Journal of Environmental Radioactivity 122 (2013) 37–42

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Radiocesium concentrations in the bark, sapwood and heartwood of three tree species collected at Fukushima forests half a year after the Fukushima Dai-ichi nuclear accident

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ARTICLE INFO

Article history:
Received 28 June 2012
Received in revised form
14 February 2013
Accepted 27 February 2013
Available online 25 March 2013

Keywords:
Fukushima Dai-ichi nuclear power plant
Radiocesium
Stemwood
Bark
Heartwood
Sapwood

ABSTRACT

Radiocesium (^{134}Cs and ^{137}Cs) distribution in tree stems of Japanese cedar (aged 40–56 y), red pine (42 y), and oak (42 y) grown in Fukushima Prefecture were investigated approximately half a year after the Fukushima Dai-ichi nuclear accident. Japanese cedar, red pine, and oak were selected from five sites, one site, and one site, respectively. Three trees at each site were felled, and bark, sapwood (the outer layer of wood in the stem), and heartwood (the inner layer of wood in the stem) separately collected to study radiocesium concentrations measured by gamma-ray spectrometry. The radiocesium deposition densities at the five sites were within the range of 16–1020 kBq m^{-2}. The radiocesium was distributed in bark, sapwood, and heartwood in three tree species, indicating that very rapid translocation of radiocesium into the wood. The concentration of radiocesium in oak (deciduous angiosperm) bark was higher than that in the bark of Japanese cedar and red pine (evergreen gymnosperms). Both sapwood and heartwood contained radiocesium, and the values were much lower than that in the bark samples. The results suggest that radiocesium contamination half a year after the accident was mainly attributable to the direct radioactive deposition. The radiocesium concentrations in the Japanese cedar samples taken from five sites rose with the density of radiocesium accumulation on the ground surface. To predict the future dynamics of radiocesium in tree stems, the present results taken half a year after the accident are important, and continuous study of radiocesium in tree stems is necessary.

1. Introduction

The massive tsunami that struck northeast Japan on March 11, 2011, caused extensive damage to the Fukushima Daiichi Nuclear Power Plant (FDNPP) operated by the Tokyo Electric Power Company and resulted in wide areas of eastern Japan, especially Fukushima Prefecture, being contaminated by the radioactive fallout. About 70% of the land is forest in Fukushima Prefecture (9720 km^2/13,781 km^2), thereby raising serious concerns over the radioactive contamination of forests and forest products.

After the Chernobyl accident, many intensive studies on radionuclide contamination of land and water, and its transfer to plants etc. were conducted, and the findings were summarized by the International Atomic Energy Agency (IAEA) in numerous reports (e.g. IAEA, 2003, 2009). The transfer process of radionuclides from the environment to trees can be divided into two stages: (1) the early phase lasting 4 to 5 y after deposition of radionuclides, and (2) a steady state phase thereafter (IAEA, 2009). Goor and Thiry (2004) presented a dynamic modeling of the total ^{137}Cs content in the stemwood of a young pine stand. They estimated that radiocesium concentrations would peak at about 15 y after the deposition. However, there are many differences in the circumstances surrounding the damaged plants in Fukushima and Chernobyl, such as the tree species, soil type, and rainfall, which may potentially result in variation in the radionuclide contamination of tree species (IAEA, 2009; Kaunisto et al., 2002; Smolders and Tsukada, 2011). Also, the soil-to-plant transfer factor of radionuclides showed high variability attributable to the soil-chemical, soil-biological, hydrological, physical and plant physiological processes, which might be influenced by external factors such as climate (Ehlken and Kirchner, 2002). Accordingly, it is unclear whether the dynamics of the radiocesium in the Fukushima forests, including the tree stems, was the same as in Chernobyl.

This study was part of an investigation project initiated by the Forestry and Forest Products Research Institute (FFPRI) to determine the level of radionuclide contamination in the forestland and

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http://dx.doi.org/10.1016/j.jenvrad.2013.02.019

forest biomass in Fukushima Prefecture. During this study, we investigated the concentrations of ^{134}Cs and ^{137}Cs in tree stems, including heartwood, sapwood, and bark, collected from the forests in Fukushima Prefecture at half a year after the Fukushima Dai-ichi nuclear accident. We initially selected three major tree species from one site and investigated differences in the contamination pattern between the tree species. Subsequently, we selected four sites with differing density of radiocesium accumulation on the ground surface, and investigated the effects of the radiocesium deposition density on the contamination level of Japanese cedar tree stems.

2. Material and methods

2.1. Study sites and samples

Five sites from three areas in Fukushima Prefecture were selected as sampling sites based on the distance from the FDNPP. The data of radiocesium accumulation on the ground surface and the air dose rates obtained from monitoring data provided by Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) (2011) were also taken into consideration. The areas selected were Kawauchi Village (including Kawauchi, Kamikawauchi, and Miyawata sites) in eastern Fukushima, Ohtama Village in central Fukushima, and Tadami Town in western Fukushima (Fig. 1). The wood and bark samples of Japanese cedar (*Cryptomeria japonica* D. Don) were collected at national forests located at Kawauchi, Ohtama, and Tadami sites and village-owned forests located at Kamikawauchi and Miyawata sites, whereas the wood and bark samples of red pine (*Pinus densiflora* Sieb.et Zucc.) and oak (*Quercus serrata* Thumb.) were collected from the national forest in Ohtama site. Japanese cedar is an evergreen gymnosperm, which is the most important plantation tree species in Japan. The red pine is also an evergreen gymnosperm, and one of the most important plantation tree species. The oak is a deciduous broad-leaved angiosperm used for cultivating the Shiitake mushroom and for charcoal. These trees were the dominant species at each site. Sampling was conducted from early August to early September 2011 (Kawauchi, Ohtama, and Tadami sites) or in late November (Kamikawauchi and Miyawata sites), and each time, air dose rates were measured at 1 m above ground (Table 1).

