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Investigation of radiocesium distribution in organs of wild boar grown in Iitate, Fukushima after the Fukushima Daiichi nuclear power plant accident

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Abstract The concentrations of radiocesium in different organs of wild boar inhabiting Iitate, Fukushima were measured, after the Fukushima Daiichi nuclear power plant accident. After dissection, about 24 parts were collected and measured using a NaI gamma ray counter. In 2012, the radiocesium concentration (^{134}Cs and ^{137}Cs) was highest in muscle (approximately 15,000 Bq kg^{-1}) and low in ovary, bone and thyroid gland, indicating large variation among tissues. Radiocesium concentrations in 24 different organs revealed the pattern of distribution of radiocesium in wild boar and indicated its availability in the ecosystem of the forests and villages where the boars matured.

Keywords Radioactive fallout · Wild boar · Fukushima Daiichi nuclear power plant · Radiocesium · ^{134}Cs · ^{137}Cs

Introduction

Large quantities of radioactive nuclides were released during the accident at the Fukushima Daiichi nuclear power plant (Tokyo Electric Power Company) in March 2011. Maps based on soil monitoring show that radiocesium was highly deposited in regions to the north-west of the power plant [1]. From the nuclear accident, radiocesium [2, 3] as well as radiostrontium [4], plutonium [5, 6] and the others [7], has been detected in the land of Fukushima prefecture. The dominant radionuclides in the environment are radiocesium because of its half-life: ^{134}Cs (half-life: 2 years) and ^{137}Cs (half-life: 30 years) as well as its volatility. The concern with the health effects has been remaining though the internal radiation exposure of the habitants was limited even at the area located 12–30 km southwest of the Fukushima Daiichi nuclear power plant just after the accident [8]. Rice, the main staple food of the Japanese diet, has been thoroughly checked and there was no rice that had more than 100 Bq/kg of radiocesium on the market even in Fukushima Prefecture [9]. There have been many ongoing projects to revive the area having relatively low air dose rate.

On the other hand, people remain evacuated from areas with high radiation levels caused by deposition of radiocesium. Iitate village is in the evacuation zone and currently the village is uninhabited (Fig. 1). Recently, damage to farm fields caused by wild animals such as monkeys and wild boar has been increasing because of the absence of villagers. Previously, control of wild-animal pests was generally carried out by hunting. This prevented damage by wild animals, and in some cases the meat of the animals was sold and processed for human consumption. However, high radiocesium levels in wild animals in the contaminated area [10–12] has led to a reduction in hunting activity.

In Japan, food obtained from around Fukushima Prefecture has been monitored since 2011 [13]. In the case of wild animals, muscle tissue is usually selected for measurement of radioactive nuclide concentrations and, although other organs are also edible, few data are available on their radionuclide levels. In cattle and pig, radiocesium concentrations differ among organs [14–16], and it is possible that this is the case in other animals.

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This paper reports the radiocesium concentrations of different organs obtained from wild boar hunted for pest control in Iitate (Fig. 1). We sampled wild boar in the winters of 2012 and 2013, approximately 20 and 33 months after the nuclear accident. Radiocesium concentrations were determined in individual organs, in the contents of digestive organs (stomach, intestine and colon), and in the blood.

Experimental

Organ sampling

In Japan, wild animals hunting are only permitted in winter season (http://www.pref.fukushima.lg.jp/sec/01210a/shuryou.html: in Japanese text). A total of nine wild boars were captured using cages during winter (Table 1). They consisted of four males, four females and one of unknown sex (4 adults, 5 juveniles). Five boars were captured in a single cage on 25 November 2012 (identified as 20121125-01 to 20121125-05) and two on 29 November 2012 (20121129-01 and 20121129-02). Two more boars were captured using separate cages on 6 December 2013 (20131206-01 and 20131206-02). All were euthanized using a hunting gun on the day following capture. They were immediately dissected and individual organ samples were transferred to vials size 20 ml. Bone, stomach, colon, bladder, small intestine were washed by tap water before transferred to vial.

