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Accumulation of Radiocesium by Mushrooms in the Environment: A Literature Review

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Abstract

During the last 50 years, a large amount of information on radionuclide accumulators or "sentinel-type" organisms in the environment has been published. Much of this work focused on the risks of food-chain transfer of radionuclides to higher organisms such as reindeer and man. However, until the 1980's and 1990's, there has been little published data on the radiocesium (^{134}Cs and ^{137}Cs) accumulation by mushrooms. This presentation will consist of a review of the published data for ^{134,137}Cs accumulation by mushrooms in nature. This review will discuss the aspects that promote ^{134,137}Cs uptake by mushrooms and focus on mushrooms that demonstrate a large propensity for use in the environmental biomonitoring of radiocesium contamination. It will also provide descriptions of habitats for many of these mushrooms and discuss on how growth media and other conditions relate to Cs accumulation.

Keywords: Concentration ratio; Transfer factor; Aggregate transfer factor; Biomonitoring; Chernobyl

Introduction

Radiocesium (primarily ^{137}Cs and ^{134}Cs isotopes) is produced mainly by the fission of nuclear fuel. Releases of ^{134,137}Cs into the environment have occurred primarily from nuclear weapons testing, nuclear fuel reprocessing and nuclear reactor accidents like that of Chernobyl in 1986. Because these processes release ^{134,137}Cs as well as other radionuclides into the environment, there has been considerable concern about the transfer of radionuclides to higher organisms in the food chain.

One of the common approaches to assess the food chain transfer of radionuclides is the radiometric measurement of radionuclides that are accumulated by organisms that comprise the lower portion of the food chain. In some cases, when these lower organisms (such as wild mushrooms) have a large affinity for radionuclides, the consumption of these organisms by humans can pose a considerable health concern from a radiological dose perspective (Grueter, 1964). Despite this realization, there is fairly limited biomonitoring data on radionuclide levels in mushrooms today. Baeza and co-workers (2004) and many other researchers that are cited in this review concur with this observation but they note that considerably more data are available for ^{137}Cs than for other ^{134}Cs, alpha- and beta-emitting radionuclides.

Background on Mushrooms and Conditions that Influence Radiocesium Accumulation

There are ~13,500 species of mushrooms and generally, three main groups of mushrooms: gilled, non-gilled, and puffballs and their relatives. Those mushrooms of interest as radiocesium accumulators are typically gilled or have pores or spines under their caps and they have stalks. Typical names for these mushrooms have the following words in them: roof, sheath, and common meadow (mushrooms); milk, crumble, death, waxy, web, and inky caps; tricholomas; ringstalks; mottle, pink, and brittle gills; and various "tooths". The common names for Cs-accumulating mushrooms are listed next to their *Latin* names as listed in **Table 1.**

Mushrooms typically prefer forests and grasslands. However, almost any ecosystem (including deserts and tundra) with the right substrates will support their growth. Mushrooms often require a particular growth medium to live in. The media may consist of a decaying portion of a tree, open grasslands, animal manure or areas directly under a tree in leaf or needle litter. Growth media for mushrooms has been defined using the following variables: wood, litter layer, 0-5 cm soil profile and >5 cm soil profile by Yoshida and researchers (1994). Kammerer et al. (1994) divided mushrooms according to their living habitats. The first group was the saprophytes, which live on and metabolically consume organic matter. The second group was the parasitic mushrooms, which live on other species in a non-symbiotic relationship. The third group was the symbiotic species, which through the use of underground mycorrihiza, form a close relationship with their host plant.

In nature mushrooms can be confused with manure, seed pods, bone, lichens, some flowering plants that are not green in color, insect sacs or galls, and rotten wood. When removed from their growth medium, mushrooms can break under their own weight. Due to their fragile structure and high water content, even gentle handling is likely to make the recognition by species difficult after collection. Photography of the mushroom prior to removal from its growth habit is highly recommended in these cases. Their above ground portions or fruiting bodies (which are used for reproduction through spore release) usually appear between spring and early winter and their emergence is typically correlated with recent rainfall.

There are several field guides, which we used to obtain general information about mushrooms as mentioned above such as Læssøe (2002), McKnight and McKnight (1987), and Roody (2003). These guides have detailed descriptions about the identification of specific species of mushrooms and the locations that they can be found in. A species identification of mushrooms can be very difficult due to similarities between various types of species. Many mushrooms are poisonous. Consumption of mushrooms is not recommended if one lacks the expertise to distinguish the poisonous ones from those that are not.

Uptake of radiocesium by basidiomycete mushrooms was observed as early as the 1960s by H. Grueter (1964; 1971). In these studies, mushrooms from sandy pine needle-covered soils had higher ^{137}Cs levels than those from soils in deciduous woods and meadows. The relatively high degree of Cs uptake was attributed to the sandy soil having a lower competition for ^{137}Cs (through sorption) than that of the soils in meadows and deciduous forests, which have a mineral composition that absorbs Cs more strongly. Additionally, organic material in soil O-horizons has a lower affinity for Cs than mineral soils and therefore, mushrooms that grow in organic soils are likely to have higher levels of Cs than those that grow in mineral soils (Kammerer et al., 1994). Kammerer and researchers (1994) also observed a higher average ^{137}Cs concentration in mushrooms that are symbiotic than those that are saprophytic and parasitic. However, the range in values for ^{137}Cs in these groups was the largest for the saprophytic species.

The depth at which underground portions of the mushrooms inhabit in the soil is also an important factor. Yoshida and researchers (1994) concluded that highest average concentration of ^{137}Cs was for those mushrooms that inhabited the surface soil (0 to 5 cm) layer (with mycelia being noticeably present at that depth). They and Kammerer et al. (1994) attribute Cs uptake to be related to individual species or groups thereof—with saprophytes having less accumulation than those mushrooms living on the uppermost portion of the soil. Additionally, the ratios of ^{137}Cs for above and below ground portions of mushrooms from conifer forests typically exceed those ratios for mushrooms in deciduous forests (Vinichuk and Johanson, 2003 and references therein).

Mushrooms from higher altitudes can have higher radiocesium levels than those at lower altitudes (Heinrich, 1993). However, the soil properties of the soils in these studies may have a greater influence on radiocesium uptake than altitude as discussed by Heinrich. This was because the soil at the higher altitude was high in humus and more acidic. Such conditions favor a greater amount of plant-available Cs percentage than that of the other soils at lower elevations.

Depth and soil horizon can also have an influence on the ratio of ^{134}Cs to ^{137}Cs in mushrooms (Yoshida et al., 1994; Kammerer et al., 1994). This was attributed to periods of time when the aerial deposition of ^{134}Cs relative to ^{137}C varied greatly (such as from Chernobyl) and the soil at greater depths did not reflect the higher levels of ^{134}Cs relative to ^{137}C because the migration of ^{134}Cs in the soil column may be slow (Oolbekkink and Kuyper, 1989 and references therein). The levels (and ratios) of ^{134}Cs and ^{137}Cs may also vary (from that of the original source term) in mushrooms because ^{134}Cs can be discriminated from ^{137}Cs by some fungal species (Guillitte et al. 1987).

Other factors in addition to growth medium characteristics such as rainfall, soil (stable) Cs and K concentrations, climate, soil pH, time of sampling, Cs source term, and growth substrate (such as rotting wood) may influence Cs uptake (as previously discussed; Oolbekkink and Kuyper, 1989 and references therein; Heinrich 1993), but most report that soil factors or conditions, such as pH and organic matter content and preferred growth medium probably have a great affect on the accumulation of Cs as well as other radionuclides by mushrooms (Battison et al., 1989). Finally, there are clearly several species of fungi that have a unique ability to accumulate Cs under a variety of conditions as will be discussed in this presentation.

Approaches to Comparing Accumulation Values

There are several approaches used to evaluate and compare the relative affinity that mushrooms have for radiocesium. We will discuss the assumptions that were made with these methods and the impact of making these assumptions.

The ratio of the Cs concentration in the mushroom (or fruiting body in Bq Cs/kg dw) relative to that of its growth medium (i.e., soil or rotting wood, etc. in Bq Cs/kg dw) is called a transfer factor (TF) or concentration ratio (CR). The TF is a metric that is used to evaluate the relative accumulation of Cs for various mushroom species.

