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Terrestrial Gamma Radiation Dose Rate in Japan Estimated before the 2011 Great East Japan Earthquake

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The natural radiation level is a good indicator to assess the influence from artificial radiations resulted from some nuclear accident. In this paper, we show the representative maps for the distribution of terrestrial gamma radiation dose rate in Japan before the grate earthquake (M 9.0) on 11 March 2011 that attacked mainly northeastern part of Japan and triggered powerful tsunami and serious nuclear accident. The sources of terrestrial gamma radiations are natural radioactive elements that have always existed in the earth. Based on the nationwide data, the average of the dose rate in Japan is estimated to be 50 nGy/h. Also the averages in the northeast and the southwest of Japan are estimated to be 56 and 40 nGy/h, respectively. The geographical variation of the dose rate can be explained in relation to the variation of rocks and soils.

Key words: natural radiation, terrestrial gamma radiation, dose rate, nationwide, Tohoku district, Japan

1. Introduction

The natural radiation level is a good indicator to assess the influence from artificial radiations resulted from some nuclear accident. The importance of the information for natural radiations has been rose recently in Japan, because, unfortunately, Japan was seriously damaged by a nuclear crisis. The progress of the crisis is summarized as follows.

An unprecedented earthquake of magnitude 9.0 occurred off the Pacific coast of Tohoku district, northeastern part of Japan, on 11 March 2011 (the 2011 Great East Japan Earthquake). The earthquake generated powerful tsunami which attacked over 1,300 km along the Pacific coast of Japan. The maximum run-up height of the tsunami measured about 40 m, and the massive seawater travelled up to 10 km inland at the maximum, with the result that many towns and infrastructures were suffered catastrophic damages.

The earthquake and subsequent tsunami also hit the Fukushima Dai-ichi Nuclear Power Station (the Fukushima NPS), which constructed and run by the Tokyo Electric Power Company, located in Okuma and Futaba towns of Fukushima prefecture (Fig. 1). The tsunami attack caused infinite damage for the reactor cooling systems of the Fukushima NPS which was a root of the melt-down/-through accident at reactors, and the damage brought leaks of huge amount of radioactive elements into the environment. The leaks triggered an evacuation of 30 km radius surrounding the Fukushima NPS. This multiple disaster due to earthquake, tsunami, and nuclear accident is the first event in our history, and is the most difficult crisis for Japan after the end of World War II.

As the result of the Fukushima NPS accident, the radiation

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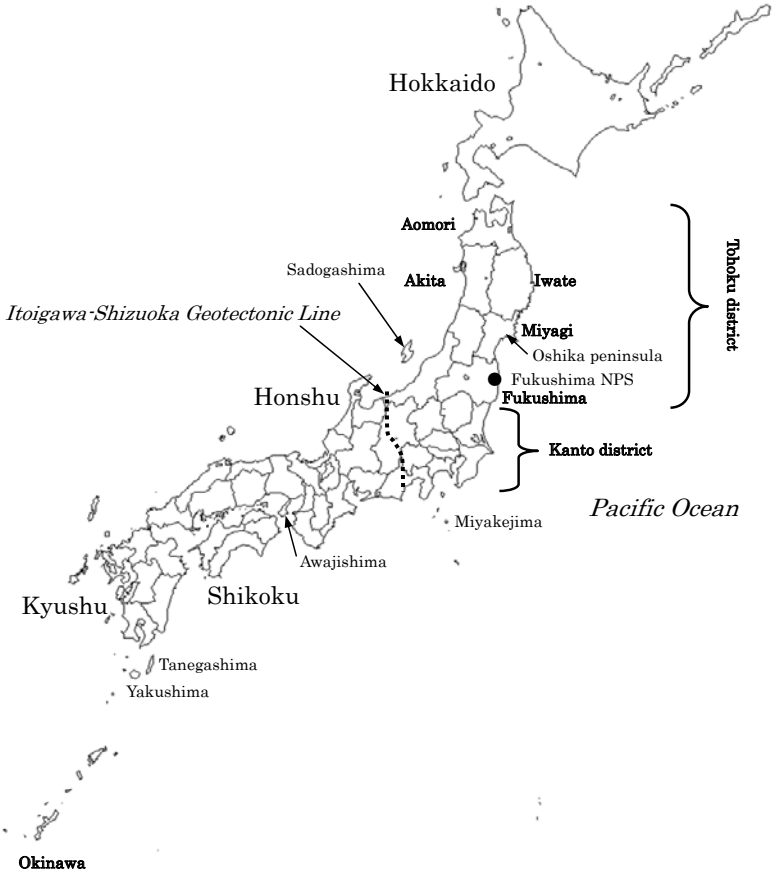

Fig. 1. Index map of locality information mentioned in this study.

environment has been drastically changed in Japan. In addition, the ejection of artificial radioactive materials from the Fukushima NPS has an impact on the environment all over the world to be exact. To make sure the influence of the enhanced radiation level due to the accident, we have to realize the detailed distribution of the natural radiation level especially in the area suffered radioactive contamination.

