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# LONG TERM STUDY OF $^{137}Cs$ IN LICHENS AT DIFFERENT LOCATIONS IN AUSTRIA

## Langzeitstudie über $^{137}Cs$ in Flechten an unterschiedlichen Standorten in Österreich

by

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Key words: Lichens, $^{137}Cs$, radioactivity, alpine environment.
Schlagwörter: Flechten, $^{137}Cs$, Radioaktivität, Alpine Stufe.

Summary: Previous studies have demonstrated that lichens can accumulate high amounts of radioactivity. Because of their long life expectancy they are suitable and inexpensive biological detectors of the nuclear fallout. In this study, lichen samples were collected from different locations in Austria over a period of more than 15 years. Samples were taken before, immediately after and a few years after the nuclear accident of Chernobyl. As a result of the accident, all species showed a very high increase in the $^{137}Cs$ activity concentration. Again, lichens appeared to be suitable detectors of local fallout patterns. The obtained data enabled us to estimate the biological half-life of $^{137}Cs$ in the soil lichen species *Cetraria cucullata, Cetraria islandica* and *Cladonia arbuscula*. For the Alpine region in the Province of Salzburg, the biological $^{137}Cs$ half-life in *Cetraria islandica* is about 2 years; the other two species showed similar results, but with much higher uncertainty.

Zusammenfassung: Zahlreiche Untersuchungen zeigten, daß Flechten aufgrund ihrer langen Lebensdauer auch einige Jahre nach einer radioaktiven Kontamination noch gut geeignete akkumulative Bioindikatoren für die Radionuklidbelastung sind. Für diese Studie wurden über einen Zeitraum von mehr als 15 Jahren, d. h. vor, kurz nach und einige Jahre nach dem Reaktorunglück von Tschernobyl, Flechtenproben von unterschiedlichen Standorten in Österreich gesammelt. Nach dem Reaktorunfall zeigten alle untersuchten Flechtenarten einen sehr deutlichen Anstieg in ihrer $^{137}$Cs Konzentration. Aufgrund der gewonnenen Daten war es möglich, für die alpine Stufe im Bundesland Salzburg die biologische $^{137}$Cs Halbwertszeit in den Bodenflechtenarten *Cetraria cucullata, Cetraria islandica* und *Cladonia arbuscula* zu ermitteln. Für alle drei Flechtenarten wurde eine biologische Halbwertszeit von etwa 2 Jahren errechnet, wobei die Unsicherheit für *Cetraria islandica* wesentlich geringer ist als für die anderen beiden Flechtenarten.

## Introduction

A large number of different radioactive nuclides were released into the environment after the atmospheric nuclear weapons tests. Among these, $^{137}$Cs was the most important long-lived fission product. The vast majority of the tests took place between 1952 and 1962. In August 1963 a limited nuclear test ban treaty was signed. Afterwards, much less frequent testing in the atmosphere occurred. The reportedly last atmospheric nuclear weapons test was carried out on the 16$^{th}$ of October 1980 by the People's Republic of China.

Large amounts of radioactivity were also released during the nuclear accident of Chernobyl on the 26$^{th}$ of April 1986. Again, $^{137}$Cs was the main long-lived fission product. Measurements have indicated that Austria was one of the most strongly affected countries. The average $^{137}$Cs area contamination after this accident was about 23 kBq per $m^2$.

A number of previous studies have demonstrated that lichens are suitable biological detectors of the radioactive fallout (e.g. HVIDEN & LILLEGRAVEN 1961, HOFMANN et al. 1988). Lichens are usually highly contaminated and their contamination correlates quite well with the soil deposition data. One of the main advantages is that samples can easily be collected from large areas, thereby providing an average contamination of this area. Especially in mountain ecosystems, lichens may gain great importance as biomonitors, because many lichens grow in this area. Moreover, the collection of soil samples may be very difficult in these elevated regions. On the other hand, a few inherent uncertainties have to be considered as well: GAARE (1987) mentioned the fact that differences in the radiocesium content of lichens can be due to a different moisture content at the time when the fallout occurred ("A dry sponge may absorb more water and contamination than a wet one. And lichens work very much like sponges in this respect"). Due to various reasons, e.g. differences in growth rates, resuspension of radionuclides from the soil-surface or differences in the effective half-life, the initial contamination patterns of lichens may slowly change with time. Thus, GASTBERGER et al. (1995) concluded that lichens are more suitable bioindicators shortly after a radioactive fallout than a few years later.