Toal et al. (2002) report the uptake of ^{137}Cs relative to the amount that is deposited by aerial deposition on the soil or the total soil ^{137}Cs inventory with the use of aggregate transfer factor or T_{ag} values. These T_{ag} values (in m^2/kg dw) are based on the amount of ^{137}Cs in the mushroom (in Bq/kg dw) relative to the ^{137}Cs content in the aerial deposition (in Bq/m^2 dw). In their study, Toal and researchers cite literature data that indicates that all of the (aerially deposited) soil ^{137}Cs is in the upper 20 cm of the soil profile.

Oolbekkink and Kuyper (1989) discuss their preference for using TF values that are based on soil radiocesium levels as opposed to (T_{ag}) values that are based on aerial deposition because the uptake of radiocesium by mushrooms occurs through their growth medium and not directly from the air. The use of T_{ag} values (as used in the later work by Toal et al., 2002) may be more applicable for the study of Cs uptake by lichens and mosses, which remove Cs directly from aerial fallout and do not have roots to remove soil Cs. However, the use of TF values requires one to assume choose a soil depth (for radiocesium activity concentration determination) at which the mushroom resides for radiocesium analysis. Toal and researchers recognize that comparisons based on ^{137}Cs inventory may not be practical and that knowing the inventory within regions of the profile that pertain to where the mushrooms reside may give a better approach for comparison.

Work by Vinichuk and Johanson (2003) shows that the total ^{137}Cs activity concentration in the soil and the fungal mycelium concentration can vary with depth, fungal type, and also with the selected increments of sampled depth (e.g., 1 or 2 cm intervals). This observation used TF values that were based on soil activity concentration (at 1 and 2 cm intervals) within this particular study. If we were to consider the impact of these observations, we find it somewhat difficult to compare the TF values obtained from one study with that of another. This is because the uptake of Cs could vary with depth because of differences in soil properties also vary with depth (such as soil organic matter content) as discussed by Kammerer et al. (1994), the density of fungal mycelium, and competition from other living species. Most all of the references that we reviewed noted the problems with estimating fungal mycelium as well as the process of generalizing Cs accumulation.

Other researchers have ratioed the radiocesium activity concentrations of the mushrooms that they analyzed to that of one species (*Xerocomus badius* also known as *Boletus badius*) which was common to most all of their sampling areas (as in Kammerer et al., 1994). This allowed these researchers to normalize their data to the radiocesium of one species. These researchers utilized TF values (based on Bq/kg fw to Bq/kg dw in the organic or O-horizon) as well.

A compilation of data on the accumulation of Cs by mushrooms will be presented in this review. We will also present published data on approaches for comparing radiocesium uptake amongst mushroom types and sampled regions as well as discuss the importance of growth media characteristics on radiocesium accumulation.

Mushrooms with a Moderate to High Affinity for Radiocesium

Data for the mushrooms that have been observed to accumulate high levels of Cs are listed in **Table 1**. The mushroom species represented here were collected in Europe, Japan and North America. Most all of the data in this table represents the above ground portions of the fungi unless otherwise noted.

Studies have also observed radiocesium in the below ground portions of fungi (Vinichuk and Johanson, 2003) and the ^{137}Cs levels tend to be lower in the buried fungal mycelium than in the above ground fruiting bodies. Haselwandter (1978), Heinrich (1993) noted that portions of the caps or fruiting bodies (stems plus caps) tend to be rich in ^{137}Cs relative to their underground fungal masses. Vinichuk and Johanson (2003) noted that symbiotic fungi have high metabolic rates. As noted by Haselwandter and Berreck (1994), a study by Clint et al. (1991) observed that Cs is complexed by cap pigments in some boletes. This might explain why high uptake of Cs in the fruiting body, which includes the cap is observed. Heinrich (1993) determined the levels of ^{137}C in the lamella (gills), cap and stalk of *Boletus edulis* and observed that the gills had 2.5 times the levels of ^{137}Cs as the cap and the stalk. Radiography studies with *Rozites caperata* also showed higher levels of ^{137}Cs in the gills relative to the cap.

Amanitas

Most *Amanita* sp. mushrooms are poisonous so they are not likely to be a concern with regard to human consumption, which is a driver for most studies on radionuclide accumulation by edible foods. *Amanitas* are mostly symbiotic and are typically found in deciduous and conifer forests. These gilled fungi have a moderate affinity for Cs as has been observed in several studies (**Table 1**). However, high uptake ^{137}Cs has been observed for *Amanita rubescens* which was growing in a spruce and fir forest that had a low cation exchange capacity, low pH and high humus content (**Table 1**; Heinrich, 1993). When cooked, *Amanita rubescens* is edible so there is some concern to man with regard to radiocesium uptake. Similar observations were made by Vinichuk and Johanson (2003) for *Amanita muscaria* (**Table 1**). In general, the reported TF values for the Amanitas in **Table 1** are less or equal to 1.0 and the T_{ag} value for *Amanita rubescens* is low relative to the other species in this table.

Boletus

Boletes or *Boletus* mushrooms have a high affinity for Cs (Byrne, 1989; Heinrich, 1993; Kammerer et al., 1994; Toal et al., 2002; Vinichuk and Johanson, 2003; Řanda and Kučera, 2004)—see **Table 1**. *Boletus* and *Suillus* are two of the primary genuses that make up the family of Boletaceae. These two types of mushrooms as well as those of the genus *Xerocomus* often have common names that have “bolete” in them.

Boletus (or *Suillus*) *variegatus* prefer growing in sandy, acidic soils whereas *Boletus edulis* or porcini mushrooms prefer growth in mossy woodlands. Although some boletes are inedible or poisonous, many boletes are prized for their culinary value. Due to their marked ability to accumulate radiocesium, they pose some concern with regard to human consumption. Boletes are typically found in deciduous and conifer forests. Cesium-137 values range from a thousand Bq/kg of ^{137}Cs to more than a hundred thousand Bq/kg of ^{137}Cs. High levels of ^{137}Cs uptake were also observed prior to the Chernobyl release in spring of 1986 (Byrne, 1988).

In contrast to the Amanitas, the reported TF values for the Boletes (**Table 1)** are as high as 5.0, which is a low value relative to TF values for other mushroom species in this table. In most cases, the high TF values that are observed for the Boletes (those with TF values greater than 1.0) have ^{137}Cs activity levels that meet *or exceed* 1000 Bq of ^{137}Cs/kg dw (or fw). Data reported for aggregate transfer values are reported in **Table 1**. Of those reported values in **Table 1**, which range from 0.00007 to as high as 0.21, the two reported T_{ag} values of 0.0027 and 0.056 for the Boletes are relatively low.

Cantharellus, Cortinarius and *Clitocybe*

Like the boletes, many chanterelle or *Cantharellus* mushrooms are prized for their culinary value. These fungi, which grow on living or rotten wood have been observed to accumulate several tens of thousands Bq/kg of ^{137}Cs—making their direct consumption by man a potential risk. *Cantharellus cibarius* and *C. tubaeformis* grow in groups in old spruce and pine forests. *Cantharellus tubaeformis* is also found in deciduous forests.

Cortinarius mushrooms such as *Cortinarius* (or *Rozites*) *caperatus* (as listed in **Table 1**) also have high affinities for Cs as noted by Byrne (1988), Kammerer et al. (1994) and others as noted in **Table 1**. *Cortinarius* mushrooms are gilled and saprotrophic species. *Cortinarius armillatus* are typically found in small groups in damp, organic-rich boggy woodlands whereas *C. caperatus* are found in small groups under conifers and deciduous trees like beech. *Cortinarius caperatus* have wrinkled or furrowed caps and they prefer acidic soils, which are likely to support Cs uptake as previously discussed.

Although they are not widely represented in the literature, the *Clitocybe infundibuliformis* (or *C. gibba*) mushroom can have ^{137}Cs and ^{134}Cs activity values as high as ten thousand Bq/kg or more. These mushrooms also live on decayed material. The have low TF values (<0.7) relative to the *Cantharellus and Cortinarius* mushrooms, which have TF values range from 1.0 to >4.0, with the exception of *Cantharellus lutescens*. No T_{ag} values were reported as noted in **Table 1**.

