Chapter 15

Mushrooms: Radioactive Contamination of Widespread Mushrooms in Japan

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Abstract High concentrations of radionuclide contamination of wild mushrooms occurred near the Fukushima Daiichi nuclear power plant and along the path of radioactive plumes. This is a serious problem for the forest ecosystem and commercial wild mushroom production. Radioactivity in wild mushrooms collected from low-level contamination forest areas throughout Japan was measured approximately 6 months after the accident. In general, the radioactivity in mushrooms did not exceed those in the neighboring forest litter. However, further accumulation of ^{137}Cs is expected in mushrooms; therefore, continuous monitoring is necessary even in low-contamination areas. We also found that residual ^{137}Cs radioactivity due to nuclear weapons tests, mainly in 1950s, besides fallout from the Fukushima nuclear accident still remained in soil and was accumulated by mushrooms.

Keywords Chernobyl nuclear accident • Nuclear weapons tests • Radioactive fallout • Radiocesium • The University of Tokyo Forests • Transfer factor • Wild mushrooms

Abbreviations

Cs	Cesium
DW	Dry weight
FW	Fresh weight

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I	Iodine
K	Potassium
NPP	Nuclear power plant
NWT	Nuclear weapons test
TF	Transfer factor

15.1 Introduction

Fungi are one of the major and important components of forest ecosystems. Radioactive contamination of mushrooms should be considered not only from the viewpoint of food but also from the viewpoint of its effects on plants and animals, including crops, domestic animals, and wood products, through its circulation in the forest ecosystem. From 1950s to 1960s, a high uptake of ^{137}Cs , derived from atmospheric nuclear weapons tests (NWT), by mushrooms was also noticed in Japan (Muramatsu and Yoshida 1997; Sugiyama et al. 1994; Yoshida and Muramatsu 1996).

Radionuclides released by the accident at the Fukushima Daiichi nuclear power plant (F1-NPP) deposited over a wide area of East Japan. Radiocesium concentrations exceeding the safety threshold were detected in mushrooms hundreds of kilometers from F1-NPP. The Japanese interim limit for imported foods was 370 Bq/kg fresh weight (FW) of radiocesium after the Chernobyl nuclear accident in 1986 (Sugiyama et al. 1994). The interim limit after the Fukushima nuclear accident was set to 500 Bq/kg FW. However, a stricter limit of 100 Bq/kg FW was introduced in April 2012. Therefore, reducing the radiocesium contamination of food has become more important.

Mushrooms have been reported to accumulate radiocesium (Byrne 1988; Kammerer et al. 1994; Mascanzoni 1987; Muramatsu et al. 1991; Sugiyama et al. 1990, 1994). For example, the transfer factors (TF) for radiocesium in mushrooms were reported to be 2.6–21 in several culture tests (Muramatsu et al. 1991; Ban-nai et al. 1994). However, the radiocesium activity ratio in mushrooms relative to the soil in a field study were rather low and the ratio was often <1 (Heinrich 1992). Different fungal species also exhibit widely varying degrees of ^{137}Cs contamination; however, saprotrophic mushrooms tend to have lower TF of ^{137}Cs than the symbiotic mycorrhizal fungi (Heinrich 1992; Sugiyama et al. 1993). Cesium shows a similar behavior to potassium. TF of ^{137}Cs and potassium in fungi is very high compared with those in vegetables (Miyake et al. 2008; Sugiyama et al. 1990). Not all mushrooms accumulate cesium at the same levels as potassium. For example, TF of cesium was lower than that of potassium in *Lentinula edodes* (Sugiyama et al. 1990). A reason for radiocesium contamination to be high in mushrooms appears to be because of potassium richness (Seeger 1978). However, fungi also absorb cesium more specifically compared with potassium (Kuwahara et al. 1998), particularly radiocesium (Tsukada et al. 1998). Further research is necessary to reveal the absorption and accumulation processes.

The radioactivity in mushrooms is an appropriate index for determining radioactive contamination of forest ecosystems. Thus, data from high and low-contamination areas are required to understand the overall situation. The University of Tokyo has

seven research forests, 250–660 km from F1-NPP. Inspections of radioactivity in food conducted by local governments and survey on low- contamination areas in the University of Tokyo Forests revealed the state of radioactive contamination of mushrooms.

