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# Uptake of $^{137}$Cs by fungi and plants due to potassium fertilization in Heby municipality in response to the Chernobyl nuclear accident

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# Abstract

The fallout from the Chernobyl nuclear accident resulted in large deposits of caesium, iodine and strontium as well as noble gases in various parts of Sweden. $^{137}$Cs has a radioactive half-life of about 30 years and is therefore one of few radio-fission products remaining in measurable quantities in the Swedish soil. Radiocaesium behaves similarly to potassium in soil-plant systems and is easily absorbed by plants. It is important to understand how $^{137}$Cs behaves in different ecosystems in order to minimize the risk toward humans.

The aim of this study was to determine how potassium fertilization influences radiocaesium content in different forest plants and fungi. Potassium fertilizer was spread once in 1992 with approximately 200 kg KCl per ha. The method of determining the $^{137}$Cs activity concentration involved collecting forest plants and fungi samples from the sites used in previous studies. These samples were then placed in a High-Purity Germanium Coaxial Photon Detector to accurately determine the $^{137}$Cs activity concentration levels. The results from this study were compared with results from earlier studies made on the same sites between the years of 1992 and 2005. This comparison was carried out in order to observe and estimate any long-term trends.

The results show that there is a large variation in the $^{137}$Cs activity concentration levels for the eight different fungi species found and analysed. *Cortinarius semisanguineus*, *Cortinarius cinnamomeus* and *Rozites caperata* were found to be the fungi species with the highest $^{137}$Cs activity concentration levels. Taking the previous years into account, the majority of the fungi species show a decrease in $^{137}$Cs activity concentration for the potassium fertilized area, which would mean that it is possible to use potassium fertilization in order to reduce the $^{137}$Cs activity concentration uptake in fungi.

With regard to plant species, it was determined that heather is the plant that shows the highest $^{137}$Cs activity concentration levels. When comparing the levels of $^{137}$Cs in the plant species with those found in previous studies it clearly shows that the use of potassium fertilization as a countermeasure reduces the $^{137}$Cs activity concentration uptake in all plant species measured.



*Keywords:* Radiocaesium; $^{137}$Cs; potassium; potassium fertilization; forest plants; fungi; countermeasure; Chernobyl nuclear accident

# Sammanfattning

## Upptag av $^{137}Cs$ i skogsväxter och svamp efter kaliumgödsling i Heby kommun efter Tjernobylolyckan

Tjernobylolyckan resulterade i utsläpp av stora halter radiocesium, jod, strontium och ädelgaser i delar av Sverige. Den fysikaliska halveringstiden för $^{137}Cs$ är ca 30 år och är alltså en av få isotoper som finns kvar att mäta i den svenska jorden. Radiocesium och kalium är kemiskt lika när det gäller jord-växt system och upptas lätt av växter. Det är därför viktigt att försöka förstå hur $^{137}Cs$ uppträder i olika ekosystem för att minimera risken för människan.

Syftet med denna studie var att undersöka hur kaliumgödsling påverkar radiocesiumhalten i olika skogsväxter och svamp. Kaliumgödsling utfördes en gång 1992 med ca 200 kg KCl per ha. Skogsväxter och svamp plockades och $^{137}Cs$ halten bestämdes med hjälp av gammadetektorer. Resultaten jämfördes med tidigare studier som har gjorts på samma provplatser 1992 till 2005 för att kunna se ett långsiktigt samband.

Resultaten visade på stora variationer av $^{137}Cs$ upptag för de olika svamparterna. *Cortinarius semisanguineus, Cortinarius cinnamomeus* och *Rozites caperata* var de svamparter med högst $^{137}Cs$ aktivitet. Vid jämförelse med tidigare års värden visar majoriteten av svamparterna en minskning av $^{137}Cs$ aktivitet för området som har kaliumgödslats, vilket betyder att det skulle vara möjligt att använda kaliumgödsling för att minska upptaget av $^{137}Cs$ i svamp.

När det gäller växterna så är ljung den växt som visar högst $^{137}Cs$ upptag. Vid jämförelse med tidigare års värden syns det tydligt att det är möjligt att använda kaliumgödsling i skogsmark som en motåtgärd för att minska $^{137}Cs$ upptaget i växter.


*Nyckelord:* Radiocesium; $^{137}Cs$; kalium; kaliumgödsling; skogsväxter; svamp; motåtgärd; Tjernobylolyckan

# Contents

# 1. INTRODUCTION

The 26th of April 1986, will forever be remembered for the nuclear reactor accident which occurred at the Chernobyl Nuclear Power Plant. To this date, it is the only level 7 instance on the international Nuclear Event Scale to have occurred. It resulted in large deposits of caesium, iodine and strontium as well as noble gases in various parts of Europe and Sweden.

$^{137}$Cs has a radioactive half-life of 30 years and is therefore one of few radio-contaminants left in measurable quantities in the Swedish soil. Radiocaesium behaves similarly to potassium and is easily absorbed by plants (Willey *et al*., 2005). It is important to understand how $^{137}$Cs behaves in different ecosystems in order to minimize the risk toward humans.

The radiocaesium uptake by plants and fungi in the Swedish forest has been very high since the Chernobyl accident (Fawaris & Johanson, 1995; Nikolova *et al*., 1997). High levels of $^{137}$Cs activity concentrations have been found in plant species belonging to the Ericacea family such as bilberry (*Vaccinium myrtillus*), heather (*Calluna vulgaris*) and lingonberry (*Vaccinium vitis-idea*) as well as various fungi species forming ectomycorrhiza (Nikolova & Johansson, unpublished observations). Game animals consume these plants and fungi and one of the major pathways of $^{137}$Cs activity concentration to man is through game animals (Johansson, 1994). It is therefore of great interest to determine how potassium fertilization influences the $^{137}$Cs activity concentration in food products coming from the forest ecosystems in order to clarify the possibility to reduce the levels in forest food products.

## 1.1 AIM

The aim of this study was to determine how the application of potassium fertilizer, which was spread once in Heby municipality in 1992, influences caesium content in different forest plants and fungi. By tracking the changes in radiocaesium content in the plants and fungi in Heby municipality, we can compare year 2009 values with measurements obtained from years 1992-2005 and estimate a long-term trend.

# 2. BACKGROUND

## 2.1 BASIC INFORMATION REGARDING NUCLEAR POWER AND RADIOACTIVITY

Splitting uranium atoms produce large amounts of energy. This technology, called atomic fission, is used in nuclear power plants today to produce electricity. In the nuclear reaction process, a self-sustaining chain reaction of atom splitting is started by bombarding $^{235}U$ with neutrons. $^{235}U$ is split into nuclides which in their turn decay in a chain of successive breakdown towards a stabile element. In one chain of reactions, $^{137}Cs$ is an intermediate element and decays into stabile $^{137}Ba$. The newly formed neutrons that are released can be used to split new uranium nuclei to continue the chain reaction.

### 2.1.1 Alpha, beta and gamma radiation

Radioactivity is the spontaneous disintegration of atomic nuclei. The three types of natural radiation are called alpha, beta and gamma radiation.

An alpha particle consists of two neutrons and two protons that emits at a radioactive disintegration. The alpha particle can easily be stopped with thin layers of solid material e.g. a sheet of paper or skin (see Figure 2.1). Plutonium is an example of a radioactive element with alpha radiation (Andersson *et al*., 2002).

A beta particle, which is the most common radiation, is either a high energy, high speed positron ($\beta^+$) or an high energy, high speed electron ($\beta^-$). The beta particle can be stopped by thick clothes or glass (see Figure 2.1). Iodine, caesium and strontium are all examples of radioactive elements with beta radiation (Andersson *et al*., 2002). Both alpha and beta radiation are in the form of particles.

Gamma radiation is electromagnetic radiation, like X-rays, with very short wavelength. It can penetrate deep into human bodies from long distances (see Figure 2.1). Iodine and caesium are examples of radioactive elements with gamma radiation (Andersson *et al*., 2002).

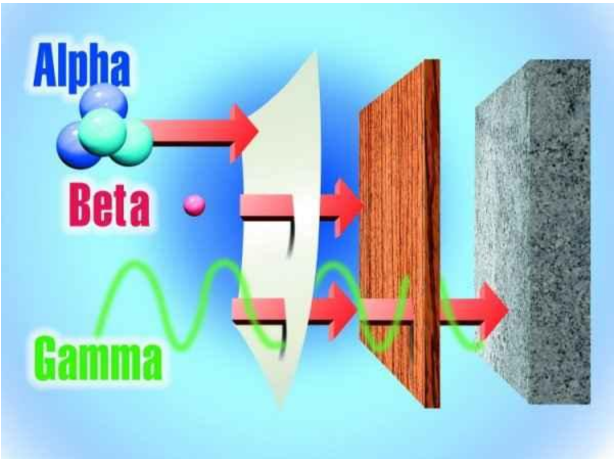


Figure 2.1. Alpha, beta and gamma radiation (Idaho Department of Environmental Quality website, 2009-10-28).

### 2.1.2 Half-life

Half-life is the period of time, for a substance of a given amount undergoing decay, to decrease by half of its initial activity. There are different types of half-life's defined as:

- Radioactive half-life is the average time required for a quantity of radionuclides to decay to half of their initial rate.

- Biological half-life is the time it takes for a living tissue, organ or individual to eliminate half of a given amount of a substance that has been introduced into it.

- Effective half-life is the combined measure of the radioactive and biological half-life.

- Ecological half-life is less precise than the radioactive and biological half-life. It is defined as the radioactive half-life for the animals and plants living in the area.

