Absorbed Dose Rate in Air at the NIFS Site before the Deuterium Plasma Experiment in LHD

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(Received 20 April 2017 / Accepted 22 May 2017)

The absorbed dose rate in air was measured at the National Institute for Fusion Science (NIFS) site before the deuterium plasma experiment in the Large Helical Device (LHD). A pocket survey meter was used for the measurement of 1 cm dose equivalent rates in units of μSv h^{-1} and these results were converted to absorbed dose rates in air (units: nGy h^{-1}) using a conversion factor. The arithmetic mean of the absorbed dose rates in air based on 257 measurement points at NIFS site was 45 nGy h^{-1}. The result of this study suggests that the building material and/or paving stone enhance the dose rates in air at the NIFS site.

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Keywords: absorbed dose rate, environmental radiation, background measurement, deuterium plasma experiment, NIFS site

DOI: 10.1585/pfr.12.1305029

The Large Helical Device (LHD), which was constructed in 1998 at the National Institute for Fusion Science (NIFS) [1], is one of the largest heliotron-type plasma experiment device with superconducting coils. A new project—The deuterium plasma experiment (DD experiment) to obtain higher performance plasma—is scheduled to begin in 2017 and last for nine years. In the DD experiments, tritium and neutron are generated as a result of a nuclear fusion reaction in the deuterium plasma.

$$\mathrm{D} + \mathrm{D} \rightarrow \mathrm{T} + \mathrm{p},$$

$$\mathrm{D} + \mathrm{D} \rightarrow {}^{3}\mathrm{He} + \mathrm{n},$$

where, D is deuterium, T is tritium, p is photon, ^{3}He is helium-3, and n is neutron. The maximum annual amount of tritium production is estimated to be approximately 37 GBq in the first 6 years, and 55.5 GBq in the remaining 3 years. More than 95% of the produced tritium is planned to be removed using a tritium recovery system [2, 3]. The DD experiments on the LHD will be conducted in consideration of the DD neutron yield [4, 5]. To evaluate the experiment's impact on the environment precisely, it is important to understand the background radiation levels in the environment surrounding the NIFS site. We have monitored about tritium concentration in the natural water collected at Toki, Tajimi, and Mizunami cities since 1982 before the construction of the NIFS facilities. We have also monitored tritium concentration in tap water at the Institute of Plasma Physics, Nagoya University, located approximately 30 km southwest of the NIFS site. Part of the data on natural water has already been reported [6]. In addition, recent tritium concentrations in air and plant samples have been reported [7, 8]. However, there are no detailed reports on the distribution of environmental radiation at the NIFS site. In this study, we report on the absorbed dose rate in air at the NIFS site to understand the background environmental radiation level in this area.

Location of the NIFS site is shown in Fig. 1. Measurements of 1 cm dose equivalent rate (μSv h^{-1}) were conducted in the period from July 29, 2016 to October 18, 2016 using the pocket survey meter (PDR-101, Hitachi-Aloka Co., Japan). The γ-ray pulse height distributions were measured using a 3-inch × 3-inch NaI(Tl) scintillation spectrometer (EMF-211, EMF-Japan, Japan). These measurements were conducted at a surface 1 m height above the ground (pavement). Sampling time of EMF-211 was set at 900 s. The obtained γ-ray pulse height distributions were unfolded by a 22×22 response matrix for the evaluation of the absorbed dose rates in air [9]. In this calculation, the natural radionuclides were assumed to be an infinite plane source on the ground. A conversion factor from the 1 cm dose equivalent rate (μSv h^{-1}) to absorbed dose rate in air (nGy h^{-1}) was obtained from simultaneous measurements (PDR-101 and EMF-211) at 12 point. Then the measurement of 1 cm dose equivalent rate was conducted at 257 point using PDR-101. Thus, the readings of the pocket survey meter (μSv h^{-1}) were converted to absorbed dose rates in air (nGy h^{-1}) using the conversion factor [10]. Longitude and latitude were also recorded at each measurement locations using a handheld Global Positioning System (GPS) device (eTrex 10J, Garmin Ltd., Switzerland). Locality information was observed at each measurement points. The weather condition was sunny throughout the measurement period. An isopleth map of the absorbed dose rate in air was drawn using the GMT 5.2.1 (Generic Mapping Tools, open source supplied by

