

ENVIRONMENTAL TRITIUM AROUND A FUSION TEST FACILITY

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Received June 13 2003, amended February 10 2004, accepted February 24 2004

Deuterium plasma operations using a large fusion test device have been carried out since 2017 at the National Institute for Fusion Science. A small amount of tritium was produced by the fusion reaction, $d(d, p)t$. Then, a part of the tritium was released into the environment. Thus, monitoring the level of tritium in the environment around the fusion test facility is important. This is done before starting the deuterium plasma experiment. The environmental tritium concentrations indicated that they are at background levels in Japan. After starting the deuterium plasma experiment, the environmental tritium around the fusion test facility was within the range of environmental variation. This suggests that there was no impact of tritium on the environment during the first deuterium plasma experimental campaign.

INTRODUCTION

Problems of energy development are directly associated with the long-term prosperity of humanity. As for the development of a baseload power plant, nuclear fusion reactors are expected to be candidates for future power plants. The fuel of the nuclear fusion reactor would be the hydrogen isotopes deuterium (D) and tritium (T). A few of the large fusion test devices, such as the tokamak fusion test reactor (TFTR) and joint European torus (JET) carried out D–T plasma experiments in the 1990s. The inventory of tritium in these facilities was less than 10 g. Although tritium in the facilities was confined by a multibarrier system and recovered by a tritium removal system, a small amount of tritium was discharged via a stack. As a result, the levels of environmental tritium around the facilities was slightly increased.^{1–3} Likewise, the environmental tritium around nuclear facilities, such as nuclear power plants, spent fuel reprocessing facilities, and laboratories, increased by long-term tritium discharge.^{4–7} Therefore, monitoring environmental tritium around nuclear facilities is an important issue.

At the National Institute for Fusion Science (NIFS), plasma experiments using deuterium gas have been conducted using a fusion test device—Large Helical Device (LHD)—since 2017. When the deuterium gas was used in the LHD, a small amount of tritium was produced by the fusion reaction, $d(d, p)t$. The tritium and stable hydrogen isotopes (H, D) were exhausted from the LHD vacuum vessel and recovered as water by an exhaust detritiation system.⁸ However, part of tritium was released into the environment via the stack. The tritium concentration in the stack was monitored by active tritium samplers.^{9, 10} To assess the environmental

impact of tritium around the facility, the tritium concentration in environmental water samples collected in the Tono area, free water tritium (FWT) and organically bound tritium (OBT) in pine needle samples collected at the NIFS site, and tritium concentrations of tritiated water vapor (HTO), hydrogen (HT) and methane (CH_3T) in the atmosphere were monitored prior to conducting the deuterium plasma experiment.^{11–13} The concentrations of environmental tritium in the water samples have been made available on a website.¹⁴ In this work, the variation of tritium in water samples is briefly described. However, the environmental impact of tritium in OBT/FWT and the atmosphere around the NIFS site is primarily discussed.

MONITORING AND ANALYTICAL METHOD

Location of NIFS and the operation of LHD

The location of NIFS is shown in Fig. 1. The NIFS site [35.32° North, 137.17° East] is located approximately 100 km inland north from the Pacific coastal areas and at a distance of 100 km or more from the nuclear power plants. The facility stands on a hill, and its altitude above sea level is approximately 200 m.

LHD plasma experiments using hydrogen gas have been carried out since 1998. A similar experiment using deuterium gas was conducted from 7 March 2017. The total amount of released tritium via the stack from 6 March 2017 to 31 March 2018 was approximately 0.13 GBq.¹⁵

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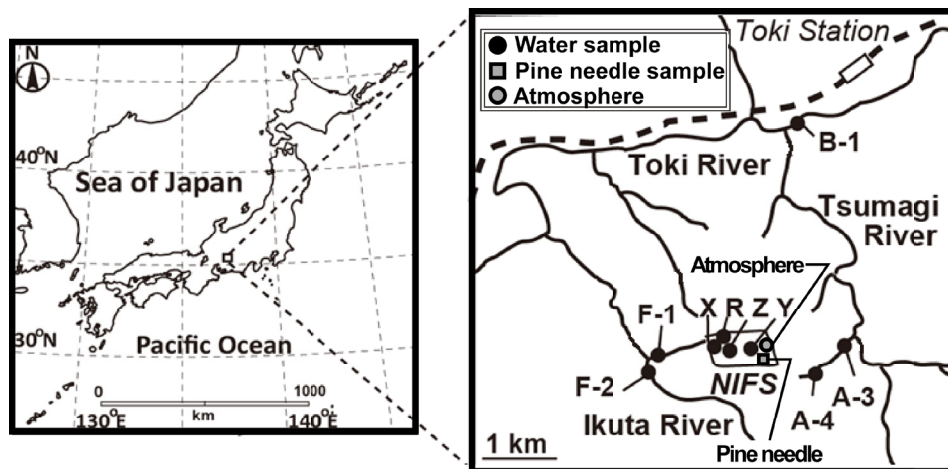