Hebeloma sp., *Hydnum repandum, Hygrophorus russula* and *Hypholoma fasciculare*

Most *Hebeloma* sp. and *Hypholoma fasciculare* are poisonous (or inedible) mushrooms that are gilled. Depending on species, *Hebeloma* fungi have a variety of growth habits but they typically inhabit organic-rich material at the soil surface (Yoshida et al., 1994). This preference for organic growth media has been attributed to high Cs accumulation as previously discussed. *Hypholoma fasciculare* prefer growth on rotten deciduous tree stumps and roots.

Hygrophorus russula mushrooms grows in fairy ring formations, in groups or as scattered single mushrooms in oak forests. *Hydnum repandum* grows in groups or small clusters in conifer and deciduous woods. Unlike most *Hebeloma* sp. and *Hypholoma fasciculare,* the *Hygrophorus russula* and *Hydnum repandum* mushrooms are edible. These mushroom species have been observed to accumulate up to several thousand Bq/kg of ^{137}Cs (see **Table 1**). The TF values for *Hydnum repandum* are high (typically 1 to >4.0) and they compare well with the ^{137}Cs activity levels for these mushrooms.

For *Hypholoma fasciculare,* the T_{ag} values were that were reported in **Table 1** were close to that of the highest reported within the table (T_{ag} values of 0.09 to 0.1). No T_{ag} values were reported for *Hebeloma* sp., *Hydnum repandum* and *Hygrophorus russula* as noted in **Table 1**.

Inocybes

Most *Inocybes* are poisonous. They tend to have similar characteristics such as fibrous caps, gills and dark spore prints (spore prints of mushroom caps are often used for mushroom identification as noted in Læssøe (2002), McKnight and McKnight (1987) and Roody (2003). Depending on the species, they can be found in a variety of habitats and many will grow in bare soil, in the absence of decaying wood. **Table 1** presents data for Inocybes which indicate that radiocesium activity concentrations are typically low but some may be as high as ~900 Bq ^{137}Cs/kg. No T_{ag} or TF values were reported as noted in **Table 1**.

Laccaria and Lactarius

When young, the *Laccaria amethystina* are easily recognized because of its 2 to 5 cm diameter amethyst-colored cap and gills. However, with age this *Laccaria* species which grows in the forest litter of moist woodlands, can be confused with other members of its genus. *Laccaria amethystina* can accumulate large amounts of ^{137}Cs—up to nearly 120000 Bq/kg (**Table 1**). The *Lactarius* mushrooms accumulate several tens of thousands of Bq/kg of ^{137}Cs (**Table 1**). All members of the *Lactarius* genus uniquely exude a white or colored milk-like substance from their "crumbly" flesh when it is ruptured. Examples of these mushrooms are the poisonous *Lactarius necator*, *L. rufus* and the edible *L. deliciosus.*

For *Lactarius*, the T_{ag} and TF values were highly variable—ranging from T_{ag} values of 0.00007 to 0.068 and TF values of 0 to a high of 23.7. This suggests that the accumulation behavior of this genus varies widely. There is limited data for *Laccaria* but the reported TF values are high (0.36 to 3.0) relative to other species in **Table 1**.

Lepiota (or *Macrolepiota*) *procera*, *Lepista* sp. and *Mycena galericulata*

Lepiota (or *Macrolepiota*) *procera* or the parasol mushroom has an umbrella like shape and is edible . Their fruiting bodies of *Lepista nuda and Mycena galericulata* appear as troops and tufts on rotting stumps. These three fungi are common in temperate North America and Europe and they have been observed to accumulate a few hundred to a few thousand Bq/kg of ^{137}Cs (**Table 1**).

As was the case for *Lactarius*, the T_{ag} values for *Lepiota procera, Lepista* and *Mycena galericulata* were highly variable—ranging from T_{ag} values of 0.003 to 0.21. However, the TF values were lower and ranged from 0.003 to 0.084. These observations suggest that the accumulation behavior of this genus can vary.

Paxillus involutus, Rhodophyllus and *Russula* sp.

Paxillus involutus can accumulate nearly one million Bq/kg of ^{137}Cs (**Table 1**; Vinichuk and Johanson, 2003). This rather unprecedented amount of ^{137}Cs uptake was associated with mushrooms that were collected in the Ukraine following the Chernobyl accident. *Paxillus involutus* mushrooms are fairly common. They are found in conifer or birch woodlands and in gardens and parks. Fortunately, *Paxillus involutus* are poisonous and not consumed by humans.

The *Russula* mushrooms require symbiosis with trees or occasionally with shrubs in the form of mycorrhizal associations. Some *Russula* mushrooms are not edible whereas *Rhodophyllus crassipes (or Entoloma rhodopolium*) are poisonous. *Russula* and *Rhodophyllus* mushrooms tend to accumulate a few hundred to a few thousand Bq/kg of ^{137}Cs (**Table 1**).

TF values for *Paxillus involutus* mushrooms range form 2.01 to 21.6. These values are somewhat expected given the high levels of ^{37}Cs that were found to be present. When the levels of ^{137}Cs were ratioed to *Boletus badius*, in the study by Kammerer et al. (1994), the ratio was slightly lower than higherst value for *Russula olchroleuca* mushrooms, which had lower reported TF and T_{ag} values than that of *Paxillus involutus.* These findings indicate some likely inconsistencies in the methods (TF, ratio values etc…) used to report these data from study to study.

<u>*Sarcodon imbricatus, Suillus* sp., *Tylopilus felleus* and *Tricholoma flavovirens*</u>

Sarcodon imbricatus are found in conifer as well as deciduous forests and it has been observed to accumulate close to 100000 Bq/kg of ^{137}Cs (Table 1). They are edible although some have been poisoned by this mushroom. The *Tylopilus felleus* and *Suillus* mushrooms are also boletes. All of these mushrooms can accumulate a few thousand to a hundred thousand Bq/kg of ^{137}Cs (**Table 1**). As was the case with TF data for *Lactarius olchroleuca* and *Paxillus involutus*, the TF values for *Sarcodon imbricatus* were high (22.2).

The *Tricholomas* or trichs typically grow on the ground rather than on a live or decaying wood form. They are perhaps best identified with the use of a field guide because they have a variety of colors, sizes and shapes, which can be confused with many other fungi. *Tricholoma flavovirens*, which accumulates moderate levels of radiocesium (from a few hundred to several thousand Bq ^{137}Cs/kg as listed in **Table 1**). No T_{ag} or TF values were reported for the *Sarcodon imbricatus, Suillus* and *Tricholoma flavovirens* mushrooms as noted in **Table 1**. *Tylopilus felleus* had TF values as high as 4.0, which based on comparison to mushrooms with similar ^{137}Cs concentrations (in **Table 1**), is somewhat to be expected.

Mushrooms with a Low Affinity for Cs Accumulation

Although not the focus of this review, several types of mushrooms often exhibit a low affinity for radiocesium. These observations are fairly independent of whether the mushrooms were sampled before or after the Chernobyl accident. Some *Agaricus* mushrooms, which are found in fields that contain livestock and in forests in addition to *Coriolus hirstus* and *Pycnoporus coccineus* do not exhibit a great propensity for Cs uptake (Byrne, 1988; Yoshida et al., 1994). Parasitic fungi such as the *Armillaria mellea* and *Pholiota aegerita* also exhibit low-to moderate uptake of radiocesium (less than a thousand Bq/kg ^{137}Cs) relative to some of the fungi that were discussed previously (Battison et al., 1989; Yoshida et al., 1994; Toal et al., 2002). Studies with collections of *Bulgaria inquinans, Calvatia excipuliformis, Lyophyllum* sp., *Lycoperdon perlatum*, *Asterophora lycoperdoides, Bulgaria inquinans* and *Calvatia excipuliformi* have found that that these species typically do not have a large activity level of radiocesium relative to that of most of the species that are listed in **Table 1** (Watling et al., 1993; Byrne, 1988; Battison et al., 1989; Yoshida et al., 1994). For example mushrooms such as *Lycoperdon perlatum* typically accumulate 310 Bq/kg of ^{137}Cs and 140 Bq/kg of ^{134}Cs or less (Byrne, 1988). In contrast, the mushroom *Lycoperdon pyriforme* had order of magnitude higher ^{137}Cs activity concentration than *Lycoperdon perlatum* but what is most noteworthy is its high T_{ag} factor (Toal et al. 2002) relative to other mushrooms that have much higher ^{137}Cs activity concentrations. Agrocybes typically accumulate low levels of ^{137}Cs but *Agrocybe erebia* can accumulate slightly more than 1500 Bq/kg of ^{137}Cs or less (**Table 1**).