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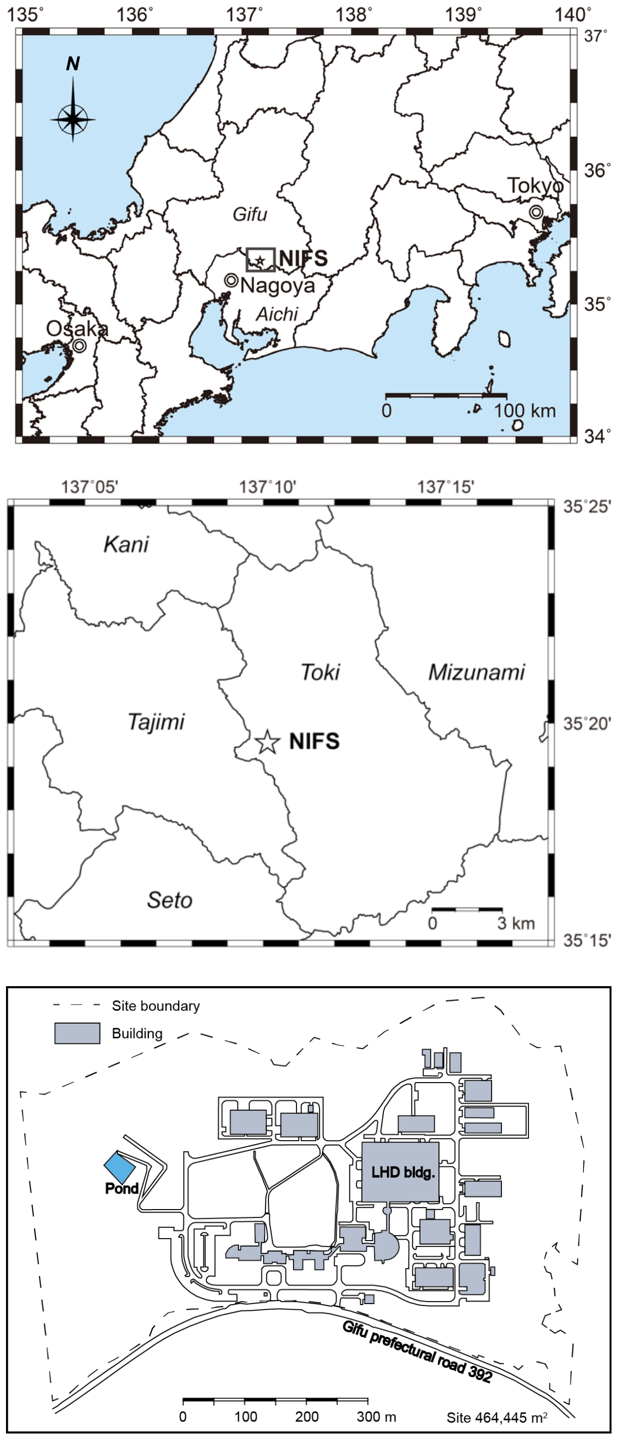

Fig. 1 Location of the NIFS site.

University of Hawaii).

The relationship between the absorbed dose rates in air obtained by a NaI(Tl) scintillation spectrometer (EMF-211) and the 1 cm dose equivalent rates measured by a pocket survey meter (PDR-101) is shown in Fig. 2. The conversion factor from the 1 cm dose equivalent rates (μSv h^{-1}) to the absorbed dose rates in air (nGy h^{-1}) was evaluated as 711.9 (Adjusted $R^2 = 0.991$, $n = 12$). The absorbed dose rates in air based on the 257 measurement points at the NIFS site were 16 - 74 (45 ± 13) nGy h^{-1}. The dose rates at Toki city, from which the contribution of cosmic rays were deducted, were reported to be about 83 nSv h^{-1} (1 point, 5 data) [11] and 56 nGy h^{-1} (21 data) [12]. The absorbed dose rate at the NIFS site was relatively lower than that mentioned above. It is suggested that this is because of the difference in geologic conditions at the measurement points. The histogram of the absorbed dose rates in air at the NIFS site is shown in Fig. 3. The histogram shows two peaks around 30 and 55 nGy h^{-1}. The isopleth map of the absorbed dose rates in air at the NIFS site is shown in Fig. 4. The isopleth map was drawn to roughly understand the background environmental radiation distribution, and the area of the buildings that was not measured was blacked out. The absorbed dose rates

