Effects of radionuclide contamination on forest trees in the exclusion zone around the Fukushima Daiichi Nuclear Power Plant

Yoshito WATANABE[1)]*, San'ei ICHIKAWA[2)], Masahide KUBOTA[2)], Toshiyuki TAKANO[3)], Masahiko MIZOGUCHI[3)], Yoshihisa KUBOTA[1)], Shoichi FUMA[1)] and Satoshi YOSHIDA[1)]

1) National Institute of Radiological Sciences, 4-9-1, Anagawa, Inage-ku, Chiba-shi 2638555, Japan
2) Japan Wildlife Research Center, 3-10-10, Shitaya, Taito-ku, Tokyo 1108676, Japan
3) Japan NUS Co., Ltd., 7-5-25, Nishishinjyuku, Shinjyuku-ku, Tokyo 1600023, Japan
*y_nabe@nirs.go.jp

A preliminary survey was performed for forest areas within the exclusion zone around the Fukushima Daiichi Nuclear Power Plant, for radionuclide contamination levels and radiation effects on trees during the first year after the March 2011 accident. Even in the most contaminated forest, approximately 3 km west of the power plant, no externally visible symptoms of radiation damage—including yellowing, malformation, and early withering of leaves—were observed in trees, indicating that massive radiation damage did not occur in the surrounding forests after the accident. Radiosensitive coniferous plants were, however, heavily contaminated by the deposition of radionuclides in reproductive organs such as cones, which could cause the exposure of developing seeds. The level of radionuclides in the cones of Japanese cedar trees changed, depending on the contamination level of the forest, which was approximately given by an ambient dose rate. The dose rate of internal exposure in the cones of the most contaminated forest, which was calculated to include exposure from the radionuclides deposited in the organs, was found to be within the criteria dose rate of 4-40 μGy/h selected for pine trees by the ICRP in Publication 108. This raises the necessity of performing more detailed analyses of the cytogenetic and reproductive damage to forest trees in the area.

Key Words: *environmental effects, biological effects, forest tree, Fukushima exclusion zone*

1. Introduction

During the Fukushima Daiichi Nuclear Power Plant accident that occurred in March 2011, radionuclides released into the atmosphere contaminated the surrounding environment. The largest radioactive plumes from the power plant were blown in the northwest direction, where forest lands are widely distributed[1)]. Even in the Chernobyl nuclear accident of 1986, radioactive plumes contaminated surrounding forests and caused massive radiation damage to forest trees[2)]. By the first summer after the accident the radiation damage was obvious in highly contaminated forest areas, referred to as the "Red Forests" due to the color of the dead tree stands. In this study, a preliminary survey was performed for the forest areas within the exclusion zone around the Fukushima Daiichi Nuclear Power Plant in order to measure the contamination levels and determine the effects of radiation on forest trees during the first year after the accident.

2. Materials and methods

A collection of tree samples was obtained in November 2011. An endemic Japanese coniferous species, Japanese cedar (*Cryptomeria japonica*), was selected for sampling at 3 locations (S1–S3) in the exclusion zone around the Fukushima Daiichi Nuclear Power Plant, as well as at a control location (S4) lying outside the exclusion zone (Fig. 1). Some branches extending to the edge of public places or streets were cut from 2-4 Japanese cedar trees at each sampling location. The ambient dose rate was measured for the trees selected for sampling at 1 m above ground level with either a NaI scintillation survey meter (TCS-161, Hitachi Aloka Medical, Tokyo) or an ionization chamber type survey meter (ICS-323C, Hitachi Aloka Medical). The samples were then transferred to a laboratory for performing measurements.

The radioactive contamination in the samples was first analyzed nondestructively by autoradiography using an imaging plate (BAS-III, Fujifilm Corporation, Tokyo). Further analysis of radionuclides in the cedar cones was performed for cones separated from the branches, air dried, and homogenized, and subsequently subjected to radioactivity measurements using a Ge semiconductor detector (GC2018, Canberra Industries Inc., Oak Ridge, TN) equipped with a multi channel analyzer (DSA1000, Canberra Industries Inc.). The radiological doses received by the cones were calculated using the ERICA tool[3].

Fig. 2 Mixed forest of coniferous and deciduous trees at location S1, November 2011.

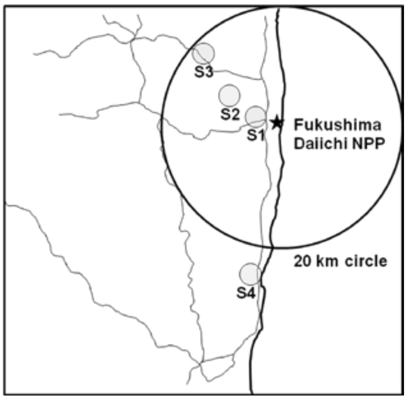

Fig. 1 Sampling locations inside (S1–S3), and outside (S4), the exclusion zone around the Fukushima Daiichi Nuclear Power Plant.