Determination of radiocesium activities

The radioactivities of samples contained in vials were measured using an NaI(Tl) scintillation counter (2480 WIZARD[2] gamma counter, PerkinElmer Inc., Waltham, MA), which equipped well-type NaI(Tl) crystal of 3-inch diameter by 3-inch long covered with lead shield with 75 mm of thickness. The energy calibration was performed using the 662 keV of gamma-ray from ^{137}Cs. The measurement time was set for 20–60 min. Radiocesium concentrations (expressed as the sum of ^{137}Cs and ^{134}Cs) were calculated from the count rates in five energy windows (300–398, 524–657, 724–862, 608–706 and 1330–1510 keV) using a protocol provided by PerkinElmer Inc. In radiocesium, the detection limit was approximately 25 Bq kg^{-1} and detection efficiency (cps kg^{-1}) was 0.194 [17]. Radiocesium activities of the blood samples in 2012 were measured using a germanium semiconductor detector (GEM-type, ORTEC, SEIKO EG&G CO., LTD., Tokyo, Japan), which was calibrated in energy and detection efficiency by the certificated reference material of ^{137}Cs, and ^{134}Cs as a solution purchased from Japan Radioisotope Association.

Results and discussion

Radiocesium concentrations (^{134}Cs and ^{137}Cs) in selected organs of wild boar

Wild animals controlled by hunting are considered to be vermin and may be consumed by humans. In addition to the muscles, organs potentially could be consumed. The radiocesium concentration in foods is measured as the sum of ^{137}Cs and ^{134}Cs activities (Bq kg^{-1}). We compared the radiocesium concentrations in different organs of wild boar with the provisional regulation value for meat (500 Bq kg^{-1}) [13] in Fig. 2a. The average radiocesium concentration in muscle tissue was about 15,000 Bq kg^{-1}, which was the highest value among the organs tested. Monitoring in Fukushima Prefecture from 2011 to 2014 indicated that the radiocesium concentration of wild boars captured within the Sousou area ranged from 98 to 61,000 Bq kg^{-1} (https://www.pref.fukushima.lg.jp/sec/16035b/wildlife-radiationmonitoring1.html), which is consistent with the present data. Because wild boars and pigs have a habit to eat soils attached to the earthworms for

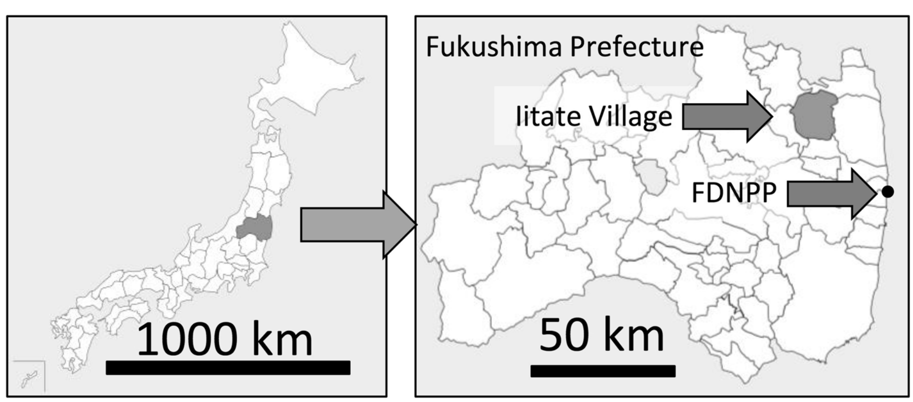

Fig. 1 Map of Iitate village, Fukushima Prefecture, Japan. FDNPP indicates Tokyo Electric Power Company's Fukushima Daiichi nuclear power plant

