Nordic nuclear safety research

NKS-294
ISBN 978-87-7893-370-6

Doses from natural radioactivity in wild mushrooms and berries to the Nordic population

Tuukka Turtiainen[1], Minna Brunfeldt[1], Tiina Rasilainen[1]

Lindis Skipperud[2], Lene Valle[2], Jelena Mrdakovic Popic [2]

Per Roos[3]

Synnöve Sundell-Bergman[4], Klas Rosén[4], Robert Weimer[4]

[1]STUK – Radiation and Nuclear Safety Authority, Finland
[2] Norwegian University of Life Science
[3] DTU-Technical University of Denmark, NUTECH
[4] SLU–Swedish University of Agricultural Sciences

January 2014

Abstract

Soil-to-berry and soil-to-mushroom transfer factors of naturally occurring radionuclides were studied in four Nordic countries. The transfer factors of uranium and thorium to both mushrooms and berries were very low, <0.001, and their concentration in mushrooms and berries contributed little to the effect dose among consumers. Transfer factors of radium isotopes to berries ranged 0.06–0.53 while those of lead and polonium had a larger range, 0.001–0.14. In the berries studied, radium isotopes, lead and polonium contributed to the effective dose approx. equal proportions. The proportion of Cs-137 was only 20% of the studied berry samples. In mushrooms, the most significant contribution to the effective dose was from Cs-137 and Po-210, about equal proportions in the studied samples. All in all, the effective doses among average consumers and the most consuming persons were below 100 µSv per year. Therefore, risk communication is not regarded necessary.

Key words

natural radioactivity, berry, mushroom, transfer factor, gathered food, effective dose

NKS-294
ISBN 978-87-7893-370-6

Electronic report, January 2014
NKS Secretariat
P.O. Box 49
DK - 4000 Roskilde, Denmark
Phone +45 4677 4041
www.nks.org
e-mail nks@nks.org

Doses from natural radioactivity in wild mushrooms and berries to the Nordic population

Final Report from the NKS-B BERMUDA activity

(Contract: AFT/B(13)5)

Tuukka Turtiainen[1], Minna Brunfeldt[1], Tiina Rasilainen[1]
Lindis Skipperud[2], Lene Valle[2], Jelena Mrdakovic Popic [2]
Per Roos[3]
Synnöve Sundell-Bergman, Klas Rosén[4], Robert Weimer[4]

[1]STUK – Radiation and Nuclear Safety Authority
[2] Norwegian University of Life Science
[3] DTU–Technical University of Denmark, NUTECH
[4] SLU–Swedish University of Agricultural Sciences

Table of contents

Contents

1. Introduction

Naturally occurring radionuclides (NORs) are the major contributors to the total effective dose of ionizing radiation of the world population [1–3]. This natural dose is primarily generated by external and internal exposures from uranium (U) and thorium (Th) and their decay products. Key problems are associated with transport of U and Th and their daughters (especially polonium (Po) and lead (Pb) isotopes) in aquatic and terrestrial ecosystems (Figure 1). Radionuclides are transferred from the site by air emissions, by leaching and run-off water, and from soils into plants, animals and finally to man. Substantial work associated with the evaluation of the radioecological situation in U deposit regions and in vicinity of U mines has been performed in several countries such as Brazil, Australia, Europe, USA and Canada [4, 5]. Special attention is paid to the most hazardous decay products of U; ^{210}Pb and ^{210}Po and ^{226}Ra in soils, waters and plants [6, 7].

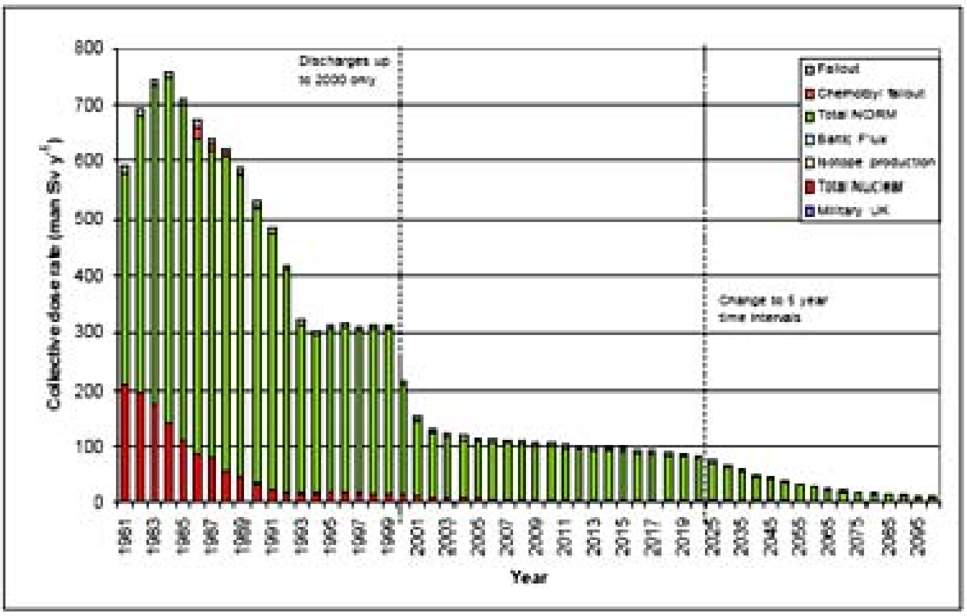


Figure 1. The calculated Collective dose rates by source to the European Union population due to discharges show that the majority of the dose is due to NORMs [1].

NORs that do not originate from industrial discharges or emissions cause also significant doses to the population, most notably radon in indoor air. Also, ground water may act as a significant pathway for exposure and therefore uranium series radionuclides have been extensively studied in the in drinking water of the Nordic Countries [8–10].

Natural radioactivity in foods, however, has been much less investigated and only few studies are available, mainly concentrating on wild gathered food. This is largely due to the legislation; there are no guideline values or maximum levels regarding NORs in food.

Data on NOR concentrations in berries and mushrooms are available from some countries. Davé *et al*. [11] reported ^{226}Ra levels in blueberries ranging 20–290 Bq/kg (dry weight) in a survey near decommissioned Canadian uranium mine. In Brazil, in a region of elevated natural radioactivity, the NOR concentrations (U- and Th-series) in mushrooms were 20–60 Bq/kg [12]. Eckl *et al*. [13] could not detect any ^{238}U (MDC 90 Bq/kg d.w.) or ^{226}Ra (MDC

50 Bq/kg d.w.) in several mushroom samples from Austria. Some samples contained 30–70 Bq/kg d.w. of ^{210}Po while most were below detection limit of 10 Bq/kg. Fungi sampled in three areas in France were analyzed by gamma spectrometry for their concentrations of ^{210}Pb and ^{226}Ra [14]. Activity concentrations of ^{210}Pb were in the range <1.76–36.5 Bq/kg d.w. Activity concentrations of ^{226}Ra were consistently lower, often by one order of magnitude. Baeza *et al.* [15–17] and Guillen *et al.* [18] have studied NOR concentrations in mushrooms as well as soil-to-fungi transfer, and bioavailable fraction during intestinal adsorption of mushrooms. The ^{210}Pb detected in 30 species of fungi ranged 0.75–202 Bq/kg d.w.

Unlike in Denmark, there are sites enriched in NORs in Finland, Sweden and Norway. The Fen in Norway, for example, contains significant levels of NORs and the outdoor gamma doses are among the highest in Europe. The Fen area contains both high levels of Th, U and daughter nuclides, in addition to enhanced levels of other metals [19–21]. Extensive mining (iron and niobium) have been conducted in these areas in early years. In 2008, the Norwegian Thorium Committee stated that there is a need for radiation protection regulation when it comes to mining and milling in such areas [22]. Before May 2009, natural occurring radionuclide material was not regulated in Norway, but the recent Norwegian Pollution Act was implemented in January 2011. The Act highlights the need for science-based assessment for the Fen area.

The maximum permitted level of ^{137}Cs in mushrooms (600 Bq/kg) leads to 0.1 mSv effective dose from about 10 kg of consumption. If the ^{210}Po levels in mushrooms are high (such as in Boletus, up to a few hundred Bq/kg measured earlier), the same consumption would lead to effective doses of several millisieverts per year. If we consider the dose constraint of 1 mSv per year for public exposure, it is well possible that among certain consumer groups this is exceeded and the public should be informed about this. As the ^{210}Po/^{210}Pb activity ratios have generally been high, up to 300, the high ^{210}Po levels in mushrooms can be reduced by preservation (desiccation, freezing) which would offer an easy method for mitigating the public exposure.

In this study we analysed ^{210}Pb, ^{210}Po, selected stable metals, uranium as well as ^{226}Ra and ^{228}Ra in some common edible fungi, blueberries and lingonberries and made dose estimates to the Nordic population from consumption of these forest products. In order to supplement the sparse data on transfer factors, also soil sampling and radioactivity analyses were included. Samples were collected at sites where elevated natural radioactivity is found as well as sites representing average levels.

The specific aims of the project were:

1. to produce data on natural radioisotope levels in wild fungi and berries in Nordic countries
2. based on 1, assess relevant doses to the Nordic population
3. to complement data on soil-to-fungi / soil-to-berry transfer factors
4. to find out if highly exposed groups exist
5. to think of proper ways of risk communication with groups among whom 1mSv/y effective dose is exceeded
6. to be prepared for possible questions about levels in commercially marketed/exported products
7. to share and strengthen know-how in analytics and environmental behaviour of natural radioisotopes among the Nordic Countries

This was accomplishes by:

1. collecting all relevant information concerning natural radioisotopes in wild mushrooms and berries in the Nordic Countries
2. collecting data on consumption rates of these products
3. collecting several representative samples of mushrooms, berries and soils in Finland, Sweden, Norway and Denmark
4. sharing our facilities and analytical capabilities in order to measure the challenging natural radioisotopes in these samples cost-effectively and with high precision

2. Literature survey

According to the few studies available from the Nordic countries, concentrations of NORs in wild berries have generally been low but surprisingly high concentrations of ^{210}Po have been documented in some mushroom species compared to its grandparent, ^{210}Pb. Vaaramaa *et al.* [23] reported ^{210}Pb and ^{210}Po concentrations in berries and mushrooms at two sites in Finland (Table1). It was obvious that mushrooms can efficiently accumulate ^{210}Po from the soil/litter as the concentrations in it were 12–2200 Bq/kg (d.w.) while ^{210}Pb concentrations ranged only 1.5–16 Bq/kg (d.w.).

Table 1. NOR concentrations (Bq/kg d.w.) in blueberry, lingonberry and various mushrooms at two forest sites [11].

Site	Sample	^{210}Pb	^{210}Po
1	Blueberry	1.7	2.5
	Lingonberry	3.2	7.5
	Mushrooms	1.5–16	12–**2200**
2	Blueberry	0.7	3.2
	Lingonberry	1.4	2.2
	Mushrooms	3.3–9.8	7.1-**860**

Paukkajavaara uranium mine and mill was commissioned in 1958. After quarrying 31 kt of ore, the mine was shut down in 1961 as unprofitable. The waste rock and tailings were left at the site uncovered. During 1985–1986, blueberry, lingonberry and fungi samples were collected at the mining site, in its vicinity and 12 km south from the site (reference site) [24]. Again, highest ^{210}Po concentrations were in mushrooms (Tables 2–4).

Table 2. NOR concentrations (Bq/kg f.w.) in blueberry at Paukkajavaara uranium mining site. The dry matter of blueberry is generally 13%.

	At the mine	Vicinity	Reference site
^{238}U			
^{228}Ra	0.61	0–0.35	
^{226}Ra	2.3	0.95–14	0.31–0.40
^{210}Pb	0.20	0.33–0.54	0.40–0.41
^{210}Po	0.30	0.11–0.33	0.25–0.40

Table 3. NOR concentrations (Bq/kg f.w.) in lingonberry at Paukkajavaara uranium mining site. The dry matter of lingonberry is generally 14%.

	At the mine	Vicinity	Reference site
^{238}U			
^{228}Ra	0.71–2.6	0–0.28	
^{226}Ra	5.5–7.2	0.56–1.1	0.47
^{210}Pb	0.51–1.1	0.42–0.70	0.42
^{210}Po	0.34–0.75	0.28–0.42	0.28

Table 4. NOR concentrations (Bq/kg f.w.) in boletus at Paukkajavaara uranium mining site. The dry matter of boletus is generally 9%.

	At the mine	Vicinity	Reference site
^{238}U	0.71		
^{228}Ra	0.26	0.43	
^{226}Ra	8.9	0.39	0.52
^{210}Pb	7.4	0.62	0.20
^{210}Po	**460**	7.2	7.8

Phosphate and niobium ores in Sokli contain above average concentrations of NOR's. In phosphate ore, the mean ^{238}U and ^{232}Th concentrations are 310 and 533 Bq/kg, respectively. In the niobium ore, the mean concentrations are 1000 and 4000 Bq/kg, respectively. STUK has carried out a radiological baseline environmental assessment at the site in 2008–2009. Decision about commissioning the mine has not yet been made. The results relating to wild berries and mushrooms are presented on table 5–6.

Table 5. NOR concentrations (Bq/kg, d.w.) in wild berries and mushrooms at Sokli, a prospective phosphate/niobium mining site.

	Berries (2008)	Berries (2009)	Mushrooms (2008)	Mushrooms (2009)
^{238}U	<mda	<mda	92	<mda
^{228}Ra	0.6–2.6	1.1–2.7	2.2	<mda
^{226}Ra	0.5–12	0.6–2.0	<mda–58	<mda

Table 6. NOR concentrations (Bq/kg, f.w.) in wild berries and mushrooms at Sokli, a prospective phosphate/niobium mining site. The highest ^{210}Po concentrations were found in boletus (130–830 Bq/kg f.w.). The dry matter of boletus is generally 9%.