Conclusions

As previously discussed, some of the primary influences on ^{134,137}Cs uptake by mushrooms are growth media, the amount of deposition upon release, soil or growth media characteristics, growth habitat (saprophytic, parasitic or symbiotic), the species of mushroom (somewhat related to the habitat choice) and other yet to be discovered factors. The source term (such as whether the radiocesium is from Chernobyl or fallout from nuclear weapons testing) and other factors as mentioned have less affect on Cs accumulation. From these studies, it is clear that several mushrooms that demonstrate a high affinity for ^{134,137}Cs uptake are edible and are fairly common. Mushrooms are also eaten by some animals such as deer, which may be consumed by man. Regular consumption of these types of species or animals that eat these mushroom species may pose a human health concern.

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Table 1. Radiocesium data for mushrooms that have a high affinity for Cs before and after Chernobyl. Concentration ratios (when reported) vary widely with mushroom radiocesium levels.

Cs Iso-tope	Species Latin Name	Species Common Name	Country	Location of Study	Date	Sampling Details and Other Observations	Cs Activity Level or Ratioed value*	Transfer Factor or T_{ag}	Source of Information
137	*Agrocybe erebia*	Leather earthscale	Japan	Akita	1987, 1990	In fruiting body; Edible; Saprotrophic	1520 Bq/kg	No data	Muramatsu et al. (1991); Yoshida and Muramatsu (1994)
134	*Agrocybe erebia*	Leather earthscale	Japan	Akita	1987, 1990	In fruiting body; Edible; Saprotrophic	97 Bq/kg	No data	Muramatsu et al. (1991); Yoshida and Muramatsu (1994)
137	*Amanita muscaria*	Fly amanita or agaric	Spain	Muňoveros	1987, 1990	In fruiting body; Poisonous	5 Bq/kg	No data	Baeza et al. (2004)
137	*Amanita muscaria*	Fly amanita or agaric	Ukraine	Zhitomir region	1996-1998	In fruiting body; From Scots pine and birch forests	8700 to 13400 Bq/kg	TF:1.0	Vinichuk and Johanson (2003)
137	*Amanita muscaria*	Fly amanita or agaric	Austria	State of Styria	1987-1989	^{137}Cs was mostly in lamellae (gills) and cap; From 500 and 800 m asl in spruce and fir forests	1 to 250 Bq/kg fw	TF:0 to 0.25	Heinrich (1993)
137	*Amanita ponderosa*		Spain	Aracena	1987, 1990	In fruiting body	5 Bq/kg	No data	Baeza et al. (2004)
137	*Amanita porphyria*	Grey veiled or Purple brown amanita; Porphyry deathcap	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badiu**:* 0.42 to 2.52	No data	Kammerer et al. (1994)
Stable ^{133}Cs	*Amanita rubescens*	The blusher; Blushing amanita	Czech Republic	Forests	Late 1990's, Early 2000	In fruiting body; Edible	Up to 1 mg/kg	No data	Řanda and Kučera (2004)
137	*Amanita rubescens*	The blusher; Blushing amanita	Austria	State of Styria	1987-1989	^{137}Cs was mostly in lamellae and cap; From 500 to 1000 m asl spruce and fir forests	2001 to 4000 Bq/kg fw	TF:0 to 0.25	Heinrich (1993)
137	*Amanita rubescens*	The blusher; Blushing amanita	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Summe r 1996	In fruiting body	150 to 220 Bq/kg	T_{ag}:0.0058 to 0.0085	Toal et al. (2002)
137	*Amanita rubescens*	The blusher; Blushing amanita	United Kingdom	Prescot	1987, 1990	In fruiting body; Ectomycorrhizal species	45.5 Bq/kg	No data	Watling et al. (1993)
137	*Boletus (or Xerocomus) subtomenosus*	Yellow cracked boletus	Austria	State of Styria	1987-1989	^{137}Cs was mostly in lamellae; From 500 and 800 m asl in spruce and fir forests	501 to 1000 Bq/kg fw	TF:0 to 0.25	Heinrich (1993)
137	*Boletus (or X.) subtomenosus*	Yellow cracked boletus	Ukraine	Zhitomir Region	1996-1998	In fruiting body; From Scots pine and birch forests	20500 to 117200 Bq/kg	TF:3.1	Vinichuk and Johanson (2003)
137	*Boletus (or X.) subtomentosus*	Yellow cracked boletus	United Kingdom	Swallow Falls	1987, 1990	In fruiting body; Ectomycorrhizal species	Below detection	No data	Watling et al. (1993)
137	*Boletus (or Xerocomus) badius*	Bay bolete	Germany	Western Germany	1966	In fruiting body (assumed); Soil cleaned off prior to analysis	1133 Bq/kg fw	No data	Greuter (1971)

137	*Boletus (or X) badius*	Bay bolete	Austria	State of Styria	1987-1989	^{137}Cs was mostly in lamellae and cap; From 500 and 800 m asl in spruce and fir forests	8001 to 16000 Bq/kg fw	TF:1.01 to 2.0	Heinrich (1993)
137	*Boletus (or X) badius*	Bay bolete	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	1320 to 4365 Bq/kg fw	TF:0.7 to 5.0; Mean:2.0	Kammerer et al. (1994)
134, 137	*Boletus (or X.) badius*	Bay bolete	Yugoslav-ia	Slovenia	1986	All; After Chernobyl	1200 to 66000 Bq ^{134,137}Cs/kg; Mean:19000 Bq ^{134,137}Cs/kg	No data	Byrne (1988)
137	*Boletus calopus*	Scarlet-stemmed bolete	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Autumn 1996	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	71.0 Bq/kg	T_{ag}: 0.0027	Toal et al. (2002)
137	*Boletus (or Xerocomus) chrysenteron*	Red cracking bolete	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Autumn 1996	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	1345 to 1570 Bq/kg	T_{ag}:0.056	Toal et al. (2002)
137	*Boletus (or X.) chrysenteron*	Red cracking bolete	Austria	State of Styria	1987-1989	^{137}Cs was mostly in lamellae and cap; From 500 and 800 m asl in spruce and fir forests	8001 to 16000 Bq/kg fw	TF:>4.0	Heinrich (1993)
137	*Boletus edulis*	King or edible bolete, cep, cepe, porcini or Penny-bun	Ukraine	Zhitomir Region	1996-1998	In fruiting body; From Scots pine and birch forests	2000 to 41200 Bq/kg	TF:2.3	Vinichuk and Johanson (2003)
137	*Boletus edulis*	King or edible bolete, cep, cepe, porcini or Penny-bun	Austria	State of Styria	1987-1989	^{137}Cs was mostly in lamellae and cap; From 500 and 800 m asl in spruce and fir forests	501 to 1000 Bq/kg fw	TF:0 to 0.25	Heinrich (1993)
Stable ^{133}Cs	*Boletus edulis*	King or edible bolete, cep, cepe, porcini or Penny-bun	Czech Republic	Forests	Late 1990's, Early 2000	In fruiting body	Up to 2.73 mg/kg	No data	Řanda and Kučera (2004)
137	*Boletus edulis*	King or edible bolete, cep, cepe, porcini or Penny-bun	United Kingdom	Linn Park	1987, 1990	In fruiting body; Ectomycorrhizal species	68.4 Bq/kg	No data	Watling et al. (1993)
Stable ^{133}Cs	*Boletus* (or *Suillus) variegatus*	Variegated bolete; Yel-lowy-brown mossiness mushroom	Czech Republic	Forests	Late 1990's, Early 2000	In fruiting body	Up to 2.06 mg/kg	No data	Řanda and Kučera (2004)
137	*Boletus* (or *S.) variegatus*	Variegated bolete; Yel-lowy-brown mossiness mushroom	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***:0.37 to 0.55; 665 to 1250 Bq/kg fw	TF:0.98 to 1.1; Mean:1.0	Kammerer et al. (1994)