Table 1 Wild boars captured in 2012 and 2013

Individual identification number	Adult/juvenile	Sex	Remarks
20121125-01	Adult	Female	Nulliparous
20121125-02	Adult	Female	Nulliparous, stomach inflammation
20121125-03	Juvenile	Male	
20121125-04	Juvenile	Male	
20121125-05	Juvenile	Female	Nulliparous, stomach ulcer
20121129-01	Adult	Female	Parous
20121129-02	Juvenile	n/a[a]	
20131206-01	Juvenile adult	Male	
20131206-02		Male	

[a] Not available

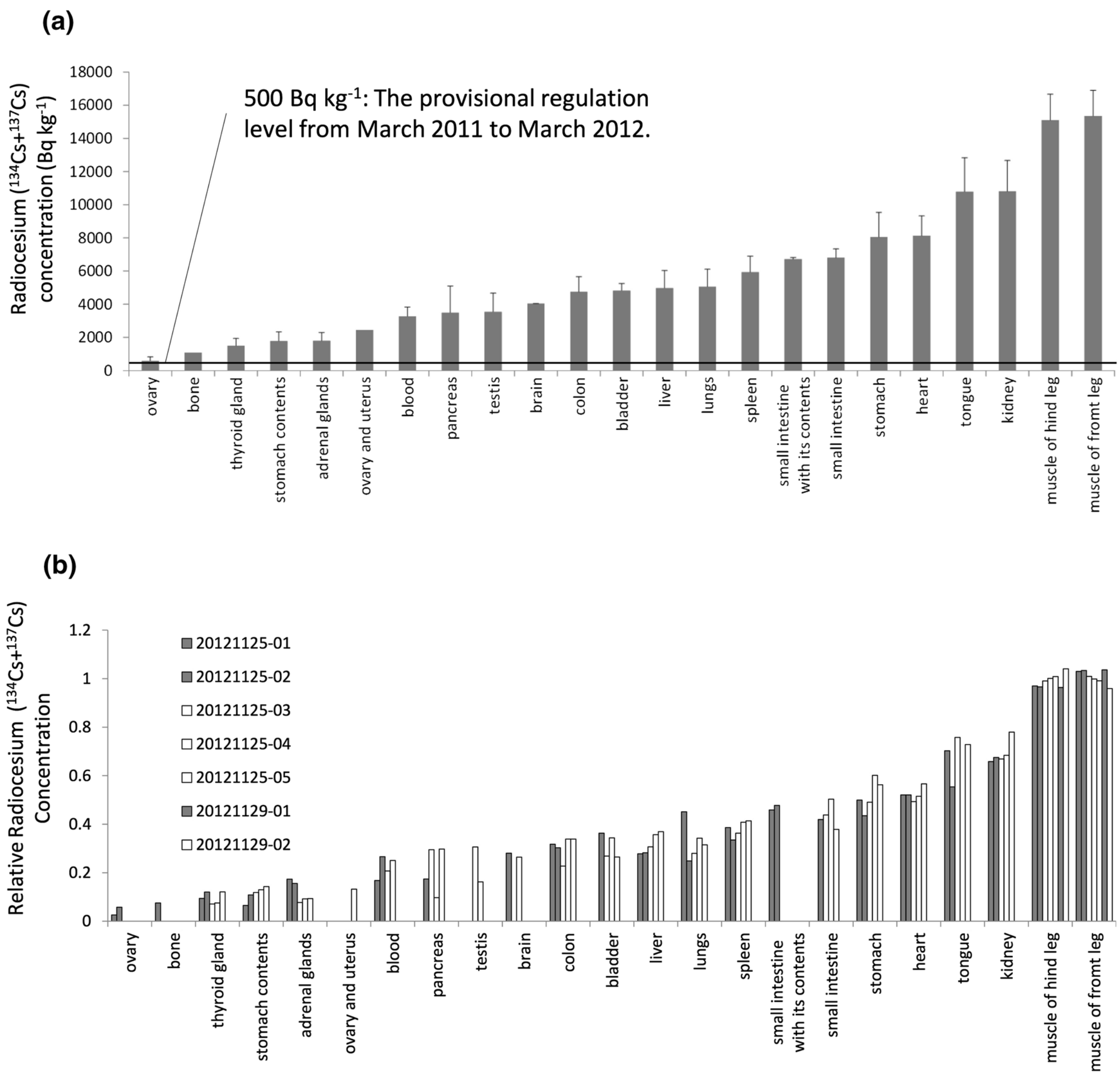

Fig. 2 Radiocesium concentration in organs of wild boar captured in 2012. The ^{134}Cs and ^{137}Cs were calculated in December 2012 and the radiocesium was shown as a sum of ^{134}Cs and ^{137}Cs. **a** Average concentrations in individual organs arranged in ascending order. The *black horizontal line* represents 500 Bq kg^{-1}, which was the provisional regulation level employed from March 2011 to March 2012 in Japan. **b** Relative values of organs in individual animals captured in 2012. The average of radiocesium concentration of muscle was set as 1. *Gray bars* represent adult boars and *white bars* represent juvenile boars. The identification numbers shown in Fig. 2b refer to those in Table 1, which provides further information on individuals

example, the radiocesium level tend to be high compared with a herbivorous animal, such as cattles. The radiocesium concentration in the ovary was the lowest among the organs (600 Bq kg^{-1}), but was still above the provisional regulation value (500 Bq kg^{-1}), and also the new standard defined after April 2014 (100 Bq kg^{-1}) [13]. Based on these data, none of the organs were distributed as food and it was recommended the organs should not be consumed. To illustrate variability in radiocesium loads among the wild boars captured in 2012, we present the radiocesium concentrations in the organs of individual animals (Fig. 2b). The relative uniformity of the activities of the muscle tissue in the five boars captured on 25 November 2012 (20121125-01 to 20121125-05) may reflect that they were captured at the same time in the same cage. Presumably, similar factors affected the whole group. The trends in radiocesium distribution were similar among adults and juveniles in 2012 (Fig. 2b).

Comparison of ^{137}Cs levels in the organs between 2012 and 2013