### 2.1.3 Transport of radioactive substances

Noble gases are released and dissipate relatively fast in the atmosphere. The alkali metals, iodine, caesium and strontium are released into the air as fuel particles and submicrometre condensed particles (IAEA, 2006). $^{131}I$ is transported faster in the air but has a half-life of only 8.1 days whereas $^{137}Cs$'s half-life is about 30 years. In the first stage after an accident it is therefore very important to regard iodine and other fast transporting substances and there risk of spreading into the air as the main priority. When some time has elapsed focus should change to long-lived radio-nuclides such as caesium as the main hazard. $^{90}Sr$ has also a long half-life but demands very high temperatures to be released into the air which made less quantity strontium release after the Chernobyl accident and therefore is not as important as $^{137}Cs$.

## 2.2 THE CHERNOBYL ACCIDENT

Reactor number four at the Chernobyl plant exploded the morning of the 26$^{th}$ of April 1986 (see Figure 2.2). The resulting steam explosion and fire released all of the xenon gas, approximately 50 % of the iodine and caesium and at least five percent of the remaining radioactive material in the reactor core into the surrounding atmosphere.

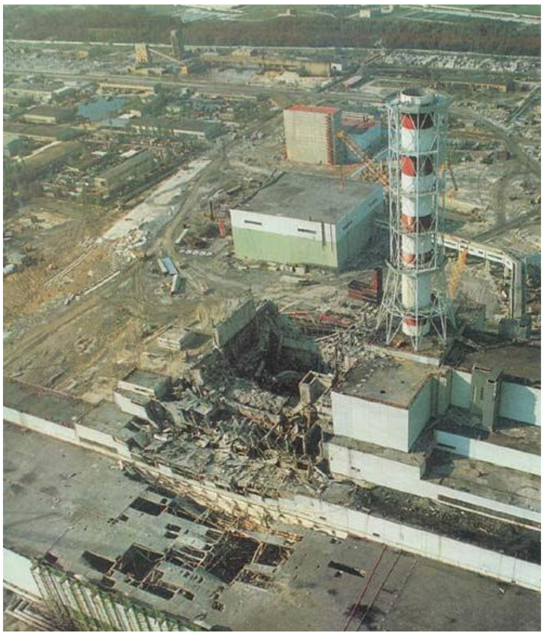

Figure 2.2. Reactor 4 at the Chernobyl Nuclear Power Plant (Think about it – European blogging competition website, 2009-10-28).

Much of the fallout was deposited close to Chernobyl but the lighter material was carried by wind to the three former republics of the Soviet Union now known as Belarus, the Russian Federation and Ukraine. To some extent there were further deposits over Scandinavia and Europe (see Figure 2.3). Wind direction and uneven rainfall left some areas more contaminated than others. Scandinavia was adversely affected with about 5 % of the totally released $^{137}Cs$ deposited in Sweden, with the highest activity concentration reaching 200 $kBq/m^2$ (IAEA, 2006). When the contaminated air masses passed over Sweden, much of the deposition was initiated by rain. Unfortunately wet deposition magnifies the negative effects and consequences.

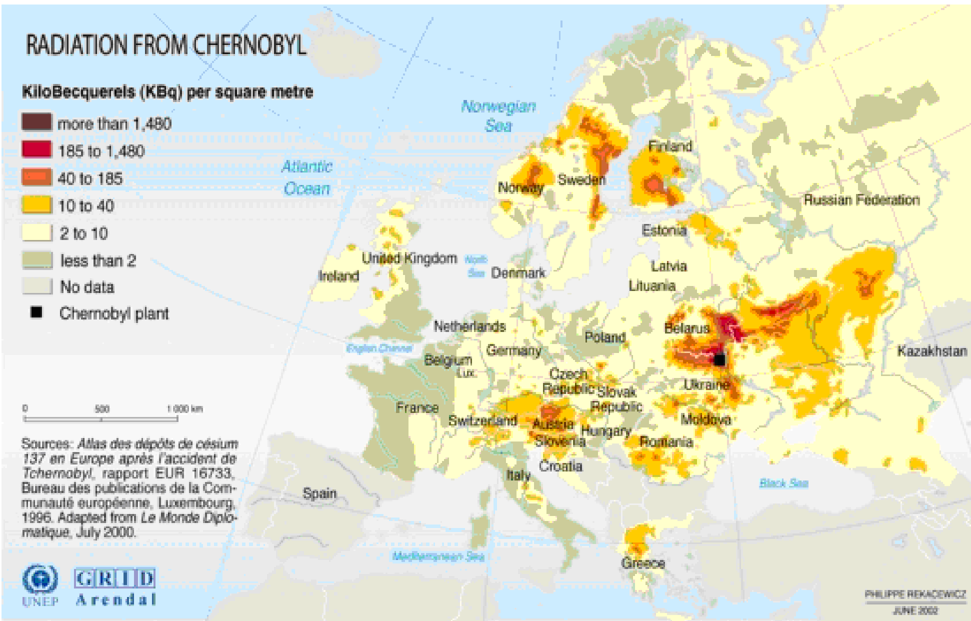


Figure 2.3. Map showing deposition of radiation after the Chernobyl accident (GRID-Arendal website, 2009-10-28).

Major releases from unit four of the Chernobyl nuclear power plant continued for ten days. The total release of radioactive substances was approximately $14*10^{18}$ Bq which included $1.3*10^{18}$ Bq of $^{131}I$, $2.9*10^{17}$ Bq of $^{137}Cs$, $1.9*10^{17}$ of $Cs^{134}$, $2.0*10^{17}$ Bq of $^{90}Sr$ and $0.003*10^{18}$ Bq of plutonium radioisotopes. The noble gases contributed about 50 % of the total release of radioactivity (Johanson, 1996; IAEA, 2006).

Observations on elevated radiation levels were announced from Sweden and Finland on April 1986. Forsmark nuclear power plant's staff were first to discover the increase in radiation levels. Initially, the findings were considered as a consequence of some failure at their own station but they were soon discounted. On the evening of 28 April it was confirmed by the USSR, Union of Soviet Socialist Republics, that a severe accident had indeed occurred at the Chernobyl nuclear power plant.

### 2.2.1 Consequences of the Chernobyl accident in Sweden

As mentioned previously, Scandinavia was adversely affected with about 5 % of the totally released $^{137}Cs$ deposited in Sweden (IAEA, 2006). Figure 2.4 shows the deposition of $^{137}Cs$ in great detail for Sweden. The first radioactive cloud was transported to Sweden and remained above the country two days after the accident, 28$^{th}$ of April. It then started to rain in some parts of Sweden and the radioactive substances came down as wet deposition.

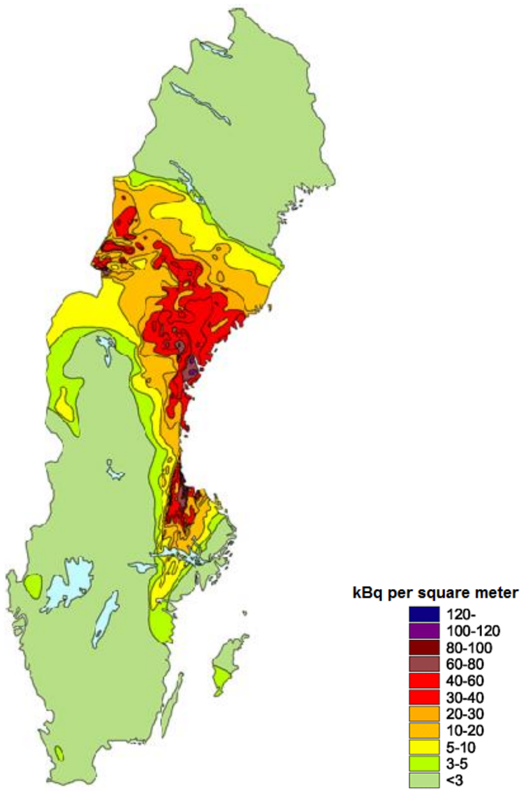


Figure 2.4. Deposition of $^{137}Cs$ in Sweden. Measurements took place between May-October 1986 (Sveriges National Atlas website, 2009-10-28).

In Uppsala, Västmanland and Gävleborgs County, the grass had just started to grow so most of the radioactive substances came directly into the soil. If the accident had happened just one month later the grass and harvest would have been at a more advanced stage and more radioactive substances would have been absorbed by the vegetation. In the north of Sweden there was still snow and ice so the downfall of radioactive substances was more irregular there.

After the accident, the National Food Administration and SSI recommended that the additional annual radiation dose from food should not exceed 1 mSv per year (SSI, 2001).

### 2.2.2 Consequences on the food chain (Environmental and health effects)

The long-term health risks of exposure of radioactive substances include cancer, birth defects, infertility and genetic abnormalities. Since each type of radiation has different physical properties, the risks and potential effects on health of each are different. Some forms of radiation can penetrate the skin, others affect the body only if inhaled, ingested, absorbed through the skin or entered through a wound (Andersson *et al*., 2002).

$^{137}$Cs is the most common of caesium's radioactive isotopes to be encountered. It is produced during fission of either uranium or plutonium fuels and is found in the environment as a result of worldwide fallout with atmospheric weapons tests and nuclear reaction accidents like the Chernobyl accident. $^{137}$Cs's chemical forms can be water soluble and can therefore be distributed almost uniformly in body fluids and is rapidly eliminated by the kidneys. Exposure to $^{137}$Cs can increase the risk of cancers such as leukaemia (Johansson, 1996).

## 2.3 RADIOCAESIUM MIGRATION

The migration of caesium in soil signifies a vertical transport in the soil profile with slow velocity. Caesium and potassium behave chemically very similarly in the soil and studies of one of them can be used to learn about how the other one moves and is taken up by plants (Willey *et al*., 2005).