## Materials and Methods

Samples of different lichen species were collected over a period of more than 15 years (1980-1996) at different locations in the province of Salzburg/ Austria. All sampling locations are characterized by an elevation of more than 1000 m above sea level and a mean annual precipitation of 1100-1500 mm. The samples were dried at a temperature of 105° C for at least 24 h and homogenized. The dry weight of each sample was about 2-10 g. The lichens were measured with high purity germanium detectors from EG & G Ortec (relative efficiency: 20% and 35%, respectively). The measuring time depended on the sample size and the $^{137}Cs$ activity concentration. The overall uncertainty (standard deviation) of the $^{137}Cs$ activity is about 5-10% for most of the samples.

Only samples from the Stubnerkogel in the Gastein valley were used for the calculation of the biological half-life. The samples were taken in the years 1993 and 1996 from different locations between the peak (2240 m above sea level) and the timberline (about 1800 m above sea level). A total of 166 lichen samples were used to calculate the effective and the biological $^{137}Cs$ half-life in *Cetraria islandica* (n=37), *Cetraria cucullata* (n=19) and *Cladonia arbuscula* (n=27). Special care was taken to compare $^{137}Cs$ activities only for lichen samples which were collected from the same spot in the years 1993 and 1996.

The following equation was used for the calculation of the biological half-life ($T_{biol}$), assuming a half-life due to radioactive decay ($T_{phys}$) of 29 years:

$$T_{eff} = \frac{T_{biol} \times T_{phys}}{T_{biol} + T_{phys}}$$

## Results and Discussion

Lichen samples collected soon after the last atmospheric nuclear weapons test, which was carried out on the 16th October 1980 by the People's Republic of China, contained considerable amounts of different short-lived fission products (e.g. $^{144}Ce$, $^{95}Zr$) originating from this test explosion. In addition, the $^{137}Cs$ activity concentrations increased statistically significant in most of the lichen samples. Quite a few samples from different lichen species were collected after the Chernobyl accident (26th of April 1986). Again, lichens appeared to be suitable detectors of local fallout patterns. Indeed, all species showed a very high increase in the $^{137}Cs$ activity concentration (see Fig. 1-3).

Because of the high explosive yields of atmospheric test explosions, parts of the radioactive material are transported into the stratosphere. The mean residence time of particulate radioactive debris in the stratosphere is about 14 months (UNSCEAR 1966). In this case, the radioactive fallout does not occur as a single event, but continues for a period of a few years. In contrast, no radioactive material was transported into the stratosphere after the Chernobyl accident. Consequently the radioactive fallout occurred within a few days and thus provided the unique opportunity to study the biological half-life of $^{137}Cs$ in various lichen species. Tab. 1 shows the calculated biological half-lives for samples collected from the Stubnerkogel.

In general, very large variations in the $^{137}Cs$ contamination can be observed among samples from the same species, even if the samples are taken only a few meters from each other (GAARE 1987). Consequently, an accurate determination of the biological half-life is only possible, if samples are taken more or less at the same spot. Since *Cetraria islandica* was the most common lichen species in this area, the samples could be collected from a very restricted area. Likewise, more samples were taken from *Cetraria islandica* than from *Cetraria cucullata* and *Cladonia arbuscula*. This may be the main reason for the comparatively small uncertainty of the biological $^{137}Cs$ half-life in *Cetraria islandica* compared to the other two species.