To compare radiocesium levels between 2012 and 2013, we present only the ^{137}Cs concentrations in each organ because these values were relatively unaffected by radioactive decay (the physical half-life of ^{134}Cs is 2 years and that of ^{137}Cs is 30 years). The ^{137}Cs concentrations in wild boars captured in 2012 are shown as averages (Fig. 3a), but the values of the two captured in 2013 are shown separately because their ^{137}Cs concentrations differed greatly (Fig. 3b, c). The order of presentation of the organs in Figs. 3b and 2c is the same as that in Fig. 3a. The ^{137}Cs concentration patterns were similar between 2012 and 2013; the highest ^{137}Cs concentration was found in the muscles, and high concentrations were also observed in the kidneys, tongue and heart. The ^{137}Cs concentration in the thyroid gland, which is known to accumulate radioiodine, was found to be relatively low. This trend is similar to that observed in cattle in 2011 [14], in which the radiocesium concentration in the muscles, kidneys, tongue, and heart were consistently high compared to the other organs.

Ohmori et al. reported the radiocesium concentration in pigs fed rice contaminated by the Fukushima Daiichi nuclear power plant accident, and the radiocesium concentrations were highest in muscle, followed by liver and digestive tract. The rank of order was similar with our data, however, the difference of radiocesium concentrations are slightly different. In the present study, the ^{137}Cs concentration of liver was less than half than that of muscle in 2012 and 2013. On the other hand, the ^{137}Cs concentration of liver of pig was 12 % less than that of muscle [18]. Green et al. reported the ^{137}Cs concentration in pig in 1961, indicating the ^{137}Cs was derived from the global fall out. The rank of order was similar with the present study; higher concentration in muscle, kidney, and heart, and lower concentration in brain, blood, and female reproductive tracts (ovary and uterus in our study) [16]. Interestingly, they reported the ^{137}Cs-to-potassium ratio was high in kidney and testis in pig, which was not observed in calf. In the present study, the ^{137}Cs concentration of kidney was high, but that of testis is relatively low among tissues (Fig. 2). To specify the accumulation mechanism among animals, we need to continue the analysis.

