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Deposition of fission and activation products after the Fukushima Dai-ichi nuclear power plant accident

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ABSTRACT

The Great Eastern Japan Earthquake on March 11, 2011, damaged reactor cooling systems at Fukushima Dai-ichi nuclear power plant. The subsequent venting operation and hydrogen explosion resulted in a large radioactive nuclide emission from reactor containers into the environment. Here, we collected environmental samples such as soil, plant species, and water on April 10, 2011, in front of the power plant main gate as well as 35 km away in Iitate village, and observed gamma-rays with a Ge(Li) semiconductor detector. We observed activation products (^{239}Np and ^{59}Fe) and fission products (^{131}I, ^{134}Cs (^{133}Cs), ^{137}Cs, ^{110m}Ag (^{109}Ag), ^{132}Te, ^{132}I, ^{140}Ba, ^{140}La, ^{91}Sr, ^{91}Y, ^{95}Zr, and ^{95}Nb). ^{239}Np is the parent nuclide of ^{239}Pu; ^{59}Fe are presumably activation products of ^{58}Fe obtained by corrosion of cooling pipes. The results show that these activation and fission products, diffused within a month of the accident.

1. Introduction

The Great East Japan Earthquake and the subsequent Tsunami on March 11, 2011, caused the cooling systems of the Fukushima Dai-ichi nuclear power plant to break down. The cooling of some of the nuclear reactors thus became impossible, and the pressure in the nuclear reactor container rose because of hydrogen buildup. Despite the venting operation performed for reactor No. 1 on March 12, the building was damaged by a hydrogen explosion. Immediately thereafter, ^{137}Cs was detected from dust collected within the premises of the power plant. Although a venting operation was performed for reactor No. 3 on March 13, a large-scale hydrogen explosion occurred the following day. On the other hand, dry venting was performed for reactor No. 2 without a hydrogen explosion, and a hydrogen explosion occurred in reactor No. 4 on March 15. For these reasons, the nuclear-reactor fuel rods and container underwent damage between March 12 and 15, and a large amount of radioactive nuclides was emitted into the environment. As of April 12, it was confirmed that the cores for the No. 1 to No. 3 reactors were damaged and that the fuel pellet had melted. In light of this, the Fukushima Dai-ichi nuclear power plant accident was elevated to a level 7 event on the International Nuclear Event Scale (INES) (Releases, 2011). The radioactive contamination in the environment is become a great concern in Japan for our survival.

In this study, environmental samples of soil, plant species, and water were collected on April 10—about one month after the accident—in front of the main gate of the Fukushima Dai-ichi nuclear power plant and 35 km away at Iitate village in Fukushima prefecture. Doses of radioactive nuclides were then measured by a Ge(Li) semiconductor detector without any chemical modification of the samples in order to comprehensively identify the nuclides that diffused into the environment.

2. Methods

Soil, plant species, and water in the environment were collected on April 10, 2011 in front of the main gate of the Fukushima Dai-ichi nuclear power plant (located at Okuma-machi, Futaba-gun) and at Iitate village, Soma-gun, Fukushima prefecture, shown in Table 1. From paddy and thicket soils, 30–80 g of soils from the surface (0–10 cm) was collected after removing plant species. From pine and straw leaves, *ca.* 10 g of plant were collected while ensuring the absence of attached soil. From paddy fields and puddles, we collected *ca.* 100 ml of water per sample using a 50-ml syringe. The skies were clear and there was hardly any wind on the sampling day. The sampling sites and spatial radiation dose at each site are shown in Fig. 4. The latter was measured by an ion-chamber-type gamma-ray detector and GM counter.

Gamma-rays from collected samples were measured using a Ge(Li) semiconductor detector (Princeton Gamma-Tec). The device, located at the Radioisotope Center in the University of Tokyo, has a relative efficiency of 34.4% at 1332 keV, and FWHM of 1.78 keV on the 1332 keV ^{60}Co γ-line and 743 eV on the 122 keV ^{57}Co γ-line. Measurements were performed on April 14 and April 22. The sample was sealed

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Table 1
Sampling sites and spatial dose of radiation.