Values found in the literature for the biological $^{137}Cs$ half-life in different lichen species range from 1 to 17 years (e.g. Liden & GUSTAFSSON 1967; ELLIS & SMITH 1987; SLOOF & WOLTERBEEK 1992). This illustrates the difficulties and uncertainties associated with the determination of biological half-lives, which is subject to many sources of error, such as variability in growth and microclimate. Probably some of the high values found in the literature can be explained by an unaccounted continuous radionuclide influx. This could be the case, if biological half-lives were determined shortly after atmospheric nuclear test explosions. Another possible reason for overestimation of effective half-lives is resuspension of radionuclides from the soil surface. In the present study, we calculated the half-lives from samples which were taken 7 and 10 years after the Chernobyl accident. Since $^{137}Cs$ penetrated into deeper soil layers within the first few years after the accident, resuspension is not likely to significantly influence the determination of the biological half-life.

In conclusion, measurements over the last 15 years proved that lichens are suitable biological detectors of radioactive fallout. Nevertheless, one has to be very careful in the interpretation of the measurements, because many sources of uncertainties have to be considered. For the Alpine region in the Province of Salzburg, the biological $^{137}Cs$ half-life in common soil-lichen species is estimated to be about 2 years.

**Tab. 1:** Biological $^{137}Cs$ half-life and uncertainty (standard deviation) in different soil-lichen species. The samples were collected from the Stubnerkogel (Province of Salzburg) in July 1993 and July 1996:

| | Biological half-life | Uncertainty ($\sigma$) |
|---|---|---|
| *Cetraria islandica* | 2.0 y | 1.6 y - 3.2 y |
| *Cetraria cucullata* | 2.7 y | 1.6 y - 23 y |
| *Cladonia arbuscula* | 2.5 y | 1.6 y - 22 y |

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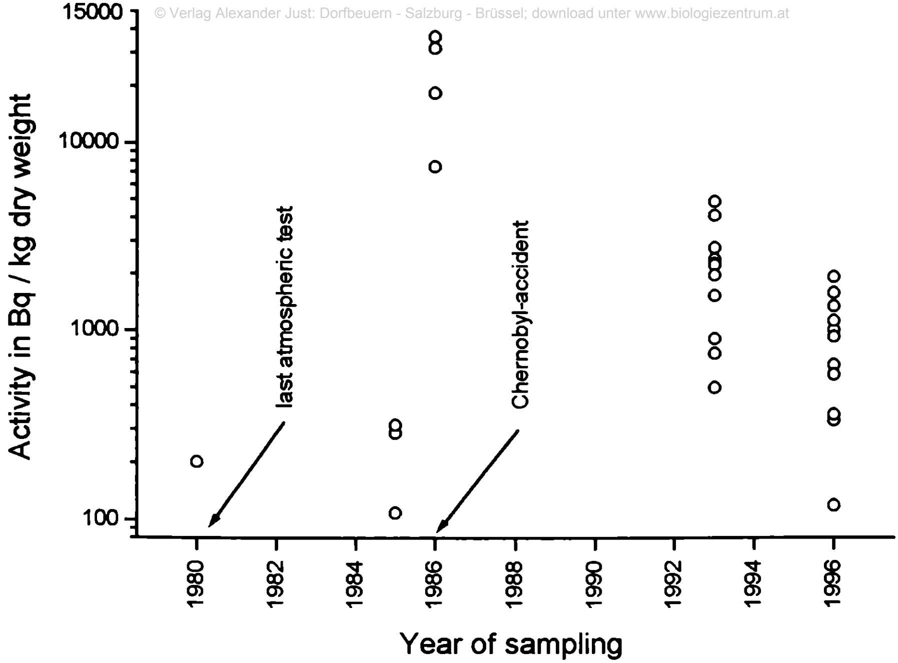


Fig. 1: Specific $^{137}Cs$ activity in *Cetraria islandica* between 1980 and 1996 at different locations in the Province of Salzburg/Austria.