From the above perspectives, in this paper, the outlines of the geographical distribution of the dose rate are shown in the following chapters and figures based on the results of *in situ* measurements conducted before the Fukushima NPS accident.

2. Source of gamma radiation

The sources of terrestrial gamma radiations are natural radioactive elements, mainly ^{238}U series, ^{232}Th series, and ^{40}K, which have always existed in the whole earth since its birth. That is to say, all the life, including human being, and all materials in the earth's environment are continually exposed to the gamma radiations. The terrestrial gamma radiation dose rate builds up and down depending on the contents of the natural radioactive elements in soils and rocks. In Japan, granitic rock zone enhances the dose rate, because the concentrations of natural radioactive elements of the granitic rocks and its weathered soils are generally higher than those of the others[1, 2].

3. Nationwide data

The first nationwide survey for the terrestrial gamma radiation has been conducted in 1967[3]. In this study, however, the survey tract was limited to coastal areas, and the radiation level was estimated in a roundabout way through spectrometric analyses of soil samples collected along the main roadways. In brief, this study was insufficient to grasp the details of the geographical variation for the dose rate in whole Japan.

From 1967 to 1977, a more extensive nationwide survey for the natural radiation level has been conducted by National Institute of Radiological Sciences (NIRS) by an integrated methodology with an ionization chamber system and NaI(Tl) scintillation detectors based on *in situ* measurement[4]. During the period of the survey, the measurements have been done before the first operation of nuclear power stations in the neighborhood of the measurement sites. In addition, the data were collected only during daytime in dry condition of soil ground, and the detectors were kept