A high organic content in soils promotes potassium's availability for uptake by vegetation as well as its mobility. The ions are more mobile compared to a mineral soil where potassium is strongly bound by the mineral particles. In the same way, caesium is slowly transported in mineral soils as a result. Due to the similarities between potassium and caesium a high concentration of potassium in the soil prevents the vegetation uptake of caesium.

High porosity, large cracks and rough sandy soils with high hydraulic conductivity result in a higher flow in the soil solution and therefore a faster transport of caesium. Other factors that have an impact on the migration of caesium are pH-value, CEC (Cation Exchange Capacity) and mixing of the soil due to biological activity and ploughing (Shenber & Eriksson, 1993; Arapis & Karandinos, 2004). The climate has an impact because more precipitation leads to larger percolation and faster transport whereas freezing temporarily prevents the solution in the soils flow.

Mineral soils usually have less downward migration of $^{137}$Cs than organic soils and podsolized soil due to fixation to mineral particles and the loose structure of many organic soils (Rosén *et al*., 1999). There was 50-80 % of the $^{137}$Cs activity concentration in the 0-1 cm layer one year after the fallout, 1987, and seven years later the highest activity was found in the upper 0-5 cm layer (Rosén, 1996). The main part of $^{137}$Cs deposited on the ground will remain within the root zone for a long time (Vinichuk & Johanson, 2003; IAEA, 2006).

Caesium's long-term retention in organic layers of forest soil has frequently been attributed to fungal and microbiological activity. Organic soils are characterised by a low radiocaesium sorption capacity while plants and particularly fungus uptake of radiocaesium growing on forest soils has been observed to be very high (Rafferty *et al*., 1999; Steiner *et al*., 2002).

## 2.4 RADIOCAESIUM UPTAKE BY FUNGI

Fungi have a large affinity for radionuclides (Vinichuk & Johansson, 2004). The consumption of fungi by humans can pose a considerable health concern from a radiological dose perspective (IAEA, 2006). Organic material in soil O-horizons have a lower affinity for caesium than mineral soils and therefore fungi growing in organic soils are likely to have relatively higher caesium levels than those that grow in mineral soils.

The various fungal species show large variations in $^{137}Cs$ activity concentration but the activity is much higher compared to plant species. Since the fallout from the Chernobyl nuclear accident many $^{137}Cs$ measurements have been carried out for different fungal species. Through these measurements, it was established that different fungal species have their mycelia in different soil horizons (Rühm *et al*., 1998). Since the radiocaesium activity concentration in these soil horizons changes over time, the activities of radiocaesium in different fungal species are also expected to behave differently over time.

### 2.4.1 Ecology of fungi

A fungus is any member of a large group of eukaryotic organisms that includes microorganisms such as yeasts and moulds, as well as the more familiar mushrooms. The fungi are classified as a kingdom that is separate from plants, animals and bacteria. Most fungi are decomposers and cause decay. Some are parasites and get their food from a host. Most forest soil has too much acid for bacteria to grow well, and so the fungi are the main decay producers (Campbell, 2002; Gadd *et al*., 2007).

Mycelium is the vegetative body of most true fungi (see Figure 2.5). The basic unit of a fungus is a threadlike tubular structure called a hypha (Campbell, 2002). These hyphae have cross-walls that give them a cellular structure and in these the divisions are not true cells. The hyphae usually contain chitin, a very resistant nitrogenous substance, but the composition may vary with age and environmental conditions (Gadd *et al*., 2007). The tips of the hyphae are full of cytoplasm with very small nuclei present, but in other regions there may be a central vacuole. In some of the species, multinucleate cytoplasm runs continuously through the tubes, in others, perforated cross-walls compartmentalize the hyphae into separate cells, yet allow chemical communication and movement of nuclei between body parts. The threads of the hyphae spread out and grow over and into their food material and may make up a visible mycelium or mesh (Campbell, 2002).

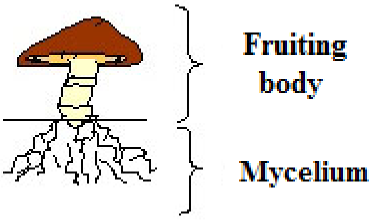

Figure 2.5. A fruit body showing its mycelium (Magnus Enterprises Inc website, 2009-11-09).

The mushrooms are a fungus that consists of a fruit body. The strands of fungus tissue digest and absorb their food in the rotting leaves on the forest ground. When these funguses have grown strong enough the cells multiply and form the fruiting body, which is the spore-producing organ of the fungus. The mushrooms often appear in the same spot on the forest ground each year where some old roots or logs lie buried, as this is the food of the hidden fungus body.

### 2.4.2 Mycorrhiza

A mycorrhiza is a symbiotic association between a fungus and the roots of a plant (see Figure 2.6), from which both fungus and plant appear to benefit (Nylund, 1980; Allen, 1991; Campbell, 2002). The plant gives the fungi carbohydrates from the photosynthesis process, while the fungi help the plants gain nutrients and water from the soil. A mycorrhizal root takes up nutrients more efficiently than what a non mycorrhizal root does. It has been estimated that at least 80 % and perhaps up to 90% of the world's plants form mycorrhizae of one form or another and you will find mycorrhizal associations from well-watered forests to the arid areas. There are several forms of mycorrhizae, with different forms of hyphal arrangement or associated microscopic structures.

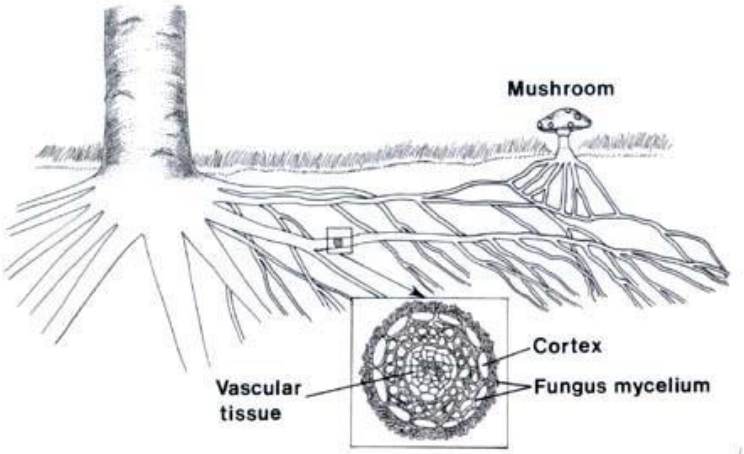

Figure 2.6. Mycorrhiza between fungi and tree (Plant pathology online website, 2009-11-09).

In vesicular-arbuscular mycorrhizae the fungus hyphae penetrate root cells and form intricately branched, shrub-like arbuscles within the cells and , at times, bladder-like vesicles as well. They are the most abundant type of mycorrhizas and the most ancient. It is likely that these fungi originated between 350 and 450 million years ago and probably played an essential role in the colonization of land by the plants (Brundrett, 2002).

In ectomycorrhiza the hyphae of the fungi form a mantle around the root and also grow into the spaces between root cells, but it does not penetrate the root cells. The hyphae form a net-like covering, called a Hartig net, around the cells (Brundrett, 2002). In this study the fungi form ectomycorrhiza with the roots of the plants.

In ericoid and orchid mycorrhizas the hyphae penetrate the root cells but neither arbuscles nor vesicles are formed.

## 2.5 RADIOCAESIUM UPTAKE BY PLANTS

Plants take up and conduct water and nutrients from the soil, and in doing so they also take up radionuclides. This is due to that the biological processes can not distinguish a stabile substance from a radioactive substance. If radioactive fallout appears during the growing season, plants will be contaminated directly on their leaves and part of the contaminant will be absorbed through the leaves. The leaf area, structure, shape and development stage as well as the type of fallout, i.e. dry or wet deposition, determine the contamination rate (Andersson *et al*., 2002). With time these factors will lose their importance and the main pathway of contamination will be by root uptake from the soil (Rosén, 1996).

Plants take up potassium and $^{137}$Cs more or less in the same proportions as they occur in the soil (Bunzl & Kracke, 1989). The higher the quantity of potassium that the vegetation takes up, the lower the uptake of caesium will be. This is due to that $^{137}$Cs and $^{40}$K have similar chemical behaviour, and plants are not able to discern a difference between the two.

Plant species such as lingonberry (*Vaccinium vitis idaea*), bilberry (*Vaccinium myrtillus*) and heather (*Calluna vulgaris*) have shown high uptake of $^{137}$Cs. According to Strandberg & Johansson, (1999), heather is generally the plant that has the highest activity concentration and lingonberry and bilberry have usually less than 30 % of the activity concentration found in heather.

## 2.6 COUNTERMEASURES

After an accident but prior to deposition, it is important to act immediately. Farmers should bring in all the animals into the barn to minimize the radioactive dose in milk and meat. The ventilation in the barn should be turned off and windows should be kept closed due to radionuclides in the air. If possible, the harvesting of crops should take place. However, if the crops are not yet ready for harvest – then they should be covered (Rosén, 1996; Andersson, 2002; Rosén & Eriksson, 2008).

