.1	124.1	83.6	115.5	99.3	90.1	108.3	121.6	137.7	104.2	138.2	151.9	124.3	125.7

(a) (mS/h) ±0.2; (b) (kBq/kg) ±0.5; (c) (Bq/kg) ±0.5; (d) (Bq/kg) ±0.5

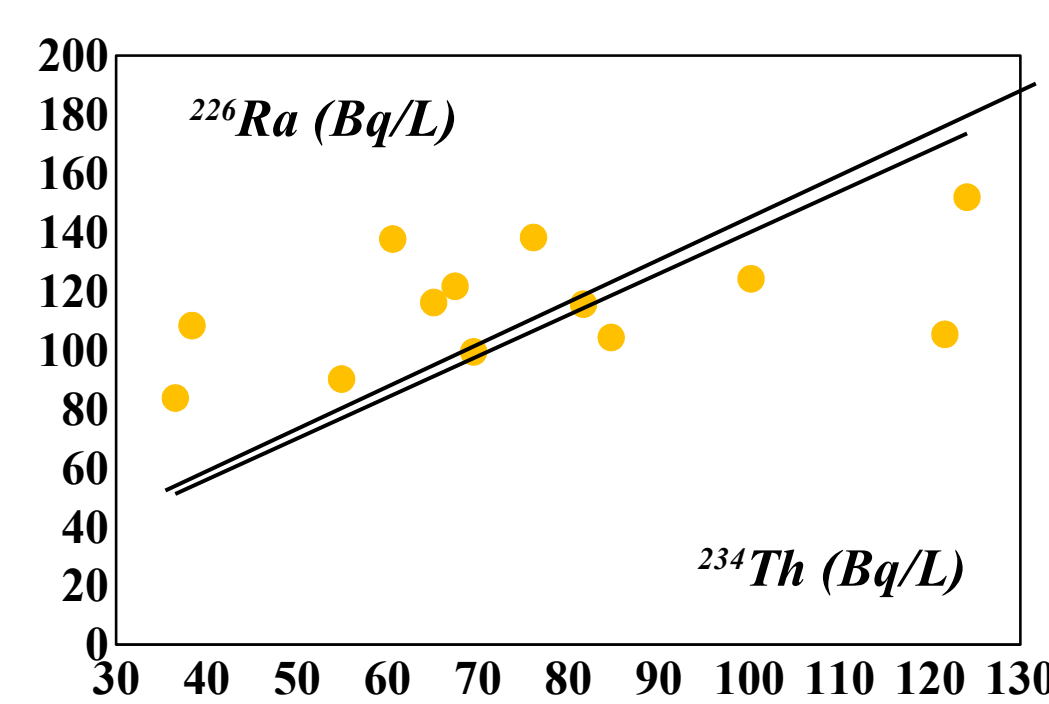


Fig.6. ²²⁶Ra activity (Bq/L) as function of ²³⁴Th activity (Bq/L) in groundwater ($y=1.398x$, $r^2=0.918$) (see uranium series).

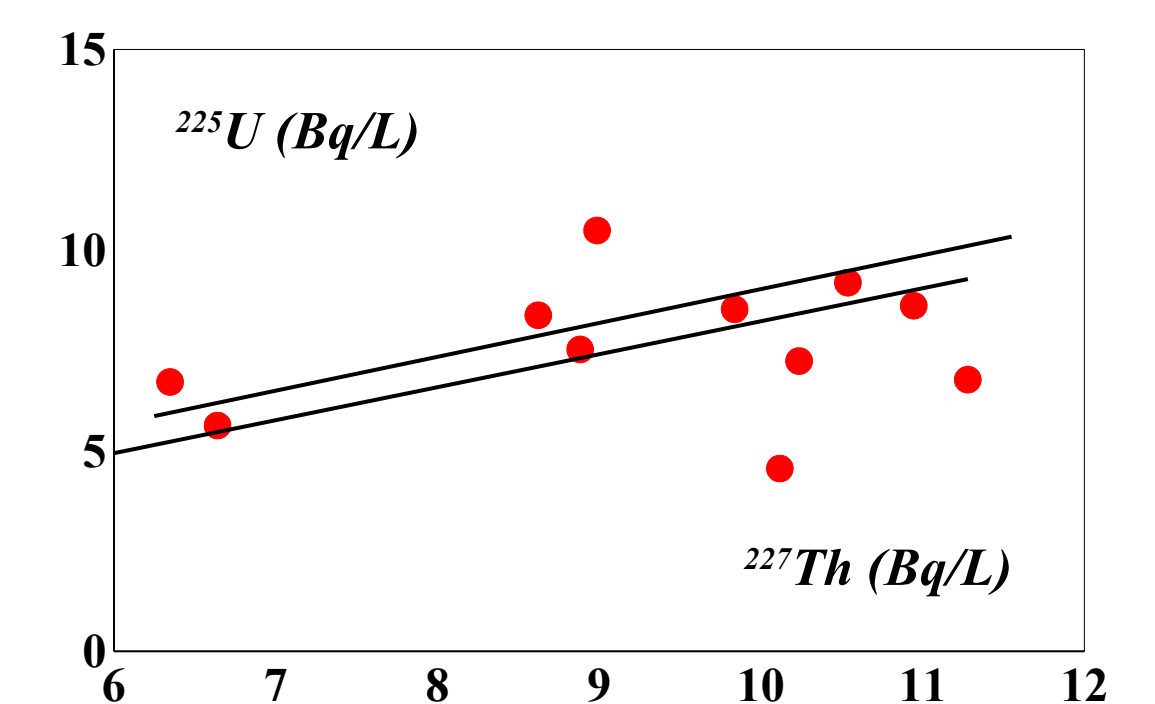


Fig.7. ²²⁵U activity (Bq/L) as function of ²²⁷Th activity (Bq/L) in groundwater ($y=0.822x$, $r^2=0.943$) (see actinium series).

5. Experimental

Soil gas radon was measured with a tube (diameter 12 mm) with a separate tip was hammered into the ground then slightly drawn back a few cm leaving the tip in the ground which opens the tube at the end. Firstly 200 mL gas were pumped out and discarded then a 100 ml gas sample was taken and the activity of the sample was measured either by an "Alpha Guard" (Genitron Instruments). Instrument was calibrated with 100 mL samples of known ²²²Rn activity. Soil gas measurements were usually performed from depths between 40 and 80 cm, furthermore it was collect a soil sample that was analyzed by gamma spectroscopy (HP-Ge detector) in the laboratory. The results are derived from one sample per site and are referred to dry mass (dried at 105 °C for 24 h). In addition the ambient dose equivalent rates were measured at the sample sites on 1 m high above ground. Radionuclide gamma activities in groundwater was performed on a samples of 25 L after drying at 80 °C at 1L. Samples were placed in a Marinelli beaker to proceed to the gamma spectrometry. Samples were measured for 60.000 seconds.

6. References

- [1] Gosselin. D.C., Smith. M.R., Lepel. E.A., Laul. J.C. 1992. Rare earth elements in chloride-rich groundwater. Palo Duro basin. Texas. USA. Geochim. Cosmochim. Acta 56. 1495–1505.
- [2] Stellato L., Coda S., Arienzo M., De Vita P., Di Rienzo B., D'Onofrio A., Ferrara L., Marzaioli F., Trifuoggi M Allocca V., 2020 Natural and Anthropogenic Groundwater Contamination in a Coastal Volcanic-Sedimentary Aquifer: The Case of the Archaeological Site of Cumae (Phlegraean Fields, Southern Italy). Water 2020. 12(12). 3463.