137	*Boletus* (or *S.*) *variegatus*	Variegated bolete; Yel-lowy brown mossiness mushroom	Ukraine	Zhitomir Region	1996-1998	In fruiting body; From Scots pine and birch forests	Mean:98800 Bq/kg	TF:2.6	Vinichuk and Johanson (2003)
137	*Boletus* (or *S.*) *variegatus*	Variegated bolete; Yel-lowy brown mossiness mushroom	Austria	State of Styria	1987-1989	^{137}Cs was mostly in lamellae and cap; From 500 and 800 m asl in spruce and fir forests	1001 to 2000 Bq/kg fw	TF:0.51 to 1.0	Heinrich (1993)
137	*Bulgaria inquinans*	Black jelly-drop cups	United Kingdom	Dollar	1987, 1990	In fruiting body; Saprotrophic; Growing on rotting wood (lignin)	390 Bq/kg	No data	Watling et al. (1993)
137	*Calvatia excipuliformis*	Pestle-shaped puffball	United Kingdom	Prescot	1987, 1990	In fruiting body; Saprotrophic; Growing on decaying litter	271.6 Bq/kg	No data	Watling et al. (1993)
137	*Cantharellus cibarius*	Chanterelle	Austria	State of Styria	1987-1989	^{137}Cs was mostly in lamellae and cap; From spruce and fir forests at 500 m asl	1001 to 2000 Bq/kg fw	TF:1.01 to 2.0	Heinrich (1993)
137	*Cantharellus cibarius*	Chanterelle	Ukraine	Zhitomir Region	1996-1998	In fruiting body; From Scots pine and birch forests	Mean: 15400 Bq/kg	TF:5.0	Vinichuk and Johanson (2003)
Stable ^{133}Cs	*Cantharellus cibarius*	Chanterelle	Czech Republic	Forests	Late 1990's, Early 2000	In fruiting body	Mean:1.04 mg/kg	No data	Řanda and Kučera (2004)
137	*Cantharellus cibarius*	Chanterelle	United Kingdom	Cleish	1987, 1990	In fruiting body; Ectomycorrhizal species	133 Bq/kg	No data	Watling et al. (1993)
137	*Cantharellus lutescens*	Yellow(ish) or golden chanterelle	Italy	Northeastern Portion	1986	All; Sampled after Chernobyl	4991 to 27626 Bq/kg	TF: 0.125 to 0.691	Battiston et al. (1989)
137	*Cantharellus lutescens*	Yellow(ish) or golden chanterelle	Italy	Northeastern Portion	1986	All; Does not include ^{137}Cs from Chernobyl	1071 to 3303 Bq/kg	No data	Battiston et al. (1989)
134	*Cantharellus lutescens*	Yellow(ish) or golden chanterelle	Italy	Northeastern Portion	1986	All; Does not include ^{137}Cs from Chernobyl	1894 to 4298 Bq/kg	TF:0.095 to 0.215	Battiston et al. (1989)
Stable ^{133}Cs	*Cantharellus lutescens*	Yellow(ish) or golden chanterelle	Czech Republic	Forests	Late 1990's, Early 2000	In fruiting body	Mean:1.53 mg/kg	No data	Řanda and Kučera (2004)
137	*Cantharellus tubaeformis*	Funnel or Trumpet chanterelle	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***:0.39 to 1.71; 1700 to 3270 Bq/kg fw	TF:0.52 to 4.3; Mean:2.3	Kammerer et al. (1994)
137	*Clitocybe infundibulifor-mis orC. gibba*	Funnel cap or clithocybe	Italy		August 1986	All; Edible, After Chernobyl	12030 to 24532 Bq/kg	TF:0.523 to 0.6133	Battiston et al. (1989)
137	*Clitocybe infundibulifor-mis orC. gibba*	Funnel cap or clithocybe	Italy		August 1986	All; Does not include ^{137}Cs from Chernobyl	1427 to 3303 Bq/kg	No data	Battiston et al. (1989)
134	*Clitocybe infundibulifor-mis orC. gibba*	Funnel cap or clithocybe	Italy		August 1986	All; Does not include ^{137}Cs from Chernobyl	5581 to 11331 Bq/kg	TF:0.465 to 0.5665	Battiston et al. (1989)

137	*Cortinarius armillatus*	Cinnabar bracelet webcap; Red banded web-cap or cort	Europe	Sweden, Switzerland, Italy, Austria and Finland	1974	In fruiting body	Mean:5185 Bq/kg	No data	Haselwandter (1978)
134, 137	*Cortinarius armillatus*	Cinnabar bracelet webcap; Red banded web-cap or cort	Yugo-slavia	Slovenia	1986	All portions; After Chernobyl	21000 to 96000 Bq $^{134,137}Cs$/kg; Mean: 51000 Bq $^{134,137}Cs$/kg	No data	Byrne (1988)
137	*Cortinarius caperatus or Rozites caperata*	The gypsy; Gypsy nitecap or rozites	Germany	Southern Bavaria	1987-1990	All portions (assumed)	Ratioed to *B. badius***: 0.64 to 1.36; 2090 to 3070 Bq/kg fw	TF:2.1 to 3.3; Mean:2.8	Kammerer et al. (1994)
134, 137	*Cortinarius caperatus or Rozites caperata*	The gypsy; Gypsy nitecap or rozites	Yugo-slavia	Slovenia	1986	All portions; Does not include Chernobyl fallout	2100 to 62000 Bq $^{134,137}Cs$/kg; Mean: 22600 Bq $^{134,137}Cs$/kg	No data	Byrne (1988)
137	*Cortinarius caperatus or Rozites caperata*	The gypsy; Gypsy nitecap or rozites	Austria	State of Styria	1987-1989	^{137}Cs was mostly in cap and lamellae; Found in a spruce and fir forest soil; 800 and 1000 m asl	>32000 Bq/kg fw	TF: >4.0	Heinrich (1993)
137	*Cortinarius caperatus or Rozites caperata*	The gypsy; Gypsy nitecap or rozites	Europe	Sweden, Switzerland, Italy, Austria and Finland	1974	In fruiting body	Mean:10370 Bq/kg	No data	Haselwandter (1978)
Stable ^{133}Cs	*Cortinarius caperatus or Rozites caperata*	The gypsy; Gypsy nitecap or rozites	Czech Republic	Forests	Late 1990's, Early 2000	Fruiting body	Mean:8.39 mg/kg	No data	Řanda and Kučera (2004)
137	*Cortinarius intergerrimus*		Austria	State of Styria	1987-1989	^{137}Cs was mostly in cap and lamellae; Found in a spruce and fir forest soil; near 800 m asl	4001 to 8000 Bq/kg fw	TF:2.01 to 4.0	Heinrich (1993)
134, 137	*Cortinarius praestans*		Yugo-slavia	Slovenia	1986	All portions; After Chernobyl	360 to 670 Bq $^{134,137}Cs$/kg; Mean: 530 Bq $^{134,137}Cs$/kg	No data	Byrne (1988)
137	*Cortinarius saturninus*		Japan	Tochigi	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	1700 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Cortinarius saturninus*		Japan+	Tochigi	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	<10 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Cortinarius semi-sanguineus*	Poison dye cort	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***:0.97 to 2.64	No data	Kammerer et al. (1994)
134, 137	*Cortinarius traganus*	Gassy webcap; He-Goat	Yugo-slavia	Slovenia	1986	All portions; After Chernobyl	5100 to 17900 Bq$^{134,137}Cs$/kg; Mean: 12000 Bq $^{134,137}Cs$/kg	No data	Byrne (1988)

