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Note

Terrestrial Half-life of Cesium on the Surface of the Ground

Michikuni Shimo

Fujita Health University, 1-98, Dengakugakubo, Kutsukake-cho, Toyoake-shi, Aichi, Japan

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The radioactivity released from the Fukushima Daiichi Nuclear Power Plant (F1NPP) into the environment after an accident clearly decreased. The decrease in radiocesium on the surface of the ground directly results in a decrease in the ambient dose rate. The term "terrestrial half-life" was used to describe the decrease of a radionuclide only from the surface of the ground due to weathering. Terrestrial half-lives of cesium on artificial pavement was determined to be 1.1—2.6 y using official monitoring dose-rate data measured in several areas of the Fukushima region.

Key words: Terrestrial half-life, cesium, Fukushima Daiichi Nuclear Power Plant accident, Ground surface, monitoring data

1. Introduction

The radioactivity released from the Fukushima Daiichi Nuclear Power Plant (F1NPP) into the environment after an accident clearly decreased, as did the ambient dose rate. The released nuclei include strontium (^{89}Sr, ^{90}Sr), tellurium (^{129m}Te, ^{127m}Te, ^{132}Te), iodine (^{131}I, ^{132}I), xenon (^{133}Xe), cesium (^{134}Cs, ^{137}Cs), barium (^{140}Ba), plutonium (^{238}Pu, ^{239}Pu, ^{240} Pu), etc.[1] In these nuclei, the most notable nuclides that caused ambient doses were ^{134}Cs and ^{137}Cs because of their high levels and long half-life.

The decrease in radiocesium on the surface of the ground directly results in a decrease in the ambient dose rate. Therefore, our concern is how radiocesium decreases in living spaces. In recent years, the behaviour of radionuclide in terrestrial and aquatic ecosystems was quantified by means of the ecological half-life[2]. In this paper, the term "terrestrial half-life" was used to describe the decrease of a radionuclide only from the surface of the ground due to weathering. The terrestrial half-life of radiocesium was evaluated using the official monitoring data of dose rates published from the government and/or the local authority.

Michikuni Shimo: Fujita Health University,
1-98, Dengakugakubo, Kutsukake-cho, Toyoake-shi, Aichi Pref., Japan
E-mail: shmmchkn@sf.commufa.jp

2. Materials and Methods

2.1. The definition of terrestrial half-life

Nuclide disintegration is described using the physical decay constant, while the decrease of the element in the body by metabolism is described by the biological decay constant. Similarly, material on the surface of the ground is also described by the decay rate resulting from the weathering effect, and this is referred to as the terrestrial decay constant. The half-life is defined as the inverse of the decay constant times 0.693. Thus, the terrestrial half-life is derived from the terrestrial decay constant. These are summarised in Table 1.

2.2. Method of analysis

The ambient dose rate D_a (μSv/h) resulted from a radionuclide released by the F1NPP accident can be

Table 1. Various decay constants and half-lives

Phenomena	Decay rate	Half-life	Remarks
Disintegration	Decay const.	Physical half-life	Nuclide
Metabolism	Elimination const.	Biological half-life	Nuclide, species, organ, age
Weathering	Weathering const.	Terrestrial half-life	Nuclide, precipitation, etc.

described by the following formula:

$$D_a = K\,A\,exp(-\Lambda t) \qquad (1)$$

where K is the conversion factor ((μSv/h)/(Bq/m^2)) of the dose rate from the sediment amount, A is sediment amount of the radioactive nuclide per unit area (Bq/m^2), Λ is the decay rate (y^{-1}), and t is lapse time (y) after sediment. Λ is described by the following formula:

$$\Lambda = \lambda + \nu \qquad (2)$$

where λ is the decay constant of the radionuclide (y^{-1}) and ν is the decay rate (y^{-1}) that results from the weathering effect.