	Berries (2008)	Berries (2009)	Mushrooms (2008)	Mushrooms (2009)
^{210}Pb	1.4–2.5	1.1–2.8	1.9–22	4–19
^{210}Po	1.0–4.9	0.6–1.2	6–**830**	6–236

Talvivaara mine started production of nickel and zinc in 2008. Separation of uranium by bioheap leaching is now being commissioned. STUK is carrying out a radiological baseline environmental assessment at the site in 2010–2012 (Table 7).

Table 7. NOR concentrations (Bq/kg d.w.) in mushrooms and berries near Talvivaara mine

	Blueberry	Lingonberry	Mushrooms
^{238}U	<mda	<mda	<mda
^{228}Ra	1.7–2.5	1.3–11	<mda
^{226}Ra	1.4–4.5	1.4–5.3	<mda–2.6

In Sweden, Johansson *et al.* [25] studied U and Th in fungi in the Forsmark area. The uranium concentration in fungal fruitbodies was 0.005–0.2 mg/kg d.w. whereas thorium concentration was lower, 0.001–0.013 mg/kg d.w.

Gwynn *et al.* studied activity concentrations of wild berries and mushrooms in northern Norway [26]. The mean activity concentrations of ^{210}Po and ^{210}Pb ranged 0.6–2.6 and 1.2–4.1 Bq/kg (d.w.) for various species of berries. Similarly to findings of Vaaramaa *et al.* [23], samples of bolete and russule exhibited moderate ^{210}Pb concentrations, in the range of 1–8 Bq/kg (d.w.). Again, much higher ^{210}Po concentrations in bolete, ranging 20–500 Bq/kg (d.w.), were found. In russule, the concentrations ranged 3–9 Bq/kg (d.w.).[1]

3. Consumption rates

2.1 Denmark

According to a Danish investigation, 56% of the population eat wild berries and only 34% eat wild mushrooms [27]. There were people who consume great amounts of forest produce, as much as 20 kg of wild mushrooms per year.

2.2 Norway

Sparse existing data on consumption of wild mushrooms regarding the average Norwegian population suggested only 0.24 kg per capita annually [28]. However, numerous ^{137,134}Cs monitoring studies in Central Norway demonstrated consumption at level 2.7 kg per capita annually in some population parts. Using of wild berries in Norwegian diet at individual level ranges from 2.6 to 4.5 kg per year. More specific, for selected individuals in Snåsa, Norway,

[1] At the time of planning the BERMUDA project, these Norwegian data were not available.

with presumed high consumption of locally produced foods, it was found an annual consumption of wild mushrooms at approx. 2.7 kg per household. For the same group, the intake of wild berries was annually approx. 24.5 kg per household. In the same study, a population of reindeer herders were asked about their dietary habits in 1999 and 2002. These herders lived in areas that were severely affected by the Chernobyl accident and stated that they had reduced their intake of wild mushrooms and berries after the accident. In 2002, consumption of mushrooms in this group was approx. 1.6 kg per household per year, while the intake of berries was about 13.1 kg per household per year. Otherwise, there is little documentation of the annual intake of mushrooms and berries among Norwegians. Since the investigations of herders specified to have a lower intake of mushrooms and berries as a result of contaminated sites, it can be assumed that the consumption of other less affected areas may be higher [28].

2.3 Sweden

No data on consumption of mushrooms and berries was found.

2.4 Finland

According to The National FINDIET 2007 survey, which was conducted by 48-hour dietary recall, 4 and 7% of men and women, respectively, consumed foods containing mushrooms [29]. According to three separate surveys, 64–82% of Finnish households use wild mushrooms in their diet [30–32]. Depending on the survey, the annual *per capita* consumption rate of mushrooms has been reported as 0.8–1.5 kg. According to Viinisalo *et al.* [33] the consumption rate varies between years and region—households in western and northern Finland consume about half as much mushrooms as households in southern and eastern Finland. According to Markkula and Rantavaara, the most consuming 10% of households consume 5.7 kg of mushrooms per person annually [30]. According to Feodoroff [32], the consumption of different mushroom species is the following: *cantharallus/cratellus* 38%, *lactarius* 25%, *boletus* 17%, *russula* 10% and others 10%.

According to FINDIET 2007 the average men and women in age group 25–64 years consume 18 and 28 grams of berries (wild and cultivated) per day. Among the older people (65–74 y.) the consumption rates are higher, 40 and 51 g/d. These figures translate into 6.6–18.6 kg of berries per year. According to Markkula and Rantavaara [30], wild berries were used by 94% of Finnish households, on average 8.3 kg per capita annually and the most consuming 10% of households use 28 kg of berries per person annually. According to Saastamoinen [34], 60% of households collected berries themselves. According to Rantakokko [35], the most consumed berries were blueberry (40% of collecting trips) and lingonberry (35% of collecting trips).

4. Field work

4.1 Danish site

The Bidstrup forest (around10 km^2) is located about 30km south of Roskilde on Zealand, longitude:11.8972, latitude:55.5558. The forest is close to the village of Hvalsø. It consist of a mix of hardwood and coniferous forest in a hilly terrain. The soil is clayish and rich in organic matter. Oak, birch, beech, maple and alder trees with occasional pine dominates in the older part of the forest. Areas of planted spruce, 20-50y old, appear on some sites. Shrubs appear on roughly 10% of the area. Grassy areas are frequent.

Due to dry weather and lack of expertise in identifying species of mushrooms all mushroom samples reported on in this work were collected in 2013 (14 October 2013) with the assistance of a trained mycologist. The late sampling resulted in a short ingrowth period for ^{210}Pb (about one month) which therefore could not be detected in any of the collected samples. Mushrooms collected in 2012 were partly of uncertain species and therefore omitted from further analysis. In 2012, samples of blackberries and raspberries were also collected although the collected material was of marginal size.

4.2 Norwegian sites

Two of the sites are TENORM-areas: Søve and Fen gruve. Norway also has sites enriched in naturally occurring radionuclides (NORM), therefore Rullekollen and Bolledalen were chosen as well. The Fen area contains significant levels of NORM and the outdoor gamma doses are among the highest in Europe. Torsnes site is used as a reference area. The Fen Central Complex in Norway contains one of the largest reservoirs of thorium (^{232}Th) and also high concentrations of iron (Fe), niobium (Nb) and rare earth elements (REE). The area also contains a moderate amount of uranium (^{238}U). The rocks, containing high concentrations of ^{232}Th and ^{238}U, have a naturally high content of naturally occurring radioactive material (NORM). In certain areas mining activities in the past for Nb and Fe has led to enhanced levels of radionuclides and elevated levels of radiation (TENORM), especially in waste locations. Several studies regarding ^{232}Th, ^{238}U and radon (^{222}Rn) and risk analysis have been conducted, but no earlier studies of concentration and uptake of naturally occurring radioactivity in mushrooms or berries and doses to the population have been conducted in this area.

The field work was carried out 31st July and 25th August 2012. The following samples of mushrooms and berries were collected: Raspberries (*Rubus Idaeus*), blueberries (*Vaccinium myrtillus*), lingonberries (*Vaccinium vitis-idaea*) and chanterelle (*Cantharellus cibarius*). Together with berries and mushrooms, leafs, stems, shrub and soil were sampled (Table 8).

Table 8. Samples collected and Fen central complex sites

Site	Area	Coordinates	Samples taken
Søve	TENORM	N59°16.902’ E009°17.162’	Soil, plants, berries, *Rubus idaeus* (raspberries)
Fen gruve	TENORM	N59°16.625’ E009°18.226’	Soil, plants, berries, *Rubus idaeus*
Rullekollen	NORM	N59°16.002’ E009°18.110’	Soil, plants, *Rubus idaeus*
Bolladalen	NORM	N59°16.424’ E009°18.945’ N59°16.467’ E009°18.822’ N59°16.451’ E009°18.881’ N59°16.544’ E009°18.464’	*Cantharellus cibarius* (chanterelle) *Cantharellus cibarius* (chanterelle) Soil, plants, berries *Vaccinium vitis-idaea* (lingonberries), *Vaccinium myrtillus* (blueberries) Soil, plants *Vaccinium myrtillus*
Torsnes	Reference	N59°16.865’ E009°17.204’	Soil, plants, berries *Rubus idaeus*

4.3. Swedish sites

Sampling was performed in pasture and meadow lands at Oviken in the middle of Sweden (N 63.021, E 14.393). The location of sampling site is shown in Figure 1. Farming and forestry are the dominating activities in this area. Alum shale is the parent material to the sedimented soils in Oviken implying potentially higher concentrations of natural radionuclides in soils. Recently the area has been recognized to be of interest for mining of e.g uranium and some prospecting activities have occurred. The highest abundance of uranium has been located in farmland very close to the old church in Oviken where the alum shale outcrops.

The selected sampling homestead Vikdrolet was located relatively close to the above mentioned area and consisted of both pasture and meadow lands as well as forest within a few 100 meters (se fig 1). The sampling scheme from that proposed by Rosén was applied for grass and soil. Each sampling area consisted of 3 circles with a radius of 3 m. Each circle was subdivided in four sectors, and a composite soil sample based upon 3 plots from each sector was prepared being soil depth 25 cm or less. Moreover, a composite grass sample was made based on 1 m^2 areas in each sector. All in all, 3 composite soil samples and 3 composite grass samples were taken from each sampling area.
Date for sampling occurred due to practical reason in the beginning of August. Unfortunately, the weather has been bad this year inferring that the berries were not quite ripened when the samples had to be taken. Close to the houses, currant and unripe raspberries were picked. Samples of grass were taken about 50 m from the house as well as samples of the alumshale that were excavated by the mining company.

About 50 m from the dwelling was a small creek. Samples were taken of the water and the sediment.

Further 50 m from the dwelling was a forested hill were samples of unripe lingonberries, wild strawberries, soil and plants of blueberry and lingonberry were taken. Somewhat further away samples of blueberries were picked and some eatable mushrooms were also found.

Table 9. Type and amount of samples collected in the area Oviken.

Sample type	Number and size of samples
Soil	3
Alum shale	1
Water	1 and 1 liter
Sediment	1 and 0,5 liter
Unripe raspberry	1 and 3 liters
Currant	1 and 4,5 liter
Blueberry plants	1
Lingonberry plants	1
Wild strawberries	1 and 0,5 liter
Unripe lingonberries	1 and 0,5 liter
Blueberries	1 and 1 liters
Mushrooms (hedgehog)	1 and 0,5 liter
Grass	2 and 1 liter each

4.4 Finnish sites

Two sites from southern Finland were chosen: Loviisa (N 60.429, E 26.318) where the soil contains higher than average levels of NOR's, and Espoo (N 60.335, E 24.679) with normal levels of radionuclides. In addition, one site is located in northern Finland, in Kuusamo (N 66.292, E 29.188) where the levels are from low to normal.

Standardized soil sampling methods were used at all the stages of the work at all test sites. Sampled sites are approximately 100 m x 100 m (1 ha) areas and they were chosen by their suitable qualities. Soil sampling design was random sampling of total 5 understory vegetation/litter/organic soil squares (25 x 25 cm) in which 5 soil cores were hammered and two mineral horizons separated. The squares and horizons were pooled and the pooled sample was considered representative for the site.

The Espoo site is predominantly coniferous forest with minor portion of broadleaved trees. The forest was classified as fresh heath, MT-group (*Vaccinium myrtillus* type). The soil is rocky and there is a bare rock formation in the middle of the site (Figure 2). Several fallen, decomposing trees are found at the site. The understory has plenty of *Vaccinium myrtillus* shrubs.

Other samples from Espoo sites were: blueberry (*Vaccinium myrtillus*), chanterelle (*Cantharellus cibarius*), funnel chanterelle (*Cantharellus tubaeformis*), black chanterelle (*Craterellus cornucopioides,* appr. 100 m off-site) and rufous milkcap (*Lactarius rufus*).


Figure 2. Fresh heath at Espoo sampling site (photo by Minna Brunfeldt).

The Loviisa site is mixed forest with coniferous and broadleaved trees. The forest was classified as grove-like heath, OMT-group (*Oxalis*-*Myrtillus* type) (Figure 3).


Figure 3. Grove-like heath at Loviisa sampling site (photo by Minna Brunfeldt).

Other samples from Loviisa site were: blueberry (*Vaccinium myrtillus*), chanterelle (*Cantharellus cibarius*), funnel chanterelle (*Cantharellus tubaeformis*), rufous milkcap (*Lactarius rufus*) and sheathed woodtuft (*Kuehneromyces mutabilis*).

The Kuusamo site is fresh heath, HMT type (*Hylocomium*-*Myrtillus* type) of forest, near the Juomasuo mining area (Figure 4). Some fallen trees and dead standing trees were observed.

Figure 4. Fresh heath at Kuusamo sampling site (photo by Minna Brunfeldt).

Other samples from Kuusamo site were blueberry (*Vaccinium myrtillus*) and lingonberry (*Vaccinium vitis-idaea*). Unfortunately, no mushrooms were observed during sampling at this site.

5. Analytical methods

Norwegian samples were prepared and analyzed at the Isotope Laboratory at the Department of Plant and Environmental Sciences (IPM) at Norwegian University of Life Sciences (UMB). The measurement of ^{232}Th and ^{238}U in plant and soil samples and some metals in soil samples was performed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The measurement of ^{210}Po in all the samples was performed by alpha spectrometry in accordance with established methods.

Finnish samples were analyzed by STUK's Regional Laboratory in Northern Finland, in Rovaniemi.

Typical soil parameters (pH, Organic content etc.) were performed by the Swedish University of Agricultural Sciences for samples from all partners.