After deposition and after samples have been taken and analysed from the specific area, contaminated harvest or the top layer of the soil should be removed to reduce the contamination of the soil. Both of these actions generate large amounts of waste material that needs to be taken care of. For this reason, the removal of the top layer of soil is not practical in larger scales. Potassium fertilization has proven to be a very effective countermeasure (Andersson *et al*., 2002). The potassium helps minimize the root uptake of radiocaesium to the harvest but it is a rather costly process in larger scales. Ploughing is another countermeasure that homogenizes the soil and distributes the nuclides over a much greater depth. This removes much of the radionuclides from the top layer of the soil where the root activity usually is highest (Rosén, 1996; Andersson, 2002; Rosén & Eriksson, 2008)

# 3. MATERIALS AND METHODS

### 3.1 THE STUDY AREA

Fungal fruit bodies and plant samples were taken between July and October 2009 in Stalbo, which is located in Heby municipality, about 40 kilometres north west of Uppsala, in central Sweden. The area had a deposition of $^{137}$Cs of about 35 000 Bq/m$^2$ after the Chernobyl accident (Nikolova & Johanson, unpublished observations). Samples were taken at three different sites - a control area of approximately 10 000 m$^2$ on a rocky part in the forest with no fertilization of potassium and two areas of approximately 50 m$^2$ and 150 m$^2$ that were treated by spreading potassium chloride. Earlier studies have been carried out at the sites on several occasions between 1992 and 2005.

### 3.2 FERTILIZATION

Potassium chloride was spread in June 1992 by a conventional centrifugal spreader commonly used in agricultural practice. The intention was to spread 200 kg potassium chloride per ha but due to the irregular ground structure we can expect some variations (Nikolova & Johanson, unpublished observations).

### 3.3 SAMPLING

A total of 53 species of fungal fruit bodies were sampled from the different areas, Appendix 1. Only 8 of them were taken out for measurements to match the species found earlier years. Samples of the green parts of heather, lingonberry and bilberry were also collected. The plant samples were dried at 60°C for at least a week and milled to a homogeneous powder when passed through a 2 mm sieve. The fungi samples were dried at 60°C and then milled to smaller pieces, where the largest pieces where about 5 mm. A representative amount was weighed and analysed.

### 3.4 SAMPLE ANALYSES

All samples were put into plastic vials prior to analysis. The activity concentrations of $^{137}$Cs and $^{40}$K were determined with solid-state ionisation chambers, containing high-purity Germanium detectors at the low background laboratory at the Department of Soil and Environment. The detectors are calibrated for full vials so for this reason two different vial sizes were used, 60 ml and 35 ml. The plant samples were analysed for an average of 6 hours and the fungi samples were analysed for an average of 2 hours. The measurement errors were about 5 % for $^{137}$Cs. The number of samples analysed, n, found in the tables in the Results section, refers to the amount of times that samples of a particular species were found and analysed. These are bulk samples consisting of a large number of fruit bodies or plants of the same species. All activity concentrations in fungi and plants are expressed as Bq/kg dry weight.

### 3.4.1 Detector

A detector is used to detect, track and identify the primary ionization created by high-energy nuclear particles. The detectors that have been used are made of germanium crystals and are almost exclusively used to detect gamma radiation (Figure 3.1). The Germanium is one of the most common semiconductors used to construct "solid-state ionization chambers".

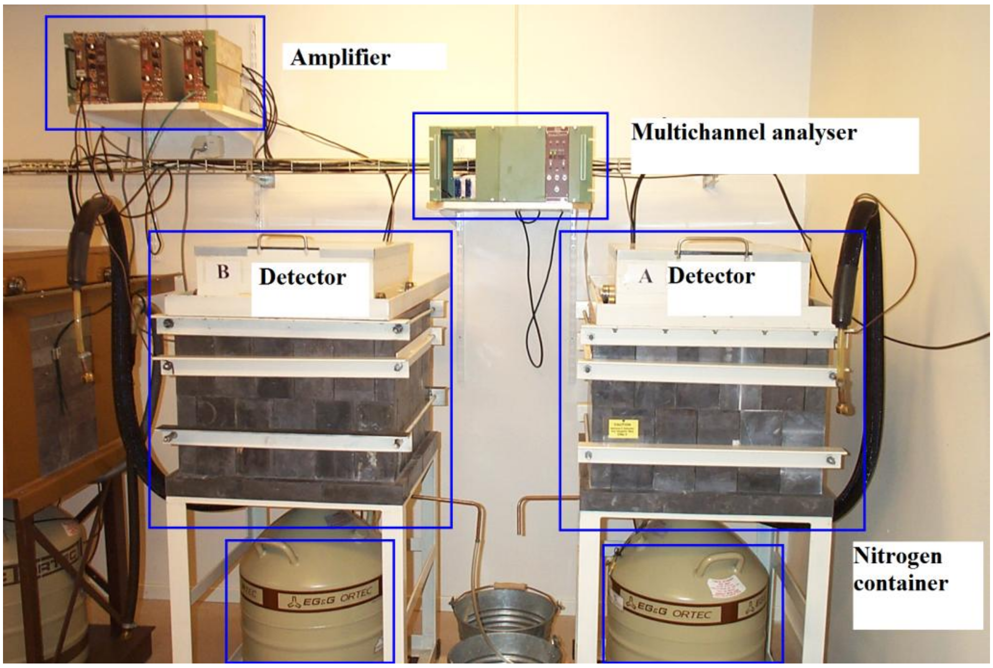


Figure 3.1. The equipment used in gamma spectroscopy includes the detectors, a pulse sorter (multichannel analyser), an associated amplifier, a nitrogen container and a computer with processing software to generate, display and store the spectrum (not shown in the figure).

In semiconductor detectors, a gamma ray interaction provides enough energy for an electron, which is fixed in its valence band in the crystal, to move to the conduction band. The electrons in the conduction band move to the positive contact that is creating the electrical field that is applied to the detector volume. The "hole" created by the moving electron is filled by a nearby electron and this effectively moves a positive charge to the negative contact. The negative contact produces an electrical signal that is sent to a charge sensitive preamplifier and converted to a voltage pulse with an amplitude value proportional to the original electron energy and on through the system for analyses (Loveland *et al*., 2006).

The germanium devices must be cooled down with nitrogen liquid to reduce the thermal noise to observe the signals. The sample is put in the device and the radiation is measured by means of the number of charge carriers set free in the detector, which is arranged between two electrodes (Loveland *et al.*, 2006). The High-Purity Germanium Coaxial Photon Detectors that were used had a relative efficiency between 13-33 %.

The gamma detectors energy scale must be calibrated for identifying unknown composition. Calibration is carried out by using the peaks of a known source, such as $^{137}Cs$. The channel scale can then be transformed to an energy scale, due to that the channel number is proportional to energy (Loveland *et al*., 2006).

## 3.5 CALCULATIONS

### 3.5.1 Transfer factors

The transfer factor, $TF_g$ ($m^2$/kg dw), is a mathematical tool used to calculate and compare the uptake of radionuclides in plant material from the soil. $TF_g$ describes the uptake as related only to soil properties and depends only on the environmental conditions. The concept of transfer factors has been used at the Department of Soil and Environment since the seventies and has been widely used after the Chernobyl accident (Rosén, 1996).

In this study the transfer factor was calculated from the activity concentration in the plant dry matter divided by the activity concentration in the soil (equation 1). The activity deposited on ground, calculated 1986, was corrected according to the radioactive half-life of $^{137}Cs$ (see Section 3.1).

$$\mathrm{TF}_g = \frac{\text{Activity concentration in plant dry matter}\left(Bq/kg\ \text{dw}\right)}{\text{Activity concentration in soil}\left(Bq/m^2\right)} \qquad (1)$$

### 3.5.2 Statistics

Statistical analysis was performed, for fungi and plant samples from year 2009, using MiniTab 15 Statistical Software (2007). Prior to analyses, data was checked for normality and $\log_{10}$ transformed if necessary to achieve normality. 2-sample-t-test was used to compare two treatments.

# 4. RESULTS

## 4.1 $^{137}$Cs ACTIVITY CONCENTRATION IN FUNGI

Table 4.1 and Figure 4.1 displays the average $^{137}$Cs activity concentration in fungal sporocarps for the different treatment areas. The final column in Table 5.1 details the difference in percentage levels of the average $^{137}$Cs activity concentration between the control area, K-, and the potassium fertilized area, K+. *Russula paludosa* had the largest percentage difference between the control area and the potassium fertilized area. The *Cortinarius semisanguineus* and *Cortinarius cinnamomeus* species had the highest $^{137}$Cs activity concentration for the control area, while the *Cortinarius semisanguineus* and *Rozites caperata* had the highest $^{137}$Cs activity concentration for the potassium fertilized area.

Table 4.1. The average $^{137}$Cs activity concentrations in sporocarp (Bq/kg) 2009.

| Species | Treatments | | | | +/- to control, % |
|---|---|---|---|---|---|
| | n* | K- | n* | K+ | |
| *Cantharellus tubaeformis* | 0 | - | 3 | 16 780 ± 6 353 | - |
| *Cortinarius cinnamomeus* | 3 | 58 622 ± 23 246 | 0 | - | - |
| *Cortinarius semisanguineus* | 4 | 82 175 ± 39 723 | 7 | 60 146 ± 24 087 | -27 |
| *Lactarius rufus* | 1 | 29 476 ± 0 | 2 | 31 114 ± 38 215 | 6 |
| *Rozites caperata* | 2 | 48 075 ± 17 442 | 4 | 36 944 ± 7 868 | -23 |
| *Russula decolorans* | 3 | 12 283 ± 2 757 | 2 | 16 591 ± 2 754 | 35 |
| *Russula paludosa* | 1 | 28 894 ± 0 | 3 | 6 601 ± 1 212 | -77 |
| *Suillus variegatus* | 4 | 46 940 ± 13 804 | 2 | 20 987 ± 5 449 | -55 |

*n – number of samples analysed, where one sample consists of many dried and crushed fruit bodies.