In fact, the ambient dose rate D (μSv/h) in Fukushima area is mainly determined by the sum of the dose rates from ^{134}Cs, ^{137}Cs and natural background radiation:

$$D = D_a + D_{bg}$$
$$= D_{134} + D_{137} + D_{bg} \qquad (3)$$

where D_{134} is the dose rate from ^{134}Cs, D_{137} is the dose rate from ^{137}Cs, and D_{bg} is the background dose rate from natural radiation. In this study, we try to calculate the half-life of cesium from the dose rate due to Cs-137, and therefore equation (3) is changed to the following:

$$D_{137} = D - D_{134} - D_{bg} \qquad (4)$$

D and D_{bg} are obtained from monitoring data, and D_{134} is determined under the assumption that there was an equal concentration of ^{134}Cs and ^{137}Cs when the accident initially occurred.

Thus, we can estimate ν using formulas (1) and (2), when we get the variation with time for dose rate from ^{137}Cs.

3. Results and Discussion

3.1. The ambient dose rate in several areas of Fukushima Prefecture

The dose rates were obtained by government and local authorities in seven areas: Fukushima City, Koriyama City, Shirakawa City, Aizuwakamatsu City, Minamiaizu Town, Minamisoma City, and Iwaki City in Fukushima Prefecture[3]. In general, the ambient dose rates were higher in areas closer to F1NPP than in areas further away. Dose rates, however, were higher in Fukushima City and Koriyama City, both of which are 80 km from F1NPP, than in Minamisoma City, which is 30 km from F1NPP. It is believed that deposition occurred by rain when the radioactive plume came to Fukushima and Koriyama areas. At two months after the F1NPP accident, the date from each monitoring showed levels that were

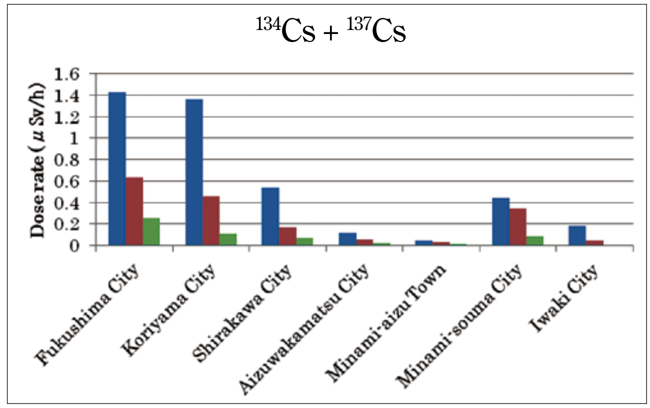

Fig. 1. Ambient dose rates due to ^{134}Cs and ^{137}Cs at the seven areas in Fukushima Prefecture. Blue: May, 2011, red: August, 2012 and green: December, 2013.

over 10 times higher than the natural levels before the accident. The background dose rates (μSv/h) due to natural radiation in seven areas were as follows: 0.04 at Fukushima City, 0.05 at Koriyama City, 0.045 at Shirakawa City, 0.045 at Aizuwakamatsu City, 0.03 at Minamiaizu Town, 0.05 at Minamisoma City and 0.055 at Iwaki City[3], and furthermore, the mean natural background dose rate is 0.038 μSv/h (0.33 mSv/y) in Japan[4].The dose rate with each natural background dose rate subtracted for each area is shown in Figure 1. It is clear that the dose rate at over two years after the F1NPP accident decreased markedly in comparison to just after the accident, with the exception of the dose rate in Minamiaizu Town.

3.2. The half-life of cesium

The variations of the dose rates with time at the seven areas are shown in Figure 2. The plotted values are the mean dose rates due to ^{137}Cs each month, which were obtained from subtracting the background dose rate and from the decreasing contribution of ^{134}Cs.