137	*Galerina mutabilis*	Scaly-veiled galerina	United Kingdom	Lake of Monteith and Harlech	1987, 1990	In fruiting body; Saprotrophic; Growing on rotting wood (lignin)	31.9 to 261.6 Bq/kg	No data	Watling et al. (1993)
137	*Hebeloma cylindro-sporum*	Ectomycorrhizal fungi	Spain	Muňoveros	1987 and 1990	In fruiting body; Often found with *Pinus pinaster*	647 Bq/kg	No data	Baeza et al. (2004)
137	*Hebeloma* sp.	a Toadstool	Japan	Akita	1983-1990	All portions; Cleaned before analyses; Mycorrhizal fungi	16300 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Hebeloma* sp.	a Toadstool	Japan	Akita	1983-1990	All portions; Cleaned before analyses; Mycorrhizal fungi	436 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Hydnum repandum or Dentinum repandum*	Hedgehog; Spreading hedgehog	Austria	State of Styria	1987-1989	^{137}Cs was mostly in lamellae and cap; Found in a spruce and fir forest; near 800 to 1000 m asl	16000 to 32000 Bq/kg ww	TF: >4.0	Heinrich (1993)
137	*Hydnum repandum or Dentinum repandum*	Hedgehog; Spreading hedgehog	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***:1.87 to 6.38; 2420 to 1500 Bq/kg fw	TF:1.1 to 4.3; Mean:2.3	Kammerer et al. (1994)
137	*Hygrophorus russula*	False russula	Japan	Tochigi	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	998 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Hygrophorus russula*	False russula	Japan	Tochigi	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	<9 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Hypholoma fasciculare*	Sulfur tuft; Sulfur tuft psilocybe	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Summer 1996	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	2317 to 2622 Bq/kg	T_{ag}:0.09 to 0.1	Toal et al. (2002)
137	*Hypholoma fasciculare*	Sulfur tuft; Sulfur tuft psilocybe	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Autumn 1996	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	781 to 1046 Bq/kg	T_{ag}: 0.0054 to 0.12	Toal et al. (2002)
137	*Hypholoma marginatum*		United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Autumn 1996	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	781 to 1046 Bq/kg	T_{ag}:0.039	Toal et al. (2002)
137	*Inocybe* sp.		Japan	Ibaraki	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	<38 to 887 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Inocybe* sp.		Japan	Ibaraki	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	<4 to 50 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Laccaria amethystine*	Amethyst deceiver or tallogill; purple laccaria	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***:0.3 to 1.96; 435 to 5115 Bq/kg fw	TF:0.36 to 3.0; Mean:1.6	Kammerer et al. (1994)
134, 137	*Laccaria amethystine*	Amethyst deceiver or tallogill; purple laccaria	Yugo-slavia	Slovenia	1986	All portions; After Chernobyl	12000 to 117000 Bq^{134,137}Cs/kg; Mean: 52000 Bq	No data	Byrne (1988)

							$^{134,137}Cs$/kg		
137	*Lactarius blennius*	Euro slimy lactarius	United Kingdom	Saline, Dollar and Cleish	1987, 1990	In fruiting body; Ectomycorrhizal species	110 to 1479 Bq/kg	No data	Watling et al. (1993)
137	*Lactarius corrugis*	Corrugated milky cap; Wrinkled milkcap	Japan	Ibaraki	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	2700 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Lactarius corrugis*	Corrugated milky cap; Wrinkled milkcap	Japan	Ibaraki	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	51.6 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Lactarius deliciosus*	Saffron milkcap	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***:0.1 to 0.18; 185 to 235 Bq/kg fw	TF:0.13 to 0.26; Mean:0.2	Kammerer et al. (1994)
137	*Lactarius deliciosus*	Saffron milkcap	Spain	La Bazagona	Not known	In fruiting body	36 Bq/kg	No data	Baeza et al. (2004)
137	*Lactarius deliciosus*	Saffron milkcap	Austria	State of Styria	1987-1989	^{137}Cs was mostly in lamellae and cap; Found in a spruce and fir forest soil; near 800 m asl	251 to 500 Bq/kg ww	TF: 0 to 0.25	Heinrich (1993)
137	*Lactarius deliciosus*	Saffron milkcap	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Autumn 1996	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	2 Bq/kg	T_{ag}: 0.000077	Toal et al. (2002)
137	*Lactarius hepaticus*	Liver milkcap	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Autumn 1996	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	1713 to 1761 Bq/kg	T_{ag}:0.066 to 0.068	Toal et al. (2002)
137	*Lactarius necator*	Mutagen lactarius	Ukraine	Zhitomir Region	1996-1998	In fruiting body; Collected in Scots pine and birch forests	Mean:52700 Bq/kg	TF:4.9	Vinichuk and Johanson (2003)
137	*Lactarius necator*	Mutagen lactarius	Austria	State of Styria	1987-1989	^{137}Cs was mostly in lamellae and cap; Found in a spruce and fir forestsl; near 800 and 1000 m asl	4001 to 8000 Bq/kg ww	TF:1.01 to 2	Heinrich (1993)
137	*Lactarius piperatus*	Pepper milk-cap; Peppery lactarius	Japan	Akita and Tochigi	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	59 to 1500 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Lactarius piperatus*	Pepper milk-cap; Peppery lactarius	Japan	Akita and Tochigi	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	21.3 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Lactarius rufus*	Rufus milk-cap; Red hot milk cap or lactarius	United Kingdom	Not specified	1980s	In fruiting body; Additionally, based on the $^{134/137}Cs$ ratio, 90% of the soil ^{137}Cs was deposited prior to Chernobyl	3900 Bq/kg	No data	Cawes and Horrill (1986); Dighton and Horrill (1988) as cited in Simkiss et al. (1993)
137	*Lactarius rufus*	Rufus milk-cap; Red hot milk cap or lactarius	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***: 1.09 to 2.04	No data	Kammerer et al. (1994)

137	*Lactarius rufus*	Rufus milk-cap; Red hot milk cap or lactarius	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Autumn 1996	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	566 to 1961 Bq/kg	T_{ag}:0.022 to 0.076	Toal et al. (2002)
137	*Lactarius rufus*	Rufus milk-cap; Red hot milk cap or lactarius	Austria	State of Styria	1987-1989	^{137}Cs was mostly in lamellae and cap; Found in a spruce and fir forest soil; near 800 and 1000 m asl	8001 to 16000 Bq/kg ww	TF:1.01 to 2	Heinrich (1993)
137	*Lactarius vellereus*	Fleecy lactarius	United Kingdom	Saline, Powmill and Loch Ard	1987, 1990	In fruiting body; Ectomycorrhizal species	117 to 880 Bq/kg	No data	Watling et al. (1993)
137	*Lactarius vellereus*	Fleecy lactarius	Austria	State of Styria	1987-1989	Mostly in lamellae and cap; Found in a spruce and fir forest soil; near 800 m asl	1001 to 2000 Bq/kg ww	TF:0.25 to 0.5	Heinrich (1993)
137	*Lactarius viestus*	Grey milk-cap	Ukraine	Zhitomir Region	1996-1998	In fruiting body; From Scots pine and birch forests	Mean:56500 Bq/kg	TF:23.7	Vinichuk and Johanson (2003)
137	*(Macro)Lepiota procera*	(Shaggy) parasol mushroom	Italy	Northeastern Portion	1986	All portions; After Chernobyl	221 to 2279 Bq/kg	TF:0.018 to 0.11	Battiston et al. (1989)
137	*(Macro)Lepiota procera*	(Shaggy) parasol mushroom	Italy	Northeastern Portion	1986	All portions; Does not include ^{137}Cs from Chernobyl	53 to 368 Bq/kg	No data	Battiston et al. (1989)
134	*(Macro)Lepiota procera*	(Shaggy) parasol mushroom	Italy	Northeastern Portion	1986	All portions; Does not include ^{137}Cs from Chernobyl	116 to 263 Bq/kg	TF:0.056	Battiston et al. (1989)
137	*(Macro)Lepiota procera*	(Shaggy) parasol mushroom	Austria	State of Styria	1987-1989	^{137}Cs was mostly in lamellae and cap; Found in a spruce and fir forest soil; 500 and 800 m asl	1 to 250 Bq/kg ww	TF:0.019 to 0.053	Heinrich (1993)
137	*(Macro)Lepiota procera*	(Shaggy) parasol mushroom	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Autumn 1996	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	14 Bq/kg	T_{ag}: 0.00056	Toal et al. (2002)
137	*Lepista irina*	Pungent false blewit	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***:0.01 to 0.11; 13 to 2110 Bq/kg fw	TF:0.003 to 2.2; Mean:0.84	Kammerer et al. (1994)
137	*Lepista nuda*	Wood or true blewit	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***: 0.02 to 0.07; 32 to 285 Bq/kg fw	TF:0.2 to 0.33; Mean:0.14	Kammerer et al. (1994)
137	*Lepista nuda*	Wood or true blewit	Japan	Tochigi	Sept.-Dec. 1990	All portions; Cleaned before analyses; Saprotrophic fungi	Up to 1990 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Lepista nuda*	Wood or true blewit	Japan	Tochigi	Sept.-Dec. 1990	All portions; Cleaned before analyses; Saprotrophic fungi	13.1 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Lycoperdon perlatum*	Puffball	Yugo-slavia	Slovenia	1986	All; After Chernobyl	300 to 310 Bq/kg	No data	Byrne (1988)
134	*Lycoperdon perlatum*	Puffball	Yugo-slavia	Slovenia	1986	All; After Chernobyl	130 to 140 Bq/kg	No data	Byrne (1988)
137	*Lycoperdon*	Stump	United	Lady Wood	Autumn	In fruiting body;	2481 to 4655		Toal et al. (2002)