It is apparent from Figure 4.1 that there is a higher $^{137}$Cs activity concentration in the control area for *Cortinarius semisanguineus, Rozites caperata, Russula paludosa* and *Suillus variegatus* compared to the potassium fertilized area. It is also noticeable that out of the six species where values can be compared, (there is a significant drop in the radiocaesium levels in 4 species in the fertilized area), *Lactarius rufus* exhibits a slight increase in levels, whilst *Russula decolorans* goes against the trend with a significant increase.

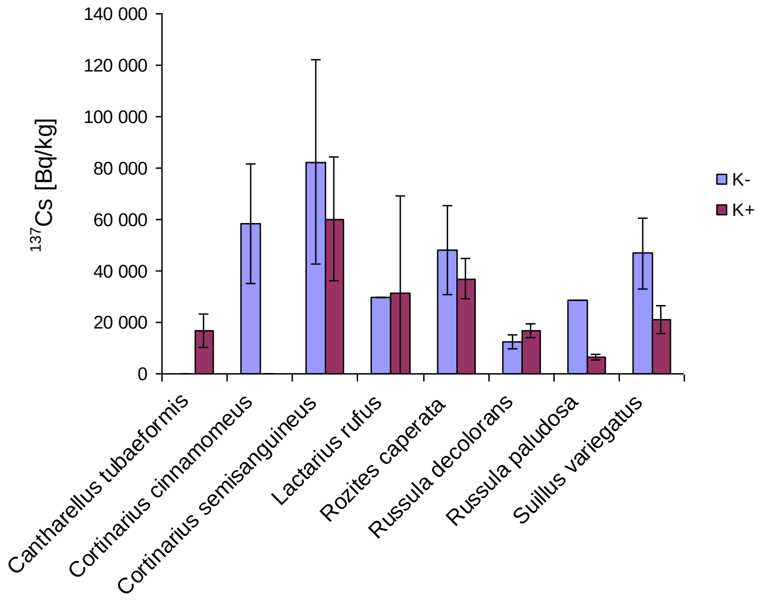


Figure 4.1. Bar graph of average $^{137}Cs$ activity concentration, in Bq/kg, in sporocarp species for year 2009. The blue bars represent $^{137}Cs$ activity from the control area, K-, and the red bars represent the $^{137}Cs$ activity from the potassium fertilized area, K+. Error bars represent ± 1 standard deviation from the mean value.

The data of the $^{137}Cs$ activity concentration in fungi from year 2009 were also compared with data from year 1992-1993 and 2000-2001, Figure 4.2, Figure 4.3 and Appendix 4. It has to be taking into account that the number of species varied from year to year, even on the same site, which can mislead the results. *Lactarius rufus, Rozites caperata* and *Suillus variegatus* show the same trend with lower $^{137}Cs$ activity concentration at the control area over the years and first higher $^{137}Cs$ activity concentration year 2000-2001 and then lower $^{137}Cs$ activity concentration year 2009 for the potassium fertilized area.

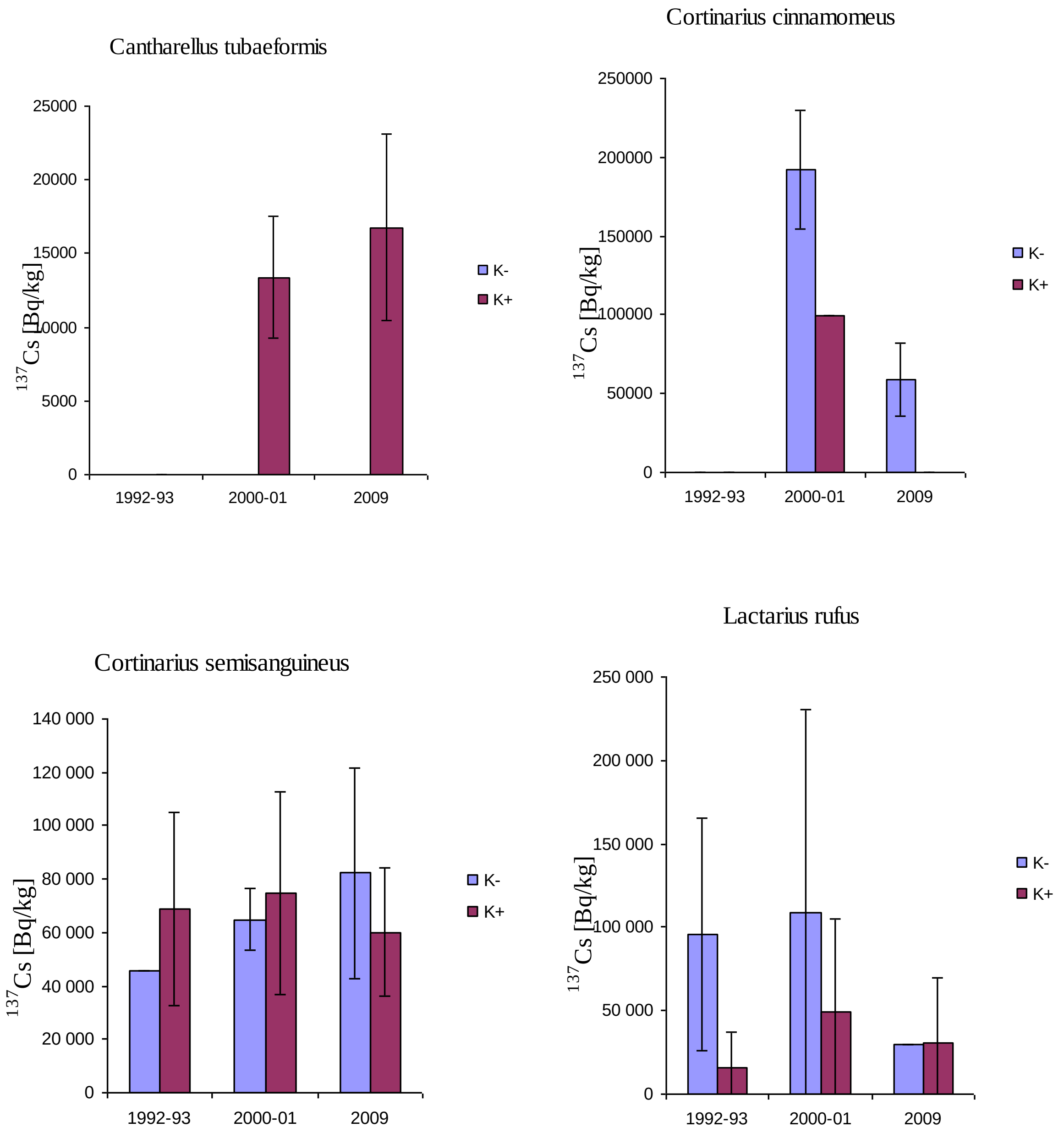


Figure 4.2. Bar graphs of average $^{137}$Cs activity concentration (Bq/kg), in the sporocarps of fungal species for the various years. The blue bars represent $^{137}$Cs activity from the control area, K-, and the red bars represent the $^{137}$Cs activity from the potassium fertilized area, K+. Error bars represent ± 1 standard deviation from the mean value.

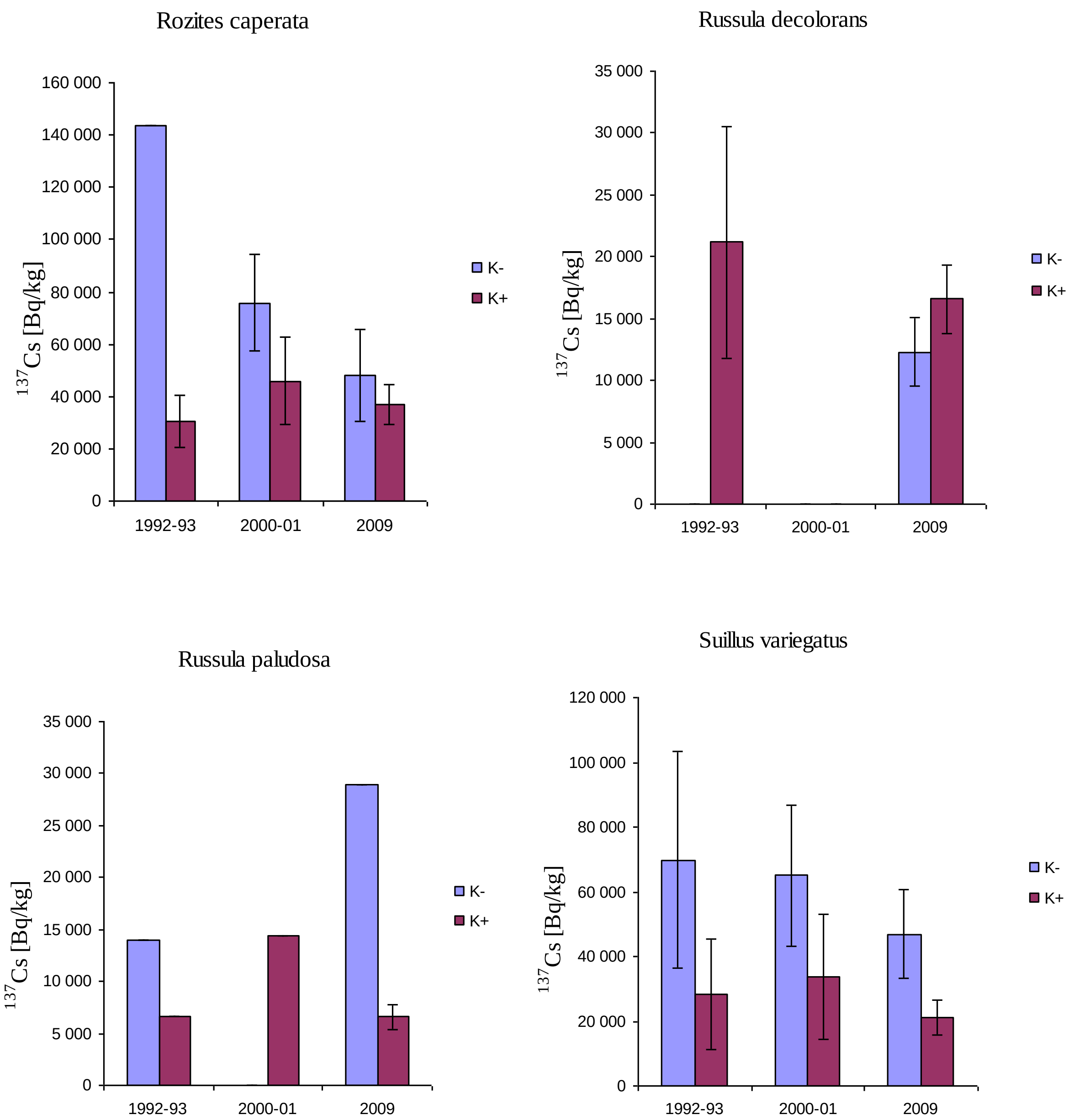


Figure 4.3. Bar graphs of average $^{137}$Cs activity concentration (Bq/kg), in the sporocarps of fungal species for the various years. The blue bars represent $^{137}$Cs activity from the control area, K-, and the red bars represent the $^{137}$Cs activity from the potassium fertilized area, K+. Error bars represent ± 1 standard deviation from the mean value.

