Radiocesium concentrations in wild mushrooms collected in Kawauchi Village after the accident at the Fukushima Daiichi Nuclear Power Plant

Kanami Nakashima, Makiko Orita, Naoko Fukuda, Yasuyuki Taira, Naomi Hayashida, Naoki Matsuda, Noboru Takamura

It is well known from the experience after the 1986 accident at the Chernobyl Nuclear Power Plant that radiocesium tends to concentrate in wild mushrooms. In this study, we collected wild mushrooms from the Kawauchi Village of Fukushima Prefecture, located within 30 km of the Fukushima Daiichi Nuclear Power Plant, and evaluated their radiocesium concentrations to estimate the risk of internal radiation exposure in local residents. We found that radioactive cesium exceeding 100 Bq/kg was detected in 125 of 154 mushrooms (81.2%). We calculated committed effective doses based on 6,278 grams per year (age >20 years, 17.2g/day), the average intake of Japanese citizens, ranging from doses of 0.11–1.60 mSv, respectively. Although committed effective doses are limited even if residents eat contaminated foods several times, we believe that comprehensive risk-communication based on the results of the radiocesium measurements of food, water, and soil is necessary for the recovery of Fukushima after this nuclear disaster.
Radiocesium Concentrations in Wild Mushrooms Collected in Kawauchi Village after the Accident at the Fukushima Daiichi Nuclear Power Plant

Kanami Nakashima¹, Makiko Orita¹, Naoko Fukuda², Yasuyuki Taira³, Naomi Hayashida⁴, Naoki Matsuda⁵, and Noboru Takamura¹*

¹Department of Global Health, Medicine, and Welfare
²Department of Radioisotope Medicine
³Nagasaki Prefectural Pharmaceutical Affairs
⁴Division of Strategic Collaborative Research Center for Promotion of Collaborative Research on Radiation and Environment Health Effects
⁵Department of Radiation Biology and Protection, Atomic Bomb Disease Institute, Nagasaki University Graduate School of Biomedical Sciences

*Correspondence to: Noboru Takamura, M.D., Ph.D.
Professor and Chairman,
Department of Global Health, Medicine and Welfare, Atomic Bomb Disease Institute, Nagasaki University Graduate School of Biomedical Sciences
1-12-4 Sakamoto, Nagasaki 852-8523, Japan
Tel: +81-95-819-7170
Fax: +81-95-819-7172

E-mail: takamura@nagasaki-u.ac.jp
Abstract

It is well known from the experience after the 1986 accident at the Chernobyl Nuclear Power Plant that radiocesium tends to concentrate in wild mushrooms. In this study, we collected wild mushrooms from the Kawauchi Village of Fukushima Prefecture, located within 30 km of the Fukushima Daiichi Nuclear Power Plant, and evaluated their radiocesium concentrations to estimate the risk of internal radiation exposure in local residents. We found that radioactive cesium exceeding 100 Bq/kg was detected in 135 of 154 dried mushrooms (87.7%). Interestingly, 17 species showed relatively higher concentrations of radiocesium and five species showed relatively lower concentrations. We calculated committed effective doses based on 16.1 grams per day and 5,876.5 grams per year (the average intake of Japanese citizens), ranging from doses of 0.256–3.748 μSv and 0.093–1.368 mSv, respectively. Although committed effective doses are relatively limited even if residents eat contaminated foods several times, we believe that comprehensive risk-communication based on the results of the radiocesium measurements of food, water, and soil is necessary for the recovery of Fukushima after this nuclear disaster.
Introduction

On March 11, 2011, a 9.0-magnitude earthquake struck the east coast of Iwate, Miyagi, and Fukushima Prefectures in Japan. The earthquake, in combination with the resulting tsunami, triggered a severe nuclear accident at the Fukushima Daiichi Nuclear Power Plant (FNPP) (IAEA, 2011a; IAEA, 2011b). Due to this accident, large amounts of radionuclides, including iodine-131 ($^{131}$I), cesium-134 ($^{134}$Cs), and cesium-137 ($^{137}$Cs) were released into the atmosphere (UNSCEAR, 2013). The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) estimated the total release of $^{131}$I, $^{134}$Cs, and $^{137}$Cs at 120.0, 9.0, and 8.8 petabecquerel (PBq), respectively.

