# Measurements on Chernobyl Fallout in Forest Vegetation*

E. BALDINI

*Istituto di Coltivazioni Arboree, Università, 40126 Bologna, Italy*

M. G. BETTOLI and O. TUBERTINI

*Centro di Radiochimica Ambientale, Dipartimento di Chimica 'G. Ciamician', Università, 40126 Bologna, Italy*

Forests play a special role in the general problem of the ionizing radiation effects on the biosphere. Interest in the biogeophysical consequences of forest irradiation depends on their extreme susceptibility to radioactive contamination, owing to the high radiosensitivity of woody plants, and to the pronounced interceptive capacity of their canopies with respect to radioactive fallout.

Three months after the Chernobyl accident the direct contamination of components of forest cenoses, located in a typical mountain area of northern Italy (Auronzo, Dolomites: 850–1200 m above sea level) was investigated. The following radionuclides were identified: $^{134}Cs$, $^{137}Cs$, $^{103}Ru$, $^{106}Rh$–$^{106}Ru$, $^{141}Ce$, $^{144}Ce$, $^{140}Ba$–$^{140}La$, $^{95}Zr$–$^{95}Nb$, $^{125}Sb$, $^{110m}Ag$.

The aim of this study was to measure the rare-earth radionuclides $^{141}Ce$, $^{144}Ce$ and $^{140}Ba$–$^{140}La$ related to $^{137}Cs$, which, using the words in much the same sense as the International Commission on Radiological Protection [1], can be appropriately described as 'critical nuclide', being a main source of radiation to all members of the community.

## Materials and Methods

On July $10^{th}$. 1986 different above-ground organs of the following forest species were sampled: spruce (*Picea abies L.*) and scotch pine (*Pinus silvestris L.*), both evergreen; larch (*Larix decidua, Mill.*). Lichens (*Usmea florida L.*) were collected from spruce branches. All these organic materials were oven-dried at 105 °C to constant weight, pulverized, homogenized and analyzed by gamma-spectrometry, using a 140 cm$^3$ PGT coaxial intrinsic germanium detector: efficiency relative to 1.33 MeV $^{60}Co$ gamma-ray efficiency obtained with a 3″ × 3″ NaI(Tl) detector at a distance of 25 cm: 30.7%; energy resolution (full width at half maximum): 2.02 keV at 1.33 MeV; shielding: 10 cm lead, 0.1 cm lead, 0.1 cm cadmium, 0.1 cm copper, 0.8 cm methacrylic resin. The detector was coupled with a 8K Cicero-Silena analyzer; the peak analysis was performed using a Silena-quantitative isotopic analysis option, mod. 8500-Quan. Counts were made on 250 cm$^3$ Marinelli beakers for 500–1200 min.

The counting efficiency in the sample geometry was determined for different photon energies from measurements on samples containing known amounts of gamma-ray reference solution QCy 44, Amersham. This solution was mixed with 'before Chernobyl' forage samples to simulate the density and the atomic number of plant material.

Data (expressed in Bq/kg dry weight) are affected by statistical counting errors ranging from ±6% to 25% at a 95% confidence level. The uncertainty due to the sampling effects and to biological variations was not determined, but, according to the sampling criteria, it was estimated as reasonably low.

Experimental data are listed in Table I.

## Results and Conclusions

The rare-earth radionuclides $^{141}Ce$, $^{144}Ce$, $^{140}Ba$–$^{140}La$ as components of radioactive fallout are normally considered devoid of importance from the point of the radiological health, because they are supposed to enter food chains to only a very small extent. But, on account of a relatively long half-life and ability to be deposited in the skeleton bones, if absorbed in the body, their presence in the environment cannot be ignored.

The samples examined are organs of conifers which, according to Sparrow [2], are among the most 'critical members' of woodland ecosystems because they are extremely sensitive to radiocontamination.

Radionuclides primarily intercepted on above-ground organs of the plants can afterwards migrate to the internal tissues or are removed from plants by rain, wind, etc. The mechanism of foliar absorption has been regarded as largely outside the aim of this investigation.

In Table II the activity ratios, decay corrected to April 29, 1986 and normalized to $^{137}Cs$, are listed for the tree organs reported in Table I. The nuclide inventory of the Chernobyl-4 reactor, the percentage released after the accident along with the ratios in the core, normalized to $^{137}Cs$, are given approximately in Table III [3, 4]. In our experiments only the ratio

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TABLE I. Radioactivity (Bq/kg d.w.[a]) Detected on July 10, 1986 in Different Ecosystems of Auronzo Forest Area (Dolomites, Italy)[b]

| Ecosystems | Samples | Radionuclides | | | |
|---|---|---|---|---|---|
| | | $^{137}Cs$ | $^{141}Ce$ | $^{144}Ce$ | $^{140}Ba-^{140}La$ |
| Spruce[d] stand | needles old[f] | 1870 | 71 | 230 | <LDA[c] |
| | needles young | 340 | <LDA | <26 | <LDA |
| | twigs (1–3 years) | 3750 | 144 | 420 | 243 |
| | cones (old) | 610 | 17 | 49 | <LDA |
| | lichens | 12100 | 354 | 1040 | 400 |
| Scotch pine[d] stand | needles old[f] | 2150 | 97 | 262 | 39 |
| | needles young | 370 | <7 | <21 | <LDA |
| | twigs (1–3 years) | 2520 | 123 | 325 | 80 |
| Larch[e] stand | twigs (1–3 years) | 1600 | 26 | 76 | <LDA |
| | needles (young) | 1360 | 33 | 104 | <29 |
| | cones (young) | 428 | <25 | <34 | <LDA |

[a]Dry weight. [b]Data performed with uncertainty of ±6% to 25%; the symbol < means an uncertainty exceeding 25%. [c]LDA (lowest detectable activity) 0.9 Bq/kg d.w. at 95% confidence level for a counting time of 1200 min. [d]Evergreen. [e]Deciduous. [f]2–3 Years.