	pyriforme	puffball	Kingdom	Forest, 0.5 km from Sellafield	1996	Cleaned before analyses; From a *Picea sitchensis* woodland	Bq/kg	T_{ag}:0.12	
137	*Mycena galericulata*	Common tufted, Rosy-gill fairy hel-met or bonnet mycena	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Autumn 1996	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	1320 Bq/kg	T_{ag}:0.12	Toal et al. (2002)
137	*Mycena galericulata*	Common tufted, Rosy-gill fairy hel-met or bonnet mycena	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Autumn 1996	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	Mean:3213 Bq/kg	T_{ag}:0.096 to 0.18	Toal et al. (2002)
137	*Mycena galericulata*	Common tufted, Rosy-gill fairy hel-met or bonnet mycena	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Winter 1996-1997	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	2984 Bq/kg	T_{ag}:0.21	Toal et al. (2002)
137	*Naematoloma subleteritium*	Brick cap	Japan	Iwate, Gunma and Akita	Sept.-Dec. 1990	All portions; Cleaned before analyses; Saprotrophic fungi	Up to 151 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Naematoloma subleteritium*	Brick cap	Japan	Iwate, Gunma and Akita	Sept.-Dec. 1990	All portions; Cleaned before analyses; Saprotrophic fungi	<6 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Paxillus involutus*	Brown roll-rim; Poison paxillus; Nak-ed brimcap	Germany	Western Germany	1963-1966	In fruiting body (assumed); Soil cleaned off prior to analysis	216 to 1097 Bq/kg fw	No data	Greuter (1971)
137	*Paxillus involutus*	Brown roll-rim; Poison paxillus; Nak-ed brimcap	Europe	Sweden, Switzerland, Italy, Austria and Finland	1974	In fruiting body	Mean:~1481 Bq/kg	No data	Haselwandter (1978)
137	*Paxillus involutus*	Brown roll-rim; Poison paxillus; Nak-ed brimcap	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***: 1.24 to 2.43	No data	Kammerer et al. (1994)
137	*Paxillus involutus*	Brown roll-rim; Poison paxillus; Nak-ed brimcap	Ukraine	Zhitomir region	1996-1998	In fruiting body; From Scots pine and birch forests	Mean:862100 Bq/kg	TF:21.6	Vinichuk and Johanson (2003)
137	*Paxillus involutus*	Brown roll-rim; Poison paxillus; Nak-ed brimcap	United Kingdom	Prescot and Rhosesmor	1987, 1990	In fruiting body; Ectomycorrhizal species	Below detection and 68.4 Bq/kg	No data	Watling et al. (1993)
137	*Paxillus involutus*	Brown roll-rim; Poison paxillus; Nak-ed brimcap	Austria	State of Styria	1987-1989	^{137}Cs was mostly in lamellae and cap; Found in a spruce and fir forest soil; 500 to 1000 m asl	8001 to 16000 Bq/kg ww	TF:2.01 to 4.0	Heinrich (1993)
137	*Panellus serotinus*	Fall oyster mushroom	Japan	Nagano and Akita	Sept.-Dec. 1990	All portions; Cleaned before analyses; Saprotrophic fungi	Up to 462 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Panellus serotinus*	Fall oyster mushroom	Japan	Nagano and Akita	Sept.-Dec. 1990	All portions; Cleaned before analyses; Saprotrophic fungi	<7 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Pholiota nameko*	Nameko mushroom	Japan	Nagano, Iwate, Ohita and Akita	Sept.-Dec. 1990	All portions; Cleaned before analyses; Saprotrophic fungi	50 to 288 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Pholiota nameko*	Nameko mushroom	Japan	Nagano, Iwate, Ohita	Sept.-Dec.	All portions; Cleaned before analyses;	<6 Bq/kg	No data	Yoshida et al. (1994); Yoshida and

				and Akita	1990	Saprotrophic fungi			Muramatsu (1994)
137	*Rhodophyllus crassipes* or *Entoloma sarcopus*	Pinkgill	Japan	Tochigi	Sept.-Dec. 1990	All portions; Cleaned before analyses; Edible; Mycorrhizal fungi	2050 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Rhodophyllus crassipes* or *Entoloma sarcopus*	Pinkgill	Japan	Tochigi	Sept.-Dec. 1990	All portions; Cleaned before analyses; Edible; Mycorrhizal fungi	<11 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Rhodophyllus rhodopolius* or *Entoloma rhodopolium*	Beech woods entoloma	Japan	Akita and Tochigi	Sept.-Dec. 1990	All portions; Cleaned before analyses; Poisonous; Mycorrhizal fungi	149 to 2210 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Rhodophyllus rhodopolius* or *Entoloma rhodopolium*	Beech woods entoloma	Japan	Akita and Tochigi	Sept.-Dec. 1990	All portions; Cleaned before analyses; Poisonous; Mycorrhizal fungi	25 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Rhodophyllus rhodopolius* or *Entoloma rhodopolium*	Beech woods entoloma	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Sum-mer 1996	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	163 to 388 Bq/kg	T_{ag}:0.0063 to 0.015	Toal et al. (2002)
137	*Russula aeruginea*	Tacky green russula	United Kingdom	Saline and Cleish	1987, 1990	In fruiting body; Ectomycorrhizal species	414.7 to 832.5 Bq/kg	No data	Watling et al. (1993)
137	*Russula mairei*	Euro emetic russula	United Kingdom	Saline and Cleish	1987, 1990	In fruiting body; Ectomycorrhizal species	251.6 to 1011.3 Bq/kg	No data	Watling et al. (1993)
137	*Russula nigricans*	Blackening russula	United Kingdom	Linn Park and Dollar	1987, 1990	In fruiting body; Ectomycorrhizal species	107.4 to 395 Bq/kg	No data	Watling et al. (1993)
137	*Russula nigricans*	Blackening russula	Japan	Nagano and Akita	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	107 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Russula nigricans*	Blackening russula	Japan	Nagano and Akita	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	<8 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Russula nigricans*	Blackening russula	Austria	State of Styria	1987-1989	^{137}Cs was mostly in cap and lamellae; Found in a spruce and fir forest soil; near 800 m asl	2001 to 4000 Bq/kg ww	TF:0.5 to 1.0	Heinrich (1993)
137	*Russula olchroleuca*	Yellow-ocher russula	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***:0.21 to 2.70; 1480 to 3870 Bq/kg fw	TF:0.53 to 1.8; Mean:1.1	Kammerer et al. (1994)
137	*Russula olchroleuca*	Yellow-ocher russula	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Sum-mer 1996	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	112 to 1558 Bq/kg; Mean:633 Bq/kg	T_{ag}:0.014 to 0.06	Toal et al. (2002)
137	*Russula olchroleuca*	Yellow-ocher russula	United Kingdom	Linn Park and Dollar	1987, 1990	In fruiting body; Ectomycorrhizal species	195.2 Bq/kg	No data	Watling et al. (1993)
137	*Russula olchroleuca*	Yellow-ocher russula	Austria	State of Styria	1987-1989	^{137}Cs was mostly in cap and lamellae; Found in a spruce and fir forest soil;	2001 to 4000 Bq/kg ww	TF:0.25 to 0.5	Heinrich (1993)