3. Results and discussion

(1) Radiation damage of trees in highly contaminated forests

The sampling location S1 was situated in the most contaminated area, approximately 3 km west of the power plant (Fig. 1), where the ambient dose rate exceeded 50 μSv/h on the sampling day in November 2011, which was about 8 months after the accident had occurred. No externally visible symptoms of radiation damage, including yellowing, malformation, and withering of leaves, were observed in radiosensitive coniferous trees such as the Japanese red pine (*Pinus densiflora*), Japanese cedar, and Japanese cypress (*Chamaecyparis obtusa*) (Fig. 2). This indicated that massive radiation damage did not occur in the forest during the first plant growth season after the Fukushima accident, unlike the “Red Forests” that formed

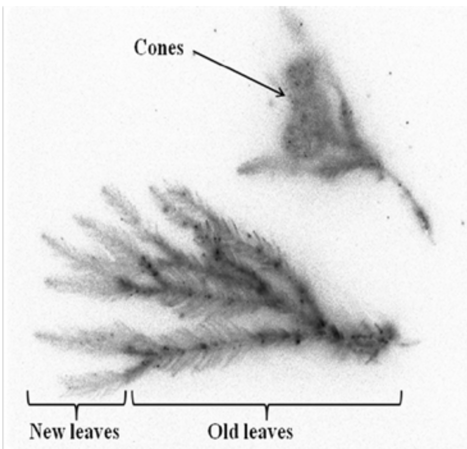

Fig. 3 Autoradiography image of branches of a Japanese cedar tree sampled at location S1, November 2011.

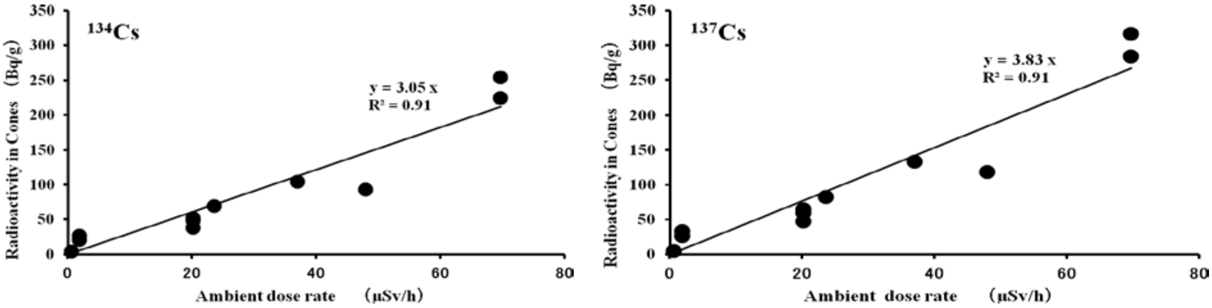

Fig. 4 Relationship between the radiocesium activities in cones of Japanese cedar trees to the ambient dose rate 1 m above ground level around the trees selected for sampling. Counting errors in the radioactivity measurement fall within the symbol size.

after the Chernobyl nuclear accident.

(2) Radionuclide levels in Japanese cedar

For more detailed analysis of the effect of radiation on forest plants, this study focused on the endemic Japanese conifer: Japanese cedar. Autoradiography of branches of the Japanese cedar, taken from the most contaminated forest area (S1), showed that radionuclides were distributed mostly in old leaves and cones that had developed prior to the accident (Fig. 3) and were therefore directly contaminated by the deposition of the radiocesium fallout. The levels of the radionuclides ^{134}Cs and ^{137}Cs in the cones changed according to the contamination levels of the forest, as measured by the ambient dose rate (Fig. 4). The radioactivities in the cones from the most contaminated forest area (S1) were around 250 Bq/g and 300 Bq/g for ^{134}Cs and ^{137}Cs, respectively.

(3) Rough estimation of the internal exposed dose rate in reproductive organs

The radiocesium contaminated plant organs should have caused internal exposure of the organs in addition to external exposure. The radiation exposure could be especially critical in radiosensitive reproductive organs such as cones, in which ovum fertilization and the following seed development proceeded from the first spring to autumn after the accident. The internal exposure dose rates received by the cones in their maturation season (in autumn) were estimated from their level of radiocesium. For a model calculation of the internal dose rates, an ideal cone was assumed, with a globular shape of diameter 2 cm and density 1 g/cm^3, and the radiocesium deposited in the cone was included in the internal contamination. Considering that the highest concentration of radiocesium observed in the cone samples was distributed uniformly in the ideal cone, the internal exposure dose rate received by the cone was estimated to be 15 μGy/h. Although this estimated internal exposure should only be a part of the complete exposure of the cone, it is still sufficiently high to be within the range of the criteria dose rate of 4-40 μGy/h selected for pine trees as the “derived consideration reference level” by the ICRP[4)]. This indicates that there was a probability for certain deleterious effects that could result in reduced reproductive success or morbidity, and highlights the necessity for further analysis of cytogenetic and reproductive changes in plants in the most contaminated forest area, as was also suggested by Garnier-Laplace et al. (2011) [5)].

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