5.1 Pre-treatment

At STUK Rovaniemi, Berries were dried in 105 °C and then blended with mortar or a household blender for the Po/Pb-analysis. The rest of the sample was ashed for later analyses. Mushrooms were dried in approx. 45 °C with a mushroom dryer and homogenized with a mortar or a household blender. Plant layer, litter and organic soil were air dried in <45 °C following the ISO-standard (ISO 11464:2006(E): 5.3.2 Air drying). Plants were stored for possible later use and litter was homogenized. Organic and mineral soils were sieved (2-mm mesh) and homogenized. Mineral soils were oven dried at 105 °C. In oven during (standard ISO 11464:2006(E): 5.3.3 Oven drying), samples were spread on a tray to a layer that was not thicker than 5 cm. Additionally, archive samples were stored for later use (Table 10).

At UMB, berries and mushroom were weight in (fresh weight) into Teflon tubes and digested using ULTRACLAVE high temperature and pressure microwave.

At DTU, wet weight was recorded at arrival to the laboratory. Samples were dried at 65 °C, dry weight recorded and samples grounded with mortar and pestle and thoroughly mixed. For polonium analysis 1-2g dry material was digested in aqua regia in the presence of ^{209}Po tracer. Polonium was plated onto silver discs and counted for 1-5 days on PIPS-detectors. A well-type HPGe-detector was used to analyse samples for gamma-emitting isotopes

Table 10. Sample pre treatment at the laboratories.

BERMUDA – Sample treatments				
Sample	Pre-treatment	Amount	Analyser/Receiver	Analysis
BERRY	1. Drying (105 °C, >24 h)	Whole sample		
	2. Blending (mortar/house hold blender)	5-30 g	STUK PSL	Po/Pb-210
	3. Ashing	1 ml	DTU/UMB. Ash stored in excicator to avoid moist (hygroscopic)	ICP-MS
	4. Gamma	Rest of the sample (ashed)	STUK - PSL	Gamma
MUSHROOM	1. Drying (approx. 45 °C in mushroom dryer)	Whole sample		
	2. Blending (mortar/house hold blender)	5-30 g	STUK PSL	Po/Pb-210
	3. Ashing	1 ml	DTU/UMB. Ash stored in excicator to avoid moist (hygroscopic)	ICP-MS
	4. Gamma	Rest of the sample	STUK - PSL	Gamma
SOIL				
Plant layer	1. Storing (drying 35 °C, vacuum packaging)	Whole sample	Stored for the possible later use	
Litter	1. Drying 35 °C [ISO 11464:2006(E) 5.3.2 Air drying]	Whole sample	STUK PSL	Po/Pb-210
	2. Ashing	1 ml	DTU/UMB. Ash stored in excicator to avoid moist (hygroscopic)	ICP-MS
	3. Blending [ISO 11464:2006(E) (5.4.1 +)5.4.2 Crushing]	Rest of the sample	STUK - PSL	Gamma
Organic soil	1.1. pH-measurement [ISO 10390:2005(E)]	10 ml (fresh soil)		pH
	1.2. Drying 35 °C [ISO 11464:2006(E) 5.3.2 Air drying]	Whole sample	STUK PSL	Po/Pb-210
	2. Grinding [ISO 11464:2006(E) (5.4.1 +) 5.4.2 Crushing]	100 ml	SLU	Soil analysis
	3. Sieving (2 mm mesh)	Rest of the sample		
	4. (Ashing possibly later)	1 ml	DTU/UMB	ICP-MS
	5. Gamma	Rest of the sample	STUK - PSL	Gamma
Mineral soil	1. Drying 35 °C [ISO 11464:2006(E) 5.3.2 Air drying]	Whole sample	STUK PSL	Po/Pb-210
	2. Grind [ISO 11464:2006(E) (5.4.1 +) 5.4.2 Crushing]	100 ml	SLU	Soil analysis
	3. Gamma (total)		STUK - PSL	Gamma
	2. Storing (dried sample, vacuum packaging)	Rest of the sample	Stored for the possible later use	

5.2 Gamma spectroscopy

Gamma spectroscopy was performed on most samples. If the measuring vial was full of the sample, the vacuum sealing developed at STUK was carried out [36]. In this method, ^{226}Ra is allowed to produce radon for at least three weeks, after which, ^{226}Ra is in equilibrium with radon daughters ^{214}Pb (295 and 351 keV) and ^{214}Bi (609, 1220, 1764 keV). If sufficient amount of material was not obtained to avoid void volume inside measuring vial, the ^{226}Ra and ^{235}U doublette (186 keV) was used. In this method, the photons originating from ^{235}U are subtracted from the peak net area by first measuring the uranium concentration by mass spectrometry and then using the natural isotope ratio (^{238}U/^{235}U = 21.44) and coincidence correction for ^{235}U in the subtraction. ^{228}Ra was calculated from 338 and 911 keV photopeaks and ^{137}Cs from 661 keV photopeak. Uranium was calculated from vacuum sealed samples by subtracting photons originating from ^{226}Ra from the 186 keV photopeak. ^{210}Pb was obtained from the 46.5 keV photopeak.

Correction for sample height and density, as well as the effect of true coincidence summing, was taken into account in the calculation of the results. The program uses a nuclide library including 105 nuclides and 600 gamma lines with decay scheme data. The uncertainties include both statistical uncertainty and uncertainty due to the efficiency calibration. Accreditation based on the standard EN ISO/IEC 17025:2005 has been given to the laboratory (code T167) by the Finnish Accreditation Service and the method, which is modified from IEC 1452 standard [37], is documented in the quality manual of the laboratory [38].

5.3 Radiochemical analyses

The ^{210}Po/^{210}Pb concentration was determined by two spontaneous depositions of ^{210}Po on silver disks carried out at approx. 6 month intervals according to the method described by Vaaramaa et al [23]. Measurements of the disks were carried out by alpha spectroscopy (Alpha Analyst® by Canberra Industries, Inc) with a measurement time of 4000 min. The determination method has been accredited by the Finnish Accreditation Service (FINAS laboratory code T167) and it is documented in the quality manual of the laboratory [38].

5.4 Mass spectrometry

At UMB, the measurement of ^{232}Th, ^{238}U and some metals was performed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The main principal of the ICP-MS is as follows:
In an ICP-MS samples are introduced as aerosol droplets into an argon plasma at a temperature of approximately 6000°C. The aerosol droplets are dried to a solid, heated to a gas and, after absorbing more energy, releasing one electron to form singly-charged ions. The ions formed in the plasma, is directed into a quadrupole that separates the ions from photons and neutrals. A collision cell is used to remove interferences and a second quadrupole is used to sort ions by their mass-to-charge ratio. A detector counts individual ions exiting the quadrupole. The quadrupole is capable of scanning at a rate of over 5000 atomic mass units per second, allowing the measurement of many elements and isotopes of elements over a short period of time [39]. The instrument used is in this experiment was an Agilent 8800 Triple Quadrupole ICP-MS (ICP-QQQ). This instrument has a third quadrupole before the collision cell which gives a better removal of interferences [40].

5.5 Soil analyses

Soil parameters were determined by the Swedish University of Agricultural Sciences (SLU) at the Department of Soil and Environment for samples from Finland and Norway. The analysis included determination of: pH together with organic content of C, P, K, Ca, Mg, S and also CEC (cation exchange capacity). The organic content analysis was performed by ICP with Al-extraction (P, K, Ca, Mg, N and C) and HNO3-extraction (S). CEC was determined using extraction with ammonium acetate. In only 6 out of 15 samples from Norway could CEC be determined because of insufficient sample size.

6. Results

6.1 Soil samples

Typical soil parameters are presented in tables 11 and 12. There are variations in these parameters from sample to sample and from site to site. Samples from Søve exhibit the highest soil pH, while Bolladalen samples have the lowest pH. Organic matter content is the exact opposite, highest at Bolladalen and lowest in Søve.

At Finnish sites, soil horizons were measured separately. The horizons were characterized as litter, organic soil horizon (O), the grayish eluviated layer (A), enrichment horizon (B) and the little affected soil horizon (C). The eluviated layer was separable only at Kuusamo sampling site. In the other two sites, traces of this layer were combined with the much larger O horizons. No large differences in these soil parameters between sites were observed.

Table 11. Measured soil parameters in soil samples. Horizon indicates different soil horizons (O=organic soil with the litter layer removed, B=enrichment horizon, C= little affected mineral soil horizon)

Site	Hori-zon	pH	Tot-N %	Tot-C %	Karb-C %	Org-C %	AL-P mg/ 100g	AL-K mg/ 100g	AL-Ca mg/ 100g	AL-Mg mg/ 100g
Søve		7.49 7.67 7.91	0.138 0.113 0.080	2.275 2.093 1.687	0.131 0.045 0.306	2.15 2.05 1.38	2.7 1.7 0.7	8.3 12.6 5.6	414.7 351.5 982.3	10.3 7.5 15.9
Fen		7.43 7.51 7.39	0.300 0.218 0.493	6.889 6.387 8.575	2.253 2.398 1.361	4.64 3.99 7.21	1.6 1.4 2.1	4.8 3.5 6.8	5223 4813 2895	40.5 39.9 54.0
Rullekolle n		6.14 6.11 6.24	0.606 0.654 0.706	7.825 8.249 9.244	0.0651 0.0650 0.0816	7.76 8.18 9.16	1.6 1.8 1.6	7.3 7.7 7.1	311.9 273.9 331.1	63.4 57.2 76.6
Bolladalen		4.04 4.40 5.38	0.668 1.79 0.653	14.75 45.54 14.19	0.0620 0.0397 0.0351	14.7 45.5 14.2	7.4 23.3 2.8	18.4 87.2 14.7	44.5 246.1 190.9	9.4 44.3 16.0
Torsnes		6.25 7.03 6.53	0.224 0.195 0.209	3.473 2.975 3.261	0.0273 0.0529 0.0408	3.45 2.92 3.22	3.3 4.1 3.5	7.5 7.2 7.7	186.7 281.7 211.5	17.3 9.4 9.5
Espoo	O	3.77	n/d	32	0.040	32	100	460	680	190
	B	4.61	n/d	3.1	0.012	3.1	8.7	29	15	6.1
	C	3.91	n/d	2.1	0.025	2.1	12	33	22.8	12
Loviisa	O	4.06	n/d	28	0.008	28	88	340	1200	190
	B	5.00	n/d	0.64	0.005	0.64	26	30	100	7.8
	C	4.69	n/d	0.79	0.014	0.77	27	22	75	8.1
Kuusamo	O	3.81	n/d	42	0.026	42	160	570	1400	260
	B	6.06	n/d	1.4	0.136	1.3	4.2	8.9	1000	280
	C	4.42	n/d	1.2	0.006	1.2	12	27	73	20

Table 12. Measured soil parameters in soil samples.

Site	Horiz on	Tot-S mg/100g	CEC cmol(+)/kg
Espoo	A	1100	85
	B	550	9.5
	C	81	7.1
Loviisa	A	720	69
	B	47	3.7
	C	49	3.5
Kuusamo	A	1200	91
	B	120	8.1
	C	54	4.3

In Norway, the analysis of soil samples showed elevated levels of ^{232}Th in all areas (3 – 6531 mg/kg or 12–26500 Bq/kg) compared to the world average of 11 mg/kg (45 Bq/kg). The concentration of ^{238}U was 0.2 – 175 mg/kg (2.5–2160 Bq/kg). The average concentration of ^{238}U for all areas except the reference area and Fen mining area was higher than the world average of 3 mg/kg (37 Bq/kg). Torsnes, the reference area, had the lowest values of ^{232}Th and ^{238}U. Areas with NORM had a higher concentration of ^{232}Th than areas with TENORM and the reference area. For ^{210}Po all the measured values, except a high concentration measured in Bolladalen, were comparable to the world average (Table 13).

Soil from certain areas contained concentrations of arsenic (As), lead (Pb), chromium (Cr) and nickel (Ni) that exceeded Norwegian standard values (Table 14). The concentrations of both radionuclides and metals in soil were very inhomogeneously distributed.

Table 13. Radionuclide concentrations (in f.w.) in soil from Fen area.

Site/metal	^{232}Th (mg/kg)	^{238}U (mg/kg)	Po-210 (Bq/kg)
Søve (N= 15) Range Average	 13 – 720 290 ± 272	 3 – 175 72 ± 66	 71 - 118 87 ± 27
Fen (N=16) Range Average	 391 – 1300 673 ± 292	 5 – 12 9 ± 2	 38 – 71 57 ± 17
Rullekollen (N=20) Range Average	 370 – 1685 1218 ± 367	 12 – 42 24 ± 6	 76 – 113 96 ± 19
Bolladalen (N=31) Range Average	 3 – 6531 1676 ± 1482	 0,2 – 70 17 ± 18	 29 – 858 371 ± 433
Torsnes (N=22) Range Average	 13 – 658 199 ± 204	 2 – 9 4 ± 2	 49 – 92 67 ± 22

Table 14. Metal concentrations in soil from Fen area mg/kg (f.w.).

