

Radon in active volcanic areas of Southern Italy (*)

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Summary. — The radiogenic gas radon is considered a valid precursor of events like eruptions and earthquakes. We are monitoring the variations in time of this gas in soils and in waters of many active volcanic areas of Southern Italy. The greatest differences in Rn content of the investigated volcanic areas are: Ischia and Campi Flegrei have more Rn than Vesuvio and Vulcano, both in soils and in waters. The thermalized waters of Ischia are enriched in Rn 15 times with respect to soils, while in the other areas soils and underground waters have comparable Rn contents.

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1. – Introduction

We have been investigating the variations of some geochemical parameters in many volcanic areas of Southern Italy (Campi Flegrei, Ischia, Vesuvio, Vulcano) for many years because of their high volcanic risk. So far we have accumulated a lot of information on the behavior of the radiogenic gas radon in the soil atmosphere and in groundwaters.

Radon is present in elevated concentrations in those areas and the high values are, in general, strictly correlated with the high contents of radioactive elements, members of U and Th chains, found in the volcanic products (Capaldi *et al.*, 1982; 1983).

The upward migration of radon is controlled by many factors, namely rock permeabilities, the presence of active fractures, fluxes of other gases, water saturation and the chemico-physical parameters of groundwaters.

2. – Instruments

Radon measurements have been carried out by the following methods:

- Track-Etch[®] (alpha particle sensitive cellulose nitrate film Kodak LR 115-type II);

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- ZnS(Ag) scintillation cells with the counting device RD200 from EDA (Canada);
- Gamma spectrometry with a Ge hyperpure crystal from EG&G Ortec.

The Rn content in groundwaters has been measured by the ZnS(Ag) cells and the EDA RD200 after Rn extraction using the methodology described by H.A. Das *et al.* (1989).

3. - Campi Flegrei Caldera

Campi Flegrei, to the north-west of Naples, is an area of active, mostly explosive, volcanism which formed about 35 000 years ago with the eruption of the trachytic Campanian Ignimbrite. This eruption was followed by caldera collapse. This caldera is affected by repeated slow up and down movements of the ground, which are known as "bradyseism". The most recent episode of uplift occurred in the period 1982-1984.

In the Campi Flegrei Caldera the first periodic measurements of Rn started with the last bradyseismic crisis in thermal waters, using the Track-Etch[®] method and gamma spectrometry (Capaldi *et al.*, 1992). Periodic measurements are still performed in five surveillance sites.

The main evidence of this investigation is that the Rn variations show high clear seasonal trends, which are superimposed on fluctuations that can be correlated with the bradyseismic activity (seismic events, uplift velocity; Avino *et al.*, 1998) and with the variations of geochemical parameters of waters and fumaroles, indicating a more