15.2 High-Level Contamination

A radioactive plume of short distance but high contamination level travelled northwest from F1-NPP (Fig. 15.1). Two major long distance plumes south and southwest bound were also observed. Thus, radioactive nuclides were dispersed throughout a wide area of East Japan, and high-level contamination was detected in wild mushrooms, particularly those in the vicinity of F1-NPP and along the plume paths.

Similar to mushrooms cultivated on wood logs, such as shiitake mushroom (*L. edodes*), the shipment of wild mushrooms was also halted in 41 out of a total of 59 cities, towns, and villages on July 27, 2012, in Fukushima Prefecture (area 13,782 km²) (<http://www.mhlw.go.jp/stf/houdou/2r9852000002gufy-att/2r9852000002gult.pdf>). Outside Fukushima Prefecture, wild mushrooms and log-cultivated mushroom shipments are restricted in some areas, particularly those along the plume paths.

Fig. 15.1 Distribution map of γ -ray air dose rate ($\mu\text{Sv/h}$) 1 m above ground level (a) and total deposition of ^{134}Cs and ^{137}Cs (Bq/m^2) on the ground surface (b). Reproduced from the results of airborne monitoring surveys conducted by Ministry of Education, Culture, Sports, Science and Technology, Japan, http://radioactivity.mext.go.jp/en/contents/6000/5188/24/203_e_0727_14.pdf

Table 15.1 Radionuclide contamination of mushrooms and lichens immediately after the Fukushima nuclear accident (modified from Kakishima et al. 2011)

	Moisture content (%) ^a	¹³¹ I (Bq/kg FW)	¹³⁷ Cs (Bq/kg FW)	¹³⁴ Cs (Bq/kg FW)
Mushrooms				
<i>Russula</i> sp. (M)	94	ND	130	ND
<i>Astraeus hygrometricus</i> (M)	86	928	1,683	1,512
<i>Morchella esculenta</i> (M/S)	74	36	78	ND
<i>Psathyrella</i> sp.	45	67	529	530
<i>Psathyrella</i> sp.	8	184	255	278
<i>Schizophyllum commune</i> (S)	73	2,301	5,719	5,506
<i>Cryptoporus volvatus</i> (S)	–	ND	ND	ND
<i>Daedaleopsis tricolor</i> (S)	91	1,631	868	812
Lichens				
<i>Dirinaria applanata</i>	7	3,438	3,558	3,219
<i>Phaeophyscia</i> sp.	5	8,436	12,641	12,413

(M) mycorrhizal fungus, (S) saprophyte

^aMoisture content (%) = 100 × (fresh weight – dry weight)/fresh weight

Shortly after the accident, extremely high concentrations of radiocesium were detected in wild mushrooms collected on April 26, 2011, from the University of Tsukuba campus (Table 15.1, Kakishima et al. 2011), which is 170 km from F1-NPP. The University of Tsukuba is located in an area where the radionuclide deposition is rather low. However, a high concentration of radionuclides, including ¹³¹I, ¹³⁴Cs, and ¹³⁷Cs, was detected in three mushroom species. Of them, two species (*Daedaleopsis tricolor* and *Schizophyllum commune*) were saprophytes that grow on dead trees. This high contamination level appeared to be mainly due to the direct deposition on long-lived fruiting bodies. Lichens showed high radioactivity. Direct deposition may have contributed to the majority of the contamination considering the lifespan of lichens. ¹³⁴Cs was not detected in 2 species of mushrooms (*Morchella esculenta* and *Russula* sp.), which had relatively lower radioactivity. This suggests that the contamination was derived from NWT or the Chernobyl accident. This assumption has been discussed later.

The radioactivity of wild mushrooms was investigated as a part of a food survey in Fukushima Prefecture (<http://www.new-fukushima.jp/monitoring/result.php>). A high level of radioactive contamination was observed along the plume paths. For example, the maximum concentration of radiocesium (28,000 Bq/kg FW) was detected in *Lactarius volemus* in September 2011, approximately 70 km from F1-NPP. However, a radioactivity concentration of 40 Bq/kg FW was also recorded for the same mushroom species at the same time in the same town. Thus, the radioactivity varied considerably. In the autumn of 2011, high radiocesium concentrations were recorded in the mycorrhizal fungi *Lactarius lividatus* (maximum = 19,900 Bq/kg FW, approximately 20 km) and *Tricholoma matsutake* (maximum = 3,300 Bq/kg FW, approximately 60 km) apart from *L. volemus* as well as in the saprophytic fungus *Grifola frondosa* (maximum = 2,800 Bq/kg FW, approximately 20–30 km). Large differences in radioactivities were observed depending on the types of mushrooms.