## 4.2 $^{137}$Cs ACTIVITY CONCENTRATION IN PLANTS

The plant samples were organized in the same way as the fungi samples shown in Table 4.2. Heather had the highest $^{137}$Cs activity concentration for both the control area, K-, and for the potassium fertilized area, K+. Heather also had the largest difference in percentage between the control area and the potassium fertilized area.

Table 4.2. Average $^{137}$Cs activity concentration in plants 2009, Bq/kg.

| Species | Treatments | | | | +/- to control, % |
|---|---|---|---|---|---|
| | n* | K- | n* | K+ | |
| Bilberry | 7 | 1 499 ± 164 | 11 | 1 246 ± 659 | -17 |
| Lingonberry | 7 | 1 110 ± 283 | 8 | 798 ± 287 | -28 |
| Heather | 7 | 5 737 ± 1 542[a] | 8 | 3 928 ± 1 468[a] | -32 |

*n – number of samples analysed, where one sample consists of many dried and crushed fruit bodies. Rows sharing the letter a are significantly different at $p \leq 0.05$.

Figure 4.4 highlights the fact that all three plants show the same tendency of higher $^{137}$Cs activity concentration in the control area than in the potassium fertilized area.

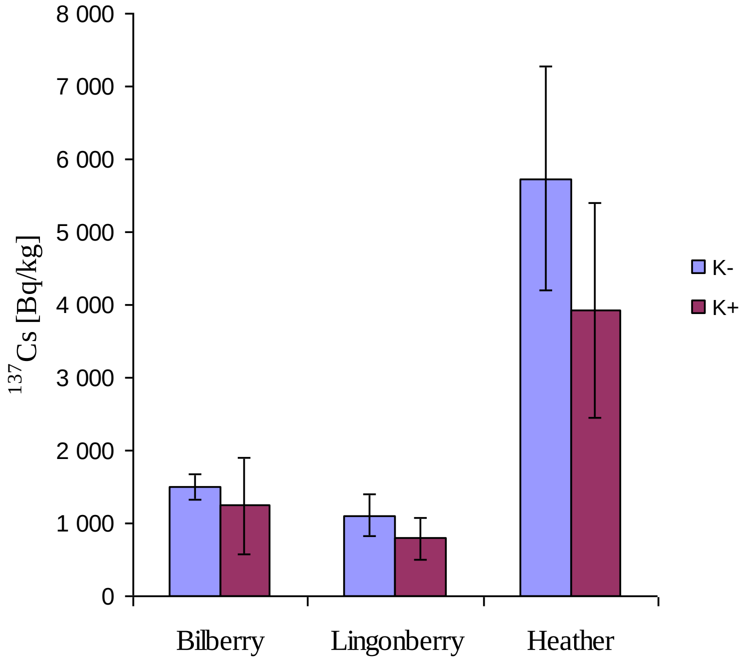


Figure 4.4. Bar graph of average $^{137}$Cs activity concentration (Bq/kg), in plant species for year 2009. The blue bars represent $^{137}$Cs activity from the control area, K- and the red bars represent the $^{137}$Cs activity from the potassium fertilized area, K+. Error bars represent ± 1 standard deviation from the mean value.

By observing the levels of $^{137}$Cs activity concentration for bilberry, lingonberry and heather in both the current and previous years' findings, Appendix 4, the following trends are applicable to each (see Figure 4.5):

1. The level of $^{137}$Cs activity concentration is always lower in the potassium fertilized area.

2. The levels of $^{137}$Cs activity concentration in both the control and fertilized area have decreased over time. The levels detected in plants from 2009 are lower than those detected in 2000-2001 whose levels in turn are lower than those recorded in 1992-1993.

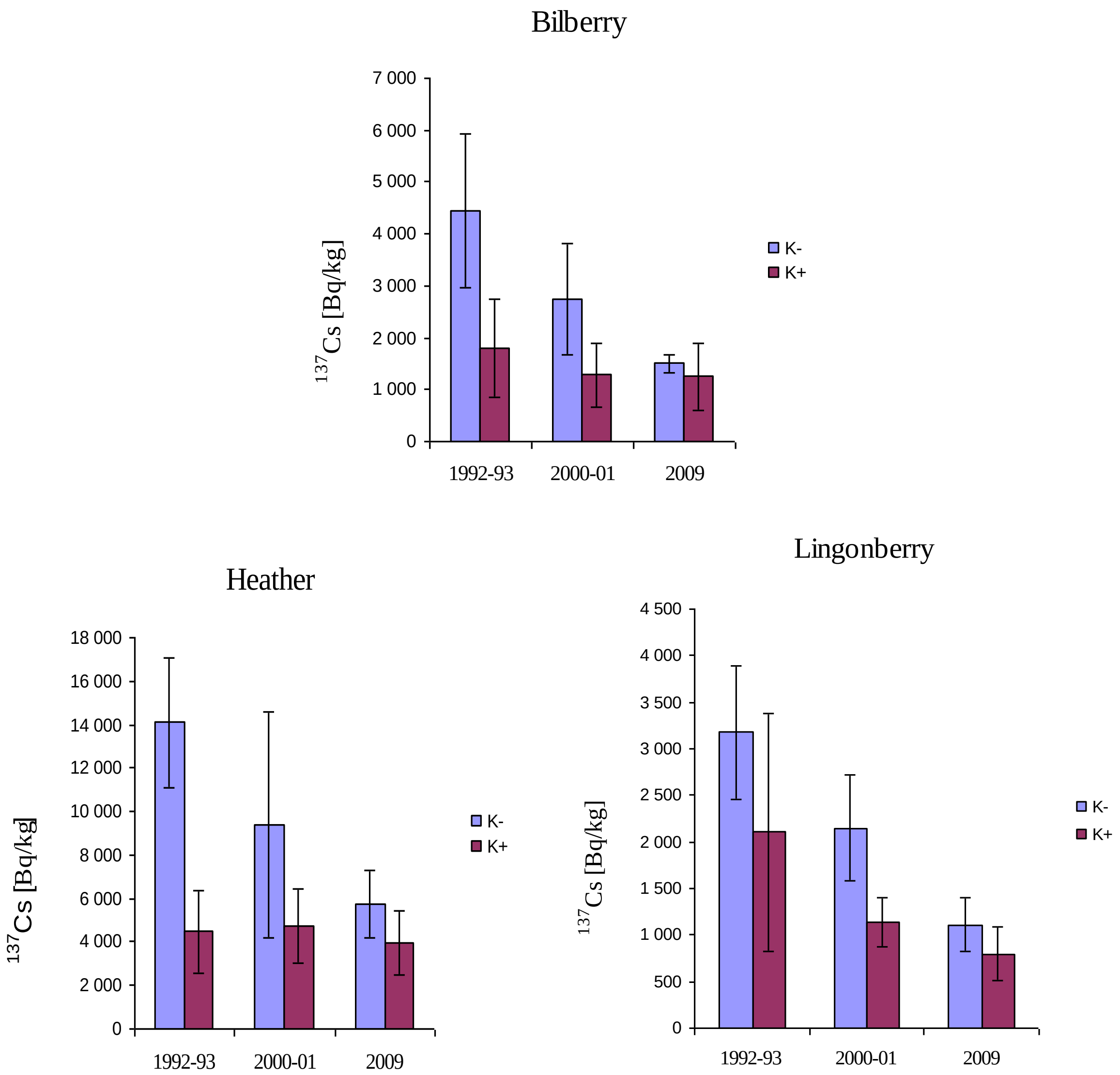


Figure 4.5. Bar graphs of average $^{137}$Cs activity concentration, in Bq/kg, in plant species for the different years. The blue bars represent $^{137}$Cs activity from the control area, K-, and the red bars represent the $^{137}$Cs activity from the potassium fertilized area, K+. Error bars represent ± 1 standard deviation from the mean value.

## 4.3 TRANSFER FACTORS

The transfer factor for fungi, calculated with equation 1, (Table 4.3), is highest for *Cortinarius semisanguineus* at both the control area and the potassium fertilized area. Heather is the plant that has the highest transfer factor at both the control area and the potassium fertilized area (see Table 4.4). When comparing the transfer factor for fungi and plant, fungi have overall the highest transfer factor.