Site/metal	Cr	Pb	Sc	Ni	Cu	As	Cd
Søve (N= 15) Range Average	 5 - 78 22 ± 21	 15 – 121 62 ± 33	 3 – 8 6 ± 1	 5 – 42 15 ± 11	 9 – 148 67 ± 47	 3 – 11 7 ± 3	 0.2 – 1.0 0.5 ± 0.3
Fen (N=16) Range Average	 20 – 100 64 ± 23	 120 - 250 173 ± 44	 33 – 79 56 ± 13	 23 – 73 48 ± 15	 10 – 127 62 ± 27	 7 – 45 18 ± 9	 0.6 – 2.2 1,2 ± 0,4
Rullekollen (N=20) Range Average	 90 – 150 103 ± 13	 59 – 358 168 ± 81	 50 – 116 98 ± 19	 66 – 110 81 ± 10	 23 – 74 45 ± 13	 6 – 32 17 ± 7	 1.2 – 2.0 1.7 ± 0.2
Bolladalen (N=31) Range Average	 4 – 81 25 ± 13	 37 – 342 151 ± 90	 1 – 213 110 ± 69	 2 – 48 25 ± 8	 7 – 47 19 ± 13	 2 – 72 25 ± 16	 0.3 – 3.1 1.9 ± 0.8
Torsnes (N=22) Range Average	 13 – 170 49 ± 42	 5 – 91 20 ± 20	 5 – 148 20 ± 29	 8 – 92 32 ± 25	 6 – 91 28 ± 28	 1 – 26 7 ± 6	 0,1 – 1,1 0.5 ± 0.3
Normverdier i norsk jord (KLIF 2009) (mg/kg)	50	60	----	60	100	8	1,5

The Loviisa sampling site was selected based on higher than average external dose rates at the area, which is located on a large rapakivi granite massif of southeastern Finland. The rapakivi granite has the highest uranium concentrations of the common rocks in Finland. The soil samples, however, exhibited normal radionuclide concentrations in the uranium and thorium series (Table 15). The Espoo sampling site, however, exhibited higher than average thorium series activity concentrations in the mineral horizons B and C, about 80 Bq/kg. In deeper soil horizons, we can assume that ^{228}Ra and the parent ^{232}Th are in near equilibrium which suggests thorium concentration of 20 mg/kg.

Due to natural deposition of ^{210}Pb (and ^{210}Po) from outdoor air radon, the topmost soil horizons (litter and organic soil) exhibited activity concentrations which are at least an order of magnitude higher than in the mineral soil horizons. ^{137}Cs concentrations varied and were the lowest at the Kuusamo sampling site.

Table 15. Activity concentrations (d.w.) in 4–5 different soil horizons at Espoo, Loviisa and Kuusamo sampling sites. All activity concentrations are expressed per dry weight and the related uncertainty is expressed using coverage factor k=1, which gives approximately a 68% confidence interval.

Location	Horizon	U-238 Bq/kg	Ra-228 Bq/kg	Ra-226 Bq/kg	Pb-210 Bq/kg	Po-210 Bq/kg	Cs-137 Bq/kg	K-40 Bq/kg
Espoo	Litter	<1.2	2.4±1.0	7.5±0.5	430±20	580±50	140±10	51±5
	O	38±8	16±2	13±1	390±30	540±40	290±20	180±20
	B	32±5	81±4	27±1	22±2	n/d	27±2	610±40
	C	27±5	79±4	23±1	53±4	n/d	80±5	750±40
Loviisa	Litter	1.2±0.5	1.6±0.9	9.5±0.5	460±30	500±50	150±10	45±6
	O	45±10	11±1	31±1	330±20	440±40	510±30	380±20
	B	26±5	25±1	31±1	17±1	n/d	9.8±0.6	1000±100
	C	39±5	24±1	25±1	22±1	n/d	31±2	1000±100
Kuusamo	Litter	<1.2	8.9±1.7	8.1±0.6	410±30	400±30	34±2	48±7
	O	9.6±4.0	5.0±0.5	12±1	330±20	450±40	83±5	63±6
	A	26±9	12±1	22±1	<200	n/d	24±1	290±20
	B	20±3	16±1	19±1	10±1	n/d	1.7±0.1	310±20
	C	16±3	16±1	11±0	<60	n/d	7.6±0.4	480±20

Stable lead, selenium (^{210}Pb and ^{210}Po analogues) and uranium analyses were performed on the litter and organic soil horizons by mass spectrometry (Table 16). The samples were digested by nitric acid and, hence, the mineral component of the organic soil was not determined. Unfortunately, the detection limits of the metals at the commercial laboratory were high and good results were obtained only for stable lead.

Table 16. Results (d.w.) of the stable element analyses for lead and selenium carried out by MetropoliLab, Helsinki. The results of lead and selenium hold 20% uncertainty and those of uranium 40%.

Location	Sample	Pb mg/kg	Se mg/kg	U mg/kg
Espoo	Litter	10	<1	<0.1
	Organic soil	58	<1	0.1*
Loviisa	Litter	15	<1	0.1
	Organic soil	55	<1	0.7*
Kuusamo	Litter	8.1	<1	<0.1
	Organic soil	34	<1	0.1*

* Acid digestion of organic soil, mineral component (in which most uranium resides) was discarded

6.2 Plant and mushroom samples

The concentrations of ^{238}U, ^{232}Th and ^{210}Po in raspberry plant indicate that ^{232}Th has the highest concentration in the plant, but due to high specific activity ^{210}Po has the highest activity concentration in the plant. Concentrations of all radionuclides in leaf, stems and berries are low compared to the content of radionuclides in soil, and no significant differences in concentration were discovered between the areas. Berries have lower content of all the radionuclides compared to the other plant parts.

For lingonberries, blueberries and chanterelle the highest concentration of ^{238}U and ^{232}Th is found in shrub of blueberry and in chanterelle sampled in July. For ^{210}Po the highest concentrations were found in shrub of lingonberry and shrub of blueberry. The concentration of ^{210}Po is also higher in the chanterelle collected in July than the concentration collected in August. Lingonberries have higher concentration of all the radionuclides than blueberries and raspberries (Tables 17 and 18).

Table 17. Total concentrations of ^{232}Th, ^{238}U and ^{210}Po in berries and plant parts of raspberries collected in Norway (f.w.).

Part of plant Site	^{232}Th (mg/kg)	^{238}U (mg/kg)	^{210}Po (Bq/kg)
Raspberries			
Søve (N=1)	< 0.0008	< 0.00020	0.09
Fen (N=1)	< 0.0008	< 0.00020	0.2
Rullekollen	--------	-------	--------
Torsnes (N=1)	0.00095	< 0.00020	0.2
Leaves			
Søve (N=2) (Avg ± SD)	0.0059 ± 0.0013	0.0032 ± 0.0003	7.0 ± 1.2
Fen (N=2) (Avg ± SD)	0.070 ± 0.053	0.0013 ± 0.0007	13 ± 11
Rullekollen (N=2) (Avg ± SD)	0.0099 ± 0.0050	0.0008 ± 0.0007	4.3 ± 0.03
Torsnes (N=1)	0.035	0.0072	9.5
Stem			
Søve (N=2)(Avg ± SD)	0.0037 ± 0.0035	0.0019 ± 0.0002	6.5 ± 5.9
Fen (N=2)(Avg ± SD)	0.0068 ± 0.0005	0.0007 ± 0.0003	8.7 ± 9.8
Rullekollen (N=2) (avg ± SD)	0.020 ± 0.025	0.0015 ± 0.0017	3.8 ± 0.6
Torsnes (N=1)	0.0035	0.0013	4.4

Table 18. Total concentrations of ^{232}Th, ^{238}U and ^{210}Po in lingonberries, blueberries and chanterelle collected in Norway (f.w.).

	^{232}Th (mg/kg)	^{238}U (mg/kg)	^{210}Po (Bq/kg)
Lingonberries (N=1)	0.090	0.0011	0.5
Lingonberry plant (N=2) (Avg ± SD)	0.0093 ± 0.0051	0.00070 ± 0.00006	16 ± 3
Blueberries (N=1)	0.0062	< 0.00020	0.2
Blueberry plant (N=2) (Avg ± SD)	0.10 ± 0.14	0.0012 ± 0.0009	12 ± 1
chantarelle July (N=1)	0.13	0.0078	5.3
Chantarelle August (N=2) (Avg ± SD)	0.020 ± 0.009	0.0006 ± 0.0002	2.0 ± 0.5

The concentrations of radionuclides in berries collected in Finland were generally low and compare favourably to values reported by previous studies and concentrations measured by UMB during this study (Table 19). At Kuusamo sampling site both lingonberries and blueberries were collected and the concentrations of radium isotopes, ^{210}Pb and ^{210}Po were similar.

Table 19. The activity concentrations (d.w.) in collected berries at Espoo, Loviisa and Kuusamo sampling sites. All activity concentrations are expressed per dry weight and the related uncertainty is expressed using coverage factor k=1, which gives approximately a 68% confidence interval.

Location	Berry	U-238 Bq/kg	Ra-228 Bq/kg	Ra-226 Bq/kg	Pb-210 Bq/kg	Po-210 Bq/kg	Cs-137 Bq/kg	K-40 Bq/kg
Espoo	*Vaccinium myrtillus*	<0.03	0.90±0.07	0.87±0.18	0.67±0.06	0.57±0.07	59±3	90±5
Loviisa	*Vaccinium myrtillus*	<0.02	1.2±0.1	3.6±0.4	1.1±0.1	0.65±0.07	58±3	86±5
Kuusamo	*Vaccinium myrtillus*	<0.03	2.7±0.2	3.8±0.6	1.4±0.1	0.61±0.09	75±4	320±20
	Vaccinium vitis-idaea	<0.04	2.1±0.2	2.2±0.8	1.9±0.2	0.70±0.11	26±2	160±10

Table 20. Results (d.w.) of the element analyses for lead and selenium carried out by MetropoliLab, Helsinki. The results of lead and selenium hold 20% uncertainty, those of uranium 40%.

Location	Sample	Pb mg/kg	Se mg/kg	U mg/kg
Espoo	*Vaccinium myrtillus*	2.9	<1	<0.1
Loviisa	*Vaccinium myrtillus*	16	<1	<0.1
Kuusamo	*Vaccinium myrtillus*	1.4	<1	<0.1
	Vaccinium vitis-idaea	0.92	<1	<0.1

Much higher ^{210}Pb and ^{210}Po activity concentrations were measure in mushrooms (Table 21). It is interesting that the measured values did not vary greatly and were in the same order of magnitude. The ^{210}Pb and ^{210}Po levels reported by previous studies indicated large variation in the concentrations (e.g. [23] and [24]). In this study we were unable to find *boletus* at the sampling sites which is unfortunate considering the fact that the highest activity concentrations of ^{210}Pb and ^{210}Po have been reported for this genus.

The isotopes of radium were generally below detection limit. Many of the samples were counted much shorter times with gamma spectroscopy than the other samples, which explains the rather high detection limits for these samples.

Table 21. The activity concentrations (d.w.) in mushrooms collected at Espoo and Loviisa sampling sites. All activity concentrations are expressed per dry weight and the related uncertainty is expressed using coverage factor k=1, which gives approximately a 68% confidence interval.

Location	Mushroom	U-238 Bq/kg	Ra-228 Bq/kg	Ra-226 Bq/kg	Pb-210 Bq/kg	Po-210 Bq/kg	Cs-137 Bq/kg	K-40 Bq/kg
Espoo	*Lactarius rufus**	<1.2	n/d	n/d	13±1	26±3	n/d	n/d
	Cantharellus cibarius	<1.2	<12	<7.3	13±1	17±2	1700±100	1500±100
	Craterellus tubaeformis	<1,2	<5.4	3.6±1.1	12±1	25±3	3800±200	1300±100
	Craterellus cornucopioides	<1.2	<6.3	<3.9	6.2±0.5	12±1	420±20	1600±100
Loviisa	*Lactarius rufus*	<1.2	<11	<8.9	12±1	11±1	2200±100	480±50
	Kuehneromyces mutabilis	<1.2	<27	22±4	3.9±0.4	4.1±0.6	1100±100	1100±100
	Cantharellus cibarius	<1.2	<6.9	<3.9	8.3±0.7	11±1	1200±100	1400±100
	Craterellus tubaeformis	<1.2	<9.5	<6.4	12±1	39±4	3400±200	1300±100

* due to a very small sample, gamma spectroscopy was not performed

Table 22. Results (d.w.) of the stable element analyses for lead and selenium carried out by MetropoliLab, Helsinki. The results of lead and selenium hold 20% uncertainty, those of uranium 40%.

Location	Sample	Pb mg/kg	Se mg/kg	U mg/kg
Espoo	*Lactarius rufus*	1.5	<1	<0.1
	Cantharellus cibarius	0.89	<1	<0.1
	Craterellus tubaeformis	0.89	<1	<0.1
	Craterellus cornucopioides	1.0	<1	<0.1
Loviisa	*Lactarius rufus*	1.2	<1	<0.1
	Kuehneromyces mutabilis	1.1	<1	<0.1
	Cantharellus cibarius	2.3	<1	<0.1
	Craterellus tubaeformis	1.1	<1	<0.1

The Vikdrolen samples from Sweden showed high concentrations and uneven distribution of ^{226}Ra in top soil, up to 770 Bq/kg (d.w.). The ^{228}Ra concentration was significantly lower, approx. 40 Bq/kg (d.w.). No radium isotopes, however, were detected in the mushrooms or berries. All radium concentrations in berries from Harbo site were also below detection limits (Table 23).

Table 23. The activity concentrations (d.w.) in mushrooms, berries, soil, water and sediment collected at Vikdrolen and Harbo sampling sites. All activity concentrations are expressed per dry weight and only values with less than 5% error are reported.

