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Activities of the ^{7}Be and ^{137}Cs nuclides in mushrooms from Southern and Western Finland

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Summary. We report the results from activity measurements of ^{7}Be and ^{137}Cs nuclides in mushrooms in Southern and Western Finland. Fifty-three samples were studied, and they showed large variations especially in the ^{137}Cs activity both regionally and between mushroom species.

1. Introduction

Radioisotopes occurring in nature mainly arise from three sources:

- the cosmogenic, or very-longlived, isotopes from the times of the origin of the earth, *e.g.*, ^{40}K, ^{232}Th and ^{235,238}U and their daughters, especially the decay chains of the two uranium isotopes (giving, for instance, the radon isotope ^{222}Rn),
- continuously produced shorter-lived isotopes like ^{7}Be, ^{14}C and ^{26}Al, mainly originate from spallation in the athmosphere by the cosmic radiation, and
- isotopes produced by the activities of mankind, notably tests of nuclear bombs in the 1950s, and accidents like the one in Chernobyl in 1986 [1]. The best known isotope from these events is ^{137}Cs.

The present study focuses on the two latter groups, and especially on ^{7}Be and ^{137}Cs. The study is carried out in the region of Southern, South-Western and Western Finland, *cf*. Fig. 1, by measuring the characteristic γ-radiation from the isotopes ^{7}Be and ^{137}Cs in mushroom species. If present, the ^{7}Be isotope tells about the production and wind condition differences and the ^{137}Cs isotope evidently about the wind and fallout conditions after the Chernobyl accident. The distribution of this isotope in Finland is illustrated in Fig. 1. Further, it is of interest to study whether there are uptake differences between different mushroom species.

2. Experimental methods

Among the surveyed isotopes in our environment the most common is the ^{137}Cs, produced by nuclear activities. This radionuclide is also followed officially by the Finnish Radiation and Nuclear Safety Authority (STUK), see *e.g.*, [2] for a recent report from Finland. Our surveys of the ^{7}Be and ^{137}Cs activities in the South-Western regions of Finland consider 53 mushroom samples from 9 different regions. The samples were collected during August–October 2009.

One may follow the accumulated rainfall in Turku, South-Western Finland ($62 \pm 35'$ N, $23 \pm 25'$ E) from the data logger situated at the Process Design Laboratory at Åbo Akademi [3]. There has been steady rainfall (≈ 250 mm) since Midsummer; thus the mushroom growth has potentially absorbed (if at all) most of the ^{7}Be fallout deposited with precipitation. The ^{137}Cs activity is independent of this, and mostly represents the fallout distribution originating from April 1986, just over one half-life ago.

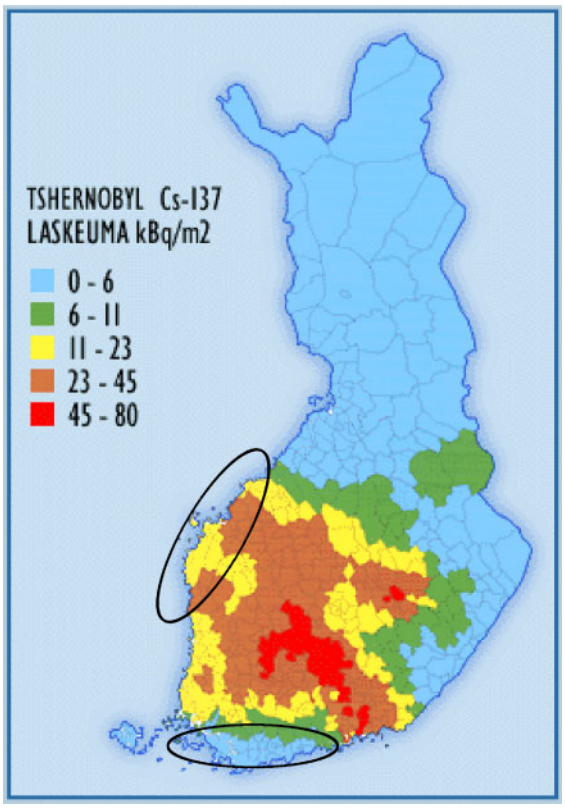

Fig. 1. Survey of ^{137}Cs fallout in Finland, in kBq/m^2, as reported in [11] by the Finnish Radiation and Nuclear Safety Authority. The regions of South and Western Finland covered in the present study are indicated by the ovals.