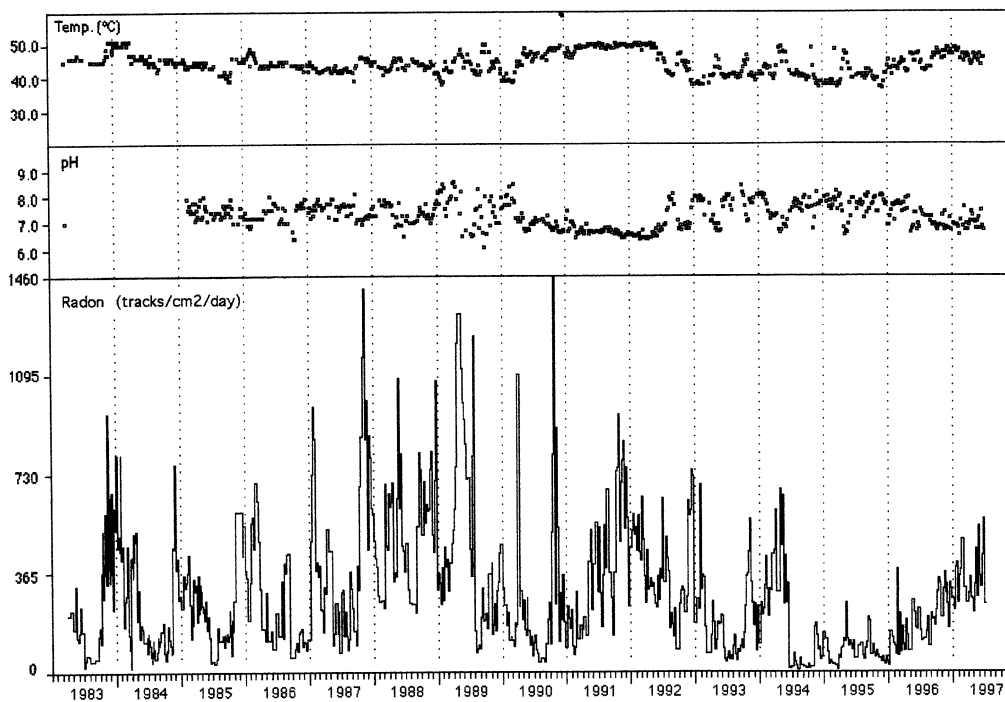


Fig. 1. - The Rn variation in time is shown for a water well in the Campi Flegrei Caldera, Pozzo Damiani. Also temperature and pH are reported. Measurements are carried out weekly.

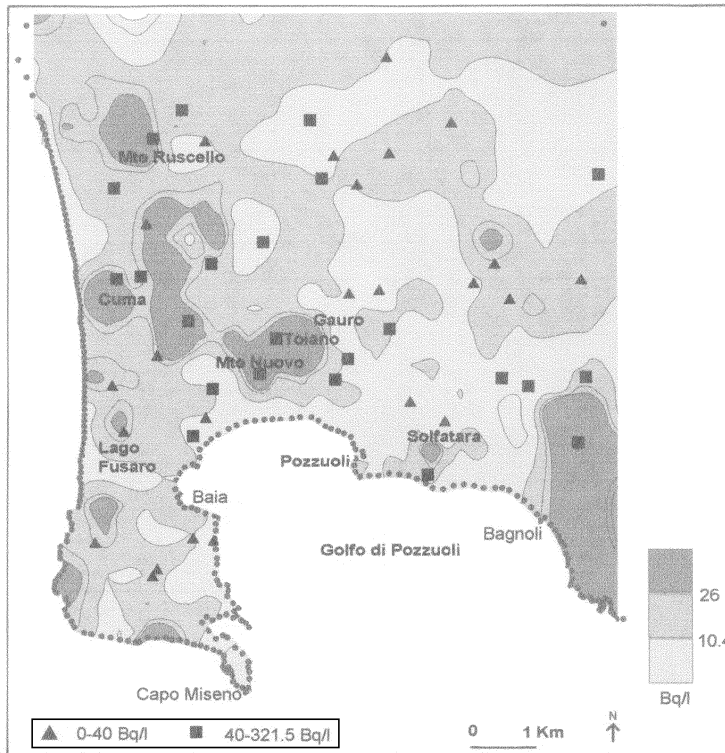


Fig. 2. – Map of Rn (values in Bq/l) in soil gases (grey levels) and in groundwaters (symbols) in Campi Flegrei.

general correlation with the thermodynamical state of this volcanic centre (Tedesco *et al.*, 1996). Figure 1 shows the Rn variations in groundwaters as measured in one of the monitored wells.

Radon content in soil gases was measured starting in 1986 using the Track-Etch® method (Capaldi *et al.*, 1988). Moreover, we carried out mappings of Rn emanation in all the caldera using the ZnS(Ag) scintillation cells to measure the alfa decay of Rn. The mappings have been performed many times in the last few years in about 350 sites uniformly distributed. Figure 2 shows the Rn content of soils measured in July 1996. This distribution indicates that the highest values of Rn in soils are localized in the central part of the caldera from Mt. Ruscello, Mt. Nuovo, Toiano and Gauro craters. Other high Rn values have been measured to the south of the Solfatara Crater at Pozzuoli and in the westernmost part of the caldera (Fusaro Lake, Cuma).

The high Rn outpouring in this caldera can be attributed to many concomitant causes: elevated temperatures of the soils; the presence of sustained fluxes of fluids from the depth, especially in the area of Solfatara Crater and in the Mofete-Fusaro area (as geothermal exploration pointed out); the presence of caldera border and variations in the underground permeability.

Radon has also been measured in 47 water wells and springs, in order to reconstruct its underground circulation. Radon dissolved in groundwaters was

extracted soon after the sampling and measured by ZnS(Ag) scintillation cells. Figure 2 also exhibits the Rn values of underground waters. The Rn content ranges from 0.92 Bq/l up to 321.5 Bq/l.