Location	Sample type	Pb-214 Bq/kg	Bi-214 Bq/kg	Ra-226 Bq/kg	Pb-212 Bq/kg	Ac-228 Bq/kg	Cs-137 Bq/kg	K-40 Bq/kg
Vikdrolen	**Fungi**							
	Macrolepiota procera	-	-	-	-	-	3876	-
	Hedgehog mushroom	-	-	-	-	-	-	19038
	Clavaria mushroom	-	-	-	-	-	1711	17818
	Berries							
	Vaccinium myrtillus (unripe)	-	-	-	-	-	-	-
	Vaccinium myrtillus (ripe)	-	-	-	-	-	-	-
	Vaccinium myrtillus (ripe)	-	-	-	-	-	-	376
	Vaccinium myrtillus (ripe)	-	-	-	-	-	-	344
	Ribes rubrum (ripe)	-	-	-	-	-	-	796
	Ribes rubrum (mixed ripe/unripe)	-	-	-	-	-	-	715
	Ribes rubrum (unripe)	-	-	-	-	-	-	819
	Ribes rubrum (unripe)	-	-	-	-	-	-	801
	Rubus idaeus (ripe)	-	-	-	-	-	-	-
	Rubus idaeus (unripe)	-	-	-	-	-	-	-
	Fragaria vesca	-	-	-	-	-	-	687
	Vaccinium vitis-idea (unripe)	-	-	-	-	-	-	-
	Soil							
	Top soil	766	755	761	35	44	16	1110
	Top soil	-	-	-	-	-	-	-
	Top soil	123	135	129	-	10	42	618
	Top soil	70	63	67	-	28	42	649
	Top soil	169	178	174	-	20	50	925

Table 23. Continued from previous page.

Location	Sample type	Pb-214 Bq/kg	Bi-214 Bq/kg	Ra-226 Bq/kg	Pb-212 Bq/kg	Ac-228 Bq/kg	Cs-137 Bq/kg	K-40 Bq/kg
Vikdrolen	**Sediment stream**							
	Sediment	175	195	185	29	36	-	859
	Sediment	50	50	50	19	23	2	964
	Sediment	135	150	143	24	30	-	1130
	Sediment	445	486	466	38	571*	-	856
	Sediment	312	365	339	31	37	7	1050
	Sediment ditch							
	Sediment	1640	1610	1625	63	93	-	583
	Sediment	-	-	-	-	-	-	-
	Sediment+water	-	-	-	-	-	-	-
	Water							
	Water	-	-	-	-	-	-	-
	Water	-	-	-	-	-	-	-
	Plant							
	Vaccinium myrtillus	-	-	-	-	-	-	-
	Vaccinium myrtillus	-	-	-	-	-	-	-
	Rubus idaeus	-	-	-	-	-	-	-
Harbo	**Berries**							
	Vaccinium myrtillus (ripe)	-	-	-	-	-	2197	-
	Vaccinium myrtillus (ripe)	-	-	-	-	-	1608	-
	Vaccinium vitis-idea (ripe)	-	-	-	-	-	935	424
	Vaccinium vitis-idea (ripe)	-	-	-	-	-	1185	-

* error 5,3 %.

The top soil at the Danish site (0–5 cm) contained 390 Bq/kg (d.w.) of ^{210}Po and 310 Bq/kg (d.w.) of ^{210}Pb. These values were similar to those measured at the Finnish and Norwegians sites. The highest concentrations of ^{210}Po (589 and 94.1 Bq/kg d.w.) were found in false chanterelle (*Hygrophoropsis aurantiaca*) which is edible but seldom collected since it is generally not considered tasty. Hygrophoropsidaceae belong to the Boletales and are phylogenetically related to *bolete* [41].

Table 24. The measured activity concentrations at the Danish site. Counting time was adjusted so that uncertainty was below 10% in all cases.

	Dry weight	Dry weight	Dry weight
	^{210}Po [Bq/kg]	^{137}Cs [Bq/kg]	^{210}Pb [Bq/kg]
Sheathed woodtuft (*Kuehneromyces mutabilis*)	5.6	48	<10 Bq/kg
False Chanterelle (*Hygrophoropsis aurantiaca*)	598	NM	<10 Bq/kg
Clouded agaric or cloud funnel (*Clitocybe nebularis*)	3.2	49	<10 Bq/kg
Charcoal burner (*Russula cyanoxantha*)	5.2	30	<10 Bq/kg
Bay bolete (*Boletus badius*, previous *Xerocomus badius*)	4.3	285	<10 Bq/kg
Dotted stem bolete (*Boletus luridiformis*)	13.5	110	<10 Bq/kg
Dotted stem bolete (*Boletus luridiformis*)	19.3	161	<10 Bq/kg
False Chanterelle (*Hygrophoropsis aurantiaca*)	94.1	3.5	<10 Bq/kg
Penny bun, porcino or cep (*Boletus edulis*)	21.7	86	<10 Bq/kg
Champignon mushroom (*Agaricus bisporus*)	0.9	0.8	<10 Bq/kg
Blackberries (*Rubus fruticosus*)	0.2	ND	NM
Raspberries (*Rubus idaeus*)	0.2	ND	NM
Site-A: Soil upper 5 cm (litter)	390	56	310
Site-A: Soil 5-25 cm (clay with organic matter)	110	12	97

6.3 Transfer factors

Calculations of transfer factors (Figures 5 and 6, data in appendix) for raspberry plant indicate a higher uptake in leaves than in berries. Transfer factors for the aboveground plant parts in areas with NORM and TENORM are low. This is probably due to plant roots acting as a barrier that prohibits uptake to leaves, stems and berries. The highest uptake of ^{232}Th and ^{238}U is found in the chanterelle collected in July. Chanterelle collected in August has a lower uptake. This may be due to variations in uptake due to the degree of maturity. The highest uptake of ^{210}Po is found in shrub of lingonberry and shrub of blueberry. The relationship between uptake in the chanterelle collected in July and August is also noticeable for ^{210}Po.

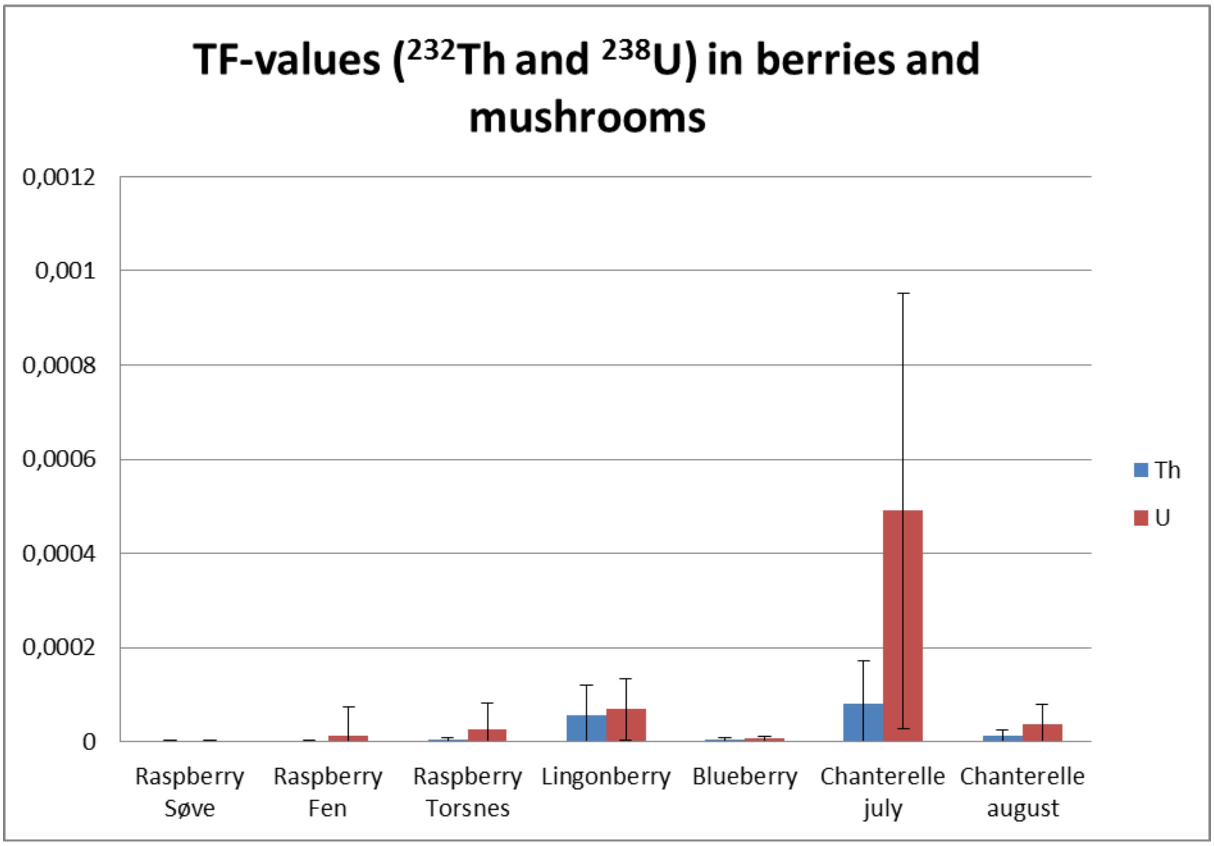


Figure 5. Transfer factors of U and Th in berries and mushrooms from Fen area, Norway.

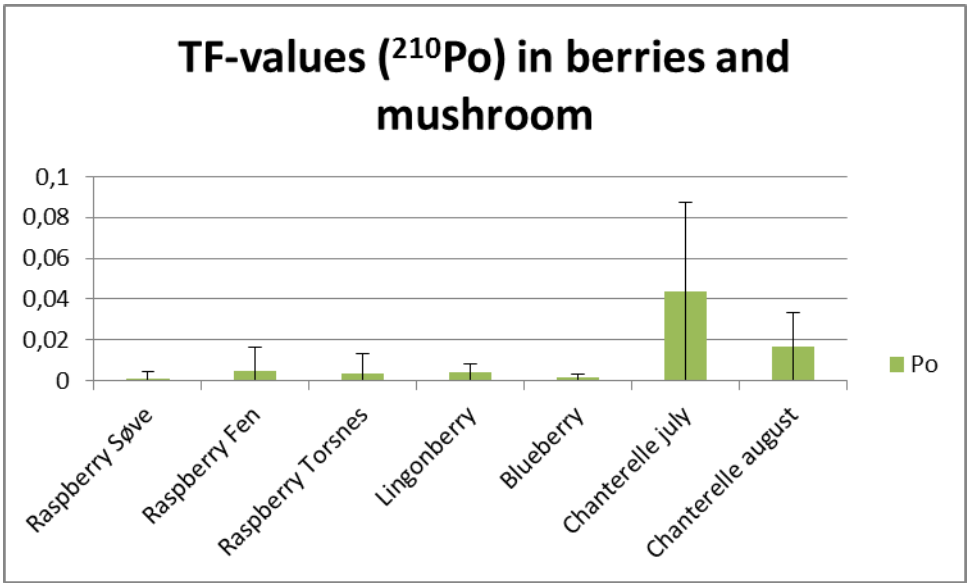


Figure 6. Transfer factors of Po-210 in berries and mushrooms from Fen area, Norway.

The roots of the *vaccinium* plants are in the organic soil and hence the transfer factors were calculated for this horizon (Figure 7). As all the uranium analyses of ashed berry samples carried out by the MetropolLab were below detection limit of 0.1 mg/kg, we can only provide upper limits for the transfer factors. For the blueberry samples from Espoo, Loviisa and Kuusamo, these values were <0.0007, <0.0005 and <0.004, respectively. The TF for Kuusamo lingonberry was <0.003.

The transfer factors for radium isotopes varies between 0.058 and 0.53 being 0.2 on average (Figure 7). The transfer factor seemed to be more depended on sampling location than on species as both the blueberry and the lingonberry in Kuusamo had the highest TF's. The difference of TF between the isotopes at Kuusamo may be due to the randomized soil sampling: it is possible that the soil samples had higher than average ^{226}Ra concentration and thus were not representative, or naturally vice versa.

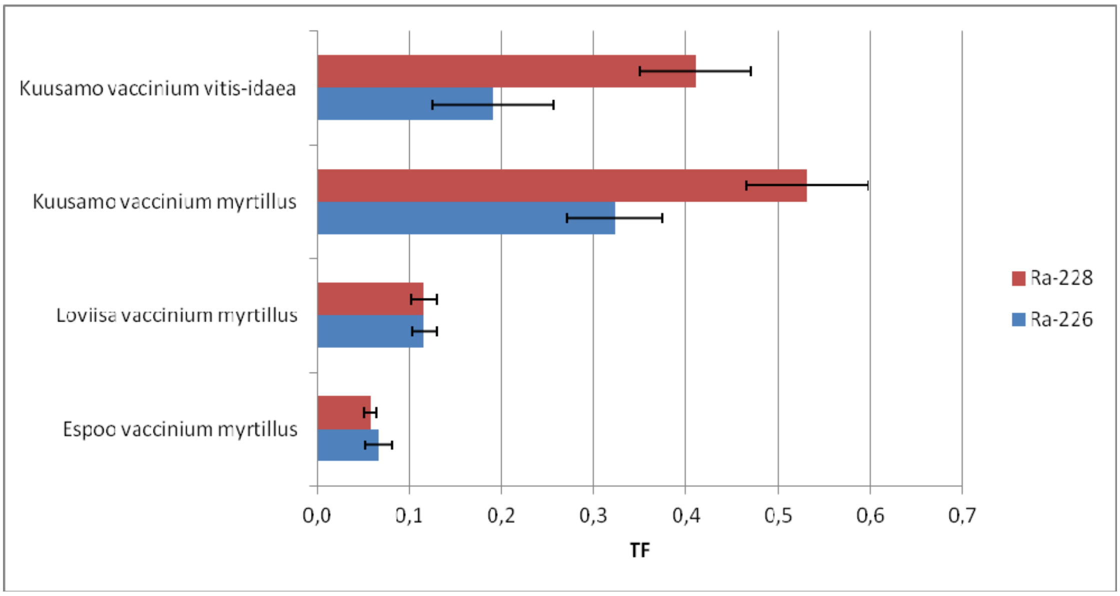


Figure 7. Transfer factors of radium isotopes (organic layer – berry) for berries collected in Finland.