To minimize the internal radiation exposure of local residents, Japanese national and prefectural governments began to monitor selected foodstuffs (milk, vegetables, grains, meat, fish, etc.) on March 16, 2011. Those containing radioactive material that exceeded the provisional regulation values as recommended on March 17, 2011, by Japan’s Ministry of Health, Labour and Welfare (MHLW) were prohibited from distribution on March 21, 2011, and from consumption on March 23, 2011 (Hamada, Ogino & Fujimichi, 2012; Merz, Steinhauser & Hamada, 2013; Merz, Shozugawa & Steinhauser, 2015). Due to this stringent food-control policy, internal radiation from radioactive cesium and radioactive iodine was relatively limited (Harada et al., 2012; Koizumi et al., 2012; Hayano et al., 2013). Fukushima Prefecture reported the results of internal
radiation doses measured with a whole-body counter in residents of Fukushima Prefecture and its evacuees from June 2011 to February 2015. Of these, 233,199 (99.9%) showed a committed effective dose of <1 mSv; the maximum recorded level was 3 mSv, which was measured in two individuals (Taira et al., 2014).

However, based on the experience after the 1986 accident at the Chernobyl Nuclear Power Plant, it is well known that radiocesium tends to concentrate in wild mushrooms (Skuterud et al., 1997; Jesko et al., 2000; Hille et al., 2000; Hoshi et al., 2000; Travnikova et al., 2001; Sekitani et al., 2010; Guillén & Baeza, 2014). Hoshi et al. reported that children consuming mushrooms showed a relatively high $^{137}$Cs body burden near Chernobyl, which suggests that mushrooms are one of the main contributors to internal radiation exposure from radiocesium after nuclear disasters (Hoshi et al., 2000). Although the evaluation of radiocesium concentrations in wild mushrooms is important, comprehensive studies have not been conducted to measure the concentrations of radiocesium in mushrooms in a certain area and to clarify the risk of internal exposure in the residents of Fukushima. In this study, we collected wild mushrooms from the Kawauchi Village of Fukushima Prefecture, located within 30 km of the FNPP (Fig. 1), and evaluated their radiocesium concentrations to estimate the internal radiation exposure of local residents.
Materials & Methods

Sampling of Mushrooms

Prior to the study, we obtained approval from the Kawauchi Village Office (Approval Number: 20130120). Wild mushrooms were collected in Kawauchi Village (at the public office, N37° 20’, E140° 48’), located within 30 km of the FNPP, from September through November 2013, 30–32 months after the accident. In cooperation with the residents of the village, we collected 154 mushroom samples from a total of 22 species.

After collection, all samples were dried in a fixed-temperature dryer (60°C for 24 h, then 105°C for 1 h). They were then placed in plastic containers made of polypropylene and analyzed with a high-purity germanium detector (ORTEC®, GMX30-70, Ortec International Inc., Oak Ridge, TN, USA) coupled with a multi-channel analyzer (MCA7600, Seiko EG&G Co., Ltd., Chiba, Japan) for 3,600 s. The measuring time was set to detect the objective radionuclide, and the gamma-ray peaks used for the measurements were 604.66 keV for $^{134}$Cs (2.1 y) and 661.64 keV for $^{137}$Cs (30 y). Decay corrections were made based on the sampling date, and detector efficiency calibration was performed for different measurement geometries using mixed-activity standard volume sources (Japan Radioisotope Association, Tokyo, Japan). All measurements were performed at Nagasaki University (Nagasaki, Japan). The sum of $^{134}$Cs and $^{137}$Cs concentrations was indicated as “concentrations of radiocesium.” For the six mushrooms in which only $^{137}$Cs was detected,
concentrations of $^{137}$Cs were indicated as “concentrations of radiocesium.” To calculate the committed effective doses, we calculated the ratio of radiocesium concentrations in dried and raw mushrooms using 81 samples of *Sarcodon aspratus*, and found that it was 1:8 (data not shown).

