Estimation of depth profile of radiocesium in soil based on characteristics of gamma-ray spectra obtained by airborne radiation monitoring

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A large amount of radiocesium (^{134}Cs and ^{137}Cs) were released into the atmosphere as a result of 2011 Fukushima Daiichi Nuclear Power Plant (FDNPP) accident. To estimate the impact of the accident to the environment, dose rate around FDNPP have been measured by Ministry of Education, Culture, Sports, Science and Technology of Japan. However six years passed since then, dose rate nearby FDNPP have been high in spite of decontamination work. The result means that it is necessary to propose of effective decontamination method as soon as possible. Information of depth profile of radiocesium in soil is important for effective decontamination method. In many cases, general measurement method of depth profile of radiocesium is troublesome due to collection and measurement of soil samples. In our previous studies, we have developed the radiation measurement techniques using unmanned aerial vehicle such as helicopter and unmanned multi rotor helicopter for rapid measurement of dose rate distribution over wide areas. In this paper, we attempt to establish the estimation method of depth profile of radiocesium in soil based on characteristics of gamma-ray spectra obtained by airborne radiation monitoring. This method expects to be useful for effective selection of area that is needed to decontaminate with high priority.
The extended farm land of National Livestock Breeding Center in Fukushima Prefecture was selected for verifying this method. This farm is located on approximately 100km south west of FDNPP in Nishigo-village. Dose rate in the farm was measured with three $LaBr_3$:Ce scintillators (3.8cmΦ×3.8cmH) using unmanned helicopter, R MAX G1 (YAMAHA Co., Ltd) at 6-10, Jun. 2016. The Spectra of $LaBr_3$:Ce scintillators showed the best resolution of the three systems, able to clearly distinguish the 605keV energy peaks of ^{134}Cs from the 662keV energy peak of ^{137}Cs. However, background of spectra of $LaBr_3$ were highly affected by self-contamination of the nuclides such as daughter nuclide of ^{227}Ac and ^{138}La in the detecter. Self-localization of the helicopter was controlled by flight programs based on differential GPS (Gloval position system). When used for monitoring, the flight altitude(altitude above grand level) of the helicopter was 20-30m and its velocity was approximately 8.0m/s. The distance from one measurement line to the other was 20-30m. The γ-ray spectra were measured per 1s continuously with position data. In addition, ratio of peak-compton (RPC) was defined by the ROI (region of interest) ratio of scattered area (50-450keV) and photo peak area (450-760keV) on γ-ray spectrum for evaluating of influence with the depth profile of radiocesium in soil. The deeper radiocesium exist in soils, the more γ-ray was scattered by soil particles compared with direct γ-ray. Thus, value of RPC changes by depth profile of the radiocesium in the soil.
Soils were sampled by liner soil sampler (0-30cm) and root auger (30-60cm) for measurement of depth profile of radiocesium. Quantitative analyses of radiocesium in the samples in the containers were conducted at the Institute for University of Tokyo using NaI(Tl) scintillators. In addition, the parameters (Depth: $D_{20\text{-}90}$) about depth profile of radiocesium were calculated for evaluating of influence with scattered γ-ray. For examples, D_{90} at that the soil contains 90% of the inventory of radiocesium. It is estimated that the higher value of the parameters, the deeper radiocesium exist in soils.

Result of aerial monitoring indicated that relationship between RPC and D_{90} has good correlation. It is suggested that feature on gamma-ray spectra of $LaBr_3$:Ce scintillators were affected by depth profile of radiocesium. Thus, it supported the hypothesis that the deeper radiocesium exist in soils, the more γ-ray was scattered by soil particles compared with direct γ-ray. Furthermore, result of quantitative analyses suggested that the depth profile of radiocesium in the farm were irregular. The irregular profiles of radiocesium in soil were result in the decontamination called reversal tillage. It was expected that the depth profile of radiocesium will show an exponential distribution with depth in many cases. However, the maximum concentration progressively moved from the surface layer to deeper ground layers when the decontamination was performed. In summary, it is hoped that this method will help in rapidly selecting of area that is needed decontamination with high priority by focusing on the feature on gamma-ray spectra.
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