TABLE II. Activity Ratios (Bq/kg d.w.) Decay Corrected to April 29, 1986, and Normalized to $^{137}Cs$ for some Organs Listed in Table I

| Species | Organs | Radionuclides | | | |
|---|---|---|---|---|---|
| | | $^{137}Cs$ | $^{141}Ce$ | $^{144}Ce$ | $^{140}Ba-^{140}La$ |
| Spruce | needles (old) | 1 | 0.18 | 0.14 | –[a] |
| | twigs (1–3 years) | 1 | 0.18 | 0.13 | 3.4 |
| | cones (old) | 1 | 0.13 | 0.09 | – |
| Scotch pine | needles (old) | 1 | 0.21 | 0.14 | 0.9 |
| | twigs (1–3 years) | 1 | 0.23 | 0.15 | – |
| Larch | twigs (1–3 years) | 1 | 0.11 | 0.09 | – |
| Lichens | thallus | 1 | 0.13 | 0.10 | 1.7 |

[a]Symbol – means that ratio cannot be calculated because nuclide activity is lower than LDA or affected by uncertainty >25%.

TABLE III. Nuclide Inventory, Percentage Released and Ratios in Core Normalized to $^{137}Cs$ of the Chernobyl-4 Reactor

| Nuclide | Inventory (Bq) $\times 10^{-18}$ | Percentage released (%) | Ratios in core |
|---|---|---|---|
| $^{137}Cs$ | 0.29 | 13 | 1 |
| $^{141}Ce$ | 4.4 | 2.3 | 15 |
| $^{144}Ce$ | 3.2 | 2.8 | 11 |
| $^{140}Ba-^{140}La$ | 2.9 | 5.6 | 10 |

TABLE IV. Normal Melting and Boiling Points of Cesium, Lanthanide Elements and Oxides

| Elements or oxide | Melting point (°C) | Boiling point (°C) |
|---|---|---|
| Cs | 28.6 | 670 |
| Ba | 725 | 1640 |
| Ce | 799 | 3426 |
| La | 921 | 3457 |
| $Ce_2O_3$ | 1692 | |
| BaO | 1918 | 2000 |

$^{141}Ce/^{144}Ce$ substantially agrees with the same ratio processed from Table III.

We believe that the trend in radiochemical composition of fallout can be explained on the basis of the normal melting and boiling points of cesium, lanthanide elements and oxides (Table IV) [3] and the temperature of the reactor core. If we assign 2000 °C to the core temperature, Cs and Ba are identified

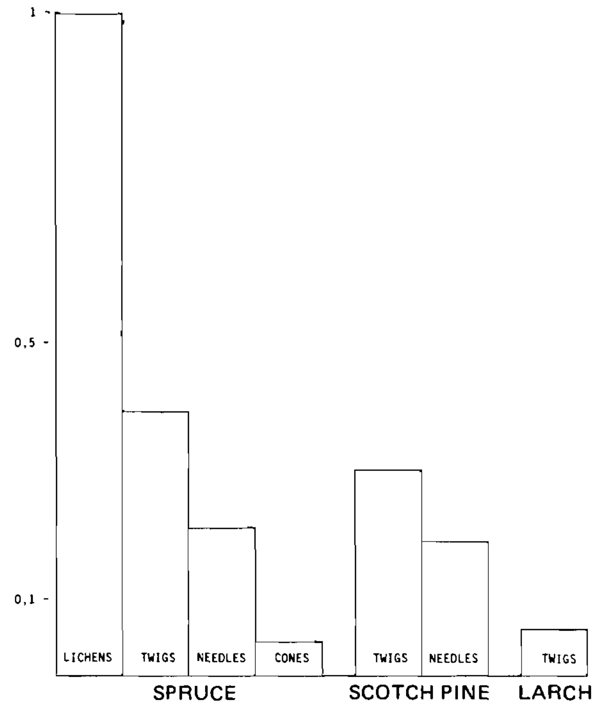


Fig. 1. $^{144}Ce$ activity of old organs of forest trees normalized to lichens assumed to be a 'biological indicator' of nuclear contamination.

as volatiles, Ce and La as refractories. If some oxidation of the nuclides is involved, Ba might behave as refractory.

Lichens are symbiotic organisms composed of fungi and algae. They grow very slowly and have a wide specific surface; they can effectively retain remarkable amounts of radionuclides. This could make it possible to use them as 'biological indicators' of the radioactive contamination of a region [5, 6] (Fig. 1).

## References

1 International Commission on Radiological Protection, 'Publication no. 6', Pergamon, Oxford, 1964.
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