94 *Committed Effective Dose*

The committed effective dose from mushroom concentration intake was calculated using the following formula:

$$H_{\text{int}} = C \cdot D_{\text{int}} \cdot e$$

where $C$ is the activity concentration (median) of detected artificial radionuclides (radiocesium) (Bq/kg), $D_{\text{int}}$ is the dose conversion coefficient for adult intake (age >20 years, $1.9 \times 10^{-5}$ mSv/Bq for $^{134}$Cs and $1.3 \times 10^{-5}$ mSv/Bq for $^{137}$Cs) (ICRP, 1995), and $e$ is the daily intake value ($17.2$ g/day, the average intake of Japanese citizens) (MHLW, 2012).
Results

The species and amounts of the collected wild mushrooms are listed in Table 1. Among the 154 mushroom samples from 22 species, 79 (51.3%) were *Sarcodon aspratus*, 11 (7.1%) were *Hypholoma sublateritium*, and 10 (6.5%) were *Armillaria mellea*. The concentrations of radiocesium ($^{134}\text{Cs} + ^{137}\text{Cs}$) in the dried mushrooms are shown in Fig. 2. Radiocesium was not detected in 19 mushrooms (12.3%); however, 1,000–9,999 Bq/kg of radiocesium was detected in 86 mushrooms (55.8%), and >10,000 Bq/kg of radiocesium was detected in 36 mushrooms (23.4%). The maximum concentration was 124,900 Bq/kg in *Cortinarius salor Fr.*

The concentration of radiocesium of each species is shown in Table 1. Radiocesium was detected in 79 of 79 samples (100%) of *Sarcodon aspratus*, 10 of 11 samples (90.9%) of *Hypholoma sublateritium*, 8 of 10 samples (80%) of *Armillaria mellea*, 6 of 6 samples (100%) of *Tricholoma matsutake*, and 6 of 6 samples (100%) of *Pholiota microspora*. However, radiocesium was not detectable in *Grifola frondosa* ($N = 3$), *Lentinula edodes* ($N = 1$), *Armillaria tabescens* ($N = 1$), and *Entoloma sarcopum* ($N = 1$). Seventeen species showed relatively higher concentrations of radiocesium, including nine species of mycorrhizal fungus and eight species of root fungus. However, five species showed relatively lower concentrations of radiocesium.

Next, we mapped the distribution of mushrooms with concentrations of radiocesium in Kawauchi
Village (Fig. 3). The calculated committed effective doses are shown in Table 2. These were calculated assuming 16.1 grams of raw mushrooms per day and 5,876.5 grams per year (the average intake of Japanese citizens). Among the 135 dried mushrooms (87.7%) that contained radiocesium exceeding 100 Bq/kg, the minimum and maximum calculated daily and annual committed effective doses ranged from 0.256–3.748 μSv/day and 0.093–1.368 mSv/year, respectively.

Discussion

In this study, radioactive cesium exceeding 100 Bq/kg was detected in 135 of 154 (87.7%) dried mushrooms collected in Kawauchi Village, Fukushima Prefecture. Kawauchi Village is located 20–30 km southwest of the FNPP, and most of its residents were evacuated during the initial phase of the accident at the FNPP. On January 31, 2012, the head of Kawauchi Village declared that residents who lived at least 20 km away from the FNPP could return to their homes, after the Japanese Prime Minister declared that the FNPP reactors had achieved a state of “cold shutdown” in December 2011 (Orita et al., 2013). Since this declaration, the village office has been working steadily towards reconstruction, including decontamination within the village. Decontamination of residential houses has been conducted since mid-2011, even within the 20 km radius of the FNPP.
However, decontamination has not been conducted in the forests of Fukushima Prefecture, including Kawauchi Village. Therefore, because all of the mushrooms in this study were collected in the forest around the village, high frequencies of radiocesium were detected.

Since the Chernobyl accident, a series of studies has been conducted to clarify the influence of radiocesium in forest-derived products, including mushrooms. Kaduka et al. (2006) analyzed the $^{137}$Cs aggregated transfer factor from the soil to different mushrooms and showed that the aggregated transfer factors depend on the mushroom’s trophic group, biological family, genus, and species (Bannai, Yoshida & Muramatsu, 1994). Bulko et al. (2014) evaluated the $^{137}$Cs uptake by forest-derived products in the Gomel region, which was the most heavily contaminated after the Chernobyl accident, and found that the accumulation of $^{137}$Cs in mushrooms and berries was directly related to the radiocesium contamination density of the soil, which is accounted for both by the form of the Chernobyl fallout and by the natural and climatic conditions that determine variations in the availability of radionuclides in the soil.