However, apart from the immediate vicinity of F1-NPP and the plume paths, the contamination concentrations in wild mushrooms in the autumn of 2011 were relatively low in Fukushima Prefecture. For example, radiocesium was undetectable in the following mushrooms collected from August to October, 2011 30–40 km from NPP: *Entoloma sarcopum* (Mycorrhizal fungi), *Lyophyllum fumosum* (M), *Ramaria botrytis* (M), and *Lyophyllum decastes* (Saprophyte). Rather low concentrations of radiocesium (19–26 Bq/kg FW) were detected in *L. volemus* (M), *Leucopaxillus giganteus* (S), *Laetiporus sulphureus* (S), and *Armillaria mellea* (S).

The earliest measurement of shiitake mushrooms in open-field log cultivation was conducted on April 3, 2011, which detected ^{131}I at 3,100 Bq/kg, ^{134}Cs at 450 Bq/kg, and ^{137}Cs at 440 Bq/kg FW. The highest concentration was recorded on April 10, i.e., ^{131}I at 12,000 Bq/kg, ^{134}Cs at 6,400 Bq/kg, and ^{137}Cs at 6,600 Bq/kg FW. Individual fruiting bodies of shiitake mushrooms were usually harvested within 1 week of their emergence from the log so that there was no possibility of direct deposition on the fruiting bodies. Rapid absorption of radionuclides from the logs was a possibility.

15.3 Low-Level Contamination

The University of Tokyo Forests comprise seven research forests located in East Japan. Mushrooms appeared in the autumn of 2011 and their possible substrates, i.e., the O horizon (organic layer, which included the litter layer), the A horizon (mineral layer and accumulated organic matter), and the Ch horizon (mineral layer with organic matter, which is little affected by pedogenic processes) of the soil, or mushroom logs were collected from six research forests listed below (Figs. 15.2 and 15.3).

UTCF: The University of Tokyo Chichibu Forest, Saitama Prefecture, 250 km from the F1-NPP

UTCBF: The University of Tokyo Chiba Forest, Chiba Prefecture, 260 km

FTRI: Forest Therapy Research Institute, Yamanashi Prefecture, 300 km

ARI: Arboricultural Research Institute, Shizuoka Prefecture, 360 km

ERI: Ecohydrology Research Institute, Aichi Prefecture, 420 km

UTHF: The University of Tokyo Hokkaido Forest, Hokkaido Prefecture, 660 km

Samples were collected from October to November 2011, which included symbiotic mycorrhizal fungi and saprophytes, and the concentrations of ^{134}Cs and ^{137}Cs were determined.

Radiocesium contamination of mushrooms was observed in all the University of Tokyo forests examined, except in ERI (Aichi) (Table 15.2). Although no radiocesium was detected in the mushrooms collected from ERI, a very small amount of ^{137}Cs was detected in the A horizon of soil from ERI. This contamination may be due to atmospheric NWTs. Radiocesium was detected in many mushroom and soil samples from UTCF (Chichibu), UTCBF (Chiba), and FTRI (Fuji).

Fig. 15.2 Locations of the University of Tokyo Forests from where samples were obtained. *F1-NPP* Fukushima Daiichi nuclear power plant, *UTCF* The University of Tokyo Chichibu Forest (Chichibu), *UTCBF* The University of Tokyo Chiba Forest (Chiba), *FTIRI* Forest Therapy Research Institute (Fuji), *ARI* Arboricultural Research Institute (Izu), *ERI* Ecohydrology Research Institute (Aichi), *UTHF* The University of Tokyo Hokkaido Forest (Hokkaido)

UTCF is located in a moderately contaminated area where the gamma ray dose rate exceeded $0.1 \mu\text{Sv/h}$ (Fig. 15.1) at some sampling sites (Table 15.3) because it is at the tip of the southwest bound plume path, despite the long distance (250 km) from F1-NPP. The dose rates in other research forests were $<0.06 \mu\text{Sv/h}$, which was within the normal range before the accident. The radioactive contamination level was low in UTCBF (Chiba), which is located outside the plume path, although its distance from F1-NPP was similar to UTCF. The contributions due to fallout from F1-NPP alone were evaluated by subtracting the natural background dose rates