Table 4.3. Transfer factor for 2009's values, soil-fungi, $m^2$/kg fungi dw.

| Species | Transfer factor | | | |
|---|---|---|---|---|
| | n* | K- | n* | K+ |
| *Cantharellus tubaeformis* | - | No data | 3 | 0.8157 ± 0.3088 |
| *Cortinarius cinnamomeus* | 3 | 2.8496 ± 1.1300 | - | No data |
| *Cortinarius semisanguineus* | 4 | 3.9945 ± 1.9309 | 7 | 2.9237 ± 1.1709 |
| *Lactarius rufus* | 1 | 1.4328 ± 0 | 2 | 1.5125 ± 1.8576 |
| *Rozites caperata* | 2 | 2.3369 ± 0.8478 | 4 | 1.7958 ± 0.3825 |
| *Russula decolorans* | 3 | 0.5971 ± 0.1340 | 2 | 0.8065 ± 0.1339 |
| *Russula paludosa* | 1 | 1.4045 ± 0 | 3 | 0.3209 ± 0.0589 |
| *Suillus variegatus* | 4 | 2.2817 ± 0.6710 | 2 | 1.0202 ± 0.2649 |

*n – number of samples analysed.

Table 4.4. Transfer factor for 2009's values, soil-plant, $m^2$/kg plant dw.

| Species | Transfer factor | | | |
|---|---|---|---|---|
| | n* | K- | n* | K+ |
| Bilberry | 7 | 0.0728 ± 0.0080 | 11 | 0.0606 ± 0.0320 |
| Lingonberry | 7 | 0.0540 ± 0.0138 | 8 | 0.0388 ± 0.0139 |
| Heather | 7 | 0.2789 ± 0.0749 | 8 | 0.1909 ± 0.0714 |

*n – number of samples analysed.

# 5. DISCUSSION

## 5.1 FUNGI

The results from 2009 for *Cortinarius semisanguineus, Rozites caperata, Russula Paludosa* and *Suillus variegatus* clearly show that it is possible to use potassium fertilization in order to reduce the $^{137}$Cs uptake in fungi. Due to lack of data, *Cortinarius semisanguineus* was the only fungi species where a statistical analysis was performed. The result from this analysis shows that there is no significant difference between the control area and the potassium fertilized area.

The majority of the species of fungi for the different years also show less $^{137}$Cs activity concentration in the potassium fertilized area than in the control area. Only 4 out of 21, K-/K+ sample comparisons in $^{137}$Cs activity concentration levels, show an increase of the $^{137}$Cs activity concentration at the potassium fertilized area. An increase in the $^{137}$Cs activity concentration for year 2000-2001 can be explained with that more radiocaesium reaches layers where the fungi have their mycelia and uptake becomes more efficient. In 1994, 85 % of the $^{137}$Cs activity concentration was found in the top 5 cm of the soil profile in an area close to Stalbo (Fawaris & Johansson, 1994). This shows that the $^{137}$Cs downward migration to deeper layers is a very slow process and would explain why the fungi $^{137}$Cs activity concentration would increase after a few years. Ectomycorrhizal species normally have there mycelia some centimetres below the surface (Strandberg, 2004).

The results from the studies strongly indicate that each individual fungi species has a different ability regarding $^{137}$Cs uptake. *Cortinarius semisanguineus* has the highest activity in the control area and the potassium fertilized area for year 2009 and also has the highest transfer factor. The ability for $^{137}$Cs uptake by fungi goes hand in hand with the transfer factor.

Based on my results for 2009, one can discuss if potassium fertilization is good to use in order to reduce the $^{137}$Cs uptake in fruit bodies of fungi. It is hard to determine why some of the results appear to contradict the major observation that potassium fertilization is good to use in order to decrease the $^{137}$Cs activity concentration. It should be pointed out that only small amounts of the different fungi species where found in some samples. This could potentially reduce the accuracy of the results, as small amounts have a larger degree of error. As pointed out above, different fungi species appear to have different abilities regarding their uptake of radiocaesium. It is beyond the objective of this particular study to determine why this is the case. However, further research on this topic in order to provide valuable findings and answers regarding the questions raised by these results are recommended.

## 5.2 PLANTS

The results from the studies of plants both year 2009 and previous year’s show that potassium fertilization could be efficient at reducing the $^{137}$Cs activity concentration in plants. This agrees with the results obtained by Kaunisto *et al*. (2002) who determined the effect of potassium fertilization in tree stands and peat on pine mire, Shenber & Eriksson (1993) who studied the potassium fertilization on farmland and Zibold *et al*. (2009) who determined the influence of fertilization on the $^{137}$Cs soil-plant transfer in a spruce forest of Southern Germany. It is only for heather where a significant difference is acknowledged between the potassium fertilized area and the control area.

Heather's uptake of radiocaesium is much more efficient than bilberry and lingonberry. It could be the effect of the increased soil-root/mycelia transfer factor. The $^{137}Cs$ activity concentration is mainly located in the green parts for heather whereas cranberry that is similar to lingonberry and bilberry showed higher $^{137}Cs$ activity concentration in the roots (Vinichuk *et al*., 2009), which could also be an explanation.

These results from 2009 strongly indicate that the potassium fertilization still has an impact on the $^{137}Cs$ uptake by plants. Lindahl *et al*. (2002) suggest that plants and fungi re-utilise nutrients in its own mycelium to minimise losses to competing organisms. This would mean that when potassium is taken up by plants and fungi it is "stuck" in the plants/fungus nutrient cycle. As the differences between $^{137}Cs$ levels in the control area and potassium fertilised area are relative, this indicates that the potassium remains in the soil for a long period of time and that its uptake into the plants continues to have an affect to the present day.

## 5.3 CONCLUSION

The results from my studies strongly indicate that potassium fertilization has the effect of reducing the $^{137}Cs$ uptake by fungi and plant species. 4 out of 6 of the fungi species from this year and 5 out of 7 fungi species from all the combined studies provide evidence of this finding. The results from all plant studies also indicate that potassium fertilization reduces the $^{137}Cs$ uptake levels. The amount of potassium in the system has decreased over time and this has led in turn to a decrease in its ability to have an effect of the $^{137}Cs$ uptake.

To summarise the findings, the results from the studies of fungi and plants both year 2009 and previous years strongly indicate that potassium fertilization could be efficient as a countermeasure for the purpose of reducing $^{137}Cs$ activity concentration.

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# Appendix 1

A record of all sporocarps collected Aug-Oct 2009.

| Fungi, Latin name | Fungi, Swedish name | Area |
|---|---|---|
| *Amanita fulva* | Brun kamskivling | K- |
| *Amanita porphyria* | Mörkringad flugsvamp | K- K+3 |
| *Amanita rubescens* | Rodnande flugsvamp | K+2 |
| *Amanita virosa* | Vit flugsvamp | K-, K+2 |
| *Boletus edulis* | Karl-johan svamp | K-, K+2 |
| *Cantharellula umbonata* | Fläckkantarell | K+3 |
| *Cantharellus cibarius* | Kantarell | K-, K+3 |
| *Cantharellus tubaeformis* | Trattkantarell | K+3 |
| *Chroogomphus rutilans* | Rabarbersvamp | K-, K+2, K+3 |
| *Collybia acervata* | Tuvnagelskivling | K- |
| *Cortinarius acutus* | Spetsspindling | K- |
| *Cortinarius armeniacus* | Aprikosspindling | K- |
| *Cortinarius brunneus* | Umbraspindling | K-, K+3 |
| *Cortinarius cinnamomeus* | Kanelspindling | K- |
| *Cortinarius collinitus* | Violettfotad slemspindling | K- |
| *Cortinarius croceus* | Gulskivig kanelspindling | K-, K+2, K+3 |
| *Cortinarius gentilis* | Gulbandad spindling | K-, K+3 |
| *Cortinarius malachius* | Malvaspindelskivling | K+2 |
| *Cortinarius mucosus* | Hedspindling | K-, K+2 |
| *Cortinarius obtusus* | Jodoformspindling | K-, K+3 |
| *Cortinarius semisanguineus* | Rödskivig kanelspindling | K-, K+2, K+3 |
| *Cortinarius traganus* | Bockspindling | K- |
| *Cystoderma jasonis* | Gulköttig grynskivling | K-, K+3 |
| *Entoloma cetratum* | Skogsrödhätting | K+3 |
| *Gymnopilus picreus* | Mörkfotad bitterskivling | K- |
| *Hebeloma bryogenes* | Mossfränskivling | K-, K+3 |
| *Hebeloma longicaudum* | - | K+3 |
| *Laccaria proxima* | Stor laxskivling | K- |
| *Lactarius camphoratus* | Kamferriska | K- |
| *Lactarius helvus* | Lakritsriska | K-, K+2 |
| *Lactarius mammosus* | Mörk doftriska | K- |
| *Lactarius musteus* | Tallriska | K- |
| *Lactarius rufus* | Pepparriska | K-, K+2, K+3 |
| *Lactarius vietus* | Gråriska | K- |
| *Leccinum holopus* | Kärrsopp | K- |
| *Leccinum scabrum* | Björksopp | K- |
| *Leccinum versipelle* | Tegelsopp | K- |
| *Paxillus atrotomentosus* | Svartfotad pluggskivling | K- |
| *Paxillus involutus* | Pluggskivling | K-, K+3 |
| *Piptoporus betulinus* | Björkticka | K- |
| *Rozites caperata* | Rynkad tofsskivling | K-, K+2, K+3 |
| *Russula betularum* | Blek giftkremla | K+2 |
| *Russula decolorans* | Tegelkremla | K-, K+2 |
| *Russula emetica* | Giftkremla | K+2 |
| *Russula paludosa* | Storkremla | K-, K+2, K+3 |
| *Russula puellaris* | Sienakremla | K- |
| *Russula versicolor* | Skarp sienakremla | K- |
| *Russula vinosa* | Vinkremla | K- |
| *Stropharia semiglobata* | Gul kragskivling | K+3 |
| *Suillus bovinus* | Örsopp | K- |
| *Suillus luteus* | Smörsopp | K- |
| *Suillus variegatus* | Sandsopp | K-, K+2 |
| *Xerocomus subtomentosus* | Sammetsopp | K-, K+2 |