Decreases in the dose rates mainly resulted from weathering effects, i.e. transportation of nuclides in water flow after precipitation and water penetration to undersurface soil. However, dose rates have not decreased consistently with time because the dose rate is related to the influence of human actions, such as decontamination and automobile traffic. In two locations in Aizuwakamatsu City[5] ((h) and (i) in Figure 2), an obvious decrease of the dose rate due to shielding by snow appeared in data, which were obtained from December to March, and these

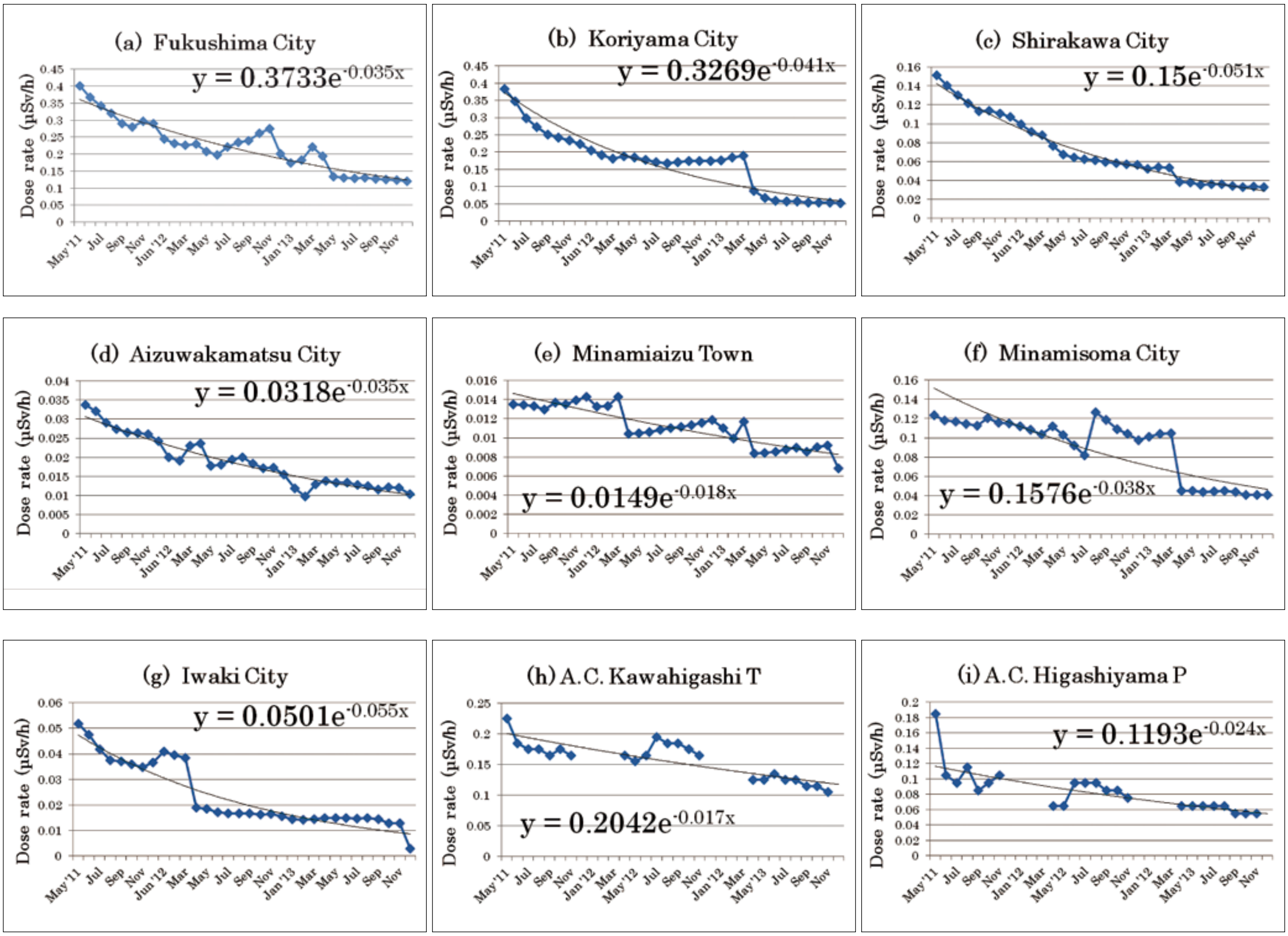

Fig. 2. Time variations of corrected dose rates from May 2011 to December 2013 in the seven areas. Dotted point is the mean value of each month.