Much smaller transfer factors were obtained for ^{210}Pb and ^{210}Po isotopes, the values for ^{210}Pb ranged between 0.0017 and 0.0059 and for ^{210}Po between 0.0011 and 0.0016. The mean TF's for ^{210}Pb and ^{210}Po isotopes were 0.0038 and 0.0014, respectively (Figure 8). Compared to radium isotopes, the transfer of lead and polonium into berries is about two orders of magnitude smaller.

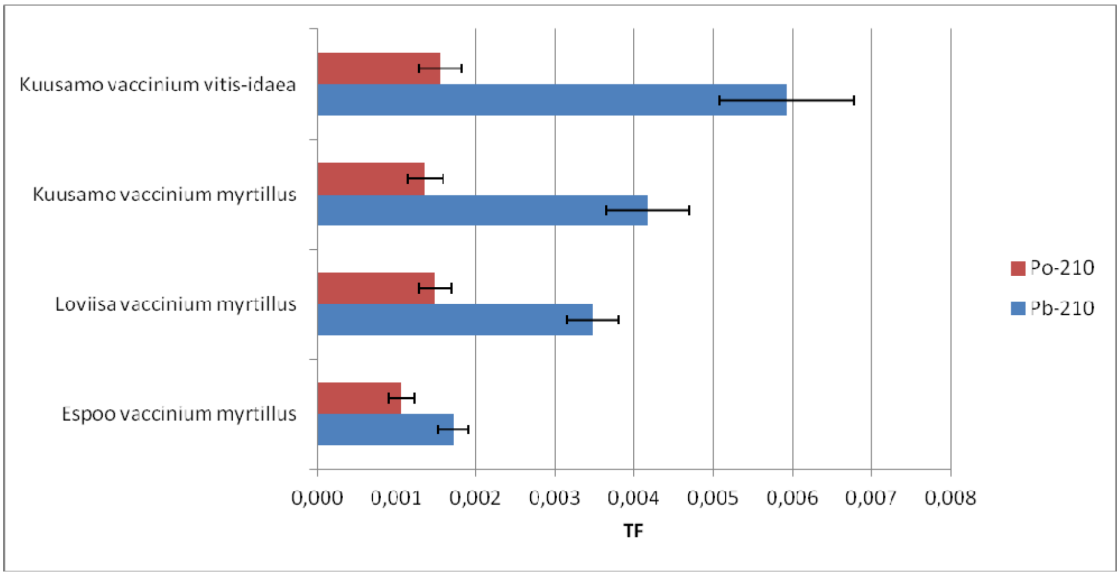
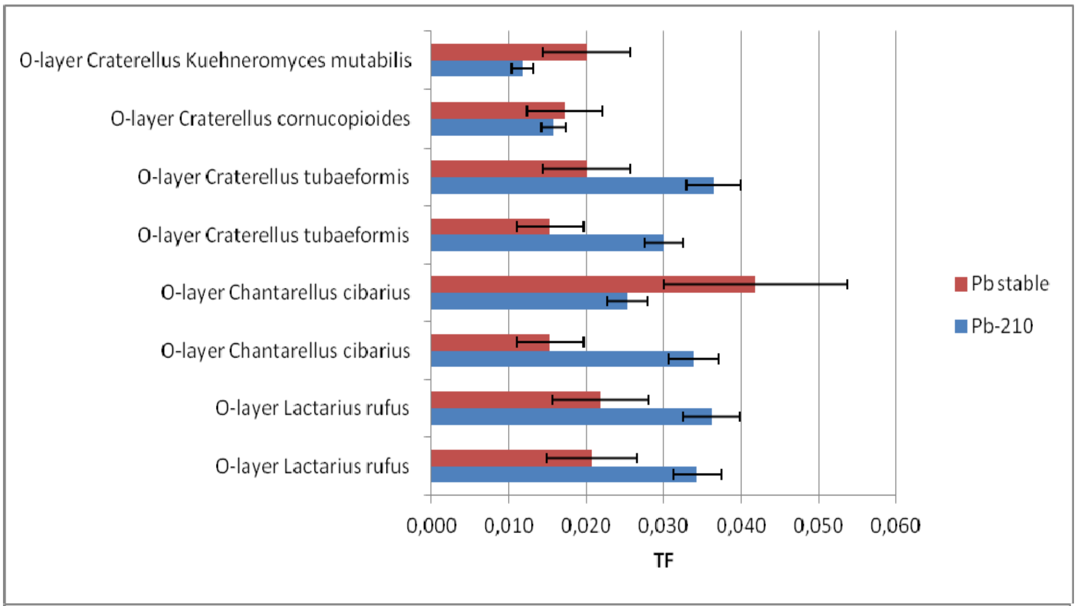


Figure 8. Transfer factors of ^{210}Pb and ^{210}Po isotopes (organic layer – berry) for berries collected in Finland.

Fungi are on of the main decomposers of decaying plant matter in soil. Therefore we wanted to investigate which soil horizon is representative for the study of radionuclides into fungal fruit bodies. Baeza et al. [16] reported that the mycelium is mainly located in the surface layer of soil (0–5 cm). We investigated the difference between litter and organic soil layer by comparing the transfer between ^{210}Pb and stable Pb (Figure 9).

Litter layer (L) had on average 15% higher ^{210}Pb activity concentrations than the organic soil layer (O-horizon). However, the O-horizon had on average 4.5 times higher stable lead concentration than the litter layer. If we assume similar behavior for these isotopes we can compare the transfer from these horizons into fungus and find out the location of lead intake by the mycelium (Figure 9). The transfer factor values calculated for the organic layer (O-horizon) had more similar values, which suggests that, although fungi are one of the main decomposers of decaying plant matter, more lead intake occurs from the O-horizon.

The transfer factors of ^{210}Pb from organic soil (O-horizon) into mushrooms varied between 0.012 and 0.036 and the mean value was 0.028. The same figures for stable lead were 0.015, 0.042 and 0.22, respectively. The transfer factor of ^{210}Po from organic soil into mushrooms varied more, between 0.009 and 0.089, and the mean value was 0.037 (Figure 10).



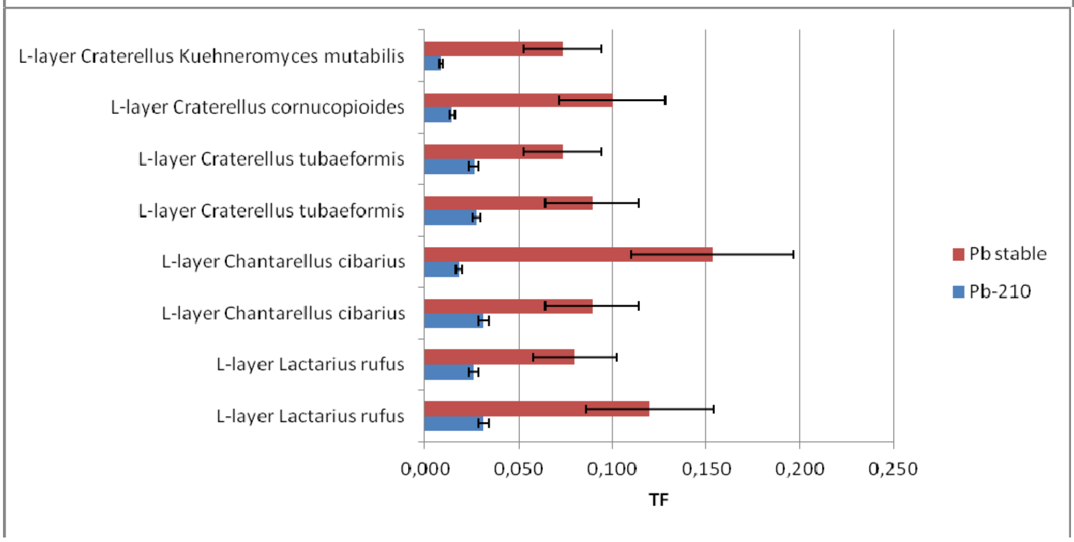


Figure 9. Transfer factors of stable lead and ^{210}Pb and mushroom for the organic horizon (O-layer) and litter (L-layer).

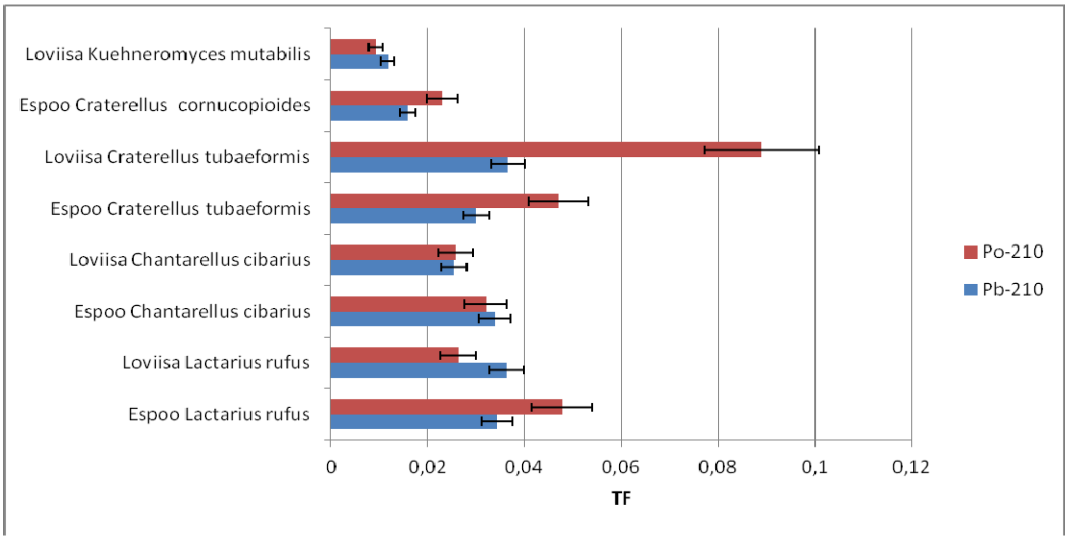


Figure 10. Transfer factors of ^{210}Pb and ^{210}Po from organic soil to mushroom.

The transfer factors for radium isotopes were difficult to asses due to the high detection limits during the measurements. Only two results were obtained for ^{226}Ra, which were 0.27±0.09 and 0.70±0.13. These values, however, compare favorably to those presented by Baeza *et al.* [15], which were 0.003–1.4 depending on mushroom species. The upper limits and the few TF's obtained for radium isotopes and uranium are presented in Table 25.

Table 25. Transfer factors of radium isotopes and uranium (organic soil – mushroom).

Location	Sample	TF U	TF ^{228}Ra	TF ^{226}Ra
Espoo	Lactarius rufus	<0.032	n/d	n/d
	Cantharellus cibarius	<0.032	<0.77	<0.56
	Craterellus tubaeformis	<0.032	<0.35	0.27±0.09
	Craterellus cornucopioides	<0.032	<0.40	<0.30
Loviisa	Lactarius rufus	<0.027	<1.0	<0.29
	Kuehneromyces mutabilis	<0.027	<2.6	0.70±0.13
	Cantharellus cibarius	<0.027	<0.65	<0.13
	Craterellus tubaeformis	<0.027	<0.90	<0.21

Summary chart of the transfer factors (organic soil – mushroom) for polonium is presented in Figure 11. The transfer factors were generally between values 0.01 and 0.1. The *Hygrophoropsis aurantiaca*, however, exhibited high TF-values (0.24–1.5) for polonium. Similar charts were not drawn for other radionuclides since the measured data was much more limited.

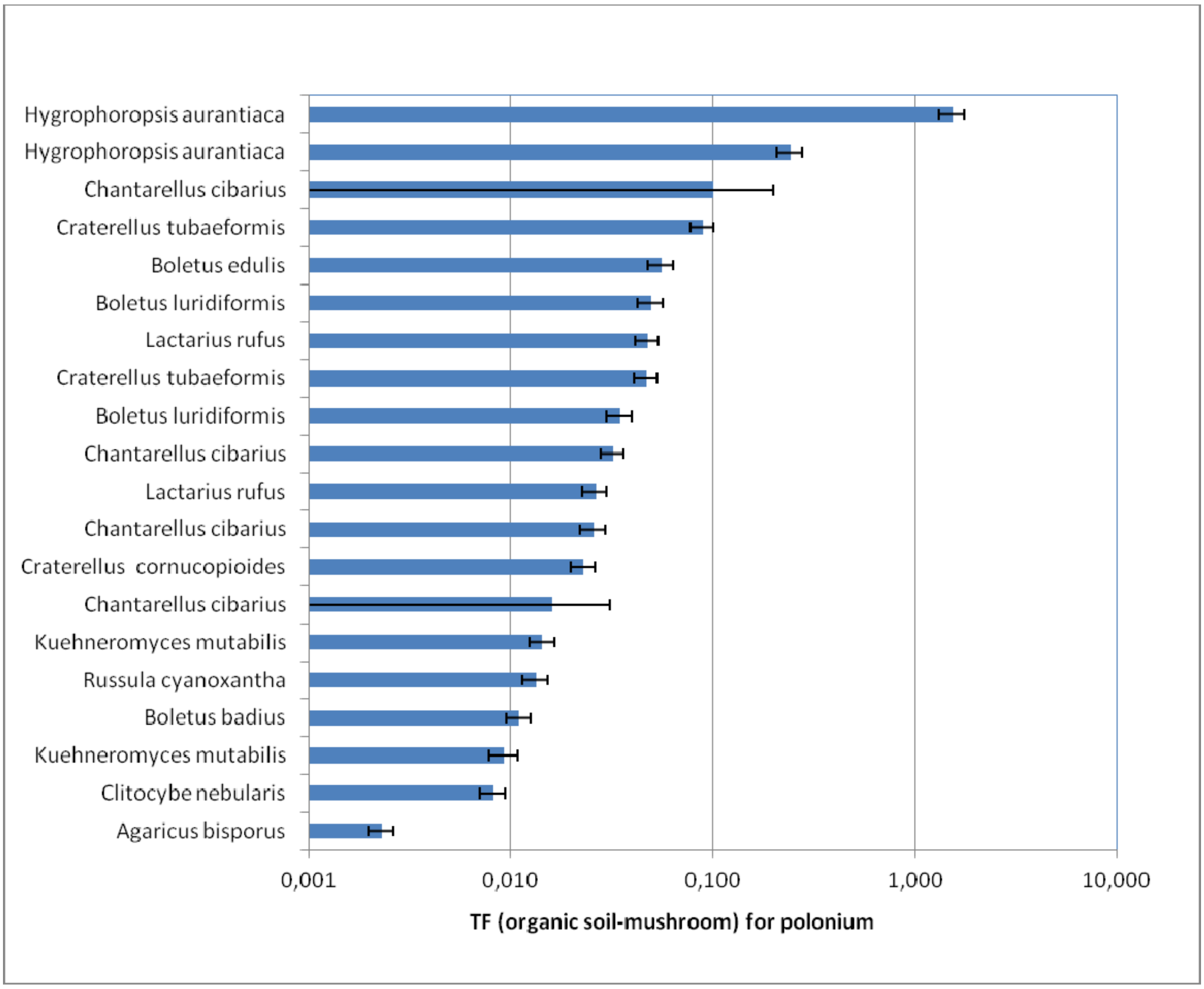


Figure 11. Summary of transfer factors (organic soil–mushroom) for polonium for all the samples.