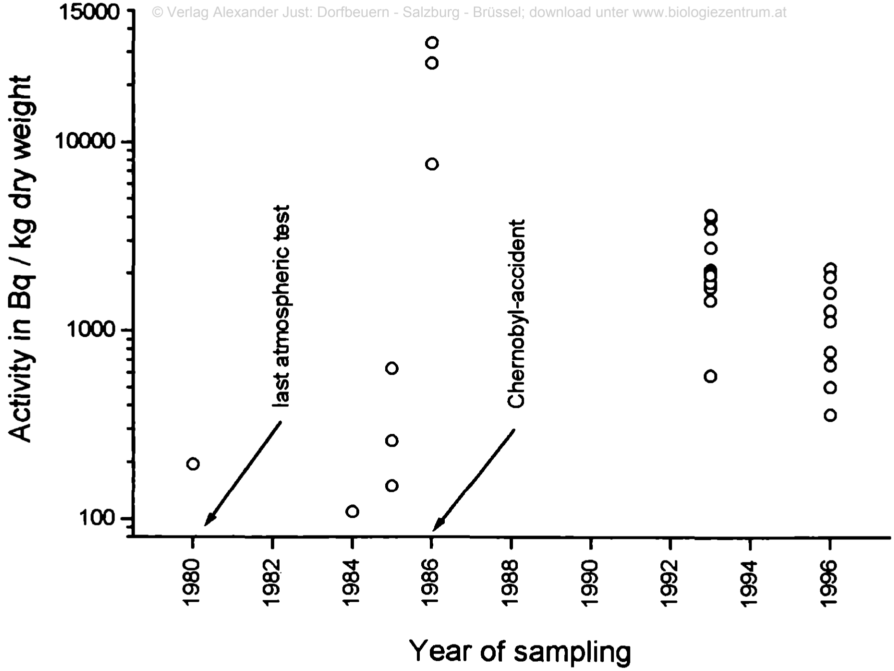


Fig. 2: Specific $^{137}Cs$ activity in *Cladonia arbuscula* between 1980 and 1996 at different locations in the Province of Salzburg/Austria.

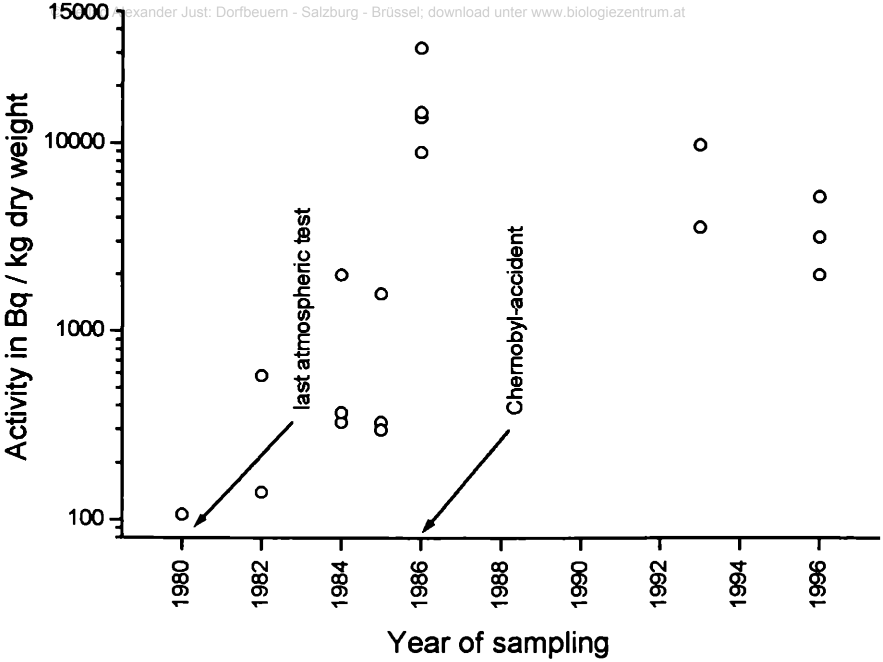


Fig. 3: Specific $^{137}Cs$ activity in *Pseudevernia furfuracea* between 1980 and 1996 at different locations in the Province of Salzburg/Austria.