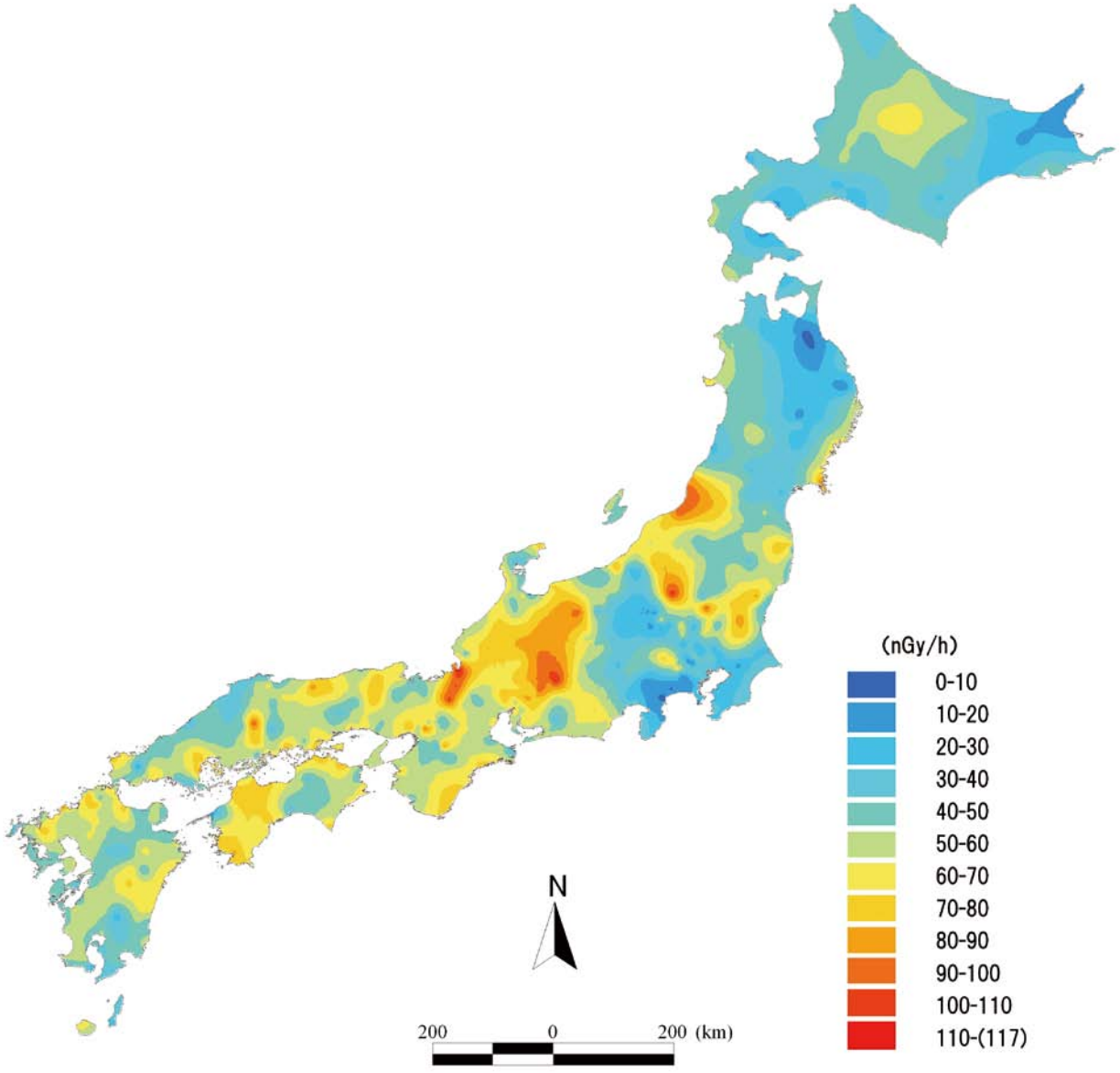

Fig. 2. Distribution of the terrestrial gamma radiation dose rate in Japan newly drawn in this study using a nationwide data set[4].

at 1 m in height from the soil ground. The complementary surveys were also carried out in small islands from 1980 to 1990. The measurements have been conducted in a total of about 800 local communities by 1990[1].

By the way, to know the terrestrial gamma radiation dose rate based on the results of the NIRS survey, it should be noted that the all data uniformly include the dose rate of 30 nGy/h (3.4 μR/h) due to the ionizing component of cosmic rays generated in the atmosphere[1, 4]. The terrestrial gamma radiation dose rates, therefore, are derived to take 30 nGy/h off each measured value. As the result, the average, maximum, and minimum of the terrestrial gamma radiation dose rates were estimated to be 50, 147, and 22 nGy/h, respectively[1, 5, 6].

Figure 2, which was newly drawn with a GIS software SuperMap based on the NIRS data[4], shows the distribution of terrestrial gamma radiation dose rate in main islands, *i.e.* Hokkaido, Honshu, Shikoku, and Kyusyu, and in some smale islands, *i.e.* Sadogashima, Awajishima, Yakushima, and Tanegashima (Fig. 1). Relatively high dose rate areas (> 50 nGy/h) occur mainly in the southwest Japan due probably to the distribution of granitic rocks and these sedimentary soils[1, 2]. On the other hand, low dose rate areas (< 50 nGy/h) distribute mainly in the northeast Japan due to the distribution of andesite, basalt, and these sedimentary soils. Especially distribution of the volcanic ash andosol (Kuroboku soil) overlaps well with the low dose areas[1].

An obvious boundary for the dose rate can be recognized in the middle part of Honshu, which separates the low dose area from high dose area. This boundary is almost identical

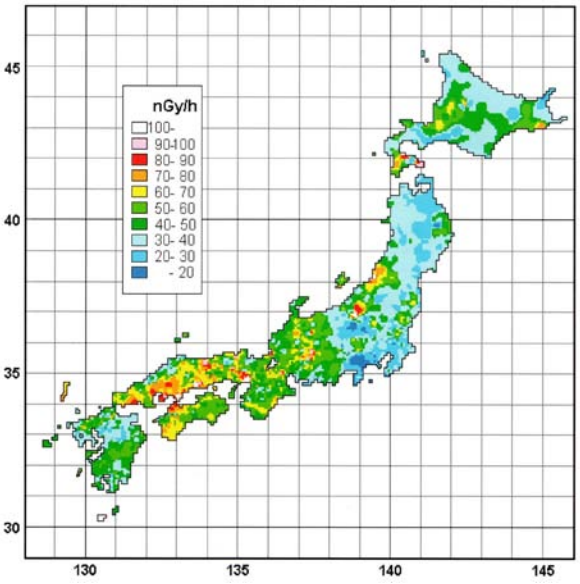

Fig. 3. Distribution of the terrestrial gamma radiation dose rate in Japan based on a nationwide database[7].