6.4 Effective doses

The highest doses from naturally occurring radionuclides in mushrooms and berries in Fen Central Complex are in mushrooms collected in July and lingonberries (Tables 26 and 27). ^{210}Po is the major attributor to the doses from berries and mushrooms in this site. To achieve doses of 0.1 mSv/a adult individuals have to consume 14 kg of chanterelle and 146 kg of lingonberries. To achieve the same doses for small children (1-year-olds), they have to consume 2 kg chanterelle and 22 kg of lingonberries. The estimated world average dose due to ingestion of natural radioactivity is 0.29 mSv/a and the total dose due to natural radioactivity is 2.4 mSv/a. To achieve these considerable doses from mushrooms and berries in Fen Central Complex, individuals have to consume a relatively large amount of mushrooms and berries. Several of the areas in this study are rocky and barren. This makes collection of large amounts of mushrooms and berries difficult, and hence it is difficult to achieve large doses for individuals. In this site the chanterelle is the only mushroom analyzed. Other species of mushroom may contain higher concentrations of radionuclides, and hence cause higher doses to the population.

Table 26. Dose calculations for berries and mushrooms (calculated from 2.7 kg mushrooms and 24.5 kg berries per person per year)

Sample	^{210}Po (µSv/year)	^{232}Th (µSv/year)	^{238}U (µSv/ year)	Total dose (µSv/ year)
Søve raspberries	2.6	---	---	2.6
Fen raspberries	5.9	---	---	5.9
Torsnes raspberries	5.9	0.022	---	5.9
lingonberries	14	2.1	0.015	16
blueberries	5.9	0.14	---	6.0
Chantarelle July	17	2.1	0.075	19
Chantarelle August 1	7.8	0.38	0.0063	8.2
Chantarelle August 2	5.2	0.30	0.0066	5.5

Table 27. Dose calculations for berries and mushrooms towards 1 year old child (calculated from 2.7 kg mushrooms and 24.5 kg berries per person per year)

Prøve	^{210}Po (µSv/ year)	^{232}Th (µSv/ year)	^{238}U (µSv/ year)	Total dose (µSv/ year)
Søve raspberries	19	---	---	19
Fen raspberries	43	---	---	43
Torsnes raspberries	43	0.04	---	43
lingonberries	108	4	0.04	112
blueberries	43	0.3	---	43.3
Chantarelle July	126	4	0.2	130.2
Chantarelle August 1	57	0.7	0.02	57.7
Chantarelle August 2	38	0.6	0.02	38.6

For the intake estimate for Finns, we make separate calculations for an average user and the most consuming 10%. The weighing of different species of berries was not carried out due to the limited number (N = 4) of samples. We calculated the mean activity concentrations and standard deviation for the measured radionuclides (in fresh weight) and used these as generic values (Table 28). ^{137}Cs was included in order to make a rough comparison on the proportion of dose due to this fall-out radionuclide and to compare the value to the large number of berry samples in which ^{137}Cs has been measured.

For an average adult user (8 kg of wild berries per year), the effective dose due to naturally occurring radionuclides (uranium, $^{228,226}Ra$, ^{210}Pb and ^{210}Po) the effective dose was estimated as 3.7±0.8 µSv per year. The effective dose for the most consuming 10% of population (28 kg/a) was assessed as13±3 µSv/a due to NOR's.

In this limited number of samples, ^{137}Cs would add 0.7±0.2 µSv to this value since the mean activity concentration was 6.9±2.3 Bq/kg (f.w.). All samples were collected, however, from areas with only moderate Chernobyl fall-out. The 26 blueberry and lingonberry samples, collected for environmental surveillance program in 2012, had mean (and range) activity concentration of 37 (2–140) Bq/kg (f.w.). It is interesting, however, that in the berry samples collected in this study, the naturally occurring radionuclides covered about 80% of the total effective dose (if we exclude ^{90}Sr, which was not measured) and hence were the main contributor to the effective dose received from eating wild berries. Isotopes of radium, ^{210}Pb and ^{210}Po contributed to the dose about equal proportions. By using the mean activity concentration of ^{137}Cs from the 26 samples measured in 2012, the proportion would be about 50%.

Table 28. Dose calculation for adult Finns from naturally occurring radionuclides in wild berries as well as from ^{137}Cs (four berry samples).

	Generic value mBq/kg (f.w.)	8 kg/a µSv/a	28 kg/a µSv/a
U-238	<4	<0.001	<0.005
Ra-228	220±100	1.2±0.5	4.2±1.9
Ra-226	330±160	0.74±0.35	2.6±1.2
Pb-210	170±80	0.91±0.42	3.2±1.5
Po-210	83±12	0.79±0.11	2.8±0.4
Cs-137	6900±2300	0.72±0.23	2.5±0.8
NOR's		3.7±0.8	13±3
total		4.4±0.8	15±3

It is difficult to assess effective doses from radium isotopes in mushrooms, since only two values were obtained for ^{226}Ra and none for ^{228}Ra, all the other concentrations were below detection limit. Here we assessed the generic value for radium isotopes by using the half value of the detection limits for the samples which were below detection limit (Table 29). The two results above detection limit for ^{226}Ra were 0.22±0.07 and 1.1±0.2 Bq/kg (f.w.). Hence, large uncertainties are related to the dose assessments regarding these isotopes.

Nevertheless, it is obvious, that ^{210}Po is an important contributor to the effective dose to the consumers of mushrooms in Espoo and Loviisa. In our study, these mushrooms contained about 1.4 Bq/kg (f.w.) of ^{210}Po, which causes about the same effective dose as ^{137}Cs. Kostiainen and Ylipieti [42] estimated that the mean effective doses for consumers of mushrooms using 1.5 kg/y consumption rate in 2000–2008. The effective doses varied between 1 and 12 µSv per year depending on the amount of Chernobyl fall-out in the area. Espoo is located in low fall-out area (0–6 kBq/m^2 1.10.87) and Loviisa in moderate fall-out area (6–11 kBq/m^2 1.10.87).

Table 29. Dose calculation for adult Finns from naturally occurring radionuclides in wild mushrooms as well from ^{137}Cs (8 mushroom samples).

	Generic value Bq/kg (f.w.)	1 kg/a µSv/a	5.7 kg/a µSv/a
U-238	<0.93	<0.004	<0.02
Ra-228	0.39±0.18	0.27±0.13	1.5±0.72
Ra-226	0.37±0.35	0.10±0.10	0.58±0.56
Pb-210	0.73±0.27	0.50±0.19	2.9±1.1
Po-210	1.4±1.0	1.7±1.2	9.6±6.7
Cs-137	120±100	1.8±1.2	10±7
NOR's		2.6±1.2	15±7
total		4.4±1.8	25±10

7 Conclusions

^{210}Po is the major attributor to the doses from berries and mushrooms. The estimated world average dose due to ingestion of natural radioactivity is 0.29 mSv/a and the total dose due to natural radioactivity is 2.4 mSv/a. To achieve these considerable doses from mushrooms and berries in Fen Central Complex, individuals have to consume a relatively large amount of mushrooms and berries. Several of the areas in this study is rocky and barren. This makes collection of large amounts of mushrooms and berries difficult, and hence it is difficult to achieve large doses for individuals. In this report, the chanterelle is the only Norwegian mushroom analyzed. Other species of mushroom may contain higher concentrations of radionuclides, and hence cause higher doses to the population.

The activity concentrations of ^{137}Cs in edible berries and mushrooms in Finland were well below the limit of 600 Bq/kg (f.w.) for commercial foodstuff, and on the average, they are only a minor part of the yearly exposure to radiation. Though, because the individual differences on consumption of wild products are remarkable, in the individual level they can be an important source of radioactive intake. However, the greatest proportion of the effective dose from wild berries and mushrooms in Finland was of natural origin.

All together, 20 mushroom samples were studied representing 12 species. The transfer factor for polonium was best studied and it had varied greatly between the species. No anomalously high concentrations of ^{210}Po were found in this study and it seems that high ^{210}Po may be related to only some mushrooms species belonging to *Boletales*.

Due to limited consumption data, dose assessments could no be carried out for the Swedish and Danish consumers.

8 References

1. Marina, II, MARINA II: Update of the MARINA project on the radiological exposure of the European community from radioactivity in North European marine waters, 2002, European Commision: Luxembourg.
2. Betti, M., et al., Results of the European Commission MARINA II study: part I - general information and effects of discharges by the nuclear industry. Journal of Environmental Radioactivity, 2004. 74(1-3): p. 243-254.
3. Betti, M., et al., Results of the European Commission Marina II Study Part II - effects of discharges of naturally occurring radioactive material. Journal of Environmental Radioactivity, 2004. 74(1-3): p. 255-277.
4. Fernandez, H.M., Management of uranium tailing: geochemical processes and radiological risk assessment. Journal of Environmental Radioactivity, 1996. 30: p. 69-95.
5. Read, R. and R. Pickering, Ecological and toxicological effects of exposureto an acidic, radioactive tailings storage. Environmental Monitoring and Assessment, 1999. 54: p. 69-85.
6. Parfenov, Y., Polonium-210 in the environmental and in the human organism. Atomic Energy Review, 1974. 12: p. 75-143.
7. Veiga, L.H.S., E.C.S. Amaral, and H.M. Fernandes, Human health risk screening of radioactive and nonradioactive contaminants due to uranium industry operation. Journal of Environmental Radioactivity, 1998. 39(1): p. 69-85.
8. Banks D., Frengstad B., Midtgård A.K., Krog J.R. and Strand T. (1998) The chemistry of Norwegian groundwaters: I. The distribution of radon, major and minor elements in 1604 crystalline bedrock groundwaters. The Science of the Total Environment, 222, 71-91.
9. Asikainen, M. & Kahlos, H. 1980 Natural radioactivity of drinking water in Finland. Health Phys. 39, 73–83.

10. Mjönes L. and Åkerblom G. (1998) Om den naturliga strålningen (About the natural radiation). Stråskyddsnytt, 4, 12-13 (in Swedish).
11. Davé NK, Lim TP & Cloutier NR. Ra-226 Concentrations in Blueberries Vaccinium angustifolium Ait.Near an Inactive Uranium Talings Site in Elliot Lake, Ontario, Canada. Environ. Pollut, Ser. B 1985; 10: 301–314.
12. Rosa MML, Maihara VA, Taddei MHT & Dias FF. Sequential determination of U and Th isotopes, ^{226}Ra, ^{228}Ra, ^{210}Pb, and ^{210}Po in mushroom. 2009 International Nuclear Atlantic Conference - INAC 2009 Rio de Janeiro,RJ, Brazil, September27 to October 2, 2009 Associacao Brasileira de Energia Nuclear – ABEN.
13. Eckl P, Hofmann W, Türk R. Uptake of natural and man-made radionuclides by lichens and mushrooms. Radiat Environ Biophys (1986) 25:43-54
14. Kirchner G & Daillant O. Accumulation of ^{210}Pb, ^{226}Ra and radioactive cesium by fungi. The Science of the Total Environment 1998; 222: 63–70.
15. Baeza A, Hernandez S, Guillen FJ, Moreno G, Manjon JL & Pascual R. Radiocaesium and natural gamma emitters in mushrooms collected in Spain. The Science of the Total Environment 318 (2004) 59–71
16. Baeza A, Guillen J, Bernedo JM. Soil–fungi transfer coefficients: Importance of the location of mycelium in soil and of the differential availability of radionuclides in soil fractions. Journal of Environmental Radioactivity 81 (2005A) 89–106.
17. Baeza A, Guillen FJ, Salas A, Manjon JL. Distribution of radionuclides in different parts of a mushroom: Influence of the degree of maturity. Science of the Total Environment 359 (2006) 255– 266.
18. Guillén J, Baeza A, Ontalba MA, Míguez MP. ^{210}Pb and stable lead content in fungi: Its transfer from soil. Science of the Total Environment 407 (2009) 4320–4326.
19. Mrdakovic Popic, J., et al., Outdoor ^{220}Rn, ^{222}Rn and terrestrial gamma radiation levels: investigation study in the thorium rich Fen Complex, Norway. Journal of Environmental Monitoring.
20. Mrdakovic Popic, J., B. Salbu, and L. Skipperud, Ecological transfer of radionuclides and metals to free-living earthworm species in natural habitats rich in NORM. Science of the Total Environment, (0).
21. Mrdakovic Popic, J., et al., Assessment of radionuclide and metal contamination in a thorium rich area in Norway. J. Environ. Monit., , 2011: p. 8.
22. Thorium, Thorium as an energy source -opportunities for Norway, 2008. p. 150.
23. Vaaramaa K, Solatie D, Aro I. Distribution of ^{210}Pb and ^{210}Po concentrations in wild berries and mushrooms in boreal forest ecosystems. Sci. Tot. Environ 2009; 408: 84–91.
24. Sillanpää T, Ikäheimonen TK, Salonen L, Taipale T & Mustonen R. Paukkajavaaran vanhan uraanikaivos- ja rikastamonalueen ja sen ympäristön radioaktiivisuustutkimukset. STUK-B-VALO56. Helsinki: STUK, 1989.
25. Johanson KJ, Nikolova I, Taylor AFS. Uptake of elements by fungi in the Forsmark area. Stockholm: Svensk Kärnbränslehantering AB, 2004.
26. Gwynn JP, Nalbandyan A, Rudolfsen G. ^{210}Po, ^{210}Pb, ^{40}K and ^{137}Cs in edible wild berries and mushrooms and ingestion doses to man from high consumption rates of these wild foods. Journal of ENvironmental Radioactivity 116 (2013) 34–41.
27. Strandberg M. The use of natural products for consumption in Denmark. Ministry of Environment and Energy, National Environment Research Institute, 1996.
28. Thørring, H., A. Hosseini, and K.L. Skuterud, Kostholdsundersøkelser 1999 og 2002. Reindriftsutøvere i Midt-Norge., in Strålevern Rapport, NRPA, Editor 2004, Statens Strålevern (NRPA): Østerås, Norway.