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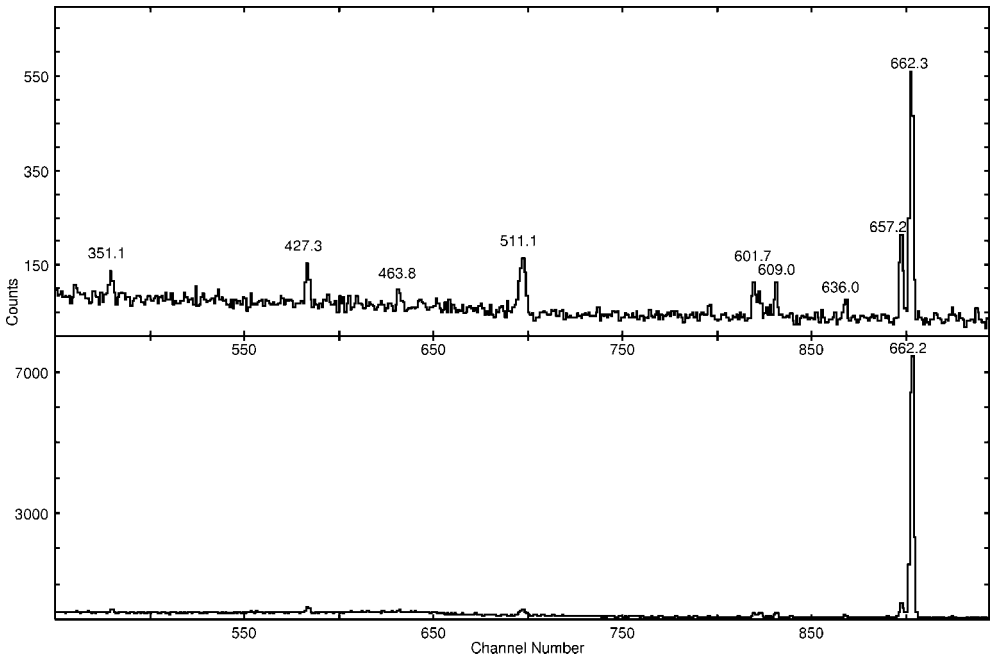

Fig. 2. Sample activity spectra, note the very large differences. Upper panel: *Cantharellus cibarius* containing little ^{137}Cs (scale 500). Lower panel: *Lactarius rufus*, rich in ^{137}Cs (scale 7000). Further, the 477 keV line from ^{7}Be is in channel 653, so its intensity is, as is seen, fairly low, and often below the detection limit.

Both ^{7}Be and ^{137}Cs decay in similar ways, that is, through beta decay (*EC* and β^-, respectively) followed by emission of a γ-ray in the daughter nucleus with similar energies, 477.6 keV (10.4% γ-rays) and 661.6 keV (85.1%) [4]. These γ-rays are observed, and the energies being close-lying, it is easy to take into account the difference in detector efficiency.

The mushroom samples were dried and crushed into powder form, the sample dry weights varied between 2.5 and 12 g, and the specimens were placed in a Petri dish (inner measures $d = 53$ mm, $h = 13$ mm) in front of the detector. The spectra were collected with an n-type Ge detector (or HPGe) in a standard singles set-up. The detector had an effective resolution about 2.0 keV at the ^{60}Co 1332 keV line. The whole set-up (source plus detector) was shielded with 5 cm lead from the surroundings, in order to allow detection of very low activities.

Sample spectra are shown in Fig. 2. To determine the peak areas, the fitted function consists of (skew) Gaussian peaks on an (at most) second order polynomial background. Two independent analyses were performed for all samples, and the obtained peak areas differed by less than 0.5%.

The results are collected in Tables 1 and 2 in the form of activity per dry mass, in kBq/kg for both ^{7}Be (where detectable) and ^{137}Cs, and the corresponding effective dose in μSv/kg (oral intake). As is seen, there are substantial differences in the activities, both region wise and between the mushroom species. The geographical coordinates are given for each sample group with about 2 km accuracy unless otherwise stated.

3. Results

The main results are collected in Tables 1 and 2. As the samples were collected between early August and mid-October, they thus contain most of the summer rainfall. The time of

Table 1. Mushrooms collected near Ekenäs and around Pargas (see legend). The activity is given in kBq/kg, and the dose in μSv/kg.

Latin name	^{7}Be	^{137}Cs	Dose
Albatrellus ovinus	0.04(4)	0.36(1)	4.8
Amanita fulva	–	0.66(2)	8.6
Boletus edulis	0.10(5)	0.40(2)	6.5
Cantharellus cibarius	0.08(4)	0.68(2)	9.8
Cantharellus cibarius	0.06(3)	0.34(1)	5.2
Cortinarius armillatus	–	2.43(2)	31.6
Cortinarius traganus	–	2.76(2)	35.9
Cortinarius triumphans	–	1.48(1)	19.2
Hydnum rufescens	0.19(8)	1.58(2)	21.1
Lactarius deterrimus	0.02(2)	0.36(1)	5
Lactarius rufus	–	1.54(2)	20.1
Lactarius spinosulus	0.07(3)	2.12(2)	28.4
Leccinum aurantiacum	0.03(2)	0.24(1)	3.6
Russula aeruginea	0.05(2)	0.42(1)	6.2
Russula claroflava	–	0.51(1)	6.6
Russula paludosa	0.20(12)	1.62(2)	21.6
Russula xerampelina	0.04(3)	0.36(1)	5.2
Tricholoma sejunctum	–	0.11(1)	1.5
Boletus edulis	0.02(2)	0.39(1)	5.4
Leccinum versipelle	–	0.08(1)	1
Cantharellus cibarius	0.01(1)	0.94(1)	12.3
Cantharellus cibarius	–	0.87(2)	11.4
Lactarius rufus	0.06(3)	2.91(2)	38.6
Russula emetica	–	1.36(3)	17.7
Russula integra	0.13(11)	2.13(3)	29.4
Suillus variegatus	–	2.29(4)	29.7
Lactarius torminosus	0.06(2)	1.22(1)	16.7
Agaricus arvensis	–	–	0
Coprinus comatus	–	–	0
Paxillus involutus	–	–	0
Paxillus involutus	–	–	0