Table 2. The terrestrial half-life of cesium

District	Ground surface	Decay rate Λ (mon^{-1})	Decay rate ν (mon^{-1})	Half-life (y)
Fukushima City	Asphalt	0.035	0.033	1.8
Koriyama City	Asphalt	0.041	0.039	1.5
Shirakawa City	Asphalt	0.051	0.049	1.2
Aizuwakamatsu City	Asphalt	0.035	0.033	1.8
Minamiaizu Town	Asphalt	0.018	0.016	3.6
Minamisoma City	Asphalt	0.038	0.036	1.6
Iwaki City	Asphalt	0.055	0.053	1.1
A.C. Kawahigashi T.	Soil/grass	0.017	0.015	3.9
A.C. Higashiyama P.	Concrete	0.024	0.022	2.6

Remarks: A.C. Kawahigashi T.: Kawahigashi Takatsuka in Aizuwakamatsu City,
A.C. Higashiyama P.: Higashiyama Parking in Aizuwakamatsu City.

were excluded from this analysis.

The variations with time for dose rate from ^{137}Cs are shown with a suitable exponential function in Figure 2. The decay rate and the half-life that were calculated from the decay rate are shown in Table 2. Surfaces of the ground around the monitoring areas, with the exception of A.C.Higashiyama P., were covered with asphalt or concrete. The decay rate Λ is the sum of the physical decay constant of ^{137}Cs and the weathering constant. The decay rate ν is a value subtracted physical decay constant of ^{137}Cs from decay rate Λ, and it represents the weathering constant. The half-life shown in column five of Table 2, therefore, is the terrestrial half-life of cesium that was calculated from decay rate B.

The terrestrial half-life of cesium was determined to be 1.1—3.9 y, with a mean value of 2.1 y. Currently, the dose rate in Minamiaizu Town is very low (0.015 μSv/h) and the dose rate level is less than the natural dose rate level (0.03 μSv/h). Therefore, the error of the ^{137}Cs dose rate is very large. The data for A.C.Kawahigashi T. was obtained from ground soil partially covered by grass. When values for Minamiaizu Town and A.C.Kawahigashi T. are omitted, the half-lives are 1.1—2.6 y, and the mean value becomes 1.7 y. The authors, therefore, think that 1.1—2.6 y (mean: 1.7 y) is a conceivable value for the terrestrial half-life of cesium on artificial pavement.

The half-lives of 1.1—2.6 y are close to 0.8-2.4 y that were taken from monitoring data during May, 2011-November, 2012, which were already published in document of Radiation Earth Science Laboratory[6]. This means that the tendency of the nuclide to decrease on a paved area is shown by the exponential function for at least several years.

The decay rates due to weathering for strontium, which obtained for red clay and white clay in Futaba Town and Okuma Town in Fukushima region, were reported as 0.20—0.30 y^{-1} [7], making the half-lives between 2.3—3.5 y. When considering the difference in nuclides, ground surface condition, and human activity, the difference between the half-life obtained by author *et al.* and the half-life of strontium is not very large.

It is inevitable that the terrestrial half-life value is imprecise, because various factors are related to nuclide decease and the variation in dose rate is huge. However, the authors think that the terrestrial half-life is practically useful for estimating the decrease in radioactivity in contaminated areas.

4. Conclusion

The terrestrial half-life of nuclides on the surface of the ground was determined taking weathering effects into consideration. Terrestrial half-lives of cesium on artificial pavement was determined to be 1.1—2.6 y using official monitoring dose-rate data measured in several areas of the Fukushima region.

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