PREDICTION OF AMBIENT DOSE EQUIVALENT RATES FOR THE NEXT 30 YEARS AFTER THE ACCIDENT

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To support recovery and rehabilitation in Fukushima, prediction models have been developed for ambient dose equivalent rate distribution within the 80 km-radius around the Fukushima Daiichi nuclear power plant. The prediction models that are based on bi-exponential functions characterized by ecological half-lives of radioactive caesium for land-use, enable Fukushima residents to obtain distribution maps of ambient dose equivalent rates for the next 30 years after the accident. Model parameters such as the ecological half-life of the short-term component and the fractional distribution of the short-term component were evaluated using ambient dose equivalent rates through car-borne surveys. The ecological half-lives for the short-term component and the fractional distributions of the short-term component in deciduous and evergreen forest areas were found to be different from those in other areas. In addition, it was found that distribution maps of ambient dose equivalent rates for the next 30 years after the accident, created by the prediction models would be useful for follow-up of the radiological situation since they provide information on the space variation of the ambient dose equivalent rates in inhabited areas.

Keywords: *ambient dose equivalent rate, ecological half-life, prediction model*

1. Introduction

It is essential to establish a radiation monitoring system allowing follow-up of the radiological situation in long-term contaminated areas[1)]. To assess current levels of contamination and its space and time distribution, radiation monitoring such as car-borne, airborne, measurements using survey meters has been performed after the Fukushima accident in 2011[2)]. At the Japan Atomic Energy Agency (JAEA), to assess the evolution of the long-term exposure situation after the Fukushima accident, prediction models have been developed for ambient dose equivalent rate distribution within 80 km-radius around the Fukushima Daiichi nuclear power plant[3) - 5)]. The prediction models were expressed using bi-exponential functions characterised by ecological half-lives -the time for half the radioactive caesium to disappear from the local environment due to natural removal phenomena and human activites- for land-use. In the present study, ecological half-lives of the short-term component and the fractional distributions of the short-term component were re-evaluated using ambient dose equivalent rates through car-borne surveys. In addition, distribution maps of ambient dose equivalent rates for the next 30 years after the accident were created using the prediction models in conjunction with the updated model parameters within the 80 km-radius around the Fukushima Daiichi nuclear power plant.

2. Materials and methods

(1) Radiation monitoring

Radiation measurements have been carrioud out using various mobile systems such as car-borne, airborne and simply walking on the ground after the Fukushima accident[2)]. In particular, ambient dose equivalent rates over wide areas in northeastern Japan were measured through a series of car-borne surveys. Eight car-borne surveys were carried out by JAEA in collaboration with many organizations until the middle of 2014: The first survey (June 4-13, 2011), the second survey (December 5-28, 2011), the third survey (March 13-30, 2012), the fourth survey (from August 20 to October 12, 2012), the fifth survey (from November 5 to December 10, 2012), the sixth survey (from June 11 to July 19, 2013), the seventh survey (from November 5 to December 12, 2013) and the eighth survey (from June 23 to August 8, 2014). The ambient dose equivalent rates obtained using the KURAMA II systems in moving car were converted to those outside the car[6]. Inside the evacuation order areas, seventeen car-borne surveys were also performed under the comprehensive monitoring plan[7].

(2) Prediction models and model parameters

According to previous studies on prediction models[8)-11)], the change with time in the ambient dose equivalent rate contribution from radioactive caesium on grounds can be expressed using the following equation:

$$Y(t) = Y(0)\left\{\alpha_{\text{short}}\exp\left(\frac{-\ln 2}{T_{\text{short}}}\cdot t\right) + (1-\alpha_{\text{short}})\exp\left(\frac{-\ln 2}{T_{\text{long}}}\cdot t\right)\right\} \cdot \frac{k\exp(-\lambda_{134}\cdot t)+\exp(-\lambda_{137}\cdot t)}{k+1} + Y_{\text{BG}} \quad (1)$$

where $Y(t)$ is the ambient dose equivalent rate at time t; $Y(0)$ is the ambient dose equivalent rate at time zero; α_{short} is the fractional distribution of the short-term component; T_{short} is the ecological half-life of the short-term component; T_{long} is the ecological half-life of the long-term component, 92y; λ_{134} and λ_{137} are the physical decay constants of ^{134}Cs and ^{137}Cs, respectively; k is the ambient dose equivalent rate ratio of ^{134}Cs to ^{137}Cs at time zero, 2.7(as of March 15, 2011); Y_{BG} is background radiation.