Fig. 15.3 Examples of collected mushrooms and forest where mushrooms were collected. (a) *Lyophyllum connatum* mushrooms, O and A horizon of soil under the mushrooms in UTHF; (b) deciduous forest where *L. connatum* mushrooms were collected; (c) *Panellus serotinus* mushrooms and wood in UTCF; (d) deciduous forest in FTRI where mushrooms of *Suillus grevillei* and *Pleurotus ostreatus* were collected; (e) *Catathelasma imperiale* mushrooms in UTCBF; (f) evergreen forest where *C. imperiale* mushrooms were collected. (a, b) Photo by K. Iguchi, UTHF; (c) photo by K. Takatoku, UTCF; (d) photo by H. Saito, FTRI; (e) photo by T. Tsukagoshi, UTCBF

Table 15.2 Radiocesium contamination of mushrooms in the University of Tokyo Forests

Location	Site number and corresponding mushroom	Concentration ^a [Bq/kg DW (Bq/kg FW)]	
		¹³⁴ Cs	¹³⁷ Cs
UTCF (Chichibu)	1 <i>Bondarzewia berkeleyi</i> (S)	102 (21)	154 (32)
	2 <i>Tricholoma saponaceum</i> (M)	162 (35)	233 (50)
	3 <i>Panellus serotinus</i> (S)	492 (68)	706 (97)
	4 <i>Trametes versicolor</i> (S)	67 (58)	89 (77)
UTCBF (Chiba)	1 <i>Catathelasma imperiale</i> (M)	ND	77 (16)
	2 <i>Catathelasma imperiale</i> (M)	ND	ND
FTRI (Fuji)	1 <i>Suillus grevillei</i> (M)	137 (6)	714 (34)
	2 <i>Suillus grevillei</i> (M)	ND	680 (32)
	<i>Pholiota lubrica</i> (S/M)	1,070 (98)	1,630 (150)
	3 <i>Pholiota lubrica</i> (S/M)	1,840 (108)	2,440 (143)
ARI (Izu)	4 <i>Pleurotus ostreatus</i> (S)	ND	ND
	1 <i>Lentinula edodes</i> (S)	53 (3)	78 (4)
	2 <i>Lentinula edodes</i> (S)	ND	68 (7)
	ERI (Aichi)	1 <i>Macrolepiota procera</i> (S)	ND
2 <i>Armillaria mellea</i> (S)		ND	ND
UTHF (Hokkaido)	1 <i>Lyophyllum connatum</i> (M)	ND	62 (6)
	2 <i>Suillus grevillei</i> (M)	ND	31 (1)

(M) mycorrhizal fungus, (S) saprophyte

^aND: not detected=concentration less than the detection limit

Table 15.3 Radiation dose rate at the mushroom collection sites

Location and month of measurement	Site number and corresponding mushroom	Dose rate ($\mu\text{Sv/h}$)	
		10 cm above ground	1 m above ground
UTCF (Chichibu) February 2012	1 <i>Bondarzewia berkeleyi</i>	0.109	0.082
	2 <i>Tricholoma saponaceum</i>	0.064	0.050
	3 <i>Panellus serotinus</i>	0.110	0.114
	4 <i>Trametes versicolor</i>	0.083	0.090
UTCBF (Chiba) January to April 2012	1 <i>Catathelasma imperial</i>	0.042	0.033
	2 <i>Catathelasma imperial</i>	0.040	0.032
FTRI (Fuji) May 2012	1 <i>Suillus grevillei</i>	0.022	0.024
	2 <i>Pleurotus ostreatus</i>	0.030	0.019
	3 <i>Suillus grevillei</i>	0.028	0.020
	3 <i>Pholiota lubrica</i>	0.022	0.029
	4 <i>Pholiota lubrica</i>	0.031	0.022
UTHF (Hokkaido) June 2012	1 <i>Lyophyllum connatum</i>	0.061	0.053
	2 <i>Suillus grevillei</i>	0.047	0.035

(Minato 2011). The dose rate because of the Fukushima accident was approximately 50 nGy/h (0.05 $\mu\text{Sv/h}$ equivalent dose rate of radiocesium) in UTCF and <25 nGy/h in UTCBF, FTRI, and ARI (Izu).