# Appendix 2

$^{137}$Cs activity concentration in selected sporocarp species collected Aug-Oct 2009, Bq/kg.

| Sample date | Species | $^{137}$Cs |
|---|---|---|
| | **K-** | |
| 2009-09-02 | *Cortinarius cinnamomeus* | 59 268 |
| 2009-09-10 | *Cortinarius cinnamomeus* | 81 538 |
| 2009-09-17 | *Cortinarius cinnamomeus* | 35 059 |
| 2009-09-02 | *Cortinarius semisanguineus* | 141 654 |
| 2009-09-10 | *Cortinarius semisanguineus* | 59 512 |
| 2009-09-17 | *Cortinarius semisanguineus* | 65 300 |
| 2009-09-30 | *Cortinarius semisanguineus* | 62 233 |
| 2009-09-30 | *Lactarius rufus* | 29 476 |
| 2009-09-17 | *Rozites caperata* | 35 742 |
| 2009-09-30 | *Rozites caperata* | 60 408 |
| 2009-09-02 | *Russula decolorans* | 14 947 |
| 2009-09-17 | *Russula decolorans* | 12 460 |
| 2009-09-30 | *Russula decolorans* | 9 442 |
| 2009-09-10 | *Russula paludosa* | 28 894 |
| 2009-09-02 | *Suillus variegatus* | 49 920 |
| 2009-09-10 | *Suillus variegatus* | 64 200 |
| 2009-09-17 | *Suillus variegatus* | 42 300 |
| 2009-09-30 | *Suillus variegatus* | 31 340 |
| | **K+2** | |
| 2009-09-10 | *Cortinarius semisanguineus* | 65 654 |
| 2009-09-17 | *Cortinarius semisanguineus* | 83 077 |
| 2009-09-30 | *Cortinarius semisanguineus* | 98 248 |
| 2009-09-17 | *Lactarius rufus* | 58 136 |
| 2009-09-17 | *Rozites caperata* | 28 459 |
| 2009-09-30 | *Rozites caperata* | 46 496 |
| 2009-09-10 | *Russula decolorans* | 14 644 |
| 2009-09-17 | *Russula decolorans* | 18 538 |
| 2009-09-02 | *Russula paludosa* | 7 316 |
| 2009-09-17 | *Russula paludosa* | 7 285 |
| 2009-09-10 | *Suillus variegatus* | 17 134 |
| 2009-09-17 | *Suillus variegatus* | 24 840 |
| | **K+3** | |
| 2009-09-10 | *Cantharellus tubaeformis* | 9 571 |
| 2009-09-17 | *Cantharellus tubaeformis* | 19 209 |
| 2009-09-30 | *Cantharellus tubaeformis* | 21 561 |
| 2009-09-02 | *Cortinarius semisanguineus* | 33 077 |
| 2009-09-10 | *Cortinarius semisanguineus* | 49 688 |
| 2009-09-17 | *Cortinarius semisanguineus* | 55 896 |
| 2009-09-30 | *Cortinarius semisanguineus* | 35 385 |
| 2009-09-30 | *Lactarius rufus* | 4 092 |
| 2009-09-17 | *Rozites caperata* | 39 720 |
| 2009-09-30 | *Rozites caperata* | 33 100 |
| 2009-09-02 | *Russula paludosa* | 5 202 |

# Appendix 3

$^{137}Cs$ activity concentration in plant species collected Jul-Aug 2009, Bq/kg.

| Sample date | Species | $^{137}Cs$ |
|---|---|---|
| | **K-** | |
| 2009-07-23 | Bilberry 1 | 1 700 |
| 2009-08-11 | Bilberry 1 | 1 730 |
| 2009-07-23 | Bilberry 2 | 1 370 |
| 2009-08-11 | Bilberry 2 | 1 310 |
| 2009-07-23 | Bilberry 3 | 1 480 |
| 2009-08-11 | Bilberry 3 | 1 520 |
| 2009-07-23 | Bilberry 4 | 1 380 |
| 2009-07-23 | Heather 1 | 4 910 |
| 2009-08-11 | Heather 1 | 4 890 |
| 2009-07-23 | Heather 2 | 4 360 |
| 2009-08-11 | Heather 2 | 5 840 |
| 2009-07-23 | Heather 3 | 7 290 |
| 2009-08-11 | Heather 3 | 4 490 |
| 2009-07-23 | Heather 4 | 8 380 |
| 2009-07-23 | Lingonberry 1 | 1 020 |
| 2009-08-11 | Lingonberry 1 | 779 |
| 2009-07-23 | Lingonberry 2 | 1 270 |
| 2009-08-11 | Lingonberry 2 | 783 |
| 2009-07-23 | Lingonberry 3 | 1 580 |
| 2009-08-11 | Lingonberry 3 | 1 130 |
| 2009-07-23 | Lingonberry 4 | 1 210 |
| | **K+2** | |
| 2009-07-23 | Bilberry 1 | 1 390 |
| 2009-08-11 | Bilberry 1 | 1 850 |
| 2009-07-23 | Bilberry 2 | 1 430 |
| 2009-08-11 | Bilberry 2 | 1 680 |
| 2009-08-11 | Bilberry 3 | 2 100 |
| 2009-07-23 | Heather 1 | 5 490 |
| 2009-08-11 | Heather 1 | 4 530 |
| 2009-07-23 | Heather 2 | 5 010 |
| 2009-08-11 | Heather 2 | 5 190 |
| 2009-08-11 | Heather 3 | 4 520 |
| 2009-07-23 | Lingonberry 1 | 1 240 |
| 2009-08-11 | Lingonberry 1 | 1 060 |
| 2009-07-23 | Lingonberry 2 | 955 |
| 2009-08-11 | Lingonberry 2 | 866 |
| 2009-08-11 | Lingonberry 3 | 683 |
| | **K+3** | |
| 2009-08-11 | Bilberry 1 | 590 |
| 2009-08-11 | Bilberry 2 | 616 |
| 2009-08-11 | Bilberry 3 | 310 |
| 2009-08-11 | Heather 1 | 2 250 |
| 2009-08-11 | Heather 2 | 2 710 |
| 2009-08-11 | Heather 3 | 1 720 |
| 2009-08-11 | Lingonberry 1 | 353 |
| 2009-08-11 | Lingonberry 2 | 585 |
| 2009-08-11 | Lingonberry 3 | 640 |

# Appendix 4

$^{137}$Cs activity concentrations in sporocarp species 1992-1993, Bq/kg.

| Species | Treatments | | | | +/- to control, % |
|---|---|---|---|---|---|
| | n* | K- | n* | K+ | |
| *Cantharellus tubaeformis* | 0 | - | 0 | - | - |
| *Cortinarius cinnamomeus* | 0 | - | 0 | - | - |
| *Cortinarius semisanguineus* | 1 | 45 881 | 5 | 107 889 | 135 |
| *Lactarius rufus* | 11 | 95 283 | 4 | 26 599 | -72 |
| *Rozites caperata* | 1 | 143 663 | 3 | 29 989 | -79 |
| *Russula decolorans* | 0 | - | 2 | 21 158 | - |
| *Russula paludosa* | 1 | 13 980 | 1 | 6 590 | -53 |
| *Suillus variegatus* | 6 | 69 855 | 6 | 37 457 | -46 |

*n – number of samples analysed.

$^{137}$Cs activity concentrations in sporocarp species 2000-2001, Bq/kg.

| Species | Treatments | | | | +/- to control, % |
|---|---|---|---|---|---|
| | n* | K- | n* | K+ | |
| *Cantharellus tubaeformis* | 0 | - | 3 | 12 173 | - |
| *Cortinarius cinnamomeus* | 2 | 192 197 | 1 | 99 292 | -48 |
| *Cortinarius semisanguineus* | 2 | 64 955 | 8 | 74 879 | 15 |
| *Lactarius rufus* | 5 | 50 796 | 2 | 49 104 | -3 |
| *Rozites caperata* | 2 | 75 699 | 2 | 46 003 | -39 |
| *Russula decolorans* | 0 | - | 0 | - | - |
| *Russula paludosa* | 0 | - | 1 | 14 447 | - |
| *Suillus variegatus* | 8 | 67 993 | 2 | 115 797 | 70 |

*n – number of samples analysed.

$^{137}$Cs activity concentrations in plant species 1992-1993, Bq/kg.

| Species | Treatments | | | | +/- to control, % |
|---|---|---|---|---|---|
| | n* | K- | n* | K+ | |
| Bilberry | 8 | 4 436 | 12 | 1 797 | -59 |
| Lingonberry | 9 | 3 174 | 8 | 2 107 | -34 |
| Heather | 13 | 14 112 | 12 | 4 463 | -68 |

*n – number of samples analysed.

$^{137}$Cs activity concentrations in plant species 2000-2001, Bq/kg.

| Species | Treatments | | | | +/- to control, % |
|---|---|---|---|---|---|
| | n* | K- | n* | K+ | |
| Bilberry | 9 | 2 742 | 9 | 1 284 | -53 |
| Lingonberry | 7 | 2 150 | 9 | 1 140 | -47 |
| Heather | 9 | 9 387 | 9 | 4 756 | -49 |

*n – number of samples analysed.