Monitoring of the radionuclide levels in the blood is more convenient than measuring the radioactivities of other tissues. Thus it is of interest to compare the ^{137}Cs concentrations in blood with those in other organs. The average ^{137}Cs concentration in the blood in 2012 was about 2100 Bq kg^{-1} (Fig. 3a) and in 2013 the values were 120 and 2300 Bq kg^{-1} for the juvenile (Fig. 3b) and the adult (Fig. 3c), respectively. The corresponding ^{137}Cs concentration ratios of blood to muscles were 0.26, 0.14 and 0.41, for the boars in 2012 (Fig. 3a), the juvenile in 2013 (Fig. 3b) and the adult in 2013 (Fig. 3c), respectively. Thus, the radiocesium concentration in blood did not vary consistently with values in organs, such as muscle, kidney and tongue. Therefore, blood is not a suitable material for monitoring the radiocesium concentration of wild boar. In addition, the ratios of ^{137}Cs concentration of blood to muscles in wild boar were much higher than the value of 0.04 reported for cattle [14], 0.007 for calf [16] and 0.10 for pig [16]. The reason why the ratio of ^{137}Cs concentration among animals differ so markedly remains unclear.

A variety of plants, insects and small animals are taken by wild boar, which are omnivores. Therefore, the radiocesium levels in stomach contents must reflect the radiocesium situation in the forest ecosystem which they inhabit. Monitoring the time course of the change in the radiocesium concentration in the stomach contents would help to clarify the availability of radiocesium to organisms in the ecosystem. In the present study, the average ^{137}Cs concentration of the stomach contents was about 960 Bq kg^{-1} in 2012 (1200 Bq kg^{-1} for the juvenile and 780 Bq kg^{-1} for the adult), which was almost the same as the concentrations in 2013, indicating that the ^{137}Cs concentration had not decreased between 2012 and 2013. Although the reason why the ^{137}Cs concentrations in organs were so different between 2012 and 2013 while the concentrations in stomach contents were the same level was unclear, it might be related to the ^{137}Cs availability for ecosystem. So, it is important to continue monitoring the ^{137}Cs concentration in stomach contents as well as in the organs to determine the fate of the available ^{137}Cs in the forest ecosystem, for example whether it further invades living organisms or is absorbed into the soil minerals. It is also important to