The radiocesium concentrations in *Panellus serotinus* and *Trametes versicolor* samples collected from UTCF exceeded the present limit of 100 Bq/kg FW (Table 15.2). *Pholiota lubrica* from FTRI had a radioactivity concentration of >200 Bq/kg FW, despite low contamination in the soil. Radiocesium accumulated in the litter layer at UTCBF and FTRI, despite the normal dose rate. Both ^{134}Cs and ^{137}Cs were detected in *L. edodes* from ARI, indicating that the radionuclides from F1-NPP travelled 360 km. No ^{134}Cs was detected in the mushroom and soil samples from UTHF (Hokkaido) and ERI, confirming that these forests were not contaminated by the Fukushima accident.

15.4 Relationship Between Mushroom Contamination and Radiocesium Concentration in the Fungal Substrates

Cesium is strongly adsorbed to soil, particularly clay. Forest soil is abundant in organic compounds; therefore, less radiocesium should be adsorbed. However, considerable proportion of ^{137}Cs in forest soil is retained by the fungal hyphae, and fungi are considered to prevent the elimination of cesium from ecosystems (Brückmann and Wolters 1994; Guillitte et al. 1994; Vinichuk and Johanson 2003; Vinichuk et al. 2005). Thus, fungal activity is likely to contribute substantially to the long-term retention of radiocesium in the organic layers of forest soil by recycling and retaining radiocesium between fungal mycelia and soil (Muramatsu and Yoshida 1997; Steiner et al. 2002; Yoshida and Muramatsu 1994, 1996). In fact, some examples have been

Fig. 15.4 Association of radiocesium contamination in mushrooms with that in their possible substrates. Note the differences in scale

reported where the ^{137}Cs radioactivity in mushrooms persisted for a long period in forests and was transferred to animals, whereas that in plants had short ecological half-lives (e.g., 3–3.5 years) (Fielitz et al. 2009; Kiefer et al. 1996; Zibold et al. 2001).

Because radiocesium contamination was higher in the O horizon than that in the A/Ch horizon of soil in the autumn of 2011, 6 months after the Fukushima accident (Fig. 15.4), most of the radiocesium had not migrated from the litter layer. Moreover, most mushrooms did not accumulate radiocesium compared with the O horizon, except for *P. lubrica* and *Suillus grevillei*. This suggests that the contamination had not reached the soil layer where most fungal hyphae are distributed. Mushrooms incorporate radiocesium as litter decomposition advances and cesium migrates into

the soil. Thus, the radiocesium concentration in European mushrooms increased for a few years after the Chernobyl accident (Borio et al. 1991; Smith and Beresford 2005). Radioactivity was already incorporated into mushrooms in UTCF. Given the high radiocesium concentration in the O horizon, the radioactivity in mushrooms will increase greatly in UTCF and in areas with a normal dose rate. Therefore, it is necessary to monitor mushroom radioactivity in low-contamination areas as well as the immediate vicinity of F1-NPP.

^{137}Cs concentration was much higher in *P. lubrica* and *S. grevillei* compared with the O horizon and Ch horizon in FTRI. However, the causes of this may differ between the two fungal species. Radionuclides from the Fukushima accident caused the contamination of *P. lubrica*, whereas the contamination of *S. grevillei* appeared to be due to NWT or the Chernobyl accident. High concentrations of radioactivity incorporation may be induced by widespread distribution of mycelia near the litter surface. Because radiocesium activity at each soil depth changes with time, radiocesium activity in different fungal species at different mycelial depths are also expected to vary with time (Rühm et al. 1998; Yoshida and Muramatsu 1994). ^{137}Cs is retained for a long time in the O horizon, which includes the litter layer of forest soil. A part of ^{137}Cs migrates very slowly into the A horizon (Kammerer et al. 1994; Pietrzak-Flis et al. 1996; Rühm et al. 1998). Thus, the changes are expected to be different between *P. lubrica* and other fungal species.

15.5 Radioactive Contamination due to Nuclear Weapons Tests or the Chernobyl Accident

Many atmospheric NWT were conducted up to 1980, which produced large amounts of radioactive fallout. Peak contamination in Japanese soils and crops was detected in 1963 (Komamura et al. 2006), after which the residual concentration of radioactive cesium decreased gradually. Chernobyl radionuclide plumes reached Japan in 1986; however, these depositions were temporary and less abundant.