29. Korkalo, L., Tapanainen, H., Reinivuo, H., Ovaskainen, M-L., 2008. Foods consumed, in: Paturi, M., Tapanainen, H., Reinivuo, H., Pietinen, P. (Eds.), The National FINDIET 2007 Survey, Helsinki, Yliopistopaino, pp. 33–45.
30. Markkula M-L. Rantavaara A. Consumption of mushrooms and other wild food products in Finland. Julkaistu: Walderhaug T, Guðlaugsson EP, toimittajat. Proceedings of the 11th meeting of the Nordic Society for Radiation Protection and the 7 th Nordic Radioecology seminar, 26.-29.8. 1996. Reykjavik, Islanti. Geislavarnir rísikins, 1997. s. 371-376.
31. Tolvanen J, Vänttinen T. Sienten käyttö -kotitaloustutkimus. Helsinki: Consumer Compass – Kuluttajatieto Oy; 1998.
32. Feodoroff R. Metsäsienten käyttö Suomessa (pro gradu- tutkielma). Kuopio: Kuopion yliopisto; 1999.
33. Viinisalo, M., Nikkilä, M., Varjonen, J. Elintarvikkeiden kulutusmuutokset kotitalouksissa vuosina 1966–2006. Kuluttajatutkimuskeskus, julkaisuja 7/2008.
34. Saastamoinen O, Kangas K, Aho H. The picking of wild berries in Finland in 1997 and 1998. Scand J For Res 2000;15:645-650.
35. Rantakokko H-K. Luonnonmarjojen käyttö Suomessa (pro gradu- tutkielma). Kuopio:Kuopion yliopisto; 1999.
36. Mauring, A., Gäfvert, T. Radon tightness of different sample sealing methods for gamma spectrometric measurements of ^{226}Ra. Applied Radiation and Isotopes (2013) 81, 92–95.
37. International Electrotechnical Commission 1995 International standard IEC 1452:1995, Nuclear instrumentation – Measurement of gamma-ray emission rates of radionuclides – Calibration and use of germanium spectrometers. (Geneve: International Electrotechnical Commission)
38. STUK 2007 Quality Manual of the Department of Research and Environmental Surveillance, Technical manual of the in–house method STUK–TKO–4
39. Perkin Elmer. (2001). The 30-minute Guide to ICP-MS. Perkin Elmer, Shelton CT.)
40. Agilent Technologies. (2012). Agilent 8800 Triple Quadrupole ICP-MS, Technology transformed. Performance redifined. Available at: [http://www.chem.agilent.com/Library/brochures/5991-0079EN_8800_ICPQQQ_Brochure.pdf] read 2nd december 2013.
41. Binder M, Hibbett DS. Molecular systematic and biological diversification of Boletales. Mycologia 2006; 98(6): 971–981.
42. Kostiainen, E., Ylipieti, J. Radioaktiivinen cesium ruokasienissä. STUK-A240. Helsinki: Edita Prima Oy, 2010.

Acknowledgements

NKS conveys its gratitude to all organizations and persons who by means of financial support or contributions in kind have made the work presented in this report possible.

Disclaimer

Appendix

Table 1: TF-values in raspberry plants

Sample	^{232}Th	^{238}U	^{210}Po
Søve			
Berry	$1.5 *10^{-6} \pm 1.6 *10^{-6}$	$1.5 *10^{-6} \pm 1.6 *10^{-6}$	0.0012 ± 0.0035
Leaf	$2.2 *10^{-5} \pm 2.1 *10^{-5}$	$4.8 *10^{-5} \pm 4.4 *10^{-5}$	0.097 ± 0.037
Stem	$1.4 *10^{-5} \pm 1.8 *10^{-5}$	$2.8 *10^{-5} \pm 2.6 *10^{-5}$	0.091 ± 0.088
Fen			
Berry	$6.5 *10^{-7} \pm 1.5 *10^{-6}$	$1.2 *10^{-5} \pm 6.2 *10^{-5}$	0.0047 ± 0.012
Leaf	$1.1 *10^{-4} \pm 9.9 *10^{-5}$	$1.6 *10^{-4} \pm 9.0 *10^{-5}$	0.31 ± 0.28
Stem	$1.1 *10^{-5} \pm 4.9 *10^{-6}$	$8.9 *10^{-5} \pm 3.6 *10^{-5}$	0.21 ± 0.25
Rullekollen			
Berry	-----	-----	-----
Leaf	$8.5 *10^{-6} \pm 5.0 *10^{-6}$	$3.5 *10^{-5} \pm 3.1 *10^{-5}$	0.081 ± 0.020
Stem	$1.7 *10^{-5} \pm 2.2 *10^{-5}$	$6.7 *10^{-5} \pm 7.6 *10^{-5}$	0.071 ± 0.021
Torsnes			
Berry	$5.0 *10^{-6} \pm 4.9 *10^{-6}$	$2.6 *10^{-5} \pm 5.6 *10^{-5}$	0.0035 ± 0.0099
Leaf	$1.8 *10^{-4} \pm 1.8 *10^{-4}$	$1.9 *10^{-3} \pm 4.1 *10^{-3}$	0.21 ± 0.58
Stem	$1.8 *10^{-5} \pm 1.8 *10^{-5}$	$3.4 *10^{-4} \pm 7.2 *10^{-4}$	0.095 ± 0.27

Table 2: TF-values (^{232}Th, ^{238}U and ^{210}Po) in lingonberry, blueberry and chanterelle from Bolladalen

Sample	^{232}Th	^{238}U	^{210}Po
Lingonberry	$5.6 *10^{-5} \pm 6.4 *10^{-5}$	$6.9 *10^{-5} \pm 6.5 *10^{-5}$	0.044 ± 0.044
Lingonberry shrub	$5.8 *10^{-6} \pm 6.1 *10^{-6}$	$4.4 *10^{-5} \pm 4.6 *10^{-5}$	0.0043 ± 0.0042
Blueberry	$3.9 *10^{-6} \pm 4.4 *10^{-6}$	$6.3 *10^{-6} \pm 5.9 *10^{-6}$	0.14 ± 0.14
Blueberry shrub	$6.4 *10^{-5} \pm 1.1 *10^{-4}$	$7.6 *10^{-5} \pm 9.9 *10^{-5}$	0.0014 ± 0.0014
Chanterelle july	$8.1 *10^{-5} \pm 9.1 *10^{-5}$	$4.9 *10^{-4} \pm 4.6 *10^{-4}$	0.10 ± 0.10
Chanterelle august	$1.2 *10^{-5} \pm 1.2 *10^{-5}$	$3.8 *10^{-5} \pm 4.2 *10^{-5}$	0.016 ± 0.017

Table 3: TF-values (organic soil – berry) for lingonberry and blueberry from the Finnish sites

Sample	Site	U	Ra-228	Ra-226	Pb-210	Po-210
Blueberry	Espoo	<0.0007	0.058±0.007	0.067±0.015	$1.7·10^{-3}±2.0·10^{-4}$	$1.1·10^{-3}±1.6·10^{-4}$
Blueberry	Loviisa	<0.0005	0.115±0.014	0.116±0.013	$3.5·10^{-3}±3.2·10^{-4}$	$1.5·10^{-3}±2.1·10^{-4}$
Blueberry	Kuusamo	<0.0041	0.531±0.066	0.323±0.051	$4.2·10^{-3}±5.2·10^{-4}$	$1.4·10^{-3}±2.2·10^{-4}$
Lingonberry	Kuusamo	<0.0030	0.410±0.060	0.191±0.065	$5.9·10^{-3}±8.5·10^{-4}$	$1.5·10^{-3}±2.7·10^{-4}$

Table 4: TF-values (organic soil – mushroom) for lingonberry and blueberry from the Finnish sites

Sample	Site	U	Ra-228	Ra-226	Pb-210	Po-210
*Lactarius rufus**	Espoo	<0.032	n/d	n/d	0.034±0.003	0.048±0.006
Cantharellus cibarius	Espoo	<0.032	<0.77	<0.56	0.034±0.003	0.032±0.004
Craterellus tubaeformis	Espoo	<0.032	<0.35	0.27±0.09	0.030±0.003	0.047±0.006
Craterellus cornucopioides	Espoo	<0.032	<0.40	<0.30	0.016±0.002	0.023±0.003
Lactarius rufus	Loviisa	<0.027	<1.0	<0.29	0.036±0.004	0.026±0.004
Kuehneromyces mutabilis	Loviisa	<0.027	<2.6	0.70±0.13	0.012±0.001	0.009±0.002
Cantharellus cibarius	Loviisa	<0.027	<0.65	<0.13	0.025±0.003	0.026±0.004
Craterellus tubaeformis	Loviisa	<0.027	<0.90	<0.21	0.036±0.003	0.089±0.012

Table 5: TF-values (organic soil – berry/mushroom) at the Danish sites

Sample		Pb-210	Po-210
Sheathed woodtuft	*Kuehneromyces mutabilis*	<0.032	0.014±0.002
False Chanterelle	*Hygrophoropsis aurantiaca*	<0.032	1.5±0.2
Clouded agaric or cloud funnel	*Clitocybe nebularis*	<0.032	0.0082±0.0012
Charcoal burner	*Russula cyanoxantha*	<0.032	0.013±0.002
Bay bolete	*Boletus badius* (*Xerocomus badius)*	<0.032	0.011±0.002
Dotted stem bolete	*Boletus luridiformis*	<0.032	0.035±0.005
Dotted stem bolete	*Boletus luridiformis*	<0.032	0.049±0.007
False Chanterelle	*Hygrophoropsis aurantiaca*	<0.032	0.24±0.03
Penny bun, porcino or cep	*Boletus edulis*	<0.032	0.056±0.008
Champignon mushroom	*Agaricus bisporus*	<0.032	0.0023±0.0003
Blackberries	*Rubus fruticosus*	n/d	0.0005±0.0001
Raspberries	*Rubus idaeus*	n/d	0.0005±0.0001

Title	Doses from natural radioactivity in wild mushrooms and berries to the Nordic population
Author(s)	Tuukka Turtiainen[1], Minna Brunfeldt[1], Tiina Rasilainen[1] Lindis Skipperud[2], Lene Valle[2], Jelena Mrdakovic Popic [2] Per Roos[3] Synnöve Sundell-Bergman[4], Klas Rosén[4], Robert Weimer[4]
Affiliation(s)	[1]STUK – Radiation and Nuclear Safety Authority [2] Norwegian University of Life Science [3] DTU-Technical University of Denmark, NUTECH [4] SLU–Swedish University of Agricultural Sciences
ISBN	978-87-7893-370-6
Date	January 2014
Project	NKS-B / BERMUDA
No. of pages	39
No. of tables	29 + 5
No. of illustrations	11
No. of references	42
Abstract	Soil-to-berry and soil-to-mushroom transfer factors of naturally occurring radionuclides were studied in four Nordic countries. The transfer factors of uranium and thorium to both mushrooms and berries were very low, <0.001, and their concentration in mushrooms and berries contributed little to the effect dose among consumers. Transfer factors of radium isotopes to berries ranged 0.06–0.53 while those of lead and polonium had a larger range, 0.001–0.14. In the berries studied, radium isotopes, lead and polonium contributed to the effective dose approx. equal proportions. The proportion of Cs-137 was only 20% of the studied berry samples. In mushrooms, the most significant contribution to the effective dose was from Cs-137 and Po-210, about equal proportions in the studied samples. All in all, the effective doses among average consumers and the most consuming persons were below 100 µSv per year. Therefore, risk communication is not regarded necessary.
Key words	natural radioactivity, berry, mushroom, transfer factor, gathered food, effective dose

Available on request from the NKS Secretariat, P.O.Box 49, DK-4000 Roskilde, Denmark.
Phone (+45) 4677 4041, e-mail nks@nks.org, www.nks.org