

Expiratory Testing as a Simple and Effective Bioassay Method for Screening Workers for Tritium Exposure in Fusion Test Facilities

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This study evaluates expiratory testing as a simple bioassay method for estimating the effective dose equivalent for individuals working inside radiation control areas in a large helical device (LHD) building at the National Institute for Fusion Science (NIFS) in Toki City, Japan. The expiratory testing apparatus is configured according to similar devices reported previously. The core components of the apparatus include the sample collection device, a water bubbler column, exhalation airflow controls, and a solution injection component. Exhaled water vapor from individual test subjects is collected and tritium levels are measured using a liquid scintillation counter. Tritium radioactivity measurements are then compared to the effective dose according to evaluation criteria estimated using the effective dose equation for tritium.

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The large helical device (LHD) was constructed in 1998 at the National Institute for Fusion Science (NIFS) in Toki City, Japan [1] and is one of the largest magnetically confined heliotron-type plasma experiment devices [2]. The deuterium plasma experiment (D-D experiment) is an advanced project that was conducted at the LHD facility to investigate high-performance plasma and the behavior of hydrogen isotopes [3]. In D-D experiments, tritium and neutrons are produced via D-D reaction in deuterium plasma. A portion of the generated tritium with a maximum energy of 1.01 MeV remained inside of vacuum vessel; then, the tritium is placed in the plasma-facing components. Accordingly, tritium requires careful handling to reduce the risk of its release into the surrounding environment, although the amount of tritium production is low.

After these experiments, maintenance workers must enter the vacuum vessel that is located inside the LHD's radiation control area. Thus, measuring and monitoring the worker's radiological exposure in relation to the effective dose for tritium for these workers is critical for protection of human health. An individual's internal radiation exposure is routinely monitored at tritium handling facilities [4] and is often accomplished by analyzing excretory fluids in the form of a bioassay test that effectively assesses the internal dose rate [5–7]. For example, tritium measurement in urine is a common method to evaluate the effective dose equivalent for workers [5]. However, this method is not ideal due to complex pre-treatment requirements associated with testing and sufficient time is required to collect data for assessing the effective dose for tritium [4, 8].

It is assumed that ingested tritium soon reaches equilibrium in bodily fluids depending on metabolism and is distributed uniformly in all forms of soft tissue [9]. When tritium is present in the human body, a portion of it is discharged as exhaled water vapor during respiration [10]. Therefore, expiratory testing is often used at tritium handling facilities as a simple bioassay method [11–13]. This method is simple and provides data faster than conventional urine testing methods, and the results can be used to estimate the internal dose rate of tritium.

Our radiation control group performed the expiratory testing method using an integrated water bubbler for the dose assessment of workers according to the NIFS safety management plan [14]. The water bubbler device was configured according to the guidelines established by the Japan Atomic Energy Agency (JAEA) for such devices [11]. This study examines the effectiveness of our novel expiratory test device for LHD deuterium plasma experiments and estimates the effective dose equivalent of tritium with respect to human exposure.

Figure 1 shows the components of the expiratory test apparatus using water bubbler. The apparatus comprises an exhaled air sample collection component, a water bubbler column that uses an Allihn type condenser without cooling water, airflow rate controls comprising a dry gas meter (DCDa-5C, Shinagawa Corporation, Japan) and digital display, and a solution injection component (Fig. 2). It is a semi-automatic device controlled by a programmable logic controller (PLC), and the device status and sequence data are displayed on the front control LCD touch panel connected to the PLC. Before conducting an expiratory test, the individual administering the test places the distilled wa-

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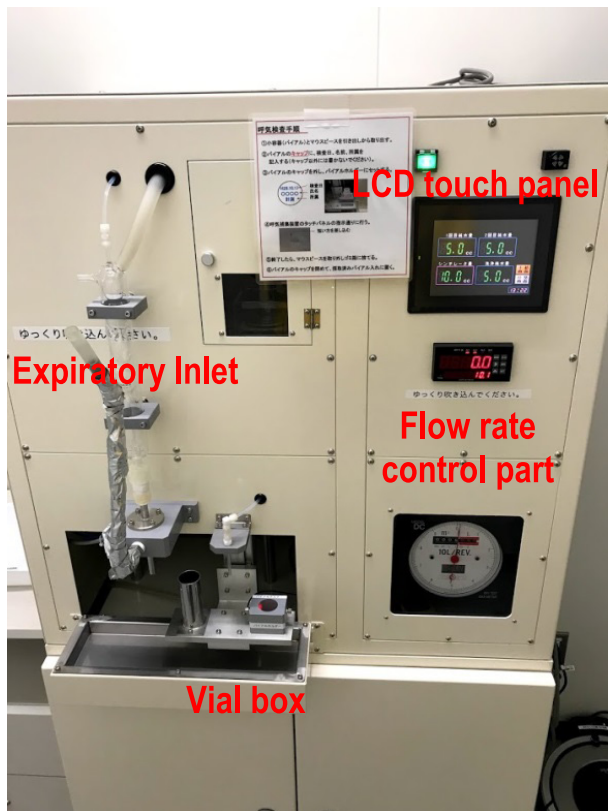