The distribution of Rn in groundwaters reveals that the central part of the Campi Flegrei caldera is characterized also by the highest Rn values in groundwaters, so that, with the exception of the Solfatara area, there is a positive correlation between the Rn values in groundwaters and those in the soil atmosphere (Avino *et al.*, 1996).

4. – Ischia Island

The island of Ischia is located to the NW of Campi Flegrei and of the Gulf of Naples. It is an active volcanic area of the Quaternary Potassic Roman Province in central-southern Italy. The last eruption occurred in 1301 AD.

The radon content of soil gases was measured using the Track-Etch[®] method, in 180 sites. Radon in waters of 50 wells and springs was extracted soon after the sampling and measured by ZnS(Ag) scintillation cells. Our results indicate that the Rn content in soils and groundwaters of Ischia (fig. 3) is higher than that measured in the other areas considered.

The highest values both in soils and in groundwaters have been found in the western part of this island. This evidence is well correlated with the presence of hydrothermal activity strikingly correlated with the main tectonic elements of Ischia. The highest values of Rn in groundwaters seem to be aligned in the NW direction.

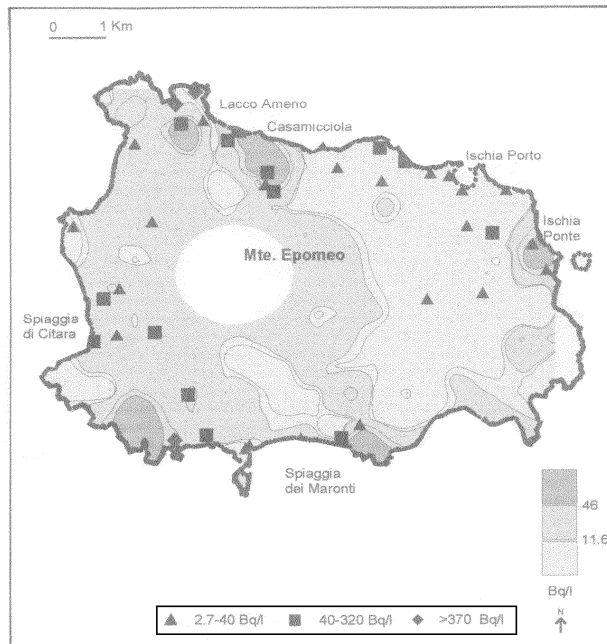


Fig. 3. – Island of Ischia: map of Rn (values in Bq/l) in soil gases and in groundwaters (symbols).

5. – Somma-Vesuvius

Somma-Vesuvius is a composite central volcano consisting of an older collapsed stratovolcano presently forming the Monte Somma caldera rim, and of a more recent cone, Vesuvius, built up inside the caldera. The last eruption occurred in 1944.

In the Somma-Vesuvius area we are performing mappings of Rn contents in soils using scintillation cells (about 350 sites) and in waters (about 70 water wells). The radon content in soil seems to be gradually increasing in time, from the first survey in 1987 until the survey of 1995. Moreover, even if this volcano exhibited the most recent volcanic activity, the Rn contents are the lowest as compared to the other investigated areas in Campania.

The highest Rn values both in soils and in groundwaters have been measured in the south-eastern part of the investigated area. Along the sea coast (fig. 4) there are medium-high values of Rn in groundwaters but low values in soils.

In these two sectors the groundwaters are highly mineralized, and two thermal indicators, as boron and mercury, are enriched in these waters.

6. – Vulcano Island

Vulcano is the southernmost island of the volcanic Aeolian archipelago in the Tyrrhenian Sea, to the north of Sicily. The Aeolian Islands have a complex structure interpreted as a typical island arc in a convergent tectonic setting.

In the Vulcano island the control of Rn content in soils and fumaroles started in 1991 in about 100 surveillance sites using Zn(Ag) scintillation cells.