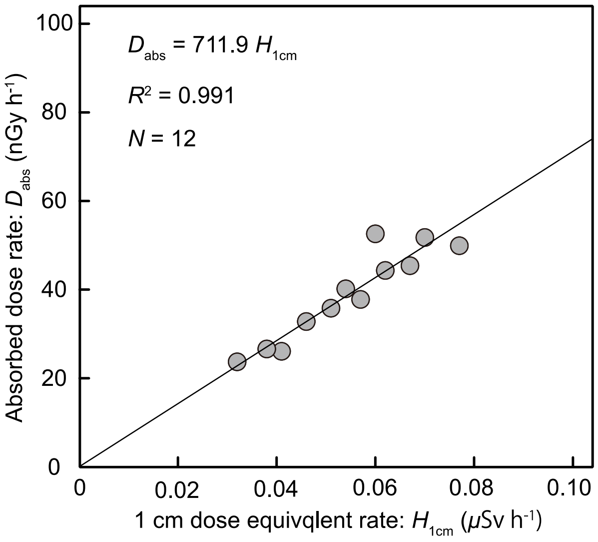

Fig. 2 The relationship between absorbed dose rate in air obtained by calibrated meter (EMF-211) and 1 cm dose equivalent rate (PDR-101).

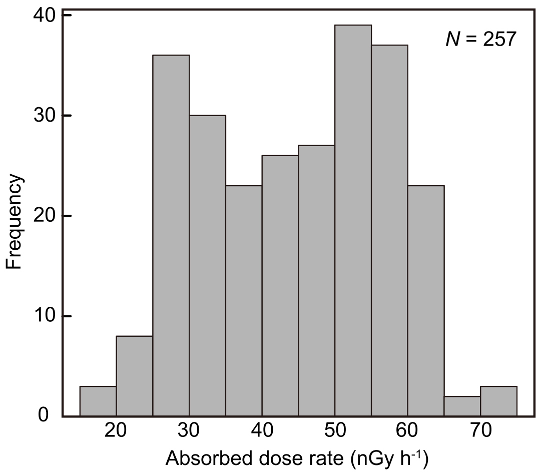

Fig. 3 Histogram of the absorbed dose rate in air at the NIFS site.

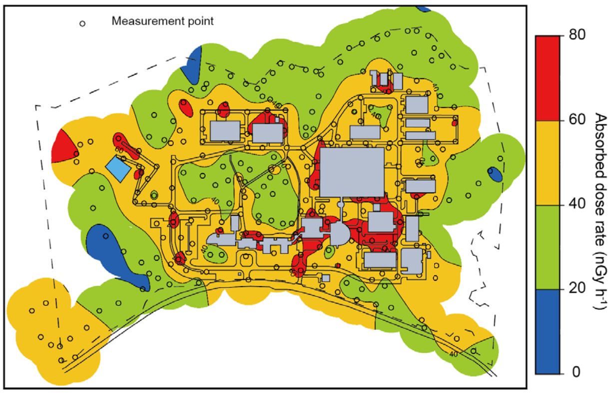

Fig. 4 Isopleth map of absorbed dose rate in air at the NIFS site.

in air around buildings were relatively higher than those values away from the buildings and roads. Therefore, the measurement points were classified into artificial locality (paved road with stone, asphalt, and parking area) and natural locality (bare field, preservation green space, grass plot, and copse). The mean ($\pm 1\sigma$) based on 110 measurement points at artificial localities and 147 measurement points at natural localities were $55 \pm 6\,\mathrm{nGy\,h^{-1}}$ and $36 \pm 10\,\mathrm{nGy\,h^{-1}}$, respectively. The absorbed dose rates in air in the artificial localities tended to be the higher than those in natural localities. The Wilcoxon signed-rank test showed significant differences between the absorbed dose rate in artificial localities and natural localities (p-value $< 2.2 \times 10^{-16}$). These results suggest that the building material and/or paving stone enhance the absorbed dose rate in air in the artificial localities.

The absorbed dose rates in air were measured by a pocket survey meter. The mean at the NIFS site was $45 \pm 13\,\mathrm{nGy\,h^{-1}}$. The absorbed dose rates in air were relatively lower than that in Toki city estimated in past studies. The absorbed dose rates in air on the artificial localities were relatively higher than those on natural localities. These observations suggest that the building material and/or paving stone enhance the absorbed dose rate in air at the NIFS site. This isopleth map of the absorbed dose rate in air at the NIFS site will be used as the background level of environmental radiation for environmental assessment after the deuterium plasma experiments are conducted.

This work was supported by the NIFS budget NIFS 10203004ULAA024.

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