The model parameters such as the ecological half-lives of the short-term component and the fractional distributions of the short-term component were evaluated using the changes with time in ambient dose equivalent rates through the car-borne surveys. They were obtained from the best curve fit when plotting the ambient dose equivalent rates over time. To identify key parameters in the prediction models, the model parameters were categorized according to land-use/land-cover. The categories were made using the precise land-use and land-cover map by the advanced land observing satellite "Daichi" (ALOS)[12]. Eight categories were classified: water, urban, paddy, crop, grass, deciduous forest, evergreen forest and bare surface in ALOS.

(3) Distribution maps of ambient dose equivalent rates

Distribution maps of ambient dose equivalent rates within the 80 km-radius around the Fukushima Daiichi nuclear power plant were created using the prediction models. The maps were made for the next 5, 10 and 30 years after the accident. To predict ambient dose equivalent rates within living areas, corrections were made to the initial ambient dose equivalent rates obtained using the mobile systems. That is, the ambient dose equivalent rates obtained using the mobile systems were corrected using the relationship of ambient dose equivalent rates between those on roads and those around roads so as to be consistent with those within living areas[2]. On the maps relative to the categories in ALOS, the ambient dose equivalent rates including the background radiations were indicated using image colors in 100m mesh units.

3. Results and discussion

(1) Model parameters

Cumulative distribution functions of the ecological half-lives of the short-term component T_{short} were obtained for both inside and outside the evacuation order areas. For inside the evacuation order areas consisting of the difficult to return, the restricted residence and the cancel preparation areas, the cumulative distribution functions of T_{short} were plotted in Fig. 1 (a), based on whether or not the land-use area falls under deciduous and evergreen forest areas. On the other hand, the cumulative distribution functions of T_{short} for outside the evacuation order areas were plotted for each land-use in Fig. 1 (b). From the figures it can be stated that the model parameters in deciduous and evergreen forest areas are different from those in other areas. In a similar fashion, cumulative distribution functions of the fractional distributions of the short-term component α_{short} for inside and outside the evacuation order areas were plotted in Figs. 2 (a) and (b), respectively. In view of the current situation that there are differences of human actitities among the areas, the model parameters for areas where human activities occur might change.

(2) Distribution maps of ambient dose equivalent rates

Figures 3 (a)-(c) show the distribution maps of ambient dose equivalent rates for the next 5, 10 and 30 years after the accident. These maps provide the radiological situation based on the prediction models in conjunction with the 50th percentile model parameters. The figures indicate the ambient dose equivalent rates over 0.2 μSv/h. It was found from a comparison with the results that the ambient dose equivalent rates decrease certainly. The ambient dose equivalent rates in 2015 might decrease to one fourth of those values by 2041. It is concluded that the distribution maps of ambient dose equivalent rates for the next 30 years after the accident would be essential information to support the implementation of all protection strategies after the Fukushima accident.

4. Conclusions

Prediction models for ambient dose equivalent rate within 80 km-radius around the Fukushima Daiichi nuclear power plant have been developed using bi-exponential functions characterised by ecological half-lives. Model parameters were obtained for each land-use. The ecological half-lives of the short-term component and the fractional distributions of the short-term component would be changeable by human activities. In addition, distribution maps of ambient dose equivalent rates were created for the next 30 years after the accident. It was found that the distribution maps would be useful for follow-up of the radiological situation after the Fukushima accident. We plan in the near future to update the prediction models using bi-exponential functions.

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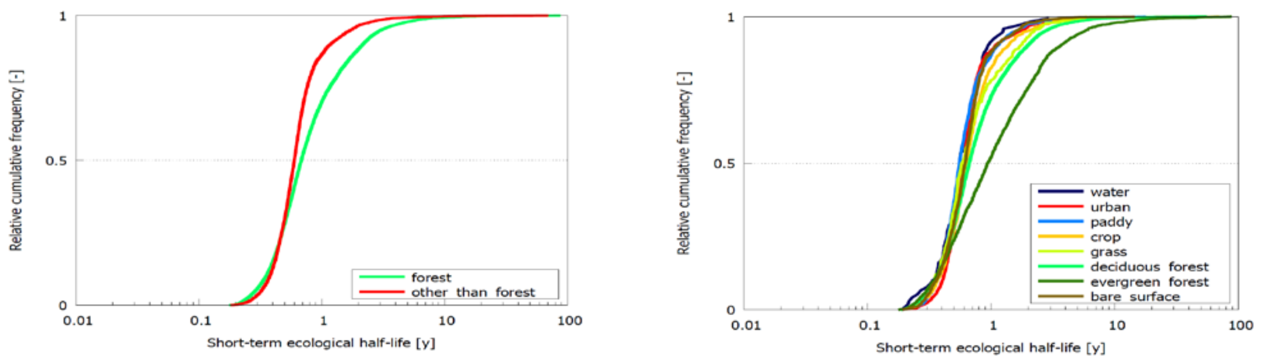
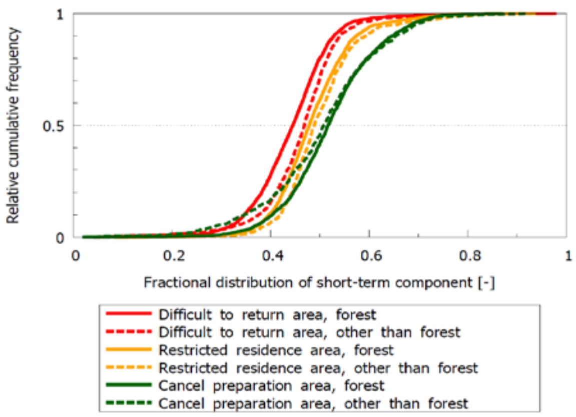