Fig. 1. Location of NIFS site and the sampling points of water, pine needle, and atmosphere

Sampling and analytical method

The sampling points of water, pine needles, and atmosphere are shown in Fig. 1. The water samples were collected from rivers (Tsumagi River: A-3, A-4, Toki River: B-1, and Ikuta River: F-1, F-2) around the NIFS site, drain water (X), tap water (Y), subsoil flow (Z), and rainwater (R) in the NIFS site. The sampling was conducted every three months (February, May, August, and November). Each water sample was distilled after passing through a membrane filter. After the water samples were distilled, part of the samples was mixed with a liquid scintillator (Ultima Gold LLT, PerkinElmer) and counted by a low-background liquid scintillation counter for 1500 min. The detection limit was approximately 0.28 Bq/L. The detailed procedure has been described elsewhere.¹¹

Pine needle samples were collected four times a year (every three months: beginning with May, and continuing in August, November, and February) at the NIFS site. Each time, approximately 600 g of fresh one-year-old pine needles were collected and stored in a freezer. The stored samples were later separated into 200 g portions, and a representative fiscal year sample (800 g) was made by mixing 200 g of each sample collected for each of the four sampling months. The pine needle samples were analysed by Kyushu Environmental Evaluation Association. The analytical method of the FWT and OBT was applied with Takashima's procedure based on a MEXT report.^{16, 17} Free water in the pine needle samples was recovered by a freeze-drying method, and then the dried sample was combusted to recover water as OBT. The tritium concentration in the recovered water was determined by a low-background liquid scintillation counter (LSC-LB5, Hitachi). The

detailed analytical procedure and method have been described elsewhere.¹²

The sampling point of the atmosphere in the NIFS site was located approximately 200 m northeast from the stack. The atmosphere tritium sampler can collect atmospheric HTO, HT, and CH₃T separately using catalysts with different temperatures at a height of 6 m from the ground once a month. In the first process, HTO in the air was collected by a molecular sieve 3A (MS3A) packed column. In the next process, to collect the HT in the air, the hydrogen gas in the air was oxidized into water at 100 °C. The water was collected in the MS3A column. In the last process, the CH₃T was oxidized by a catalyst heated to approximately 350 °C. The oxidized water was collected in the MS3A column. The collection time was 300–650 h, and the collected volume was approximately 20 m³ in summer and about 40 m³ in winter at a rate of 500–2000 cm³/min. After the sampling operation, the water collected in the MS3A columns was desorbed at a heating temperature of 400 °C and was recovered by a cold trap under dry N₂ gas purge at a rate of 1 L/min for 3.5 h. The tritium concentration in the desorbed water was measured by a low-background liquid scintillation counter. The detailed specifications and the operation of the sampling system have been reported elsewhere.¹⁸

RESULTS AND DISCUSSION

Monitoring of environmental tritium around the fusion test facility was conducted before starting the deuterium plasma experiment. The environmental tritium concentrations around the NIFS site indicated that there are background levels in Japan.

Regarding the variation of tritium concentration in the water sample, the data in 2000–2018 have been made available on a website.¹³ According to the open data,

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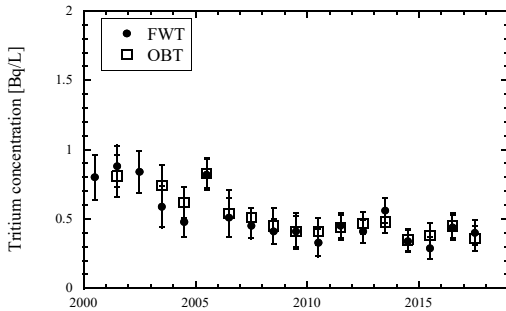


Fig. 2 Variation of FWT and OB in pine needle in 2000–2017. The data before 2012 are extracted from Ref. 12

after the 2000s, the tritium concentration in the water samples were at natural background level. The range of concentration was from N.D. to 1.36 Bq/L. The average concentrations in all sampling points before and after the operation of the deuterium plasma experiment were 0.41 ± 0.15 (1σ) Bq/L and 0.39 ± 0.10 Bq/L, respectively. This would suggest that the environmental tritium concentration in the water samples was not affected by the tritium release from the fusion test facility.