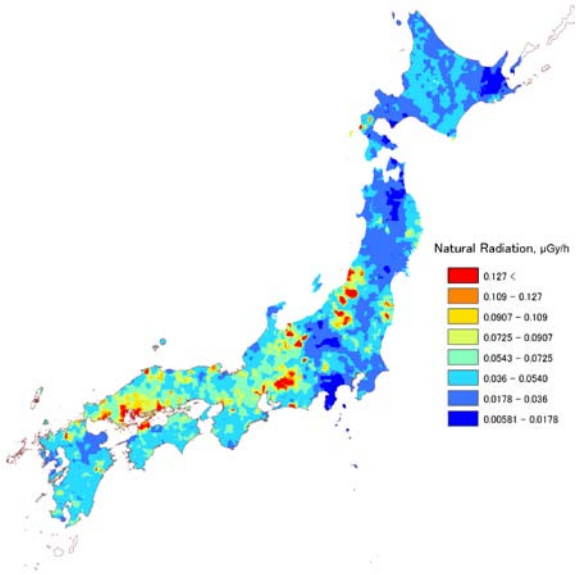

Fig. 4. Distribution of the terrestrial gamma radiation dose rate in Japan based on the analytical data for the concentrations of natural radioactive elements in the river sediment samples[10, 11].

with Itoigawa-Shizuoka Geotectonic Line (Fig.1). When a border for the dose rate is drawn along this geotectonic line, averages of the northeast and the southwest of Japan are estimated to be 56 and 40 nGy/h, respectively. That is to say, for the distribution of terrestrial gamma radiation dose rate in Japan, the high dose area lies to the west, and the low dose area to the east by and large.

Minato (2006)[7] created a database of over 4,300 entries for the terrestrial gamma radiation dose rates obtained by *in situ* measurements in Japan, and drew up a nationwide contour map of the dose rate based on the database (Fig. 3). The database was made up of the newly measurement data by Minato himself and the reported data obtained by many area studies. Although the database does not contain the NIRS data, Figure 3 takes on almost same feature as Figure 2 based on only the NIRS data. Listed papers and reports for the dose rate in Minato (2006)[7] are very useful to search the data that you need.

The Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, has conducted a geochemical mapping project. About 3,000 river sediments in Japan were collected from 1999 to 2003, and were subsequently analyzed for 53 elements[8, 9]. Based on the analytical data for the concentrations of U, Th, and K, a map of the terrestrial gamma radiation dose rate in Japan (Fig. 4) was released on the Internet[10, 11]. The distribution of the dose rate shown in Figure 4 is substantially similar to that in Figures 2 and 3. This similarity strongly indicates that the geographical variation of the dose rate can be explained conclusively in relation to the geology and mineral deposits.

4. Regional data

Besides the nationwide surveys, the terrestrial gamma radiation dose rate has been measured in many parts of Japan. In this chapter, we focus on the representative dose rates along the Pacific coast of the northeast Japan, *i.e.* Hokkaido, Tohoku, and Kanto districts (Fig. 1), before the Fukushima NPS accident. By the way, incidentally, it is considered that the serious radioactive contamination area due to the accident is limited close to the Fukushima NPS[12].

4.1. Hokkaido

In Hokkaido, the northernmost area of Japan, several surveys for the dose rates have been conducted. By a car-borne survey for all communities along main roads and outdoor spot measurements at 100 places, the dose rates were found to be from 14.9 to 116.5 nGy/h[13]. Also the average ± standard deviation were calculated to be 42.1±16.2 nGy/h. As for as the southern part, the average dose rate was estimated to be 25.5 nGy/h[14]. Wajima et al (1997)[15] pointed out that the maximum value of the dose rate reaches to around 300 nGy/h at Motta-kaigan radium hot spa in the southeastern part.

4.2. Tohoku district

After the Fukushima NPS accident, the background radiation data are essential to assess the effect of artificial radiations especially in Tohoku district, the northern part of Honshu. Fortunately, by the prefectural governments and these rerated institutes, several intensive survey for the terrestrial gamma radiation dose rates have been performed in the district before the accident.

For Aomori prefecture, the northernmost of Tohoku district, the average of the dose rate was estimated to be 28 nGy/h[16]. The regional average is higher in the western part (Tsugaru area, 31 nGy/h) than in the eastern part (Nanbu area, 25 nGy/h).