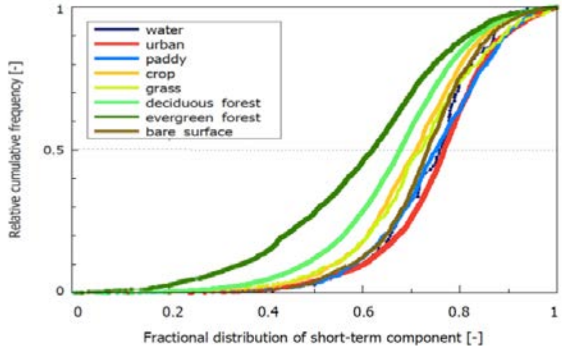
(a) inside the evacuation order areas.

(b) outside the evacuation order areas.

Figs. 1 Cumulative distribution functions of the ecological half-lives of the short-term component T_{short}.

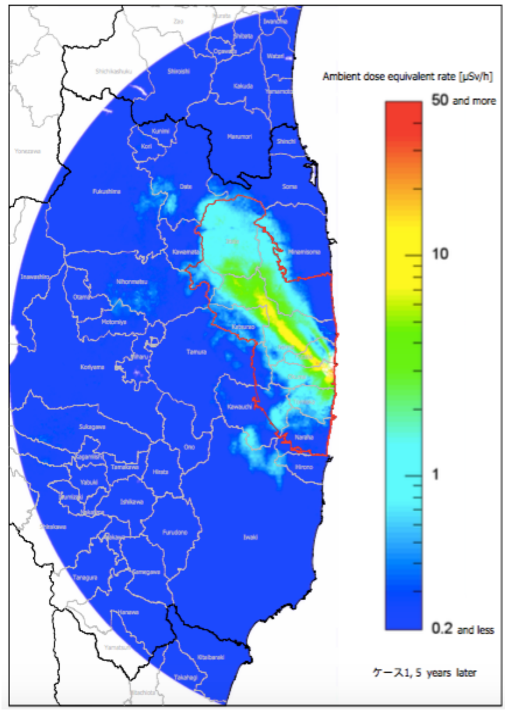


(a) inside the evacuation order areas.

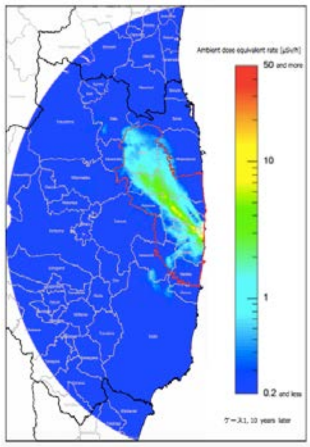


(b) outside the evacuation order areas

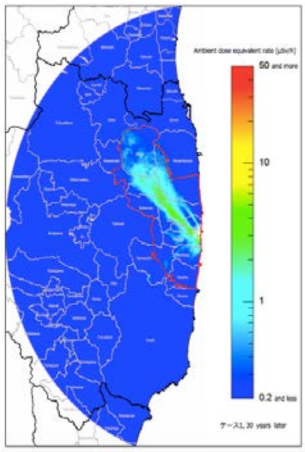
Figs. 2 Cumulative distribution functions of the fractional distributions of the short-term component α_{short}.
"Difficult to return area", "Restricted residence area" and "Cancel preparation area" mean "Areas where it is expected that the residents have difficulties in returning for a long time", "Areas in which the residents are not permitted to live", "Areas to which evacuation orders are ready to be lifted", respectively.



(a) 5 years later



(b) 10 years later



(c) 30 years later

Figs. 3 Distribution maps of ambient dose equivalent rates after the accident.
Evaluated using the 50th percentile model parameters.

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