The radiocesium (^{134}Cs+^{137}Cs) deposition data at each site were obtained from the results of airborne monitoring survey by MEXT (2011) (Table 2).

Three trees of each species were sampled at each site. Trees were felled after wrapping part of the tree stem with a sheet, from 0.5 m to 3 m above ground, to prevent radioactive contamination from litter and soil (Fig. 2). After felling, the bark was removed from stemwood on the sheet, and bark samples were put into plastic bags. Samples from stem were taken at the debarked part of stem, and were placed in plastic bags. The samples were then shipped to the laboratory.

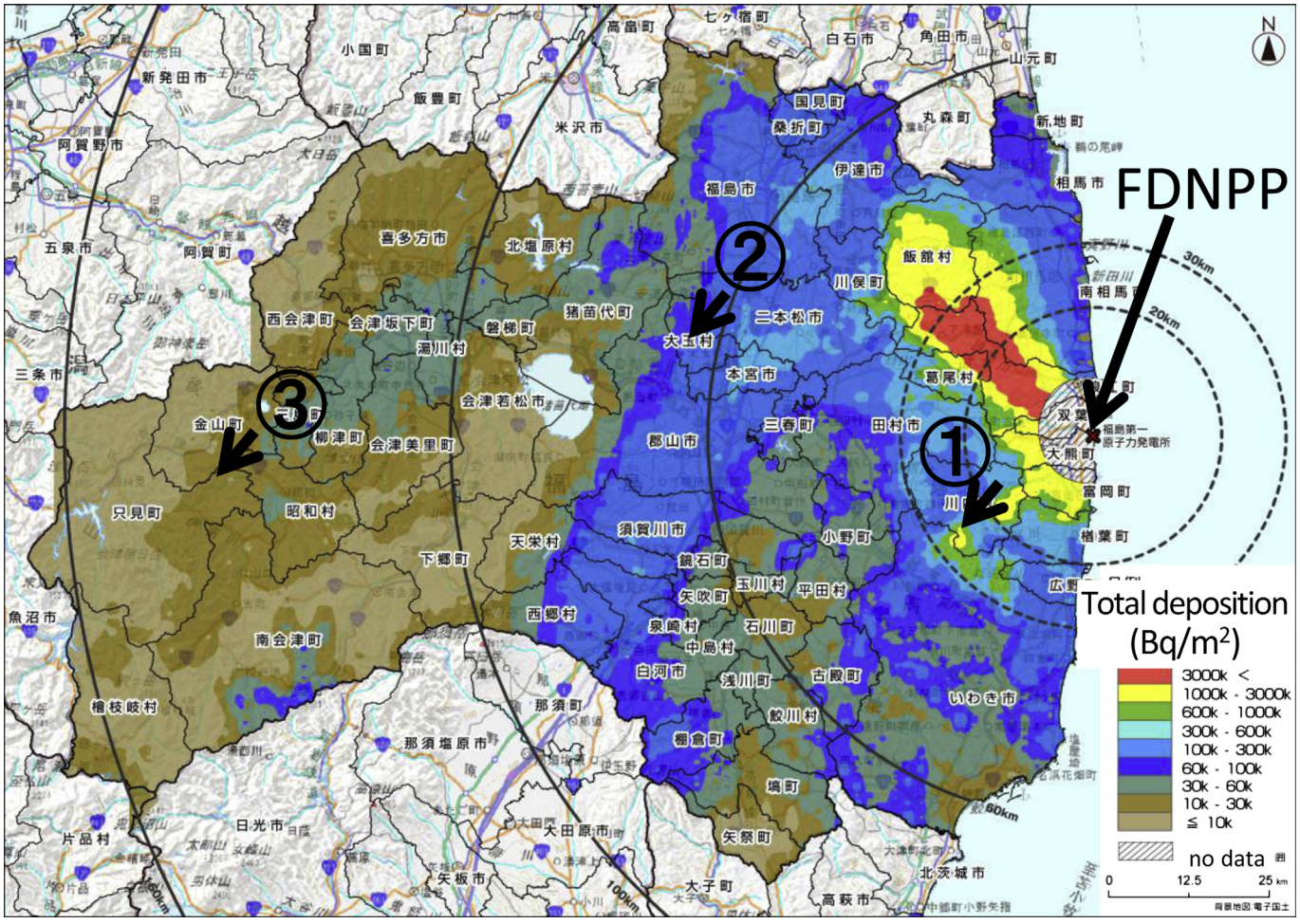

Fig. 1. Sampling sites and the radiocesium deposition in Fukushima. (1) Kawauchi Village, (2) Ohtama Village, (3) Tadami Town. The map was provided by MEXT (2011).