Fig. 1 Core components of expiratory test device.

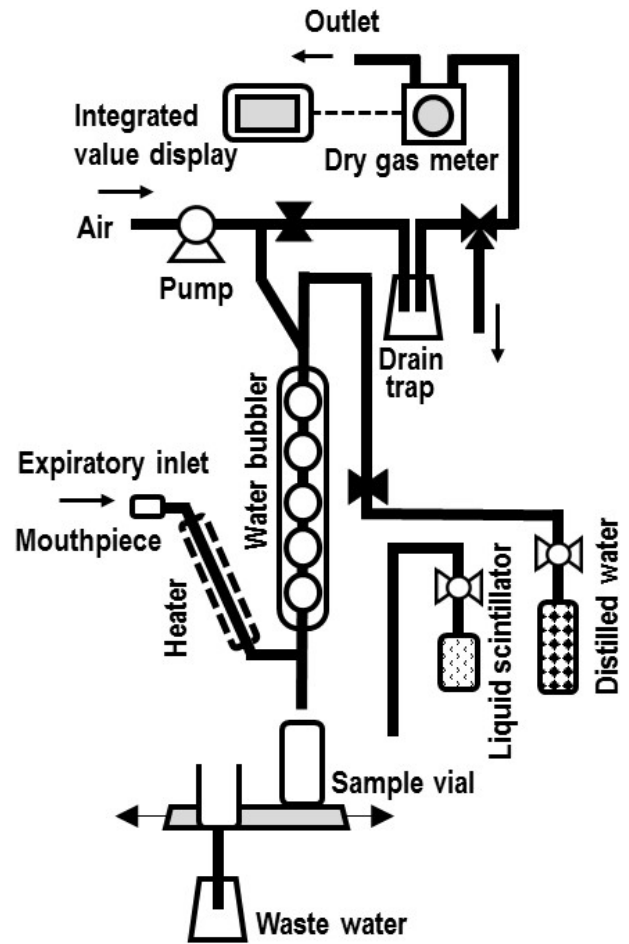


Fig. 2 Outline of expiratory test device.

ter and liquid scintillator inside the apparatus and activates the heater of the solution injection component (40°C) to prevent water vapor condensation in the expiratory injection line. The administrator must remove any air bubbles observed inside the distilled water tube by manual adjustment of valves and the liquid feeding pump.

Once the administrator renders the device ready to accept the sample, the test subject places a 20-mL vial in the sampling vial box, where an optical sensor detects the vial and proceeds to the next step. The subject then connects the mouthpiece (HC-21MP, TANITA, Japan) to the tip of the inlet tube and pushes the start button on the touch panel. Once activated, the vial box moves under the water bubbler column and 5 mL of distilled water is injected into the water bubbler chamber. The volume of exhaled air sent to the bubbler column is adjustable; herein, it was set to 10 L.

The instructions on the touch panel prompt the subject to breathe into the mouthpiece until 10 L of air are exhaled into the bubbler column, while taking care to maintain a low exhalation rate as a precaution against water bubbling over the edge of the Allihn type condenser. The exhaled water vapor containing tritium is trapped in the distilled water. When exhaled air reaches 10 L, a buzzer sounds to indicate the end of the sampling. The valves are closed, and the bubbled water is dropped into a 20-mL polyethylene vial. The bubbler column is then flushed using 5 mL of distilled water that is also dropped into the polyethy-

lene vial, and fresh air flushes the bubbler column for a few minutes to collect any residual drops of water. Herein, the standard deviation of recovered water volume was 0.4 ($n = 9$). Once the sample is collected, 10 mL of liquid scintillator is added to the vial. Finally, the bubbler column is washed with 5 mL of distilled water and then air flushes out the column for a few minutes to reduce residual tritium contamination to minimize the so-called “memory effect.” 10 mL of liquid scintillator (Ultima Gold LLT, PerkinElmer, USA) was added and mixed with the sample manually. After preparing the sample vial, the radioactivity of tritium was measured using a liquid scintillation counter (Tri-Carb4910TR, PerkinElmer, USA) for 50 min (10 min \times 5 repeats). Counting efficiency values were determined using a standard tritium solution (SRM 4361C, NIST, USA). The background counting rate in counts per minute ranged from 3 - 5 cpm, with a mean value of 4 cpm. Figure 3 schematizes the testing process.