Legend to table regions: The 18 specimen in the first group are all collected within a 70×70 m square 5 km NW of Ekenäs/Tammisaari (position 59°61′ N 23°22′ E), and the rest in regions within ~ 5 km from Pargas/Parainen (60°15′ N 21°22′ E), that is, Granvik (2), Lilltervo (6), Attu (1), and the last 4 in Pargas centre.

Table 2. Mushrooms collected along the South coast in the Western parts of Mid-North Finland (see legend). The activity is given in kBq/kg, and the dose in μSv/kg.

Latin name	^{7}Be	^{137}Cs	Dose
Cantharellus tubaeformis	0.12(4)	1.49(2)	21.3
Cantharellus cibarius	–	0.12(1)	1.6
Cantharellus cibarius	–	1.58(2)	20.6
Cantharellus cibarius	–	0.46(1)	6
Cantharellus cibarius	–	0.06(2)	0.7
Coprinus comatus	–	–	0.1
Craterellus cornucopioides	0.11(5)	8.06(5)	106.2
Hygrophorus hypothejus	0.21(6)	4.66(4)	63.3
Hygrophorus hypothejus	0.38(12)	11.75(1)	153.7
Russula decolorans	0.17(12)	10.70(6)	138.6
Russula decolorans	0.04(3)	4.64(3)	60.9
Cantharellus cibarius	–	0.74(2)	9.6
Lactarius rufus	0.23(9)	20.40(9)	268.3
Leccinum versipelle	0.06(2)	1.45(2)	19.6
Leccinum versipelle	0.06(3)	3.28(3)	42.7
Russula paludosa	0.03(3)	2.20(2)	28.9
Suillus luteus	–	2.03(2)	26.4
Cantharellus cibarius	0.04(2)	0.41(1)	5.5
Cantharellus tubaeformis	–	8.81(7)	114.5
Hygrophorus hypothejus	–	100.30(3)	1303.9
Sarcodon imbricatum	–	21.57(9)	280.5

Legend to table regions: The first group is a number of randomly-chosen regions along the South and South-West coast. Further, the next 6 are from Korsholm/Mustasaari, Norra Vallgrund.

decline until measurement, of importance for ^{7}Be, was taken into account in the given activity. The peak areas were obtained from the fit, together with its statistical uncertainty, and the sensitivity is calculated as prescribed by the IUPAC standard [5].

The tables clearly show the presence of ^{137}Cs, in strongly varying amounts, in all samples except for the ones from the centre of Pargas. The reason for this is not known. As is clearly seen, there are high activities in the northern region, and they do coincide with the ^{137}Cs distribution of Fig. 1, as expected. The amount of ^{7}Be is below the detection limit for many samples, whereas it is also fairly high in relation to ^{137}Cs in several samples.

In plants it has been observed, cf. [6], that there are significant differences regarding the ^{7}Be activity in leaves, between 70 and 1060 Bq/kg. See also [7]. In the present case, the ^{7}Be activities only vary within a factor of ten (where observable). The amounts of ^{137}Cs has also been studied in a review of edible mushroom radioactivity [8], comparing wild and cultivated mushrooms, and in a literature review of the accumulation of radiocaesium in mushrooms in the environment [9], concentrating on the accumulation of ^{134,137}Cs.

4. Conclusions

As is seen in the tables, the ^{137}Cs activities typically vary between ≈ 0.2 and a few kBq/kg, and the extremes are found in the northern region. The ^{7}Be activities are much less, but they also vary.

The 18 samples from the 70×70 m square west of Ekenäs show great variations, especially in ^{137}Cs. Since all specimens are collected in a very narrow region, these variations have to be due to differences between the species. However, the ^{7}Be and ^{137}Cs activities do not seem to be correlated.

The region in and around Pargas is peculiar in the sense that the centre seems void of any radioactivity, whereas the surrounding regions behave much like in Ekenäs.

The northern region shows variations similar to the above-mentioned, but in addition some species shows very much higher activities, especially the *Hygrophorus hypothejus*. The "mixed region" also shows activity variations like the other ones, except for the Aura region (north of Åbo/Turku) that shows higher levels.

The follow-up of ^{7}Be in air has also been done by the Finnish authority STUK, and great monthly variations have been observed, thus the content in mushrooms also reflects weather variations, see [10].

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