Sample			Place	Distance from the main gate (km)	Dose of radiation (μSv h^{-1})
s1	Soil	Paddy	Around the nuclear plant	1.5	75
s2		Paddy	Near Kumagawa river	4.1	43
s3		Garden plant	In front of the main gate	0.0	100
s4		Paddy	Nagadoro, Iitate village	35.0	17
s5		Paddy	Komiya, Iitate village	35.0	11
p1	Plant species	Straw	Around the nuclear plant	1.5	75
p2		Leaf of pine	In front of the main gate	0.0	100
p3		Leaf of pine	In front of the main gate	0.0	100
p4		Straw	Komiya, Iitate village	35.0	11
w5	Water	Puddle	Around the nuclear plant	1.0	67
w6		Paddy	Around the nuclear plant	1.5	75

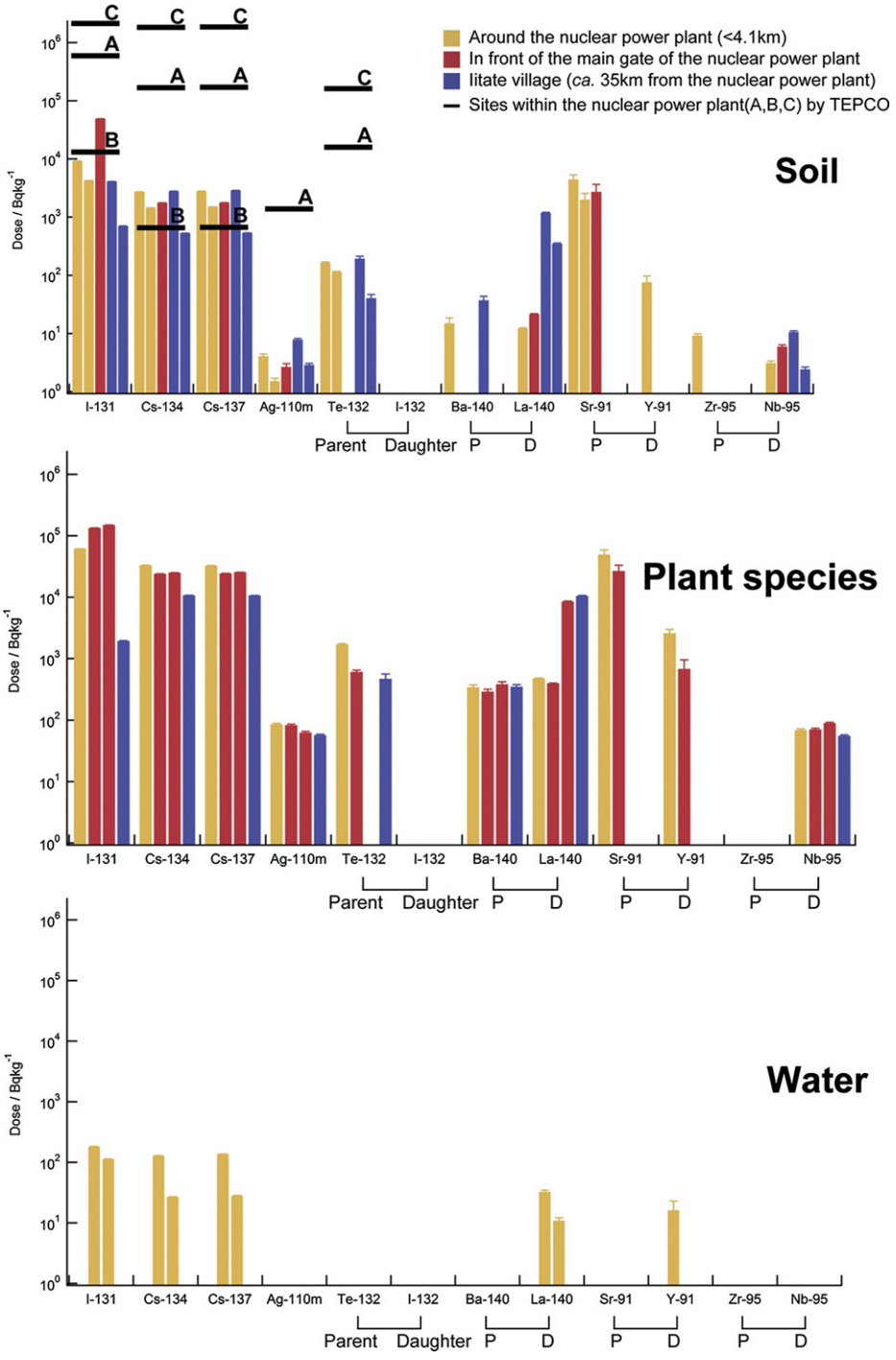

Fig. 1. Fission products (Bq kg^{-1}) in samples collected around the Fukushima Dai-ichi nuclear power plant and at Iitate village.