The method of internal dose assessment was previously reported [9, 12, 15], and the effective dose (E_d : μ Sv) for tritium is estimated using the following equation:

$$E_d = \frac{A_T}{V_W \times C_{eff}} \times B_W \times C_F,$$

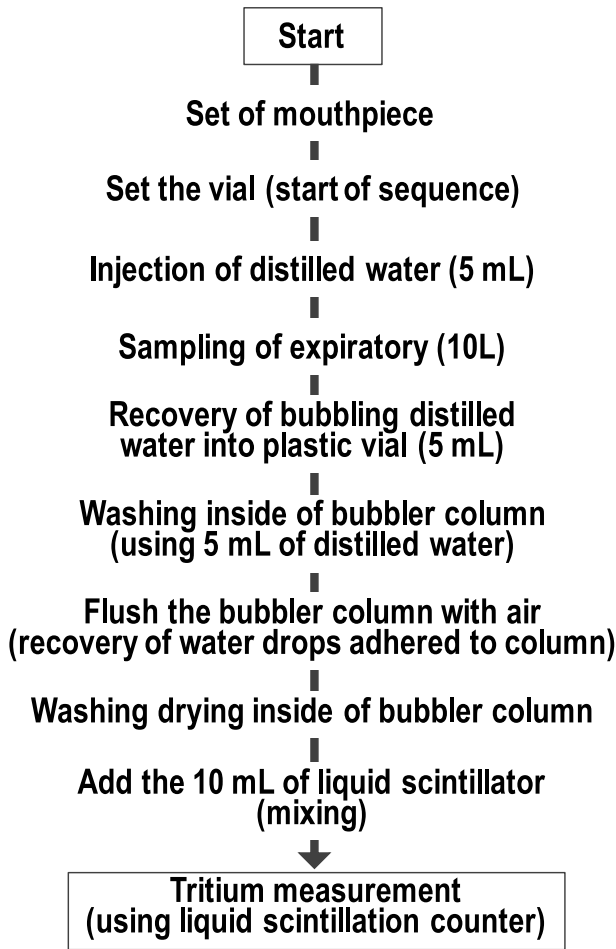


Fig. 3 Schematic of expiratory testing process.

where A_T is the tritium amount in exhaled water vapor collected by the water bubbler (Bq), V_W is the average amount of water vapor contained in 10 L of exhaled air, C_{eff} is the collection efficiency of exhaled water vapor sent to the water bubbler, B_W is the water content of the reference man, C_F is the dose coefficient of workers for inhalation of tritiated water (1.8×10^{-5} : $\mu\text{Sv/Bq}$) [16].

A V_W of 0.38 g was used in accordance with results of a previous study [12]. Tsujimoto et al. reported that the collection efficiency of exhaled water vapor (C_{eff}) ranges from 85% to 96% [12]; therefore, we used C_{eff} value of 0.85. The International Commission on Radiological Protection (ICRP) recommends using a B_W value of 42,000 g for the Caucasian Reference Man (CRM) [17]. Given that the average physical size of the Japanese male is slightly

Table 1 Management criterion of expiratory test with count rate from the liquid scintillation counter and decision criteria.

Judgement	Count per minute (cpm)	State (Effective dose: μSv)
ND	< 5	Not detected
A	5 ~ 10	0 ~ 1
B	10 ~ 100	1 ~ 10
C	100 <	Require re-examination

less, a value of 37,000 g was used to represent the Japanese Reference Man (JRM) [18]. As mentioned previously, the average background counting rate was measured inside the control area and ranged from 3 - 5 cpm. Therefore, the detection limit was set under 5 cpm.

The evaluation criteria are listed in Table 1. If a subject's test results indicated a count rate > 100 cpm (Judgment C in Table 1), the result must be verified using a bioassay test such as the urine testing method. The methodology and apparatus described in this paper are currently used to protect workers from radiation exposure risks at the LHD at the NIFS.

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