						500 to 1000 m asl			
137	*Russula xerampelina*	Crab russula	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badiu***:0.29 to 1.16; 620 to 5175 Bq/kg fw	TF:0.83 to 5.4; Mean:2.0	Kammerer et al. (1994)
137	*Russula sardonia*	Changeable or pungent russula	United Kingdom	Lady Wood Forest, 0.5 km from Sellafield	Summer 1996	In fruiting body; Cleaned before analyses; From a *Picea sitchensis* woodland	1558 Bq/kg	T_{ag}:0.06	Toal et al. (2002)
137	*Sarcodon aspratus*		Japan	Iwate	Sept.-Dec. 1990	All portions; Cleaned before analyses; Edible species; Mycorrhizal fungi	2080 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Sarcodon aspratus*		Japan	Iwate	Sept.-Dec. 1990	All portions; Cleaned before analyses; Edible species; Mycorrhizal fungi	16.1 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Sarcodon imbricatus*	Blue-footed Scaly tooth or Scaly hydnum	Ukraine	Zhitomir region	1996-1998	In fruiting body; From Scots pine and birch forests	Mean:97900 Bq/kg	TF:22.2	Vinichuk and Johanson (2003)
137	*Sarcodon imbricatus*	Blue-footed Scaly tooth or Scaly hydnum	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***:0.29 to 1.16; 410 to 1170 Bq/kg fw	TF:0.1 to 1.2; Mean:0.59	Kammerer et al. (1994)
137	*Sarcodon imbricatus*	Blue-footed Scaly tooth or Scaly hydnum	Austria	State of Styria	1987-1989	^{137}Cs was mostly in cap and lamellae; Found in a spruce and fir forest soil; 800 m asl	501 to 1000 Bq/kg ww	TF:0.25 to 2.0	Heinrich (1993)
137	*Scleroderma citrinum*	Earthball	United Kingdom	Balfour Estate	1987, 1990	In fruiting body; Ectomycorrhizal species	497.6 Bq/kg	No data	Watling et al. (1993)
137	*Suillus bovinus*	Euro cow bolete; Shallow pored fungus or boletus	Japan	Akita, Ibaraki and Tochigi	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	77 to 1330 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Suillus bovinus*	Euro cow bolete; Shallow pored fungus or boletus	Japan	Akita, Ibaraki and Tochigi	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	<17 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Suillus bovinus*	Euro cow bolete; Shallow pored fungus or boletus	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***:0.27 to 0.4; 660 to 760 Bq/kg fw	TF:0.35 to 0.98; Mean:1.0	Kammerer et al. (1994)
137	*Suillus* (or *Boletus*) *cavipes*	Hollow-stemmed boletus; Hollow stalk	Italy	Northeastern Portion	1986	All portions; After Chernobyl; Grows on acidic soils; Saprophytic	1460 to 5146 Bq/kg	TF:0.146 to 0.64	Battiston et al. (1989)
137	*Suillus* (or *Boletus*) *cavipes*	Hollow-stemmed boletus; Hollow stalk	Italy	Northeastern Portion	1986	All portions; Does not include ^{137}Cs from Chernobyl; Grows on acidic soils; Saprophytic	389 to 1843 Bq/kg	No data	Battiston et al. (1989)
134	*Suillus* (or *Boletus*)	Hollow-stemmed	Italy	Northeastern Portion	1986	All portions; Does not include ^{137}Cs	557 to 1738 Bq/kg	TF:0.014	Battiston et al. (1989)

	cavipes	boletus; Hollow stalk				from Chernobyl; Grows on acidic soils; Saprophytic		to 0.44	
137	*Suillus granulatus*	Dotted-stalk bolete	Ukraine	Zhitomir Region	1996-1998	In fruiting body; From Scots pine and birch forests	Mean:44200 Bq/kg	TF:12.2	Vinichuk and Johanson (2003)
137	*Suillus granulatus*	Dotted-stalk bolete	Japan	Ibaraki	Sept.-Dec. 1990	All portions; Cleaned before analyses	136 to 1150 Bq/kg	TF:16 (0 to 5 cm of soil)	Yoshida et al. (1994); Muramatsu et al. (1991); Yoshida and Muramatsu (1994)
134	*Suillus granulatus*	Dotted-stalk bolete	Japan	Ibaraki	Sept.-Dec. 1990	All portions; Cleaned before analyses	<13 Bq/kg	No data	Yoshida et al. (1994); Muramatsu et al. (1991); Yoshida and Muramatsu (1994)
137	*Suillus granulatus*	Dotted-stalk bolete	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***:0.07 to 0.26; 595 to 1080 Bq/kg fw	TF:0.05 to 0.53; Mean:0.29	Kammerer et al. (1994)
137	*Tricholoma album*		United Kingdom	Rhosesmor	1987, 1990	In fruiting body; Ectomycorrhizal species	Below detection	No data	Watling et al. (1993)
137	*Tricholoma atrosquam-osum*	Dirty trich complex	United Kingdom	Powmill	1987, 1990	In fruiting body; Ectomycorrhizal species	732 Bq/kg	No data	Watling et al. (1993)
137	*Tricholoma cingulatum*		United Kingdom	Saline	1987, 1990	In fruiting body; Ectomycorrhizal species	247.2 to 3500 Bq/kg	No data	Watling et al. (1993)
137	*Tricholoma flavovirens*	Firwood agaric; Cava-lier; Man-on-horseback	Japan	Ibaraki	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	3110 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Tricholoma flavovirens*	Firwood agaric; Cava-lier; Man-on-horseback	Japan	Ibaraki	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	<65 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Tricholoma pessandatum*	Golden orange tricholoma	Spain	Muňoveros	Not known	In fruiting body	122 Bq/kg	No data	Baeza et al. (2004)
137	*Tricholoma portentosum*	Sticky gray trich	Japan	Ibaraki	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	424 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Tricholoma portentosum*	Sticky gray trich	Japan	Ibaraki	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	<11 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Tricholoma terreum*	Grey agaric; Dark gray trich	Spain	Muňoveros	Not known	In fruiting body	49 Bq/kg	No data	Baeza et al. (2004)
137	*Tricholoma terreum*	Grey agaric; Dark gray trich	Japan	Ibaraki	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	602 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
134	*Tricholoma terreum*	Grey agaric; Dark gray trich	Japan	Ibaraki	Sept.-Dec. 1990	All portions; Cleaned before analyses; Mycorrhizal fungi	<21 Bq/kg	No data	Yoshida et al. (1994); Yoshida and Muramatsu (1994)
137	*Tylopilus felleus*	Bitter bolete	Germany	Southern Bavaria	1987-1990	In fruiting body (assumed)	Ratioed to *B. badius***:0.35 to 1.57	No data	Kammerer et al. (1994)
137	*Tylopilus felleus*	Bitter bolete	Austria	State of Styria	1987-1989	^{137}Cs was mostly in cap and lamellae; Found in a spruce	4001 to 8000 Bq/kg ww	TF:2.01 to 4.0	Heinrich (1993)

						and fir forest soil; 500 to 1000 m asl			
Stable ^{133}Cs	*Boletus, Laccaria, Cantharellus, Rozites cape-rata, Lactarius rufus,Tylo-pilus felleus*	Many names	Czech Republic	Forests	Late 1990's, Early 2000	In fruiting body; All of these species are known to accumulate Cs and Rb	No data provided	No data	As cited in Řanda and Kučera (2004)
137	General Basido-mycetes	Not specified	Japan	Ibaraki	1990	All portions; Cleaned before analyses	2 to 1630 Bq/kg; Mean of 483 Bq/kg	No data	Yoshida et al. (1994)
137	General Basido-mycetes	Not specified	Japan	Ibaraki	1989	All portions; Cleaned before analyses	3 to 152 Bq/kg; Mean:120 Bq/kg	No data	Yoshida et al. (1994)
137	General	Edible mushrooms	Former USSR	Dalata, Ovruc region	1990	For prepared edible portions	609 Bq/kg fw to 20800 Bq/kg ww	No data	Cooper et al. (1992)
137	General	Edible mushrooms	Former USSR	Byelorussia, Bragin region	1990	For prepared edible portions	1320 Bq/kg fw	No data	Cooper et al. (1992)
137	General	Edible mushrooms	Former USSR	Savici	1990	For prepared edible portions	5260 Bq/kg fw to 131000 Bq/kg dw	No data	Cooper et al. (1992)

* All dry weight (dw) values are reported unless otherwise noted; fw: fresh weight, ww: wet weight.

** TF: Transfer Factor typically represents the amount of Cs in mushroom (Bq/kg, dw) divided by the amount of Cs in soil or growth substrate (Bq/kg, dw); the aggregated transfer factor or T_{ag} (m^2/kg):represents the amount of Cs in mushroom (in Bq/kg, dw) divided by the amount of aerial deposition of radiocesium (in Bq/m^2) as in Toal et al. (2002). TF values calculated by Kammerer et al. (1994) are based on (Bq/kg, fw) divided by the amount of Cs in O-horizon of soil (Bq/kg, dw)

*** Values in Kammerer et al. (1994) are expressed relative to the other mushroom *B. badiu*s because it was common at all sites and had a fairly consistent ^{137}Cs level.

asl: Above sea level.