The FWT and OB in the pine needle samples in the NIFS site have been monitored since 1998. It is known that FWT concentration depends on the environmental tritium in the water samples, such as rainwater and soil water. Thus, the levels of FWT would be similar to that of the water samples around the NIFS site. However, the OB concentration depends on the environmental tritium concentration during the growing season. Figure 2 shows the variations of FWT and OB in 2000–2017. The tritium concentrations in pine needle samples at the NIFS site gradually decreased. The reference data of FWT and OB were observed at Shiomi Park, which is located 4.5 km south of NIFS, and similar data were observed.¹² Although the reason for the decrease of tritium concentration is not clear, it might indicate the levels of FWT and OB in this region. Since 2007, the levels of FWT and OB have been less than 0.6 Bq/L. The FWT and OB in 2017 were the same levels as the monitoring data before 2016.

The variations of HTO, HT, and CH_3T concentrations in the atmosphere from 2015 to 2018 are shown in Fig. 3. The average tritium concentrations of HTO, HT, and CH_3T were 4.3, 7.7, and 0.9 mBq/m³, respectively. The tritiated hydrogen and methane concentration levels seemed to be constant over the period of the measurements. However, the concentration of tritiated water vapor depended on the absolute humidity, because the water content in the atmosphere varied with the season in Japan. The variation range of tritium concentrations in the atmosphere did not differ before and after the start of the deuterium plasma experiment.

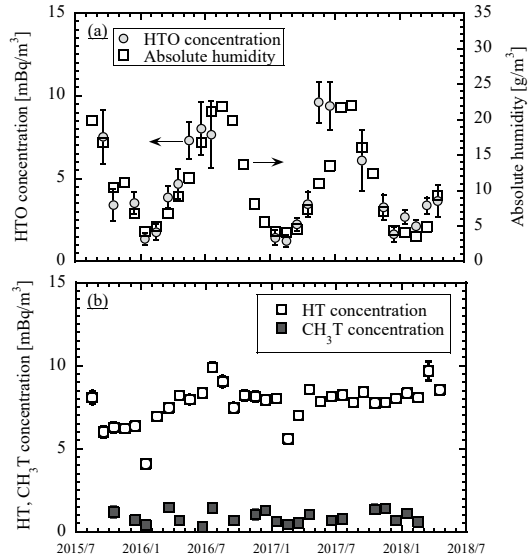


Fig. 3. Variations of atmospheric tritium concentration in 2015–2018 at the NIFS site: (a) tritiated water vapor (HTO) and absolute humidity and (b) tritiated hydrogen (HT) and tritiated methane (CH_3T)

According to Shinotsuka et al.,¹⁹ the effluent tritium concentration around the fusion test facility was calculated based on the hourly wind speeds and Pasquill stability classes, assuming a simple Gaussian plume model. In this calculation model, the amount of the released tritium was assumed to be 370 GBq. As the calculation results, the maximum effluent tritium concentration in the case of normal release mode was estimated to be approximately 20 mBq/m³. However, because the actual annual tritium release amount in 2017 was approximately 0.13 GBq, the effluent tritium concentration calculated by the model was estimated to be about 0.007 mBq/cm³. This is much lower than the environmental tritium concentration observed at the NIFS site. Therefore, the results of calculation and monitoring indicated that the environmental impact of tritium release into the atmosphere is negligible.

SUMMARY

After the start of a deuterium plasma experiment using a large fusion test device, a small amount of tritium was released into the environment. However, the levels of environmental tritium around the fusion test facility were within the range of environmental variation. This suggested that there was no recognizable impact of tritium on the environment during the first deuterium plasma experimental campaign in 2017.

FUNDING

This study was supported by the budget of NIFS (UPSX002).

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