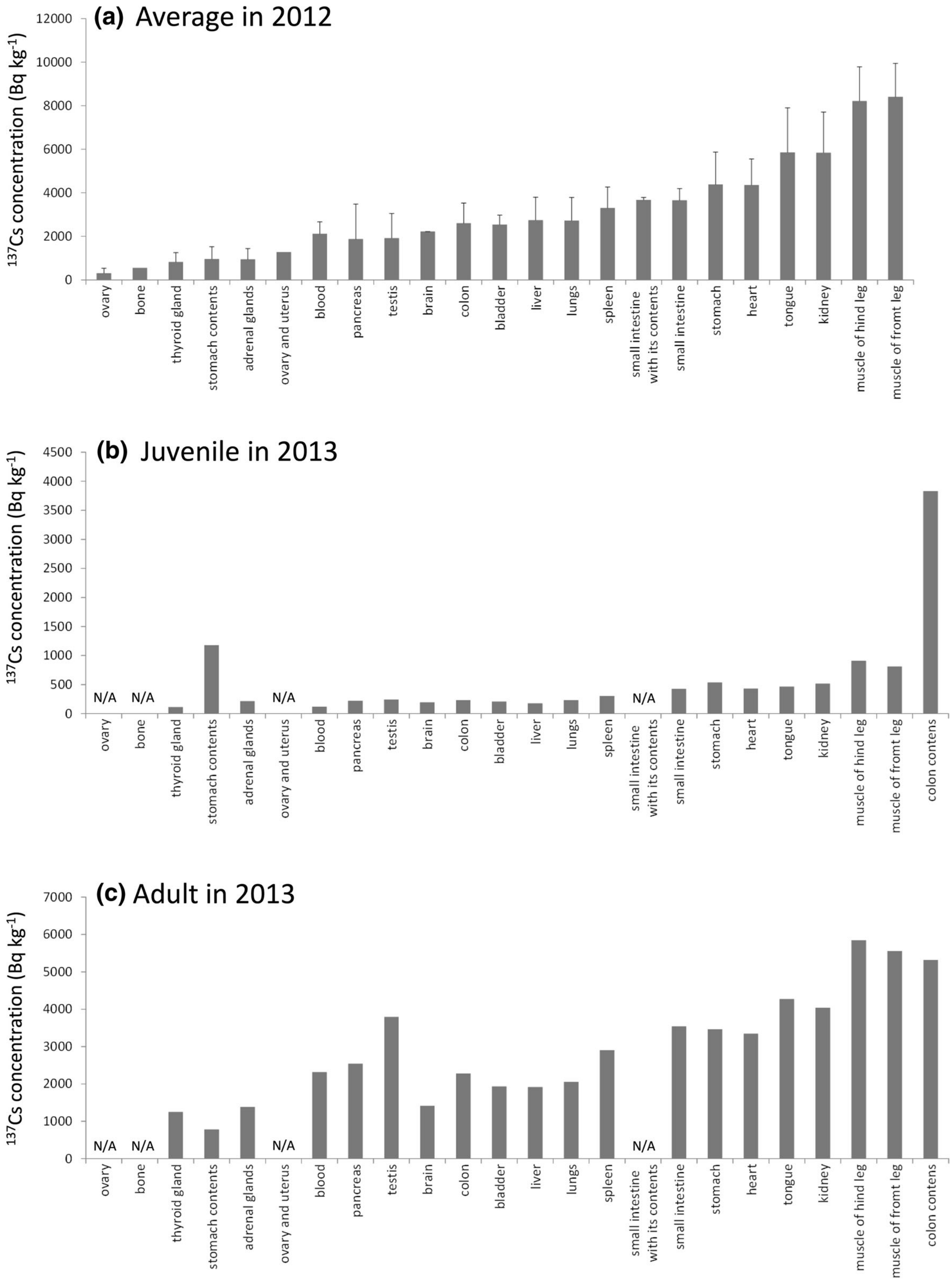

Fig. 3 Comparison of ^{137}Cs concentration in organs between 2012 and 2013. The ^{137}Cs organs are arranged in the same order as in Fig. 2. **a** Average ^{137}Cs concentrations in wild boars captured in 2012. *Error bars* show the standard deviation. **b** ^{137}Cs concentrations in the juvenile wild boar captured in 2013. *N/A* Not applicable. **c** ^{137}Cs concentration in the adult wild boar captured in 2013. *N/A* Not applicable

continue monitoring the wild boar to clarify why the ^{137}Cs concentrations were so different between juvenile and adult despite having similar ^{137}Cs concentrations in the stomach and colon contents in 2013.

Conclusions

This paper reports the state of radiocesium contamination in wild boars in 2012 and 2013 in Iitate, Fukushima after the power plant accident in 2011. The highest radiocesium concentration was found in the muscles, and high concentrations were also observed in the kidneys, tongue and heart. On the other hand, the radiocesium concentrations of ovary, bone, thyroid gland, adrenal gland, and uterus were relatively low among organs, and found to be lower than that of blood. Although the wild boars varied in radiocesium level, the trends in radiocesium distribution among organs were similar between adults and juveniles, and in 2012 and 2013. The data for stomach contents and organs provides information on the availability of radiocesium in the forest ecosystem. It is important to continue to gather the information regularly to understand the long-term fate and effects of radiocesium in the ecosystem.

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