LICHENS AS BIOMONITORS OF GEOTHERMAL RADIONUCLIDE POLLUTION

STEFANO LOPPI,* ALBERTO MALFATTI, † MAURO SANI† and NEIL E. WHITEHEAD‡

* Department of Environmental Biology, University of Siena, Via P. A. Mattioli 4, I-53100 Siena, Italy; † Operative Unit of Health Physics, U.S.L. 30, Via E. Bastianini 18, I-53100 Siena, Italy; and ‡ Institute of Geological and Nuclear Sciences, P.O. Box 31-312, Lower Hutt, New Zealand

(Received March 1996; accepted for publication January 1997)

Abstract—The epiphytic lichen Parmelia caperata was used systematically as a bioaccumulator of radionuclides in the Travale-Radicondoli geothermal field (central Italy). The results showed that radioactivity in this area is not different from that of other non-geothermal areas and that the exploitation of geothermal resources should not cause an enrichment in radioactivity. However, the survey also revealed a negative association between total β radioactivity in lichens and the distance from geothermal power plants, so that the latter may represent a source of local radionuclide pollution. © 1997 CNR. Published by Elsevier Science Ltd.

Key words: lichens, radionuclides, radon, environment, Travale, Italy.

INTRODUCTION

Italy has a significant input of electricity of geothermal origin, accounting for 1.5% of the total national energy production. In Tuscany, the region containing the only three Italian vapour-dominated fields (Larderello, Mt. Amiata and Travale-Radicondoli), the energy input from this source has increased from 4.3% in 1976 to the current 22%, with a yearly generation of 3.5 billion kWh (Allegrini et al., 1995). It is well known that the exploitation of geothermal energy may affect the surrounding environment (Axtmann, 1975) and, excluding geological and geophysical effects, that the environmental impact is related to the release of elements and compounds of toxicological relevance such as H₂S, As, B, Hg and radionuclides (Armannsson and Kristmannsdóttir, 1992).

Biological monitoring has proved very useful in the assessment of air contamination by persistent pollutants such as trace elements and radionuclides (Manning and Feder, 1980). Lichens are particularly useful in these studies since they are not dependent on root uptake and receive nutrients directly from the atmosphere; moreover, since they lack a waxy cuticle and stomata, elements are easily incorporated in their tissues (Hale, 1983). As a consequence, lichens are able to accumulate persistent pollutants to very high levels.
S. Loppi et al.

(Nieboer and Richardson, 1981), and for this reason they have been widely used for biomonitoring heavy metals, chlorinated hydrocarbons, radionuclides, etc. (Herzig, 1993; Tuominen and Jaakkola, 1973). Although studies on the radionuclide content of lichens were initiated some years ago (Salo and Miettinen, 1964), much of our knowledge is a result of the Chernobyl nuclear accident (Feige et al., 1990).

Lichens have already been used in biomonitoring geothermal-derived air pollution, mainly for mercury (Bargagli and Barghigiani, 1991), boron (Koranda, 1980) and other metals (Connor, 1979; Loppi and Bargagli, 1996), but also for the bioindication of local air quality (Loppi, 1996). In general, levels of trace elements were found to decrease and air quality to increase quickly with increasing distance from the geothermal installations.

Geothermal activities are connected with the release of radon, which is a radioactive inert gas with several isotopes, notably $^{222}$Rn from the uranium decay series (Bowen, 1989). Radon undergoes radioactive decay through a series of short-lived decay-products, except $^{210}$Pb, which has a half-life of 21 years, to $^{206}$Pb (Wilkening, 1990). In the atmosphere, these decay-products become attached to aerosol particles soon after their formation and their concentrations fluctuate with weather conditions. It is well established that lichens collect and accumulate aerosol particles (Olmez et al., 1985), so they are useful biomonitors where the continual deposition of radon decay-products results in a build-up of $^{210}$Pb in atmospheric particulates and, in turn, in lichens (Persson, 1970). To date, lichens have only been used once as bioaccumulators of radionuclides in geothermal areas (Matthews, 1981). In the latter study no difference was found between the radionuclide content of some lichen species naturally occurring in the geothermal areas of Wairakei and Karapiti (New Zealand) and in other non-geothermal areas.

In the present survey a single lichen species was used systematically as a bioaccumulator of radionuclides in a geothermal area to evaluate the pollution deriving from geothermal exploitation.

**STUDY AREA**

The survey was performed in the Travale-Radicondoli geothermal field (Tuscany, central Italy), located 22 km southwest of Siena and 15 km east of Larderello (Fig. 1). This area (about 6 km$^2$) was chosen for the study because the only local sources of air pollution are the geothermal installations, consisting of three 20 MW power plants (Pianacce, Rancia-1 and Rancia-2). The area is characterized by soft, rolling hills, with elevations ranging from 300 to 560 m. The climate is humid sub-Mediterranean, with a mean annual rainfall of 1100 mm and a mean annual temperature of 13°C (Barazzuoli et al., 1993).