Although the number of samples was limited, we found that 17 species showed relatively higher concentrations of radiocesium and that five species showed relatively lower concentrations. This suggests that the concentration of radiocesium might depend on the species of mushroom. Usually, habitat varies depending on species. To determine the factors affecting radiocesium concentrations in mushrooms, Yoshida and Muramatsu (1994) collected mushrooms and categorized them into
four different groups according to the main habitat of their mycelia: wood, the litter layer, the
surface soil layer (0–5 cm), and the following soil layer (>5 cm), and found that the surface soil
layer group showed the highest average concentrations of $^{137}$Cs. They concluded that the habitat of
the mycelium seemed to be one of the most important factors controlling radiocesium
concentration in mushrooms. Since habitat is closely associated with each particular species, it is
suspected that species type is also associated with radiocesium concentrations in mushrooms.

We calculated committed effective doses ranging from 0.256–3.748 $\mu$Sv and 0.093–1.368 mSv,
respectively, based on the average daily and annual intake of mushrooms. After the FNPP accident,
the Japanese government established provisional regulation values for $^{131}$I (300 Bq/kg for drinking
water and milk, 2,000 Bq/kg for vegetables) and for $^{134}$Cs and $^{137}$Cs (200 Bq/kg for drinking water
and milk, 500 Bq/kg for vegetables, grains, meat, fish, and eggs). Due to this strict food-control
policy, internal exposure from radioactive cesium and radioactive iodine were relatively limited
(Harada et al., 2012; Koizumi et al., 2012; Hayano et al., 2013). However, according to the
experience after the Chernobyl accident, excess intake of contaminated mushrooms is a risk factor
for internal radiation exposure among residents. Hoshi et al. (2000) conducted measurements of the
$^{137}$Cs body burden in 1991–1996 for children residing in Bryansk Oblast (Russian Federation), an
area that experienced contamination following the Chernobyl accident, and discovered that the
most common food items contributing to $^{137}$Cs intake in children were mushrooms, meat, milk, and
vegetables. Travnikova et al. (2001) also found that the individual content of $^{137}\text{Cs}$ in the bodies of inhabitants of a village in Bryansk Oblast correlated with their consumption of milk during the initial period after the accident and with their consumption of forest mushrooms during the subsequent period. Although our results showed that committed effective doses were relatively limited even if residents ate contaminated foods several times, a long-term risk evaluation for the internal radiation exposure of these individuals is needed in order to gain a better understanding of radiation safety in Fukushima.

There are several limitations of this study. First, it was conducted only in Kawauchi Village for one year. Second, we could not evaluate the relationship between radiocesium concentrations in mushrooms and soil, due to insufficient soil samples. Further comprehensive studies are necessary to evaluate the concentrations of radiocesium in mushrooms in Fukushima after the FNPP accident.

Conclusions

We evaluated radiocesium concentrations in wild mushrooms collected at Kawauchi Village in Fukushima Prefecture and found that radiocesium exists in wild mushrooms at a relatively high frequency. Although committed effective doses are relatively limited even if residents eat contaminated foods several times, we believe that comprehensive risk-communication based on measurements of radiocesium in the food and water, as well as in the soil, is necessary for the
recovery of Fukushima after the nuclear disaster.
References

Bannai T, Yoshida S, Muramatsu Y. 1994. Cultivation experiments on uptake of radionuclides by mushrooms. *Radioisotopes* **43**:77-82 (in Japanese)

Bulko NI, Shabaleva MA, Kozlov AK, Tolkacheva NV, Mashkov IA. 2014. The $^{137}$Cs accumulation by forest-derived products in the Gomel region. *Journal of Environmental Radioactivity* **127**:150-154. DOI: 10.1016/j.jenvrad.2013.02.003

Guillén J, Baeza A. 2014. Radioactivity in mushrooms: A health hazard? *Food Chemistry* **154**:14-25. DOI: 10.1016/j.foodchem.2013.12.083

