放射線災害復興学報告書

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○放射線災害復興学に関して

（放射線災害復興に関する考え，携わってきた経緯，研究経過等を記載）

Various radionuclides were released into the environment after the Fukushima Daiichi nuclear power plant (FDNPP) accident following the Great East Japan Earthquake in March 2011 (Endo et al., 2012; Yoshida and Kanda, 2012). The accident was the most serious radiation disaster and caused the most widespread contamination since the Three Mile Island nuclear power plant accident in the USA in March 1979 and the Chernobyl accident in the former Soviet Union (now Ukraine) in April 1986. Many other discharges of radioactive material from nuclear facilities to the environment have occurred, including discharges from Sellafield in the UK in the 1970s (Aarkrog et al., 1983), discharges in the Mayak area in South Ural in the former Soviet Union (now Russia) in the late 1940s and the 1950s (Kryshev et al., 1998), and discharges at the Savannah River site in the USA in the 1950s and 1960s (Carlton et al., 1994). The radioactive contamination discharged during these events spread over natural ecosystems, such as forests, because most nuclear facilities are in sparsely populated rural areas. Large areas of forest ecosystems were also contaminated during the Chernobyl and Fukushima accidents (IAEA, 2006; Hashimoto et al., 2013). Contamination in forest areas not only negatively affects the ecosystem and human lives but it can also be an important and long-lasting source of contamination to residential areas. Studies of radionuclide dynamics (specifically, studies of ^{137}Cs, which has a long half-life of 30.17 years) in forest ecosystems, including of radionuclide cycling in the ecosystems and discharges to other systems, are therefore important because they provide information that could be useful when recovering from a radiation accident. Such studies provide evidence that is useful when developing plans for remediation activities in forest ecosystems and for protecting the workers involved in the activities. Such studies are also required before forest resources (timber and non-timber products) will be used after an accident.

As I studied carbon cycle in a forest ecosystem in tropical region previously, I found that dynamics of radioactive cesium in a forest ecosystem is closely related with carbon cycle in a forest, such as litterfall and litter decomposition. In addition, through my field survey in the tropics, I understood that in so-called developing countries, more people deeply relay on forest products compared to Japan. As several developing countries have plans to build commercial nuclear facilities (World Nuclear Association from http://www.world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx), I thought that emergency preparedness for radiation disaster in forest ecosystems is very important for the developing countries; prediction of dynamics of radioactive materials in a forest ecosystem, and creating social systems that people stop using forest products immediately in an emergency situation. Many developing countries that have plants to build commercial nuclear facilities are located in tropical regions. In this climate zone, deposition of large amounts of radioactive materials in forest ecosystems has never occurred. Therefore, prediction of dynamics of radioactive materials needs to be studied thoroughly from the view of climatic parameters (e.g. carbon cycle) in such regions.

In my doctoral study, I conducted a quantitative study on dynamics of radioactive cesium in mixed deciduous forests in Fukushima focusing on carbon cycle in the Fukushima forests.

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Endo, S., Kimura, S., Takatsuji, T., Nanasawa, K., Imanaka, T., Shizuma, K. (2012) Measurement of soil contamination by radionuclides due to the Fukushima Dai-ichi Nuclear Power Plant accident and associated estimated cumulative external dose estimation. *Journal of Environmental Radioactivity* 111: 18–27.

Hashimoto, S., Matsuura, T., Nanko, K., Linkov, I., Shaw, G., Kaneko, S. (2013) Predicted spatio-temporal dynamics of radiocesium deposited onto forests following the Fukushima nuclear accident. *Scientific Reports* 3: 2564.