The geological setting consists of three sedimentary complexes (Batini et al., 1985): the Tuscan Series (carbonate, siliceous and terrigenous formations), a flysch facies formation (shale, limestone, marl, marly limestone and carbonate sandstone) and a neoautochthonous formation (clay, lacustrine sand, sand, conglomerate and gypsum).

**MATERIALS AND METHODS**

From October 1993 to March 1994, at 17 randomly selected stations (Fig. 1), 5–10 whole thalli of the foliose lichen *Parmelia caperata* (L.) Ach. were collected from trunks of isolated oak trees at a height of 1.5–2 m above ground. For comparative purposes, collections were also made in two control areas (three stations per area): Belforte, an area located close to the
Lichens as Biomonitor of Geothermal Radionuclides

Fig. 1. Travale-Radicondoli geothermal area (Larderello) with location of sampling sites and values of total $\beta$ radioactivity (Bq·g$^{-1}$, dry weight) in Parmelia caperata samples (full squares = power plants).

Travale-Radicondoli field but not subject to geothermal exploitation, and Chianti, a remote area of central Tuscany. Both control areas are similar to the Travale-Radicondoli system as regards habitat and climatic regime.

In the laboratory, the thalli were sorted to remove as much extraneous material as possible, air-dried, oven-dried at 110°C for 12 h, and finally ashed at 400°C for 12 h (Strandberg, 1994). The area investigated was fairly small and sufficiently homogeneous to infer that the eventual $^{137}$Cs from Chernobyl fallout was equally distributed (measurements in lichens gave $^{137}$Cs concentrations in the range 0.10–0.15 Bq·g$^{-1}$ and the $^{40}$K of the samples was always in the range 0.50–0.85 Bq·g$^{-1}$). We therefore deduced that the measurements of total $\beta$ radioactivity gave an estimate of the $^{210}$Pb ($\beta$-emitter) contribution. For each sample (consisting of 0.2 g), total $\beta$ radioactivity was determined using a low-background detector (Canberra 2404) with a counting efficiency of 42.3 ± 0.5%. The results were expressed in Bq·g$^{-1}$ dry weight. The analytical quality was checked by analyzing blank samples and uranium (12.5 ppm) in CaCO$_3$. Accuracy of measurements was checked by the coefficient of variation of four replicates and was found to be lower than 6%.

RESULTS AND DISCUSSION

The total $\beta$ radioactivity values in $P$. caperata thalli found in the geothermal area are shown in Fig. 1. The radionuclide content of the lichen samples, as also demonstrated by the low coefficient of variation (17%), is uniformly distributed throughout the area and does not indicate any particular association with the power plants.
It was observed that total $\beta$ radioactivity was related to the distance from the power plants by a quadratic function (Fig. 2). This relationship reveals a minimum about 500 m from the source, after which the values of total $\beta$ radioactivity rise again, suggesting that geothermal plants are a source of radionuclide contamination up to a distance of 500 m. This result is in agreement with the higher concentrations of several trace elements (Al, As, B, Cd, Cu, Fe, Hg, Mn, Pb, and Zn) in lichens within 500 m of power plants, which decrease beyond this distance in the same area (Loppi, 1995). The unusually low values found at 500 m could however be ascribed to meteorological effects. Hot gases containing Rn from geothermal power plants are known from modelling to rise and reach earth again at distances that are normally more than 500 m (Whitehead, 1985). This could give a slight "protective" effect at 500 m.

The mean radionuclide content found at Travale-Radicondoli (0.53 ± 0.09 Bq·g$^{-1}$) is not significantly different (95% confidence interval, Kolmogorov–Smirnov two-sample test) from that observed at Belforte (0.52 ± 0.04) and in the Chianti area (0.53 ± 0.09 Bq·g$^{-1}$). This result agrees with the findings of Matthews (1981), who reported that the radioactivity in geothermal areas is similar to that in non-geothermal areas. This point is also supported by the results of the Comune di Pomarance and ENEL Larderello (1990), who found that the radon content of air and soil samples of the Larderello area is similar to that of non-geothermal areas. Furthermore, Brondi et al. (1986) found that levels of $^{222}\text{Rn}$ in geothermal fluids are in general in the same range as those of natural phenomena such as thermal springs. It is important to note, however, that all values measured in the present study are one order of magnitude lower than those reported by Kosiba and Sarosiek (1993) for mosses in remote areas of Poland.
Lichens as Biomonitor of Geothermal Radionuclides

From the present results it is possible to conclude that the radioactivity of the Travale-Radicondoli geothermal area is not different from that of non-geothermal areas, and that the exploitation of geothermal resources should not cause an enrichment in radioactivity. However, the survey also revealed a negative association between total $\beta$ radioactivity in lichens and their distance from geothermal power plants, so that the latter may represent a source of local radionuclide pollution.

REFERENCES