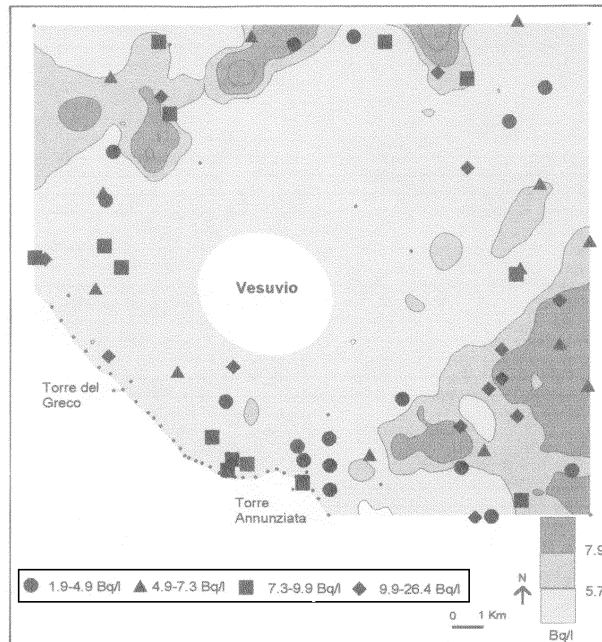


Fig. 4. – Somma-Vesuvius Volcanic area: map of Rn (Bq/l) in soil gases (legenda) and in groundwaters (symbols).

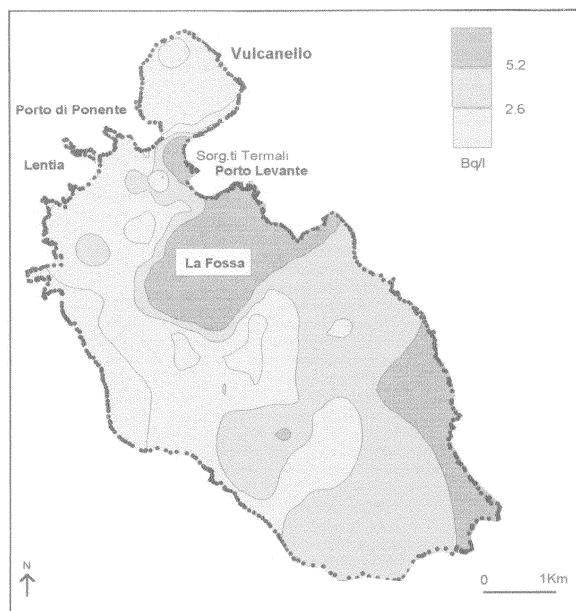


Fig. 5. – Island of Vulcano: map of Rn (Bq/l) in soil gases (legenda).

High Rn values have been measured mainly in two well-outlined areas: the Fumarole field at Porto di Levante and the area around the Fossa Crater (fig. 5). Both the areas are characterized by intense outpouring of acid hot gases.

From 1995 also the radon content of 15 thermal wells started to be measured. The wells are localized between Porto di Levante and Fossa Crater. The measurements indicate four areas with increasing Rn content in groundwaters from Porto di Levante

TABLE I. – Radon in soil atmosphere (Bq/l).

Area	Ischia	Campi Flegrei	Vesuvio	Vulcano
Range	0.32–173.4	1.76–66.1	0–32.4	0.104–42.6
Average	16.7	15.7	3.8	3.4
Standard deviation	22.9	10.7	3.7	5.6
Samples	180	350	350	100

TABLE II. – Radon in groundwaters (Bq/l). The years of last sampling for each area are reported.

Area	Ischia 1996	Campi Flegrei 1996	Vesuvio 1996	Vulcano 1997
Range	2.7–6028.2	0.92–321.6	1.97–26.4	0.83–21
Average	237	13.2	8.2	7.9
Standard deviation	955	46.3	4.4	5.2
Samples	41	47	60	18

to Fossa Crater. This distribution has been maintained during these last years, even if with decreasing values.

7. – Conclusions

The statistical values relative to the radon content of soils and groundwaters in the active volcanic areas of Southern Italy are reported in tables I and II. Data are in Bq/l.

The soils of the Phlegraean areas (Ischia and Campi Flegrei) have similar Rn contents, which are greater than those in the Vesuvio and Vulcano areas. The same difference is exhibited in the groundwaters, among which those of Ischia are relatively very high. The radon content of groundwaters appears to be comparable with the Rn content of overlying soils, except at Ischia, where waters are enriched about 15 times with respect to the soils. This evidence can be imputed to the choice of the sampling points of groundwaters at Ischia, because most of them are thermal springs and, furthermore, the highest values of Rn in soils have been measured in the areas where the thermal springs are located.

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