To evaluate the contribution of NWT and the Chernobyl accident to the radioactive contamination of mushrooms and to distinguish it from that of the Fukushima accident, we calculated the ratio of ^{137}Cs derived from NWT or the Chernobyl accident to that from the Fukushima accident based on the $^{134}\text{Cs}/^{137}\text{Cs}$ ratio of the Fukushima derivatives. The half-lives of ^{134}Cs and ^{137}Cs are 2.07 and 30.1 years, respectively. We did not need to consider any evident decay of ^{137}Cs in our study. The residual ^{134}Cs was considered to decrease to 100/129 of its initial value. Estimates on the contribution of NWT or the Chernobyl accident and the Fukushima accident in ^{137}Cs contamination are shown in Fig. 15.5.

The contribution of NWT or the Chernobyl accident was high in several fungi such as *S. grevillei* and *P. lubrica* (Fig. 15.5). ^{137}Cs was detected in mushrooms collected from UTHF where no contamination due to the Fukushima accident was confirmed. In the soil, there was a higher contribution of NWT and the Chernobyl accident in the A or Ch horizon than the O horizon. No ^{137}Cs was detected in the

Fig. 15.5 Contribution of nuclear weapons tests or the Chernobyl accident to the radiocesium contamination of mushrooms

O horizon, despite its detection in the lower A horizon in some samples from ERI and UTHF. These results suggested that NWT- and Chernobyl-derived ^{137}Cs had already migrated from the O horizon to the A or Ch horizon and were being incorporated into the fungi.

Extremely low radiocesium activity was detected in A/Ch horizon at UTHF and FTRI, whereas the presence of ^{137}Cs in *L. connatum* and *S. grevillei* indicated ^{137}Cs retention in fungal hyphae for several decades. In particular, *S. grevillei* samples from FTRI contained >500 Bq/kg DW of ^{137}Cs derived from NWT or Chernobyl accident. Similarly, *P. lubrica* was calculated to contain 66–250 Bq/kg DW. Sugiyama et al. (2000) reported the presence of ^{137}Cs in *P. lubrica* (41 Bq/kg FW) and *S. grevillei* (91 Bq/kg FW) around Mt. Fuji in 1996. Both fungal species can be characterized by their ability to retain cesium.

The widespread distribution of radiocesium contamination before the Fukushima accident was reconfirmed by the radioactivity analysis of mushrooms, including those from low-contamination areas. This originated from the global fallout due to NWT, which peaked in 1963, and the Chernobyl accident in 1986, and is still being accumulated in the ground surface layers (Yoshida and Muramatsu 1994) almost 50 and 25 years after deposition, respectively. Takenaka et al. (1998) reported that Japanese soil was contaminated with ^{137}Cs due to NWT fallout at concentrations of 100 Bq/kg DW. Similar results were obtained in this and other studies. NWT affected the wild mushrooms in Japan, more than the Chernobyl accident. The contribution of Chernobyl accident was estimated to be in the range of 7–60% and 10–30% on an average (Igarashi and Tomiyama 1990; Muramatsu et al. 1991; Shimizu et al. 1997; Yoshida and Muramatsu 1994; Yoshida et al. 1994). Because

approximately 50 years have passed since NWT, even if biological elimination from the ecosystem can be ignored, the radioactivity attributable to ^{137}Cs deposition 50 years ago was thrice as high as the present levels.

15.6 Conclusion and Future Perspectives

In addition to NWT and the Chernobyl accident, there has been serious radionuclide fallout in Japan due to the Fukushima accident. The radioactivity in forest ecosystems has been circulating. It is important to ensure the safety of forest products, such as mushrooms, game, and charcoal, derived from low and moderate-contamination areas. It is necessary to understand the behavior of radiocesium in mushrooms and their substrates as a part of forest ecosystems. Dose rate is a useful index, but it is insufficient for completely understanding mushroom contamination. It is necessary to distinguish the persistence of radiocesium due to NWT or the Chernobyl accident from the additional radiocesium attributable to the Fukushima accident, which is being absorbed into mushrooms and incorporated into the cycle of forest ecosystem. Long-term monitoring is required for the future assessment of radiocesium levels.

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