Hamada N, Ogino H, Fujimichi Y. 2012. Safety regulations of food and water implemented in the first year following the Fukushima nuclear accident. *Journal of Radiation Research* **53**:641-671. DOI: 10.1093/jrr/rrs032

Harada KH, Fujii Y, Adachi A, Tsukidate A, Asai F, Koizumi A. 2012. Dietary intake of radiocesium in adult residents in Fukushima Prefecture and neighboring regions after the Fukushima Nuclear Power Plant accident: 24-h food-duplicate survey in December 2011. *Environmental Science & Technology* **47**. DOI: 10.1021/es304128t

Hayano RS, Tsubokura M, Miyazaki M, Satou H, Sato K, Sakuma Y. 2013. Internal radiocesium...
contamination of adults and children in Fukushima 7 to 20 months after the Fukushima NPP accident as measured by extensive whole-body-counter survey. *Proceedings of the Japan Academy, Series B* **89**:157-163. DOI: 10.2183/pjab.89.157

Hille R, Hill P, Heinemann K, Ramzaev V, Barkovski A, Konoplia V, Neth R. 2000. Current development of the human and environmental contamination in the Bryansk-Gomel Spot after the Chernobyl accident. *Radiation and Environmental Biophysics* **39**:99-109. DOI: 10.1007/s004110000043

Hoshi M, Konstantinov YO, Evdeeva TY, Kovalev AI, Aksenov AS, Koulikova NV, Sato H, Takatsui T, Takada J, Endo S, Shibata Y, Yamashita S. 2000. Radiocesium in children residing in the western districts of the Bryansk Oblast from 1991-1996. *Health Physics* **79**:182-186. DOI: 10.1097/00004032-200008000-00011

International Commission on Radiological Protection (ICRP). 1995. Age-dependent doses to the members of the public from intake of radionuclides - Part 5. *Compilation of Ingestion and Inhalation Coefficients*, ICRP Publication 72. Ann. ICRP 26

Jesko T, Zvonova I, Balonov M, Thornberg C, Mattsson S, Wallstrom E, Vesanen R, Alpsten M. 2000. Age-dependent dynamics of cesium radionuclide content in inhabitants of the Bryansk
region, Russia: A seven-year study. *Radiation Protection Dosimetry* **89**:179-182

Kaduka MV, Shutov VN, Bruk GY, Balonov MI, Brown JE, Strand P. 2006. Soil-dependent uptake of $^{137}$Cs by mushrooms: Experimental study in the Chernobyl accident areas. *Journal of Environmental Radioactivity* **89**:199-211. DOI: 0.1016/j.jenvrad.2006.05.001

Koizumi A, Harada KH, Niisoe T, Adachi A, Fujii Y, Hitomi T, Kobayashi H, Wada Y, Watanabe T, Ishikawa H. 2012. Preliminary assessment of ecological exposure of adult residents in Fukushima Prefecture to radioactive cesium through ingestion and inhalation. *Environmental Health and Preventive Medicine* **17**:292-298. DOI: 10.1007/s12199-011-0251-9

Merz S, Shozugawa K, Steinhauser G. 2015. Analysis of Japanese radionuclide monitoring data of food before and after the Fukushima nuclear accident. *Environmental Science & Technology* **49**:2875-2885. DOI: 10.1021/es5057648

Merz S, Steinhauser G, Hamada N. 2013. Anthropogenic radionuclides in Japanese food: Environmental and legal implications. *Environmental Science & Technology* **47**:1248-1256. DOI: 10.1021/es3037498

Ministry of Health, Labour and Welfare (MHLW). 2012. National Health and Nutrition Survey

Ministry of Health, Labour and Welfare (MHLW). 2011. Additional Report of
the Japanese Government to the IAEA — The accident at TEPCO’s Fukushima nuclear power
stations (Second Report). Available at
http://www.iaea.org/sites/default/files/japanreport120911.pdf (accessed 30 August 2015)

Orita M, Hayashida N, Urata H, Shinkawa T, Endo Y, Takamura N. 2013. Determinants for the
return to hometowns after the accident at Fukushima Dai-ichi Nuclear Power Plant: A case study
for the village of Kawauchi. *Radiation Protection Dosimetry* **156**:383-385. DOI:
10.1093/rpd/nct082