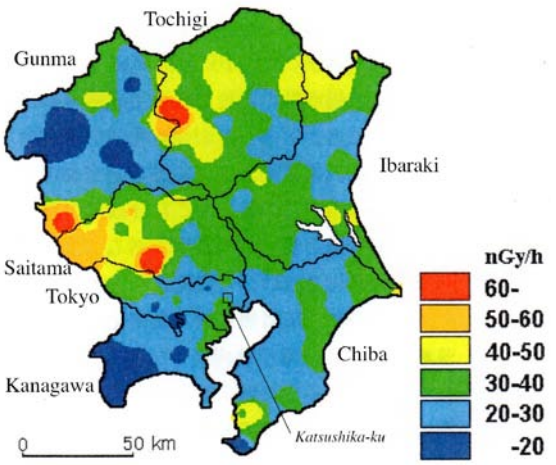

Fig. 5. Distribution of the terrestrial gamma radiation dose rate in Kanto district modified from Sugino et al (2007)[20].

For Miyagi prefecture, the average, maximum, and minimum of the dose rates were estimated to be 21.2, 35.6, and 14.9 nGy/h, respectively[17]. In Oshika Peninsula and its neighboring area (Fig. 1) where consist of the Paleozoic-Mesozoic sedimentary rocks, the dose rate is relatively higher than in the other parts of the prefecture.

An outline of the dose rate in Fukushima prefecture was examined by the Environmental Radioactivity Monitoring Center of Fukushima (1999)[18]. Based on this survey, the average ± standard deviation, maximum, and minimum of the dose rates were estimated to be 34.4±9.5, 64, and 19 nGy/h, respectively. The terrestrial gamma radiation dose rates in Namie, Futaba, Okuma, and Tomioka towns neighboring the Fukushima NPS were estimated to be 37, 34, 29, and 28 nGy/h, respectively.

Regrettably, we could not discover the data available for revealing an outline of the dose rate in Iwate prefecture. By the way, the dose rate in Morioka city of Iwate prefecture was estimated to be about 60 nGy/h in 2008[19]. And as an aside, the maximum dose rate in the Tohoku district was founded to be approximately 500 nGy/h at a spot in Tamagawa radium hot spa area in Akita prefecture measured in 1995 (Furukawa and Tokonami, unpublished data).

4.3. Kanto district

For the Kanto district (Fig. 1), which consist of Tokyo Metropolis and Ibaraki, Tochigi, Gunma, Saitama, Chiba and Kanagawa prefectures, in situ measurement of the dose rate has been carried out at 160 points, and a contour map of the dose rate was drawn up (Fig. 5)[20]. Based on this survey, the average and standard deviation of the dose rate in Kanto district were estimated to be 31.1±10.6 nGy/h. The maximum and minimum dose rates were found to be 75.5 nGy/h in Saitama prefecture and 11.1 nGy/h in Kanagawa prefecture, respectively. The prefectural averages were also estimated to be 29.1 nGy/h for Tokyo, 32.5 nGy/h for Ibaraki, 36.6 nGy/h for Tochigi, 28.5 nGy/h for Gunma, 41.1 nGy/h for Saitama, 29.6 nGy/h for Chiba, and 22.4 nGy/h for Kanagawa.

Hosoda et al. (2011)[21] conducted a full measurement of the dose rate over Katsushika-ku (Fig. 5) of Tokyo Metropolis in 2005. Based on the results, the average ± standard deviation, maximum, and minimum of the dose rates ware estimated to be 39 ±7, 91, and 17 nGy/h, respectively. In Miyakejima (Fig. 1), one of volcanic island belongs Tokyo Metropolis, also the dose rates were measured and the average was estimated to be 18.6 nGy/h[22].

5. Summary and implications

We took a broad view of the aspect for the terrestrial gamma radiation dose rate in Japan before the serious Fukushima NPS accident which has been occurred corresponding with the 2011 Great East Japan Earthquake with strong tsunami.

The nationwide average of the dose rate was estimated to be 50 nGy/h. The low dose rates (< 50 nGy/h) are widely founded in Tohoku and Kanto districts. The dose rates in the area close to the Fukushima NPS were estimated to be almost 35 nGy/h or less.

In view of the above low dose rates by nature in Japan, to completely remove the public anxieties for the public health due to the nuclear accident, it is needed to take strenuous long-term operations to retain the permissible radiation level. The data for the terrestrial gamma radiation dose rates should be effectively used more to perform optimizations of the radiation environment in Japan.

For some areas in Tohoku district, we could not discover the data available for revealing an outline of the terrestrial gamma radiation dose rates, for example, Iwate prefecture and Iitate village of Fukushima prefecture. To estimate the impact on public health due to the accident exactly, we would like to stress the necessity for the analysis on the concentrations of natural radioactive elements contained the soils in the insufficient areas for the data to know the dose rates by nature. In any case, our ultimate goal is to contribute toward overcoming difficulties resulted from the crisis after 11 March 2011.

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