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〇学位論文題目

Spatio-temporal changes in ^{137}Cs inventory in soils in neighboring mixed deciduous forests of Fukushima Daiichi nuclear power plant

〇学位論文要旨

（プログラムで修得した放射線災害復興学との関係性が判るように記載）

^{137}Cs derived from the Fukushima Daiichi nuclear power plant (FDNPP) in 2011 is expected to contaminate the surrounding forest environment for a long time. Precise studies of ^{137}Cs dynamics in a forest ecosystem are required for developing remediation activities in forest areas, radiation protection for local residents and workers, and resuming the use of the forest resources. I studied temporal changes in ^{137}Cs dynamics in forest ecosystems and environmental parameters influencing on the spatial heterogeneity of ^{137}Cs after the FDNPP accident from August 2013 (2.3 years after the accident) to November 2015 (4.7 years). The surveying ^{137}Cs contained in litter layers to soil 10 cm depth in mixed deciduous forests, approximately 40 km northeast from FDNPP. I focused following three topics; (1) spatial variation of soil ^{137}Cs in forest soils, (2) temporal changes

in vertical distribution of ^{137}Cs, and (3) downward migration of dissolved ^{137}Cs in forest soils. Based on the measurements and analysis on the sampled ^{137}Cs, I found that almost all ^{137}Cs deposited on forest ecosystems translocated to litter layers and surface soils (> 5 cm) via litterfall and precipitation by the beginning of the study, and they accounted for approximately 65% and 25%, respectively. Due to the translocation via precipitation, spatial heterogeneity of soil ^{137}Cs was predicted to be the largest during this period between the accident to beginning of the study. By August 2014, 80% of ^{137}Cs in litter layers in August 2013 migrated into surface soil through litter decomposition process and leaching, and approximately 80% of ^{137}Cs in the forest ecosystems remained in the surface soils. The spatial heterogeneity in the surface soils became relatively homogenous due to the migration. After August 2014, ^{137}Cs activities in the litter layers, the surface soils and the deeper soils (< 5 cm) did not change largely, suggesting that the so-called the "quasi-equilibrium" state (increase or decrease in ^{137}Cs activity was not observed in any compartment in an ecosystem; IAEA, 2006)" may have started in the forests. However, small amounts of dissolved ^{137}Cs still migrated after August 2015. The dissolved radioactive cesium shows high mobility and is biologically available although it was very small amounts. Therefore, I suggested that the long term monitoring on dissolved ^{137}Cs in forest soils should be conducted. In addition, I found that ^{137}Cs dynamics from forest canopy to soils was largely affected by carbon dynamics in a forest ecosystem. As similar trends of ^{137}Cs dynamics were also reported in many studies on radioactive cesium derived from the Chernobyl accident in 1986 in the former Soviet Union (now Ukraine), the temporal change in the present study was faster than the results shown in Chernobyl. The difference in two areas (Fukushima and Chernobyl) may be attributed to the difference in rates of carbon dynamics in forest ecosystems affected by such as annual temperature, forest type, and precipitation. As for the nuclear energy development and preparedness, radioactive cesium dynamics needs to be studied thoroughly from the view of climatic parameters.

○その他学術雑誌に掲載された論文

1 著者名：Takada M, Yamada T, Ibrahim S, Okuda T
論文題目：Spatial variation in soil respiration in relation to a logging road in an upper tropical hill forest in Peninsular Malaysia
雑誌名：Tropics（査読制度あり）
巻（号），頁，発行年：Vol. 24,（No. 1）1 頁-9 頁，2015

2 著者名：Takada M, Yamada T, Liang N, Ibrahim S, Okuda T
論文題目：Soil respiration change immediately after logging operations in an upper tropical hill forest, peninsular Malaysia
雑誌名：HIKOBIA（査読制度あり）
巻，頁，発行年：Vol.17，3 頁-9 頁，2015

3 著者名：Takada M, Yamada T, Kadir WR, Okuda T
論文題目：Spatial and temporal variations in soil respiration hot spots in a lowland tropical rain forest,

Peninsular Malaysia

雑誌名：Tropics（査読制度あり）

巻（号），頁，発行年：Vol. 25，（No. 2）77 頁-83 頁，2016

4 著者名：Takada M, Yamada T, Takahara T, Okuda T

論文題目：Spatial variation in the ^{137}Cs inventory in soils in a mixed deciduous forest in Fukushima, Japan

雑誌名：Journal of Environmental Radioactivity（査読制度あり）

巻，頁，発行年：Vol. 161，35 頁-41 頁，2016