Report of Japanese Government to IAEA Ministerial Conference on Nuclear Safety — Accident
at TEPCO’s Fukushima nuclear power stations. 2014. Available at
http://www.iaea.org/newscenter/focus/fukushima/japan-report (accessed 30 August 2015)

Sekitani Y, Hayashida N, Karevskaya IV, Vasilitsova OA, Kozlovsky A, Omiya M, Yamashita S,
Takamura N. 2010. Evaluation of $^{137}$Cs body burden in inhabitants of Bryansk Oblast, Russian
Federation, where a high incidence of thyroid cancer was observed after the accident at the
Chernobyl nuclear power plant. *Radiation Protection Dosimetry* **141**:36-42. DOI:
10.1093/rpd/ncq137

Skuterud L, Travnikova IG, Balonov MI, Strand P, Howard BJ. 1997. Contribution of fungi to
radiocesium intake by rural populations in Russia. *Science of the Total Environment* **193**:237-242. DOI: 10.1016/S0048-9697(96)05346-6

Taira Y, Hayashida N, Orita M, Yamaguchi H, Ide J, Endo Y, Yamashita S, Takamura N. 2014. Evaluation of environmental contamination and estimated exposure doses after residents return home in Kawauchi Village, Fukushima Prefecture. *Environmental Science & Technology* **48**:4556-4563. DOI: 10.1021/es404534y

Travnikova IG, Bruk GJ, Shutov VN, Bazjukin AB, Balonov MI, Rahola T, Tillander M. 2001. Contribution of different foodstuffs to the internal exposure of rural inhabitants in Russia after the Chernobyl accident. *Radiation Protection Dosimetry* **93**:331-339

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). 2013. Sources, effects and risks of ionizing radiation. *Report to the General Assembly, Scientific Annex A: Levels and effects of radiation exposure due to the nuclear accident after the 2011 Great East-Japan Earthquake and Tsunami, Volume I*. Available at [http://www.unscear.org/docs/reports/2013/13-85418_Report_2013_Annex_A.pdf](http://www.unscear.org/docs/reports/2013/13-85418_Report_2013_Annex_A.pdf) (accessed 30 August 2015)

Yoshida S, Muramatsu Y. 1994. Accumulation of radiocesium in basidiomycetes collected from
Japanese forests. *Science of the Total Environment* 157:197-205
Figure 1: Location of Kawauchi Village, Fukushima Prefecture

Figure 2: Distribution of radiocesium concentrations (\(^{134}\text{Cs} + ^{137}\text{Cs}\)) in mushrooms

Figure 3: Map of mushroom concentrations in Kawauchi Village
Table 1 (on next page)

mushroom list

Concentrations of radiocesium in wild mushrooms
| Species (habitat)                  | n  | 134Cs* | 134Cs (Bq/kg)** | 137Cs* | 137Cs (Bq/kg)** |
|-----------------------------------|----|--------|------------------|--------|-----------------|
| Sarcodon aspratus (surface soil)  | 79 | 79     | 290.8 (43.8–1,870.1) | 79     | 667.5 (126.8–4,504.5) |
| Hypholoma sublateritium (wood)    | 11 | 9      | 177.5 (10.3–509.2)  | 10     | 388.3 (22.4–1,087.9) |
| Armillaria mellea (wood)          | 10 | 6      | 46.3 (31.1–189.7)   | 8      | 69.8 (16.9–394.5)   |
| Tricholoma matsutake (surface soil) | 6  | 6      | 139.8 (70.0–491.4)  | 6      | 299.6 (177.5–1171.2) |
| Pholiota microspore (wood)        | 6  | 6      | 298.9 (74.5–1,706.3) | 6      | 652.5 (185.6–3,685.5) |
| Lyophyllum shimeji (surface soil) | 5  | 3      | 89.8 (64.8–107.0)   | 4      | 164.5 (95.7–193.8)  |
| Lyophyllum decastes (surface soil)| 5  | 1      | 18.4              | 2      | 16.7 (15.4–17.9)   |
| Cortinarius salor Fr. (surface soil) | 4  | 4      | 3,596.8 (363.1–5,432.7) | 4     | 7,589.4 (802.6–11,616.2) |
| Boletopsis leucomeles (surface soil) | 4  | 4      | 191.3 (69.7–763.0) | 4      | 444.3 (180.2–1,760.9) |
| Pholiota squarrosa (wood)         | 4  | 0      | ND               | 1      | 56.0             |
| Hygrophorus russula (surface soil) | 3  | 3      | 415.0 (319.4–2,661.5) | 3      | 986.9 (727.6–5,719.4) |
| Grifola frondosa (wood)           | 3  | 0      | ND             | 0      | ND               |
| Phaeolepiota aurea (surface soil) | 3  | 0      | ND             | 0      | ND               |
| Suillus bovinus (surface soil)    | 2  | 2      | 631.3 (587.0–675.7) | 2      | 1352.7 (1,272.2–1,433.3) |
| Lyophyllum fumosum (surface soil) | 2  | 2      | 84.4 (68.1–100.6)  | 2      | 153.4 (93.8–212.9)  |
| Lepista sordida (surface soil)    | 1  | 1      | 4,927.7          | 1      | 10,415.0         |
| Lepista nuda (surface soil)       | 1  | 1      | 2,975.7          | 1      | 6,429.2          |
| Panellus serotinus (wood)         | 1  | 1      | 35.5             | 1      | 88.7             |
| Pleurotus ostreatus (wood)        | 1  | 1      | 23.5             | 1      | 57.2             |
| Lentinula edodes (wood)           | 1  | 0      | ND             | 0      | ND               |
| Armillaria tabescens (wood)       | 1  | 0      | ND             | 0      | ND               |
| 27 | *Entoloma sarcopum* (surface soil) | 1 | 0 | ND | 0 | ND |
|---|---|---|---|---|---|---|
| 28 | *Number of detected mushrooms* |
| 29 | **Median (minimum–maximum)** |
| 30 | ND: not detected |
| 31 | |
| 32 | |
| 33 | |
Table 2 (on next page)

committed effective dose

Committed effective dose due to wild mushroom intake
Table 2. Committed effective dose due to wild mushroom intake

| Species                        | n  | mSv/year*          |
|-------------------------------|----|--------------------|
| *Sarcodon aspratus*           | 79 | 0.09 (0.02–0.59)   |
| *Hypholoma sublateritium*     | 10 | 0.05 (<0.01–0.15)  |
| *Armillaria mellea*           | 8  | 0.01 (<0.01–0.05)  |
| *Tricholoma matsutake*        | 6  | 0.04 (0.02–0.15)   |
| *Pholiota microspora*         | 6  | 0.09 (0.02–0.50)   |
| *Lyophyllum shimeji*          | 4  | 0.03 (0.01–0.03)   |
| *Lyophyllum decastes*         | 2  | <0.01 (<0.01–<0.01)|
| *Cortinarius salor Fr.*       | 4  | 1.05 (0.11–1.60)   |
| *Boletopsis lecomelas*        | 4  | 0.06 (0.02–0.23)   |
| *Pholiota squarrosa*          | 1  | <0.01               |
| *Hygrophorus russula*         | 3  | 0.13 (0.10–0.78)   |
| *Suillus bovinus*             | 2  | 0.19 (0.17–0.20)   |
| *Lyophyllum fumosum*          | 2  | 0.03 (0.02–0.03)   |
| *Lepista sordida*             | 1  | 1.44                |
| *Lepista nuda*                | 1  | 0.88                |
| *Panellus serotinus*          | 1  | 0.01                |
| *Pleurotus ostreatus*         | 1  | 0.01                |

*Median (minimum–maximum)
Map of Kawauchi village

Location of Kawauchi Village, Fukushima Prefecture

Fig. 1
dried and raw mushrooms

Relationship of radiocesium concentrations between dried and raw mushrooms.
all mushrooms

Distribution of radiocesium concentrations (134Cs + 137Cs) in all mushrooms
Sarcodon aspratus

Distribution of radiocesium concentrations (134Cs + 137Cs) in Sarcodon aspratus.
other mushrooms

Distribution of radiocesium concentrations (134Cs + 137Cs) in other mushrooms.

![Bar chart showing distribution of radiocesium concentrations in other mushrooms.](image-url)
mushroom map

Map of mushroom concentrations in Kawauchi Village