Development of a novel system for monitoring tritium in gaseous form (postprint)

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Abstract

Tritium real-time measurement in glovebox or workplace is important to ensure safe operation of tritium. A novel tritium monitor system including an open-walled ionization chamber, an electrometer and an IPC (Industrial Personal Computer) has been developed to measure tritium in gaseous form. Using mesh walls, instead of sealed wall, the open-walled ionization chamber has less tritium absorption and lower memory effect. In addition, tritium gas can diffuse into the chamber' s sensitive region without the assistant of sampling system and ion trap, which are installed at the front-end of commonly used flow-through ionization chambers. Background signal of this monitor system is about 3.7$×$105 Bq/m3, and after exposed to tritium concentration at about 1011 Bq/m3 for 4h, background of the monitor can recover after purging it several times with dry air. It is suitable for longtime tritium measurements in both glovebox and workplace.

Full Text

Preamble

A novel tritium monitoring system for gaseous tritium has been developed, consisting of an open-walled ionization chamber, an electrometer, and an industrial personal computer (IPC). By employing mesh walls instead of sealed walls, the open-walled ionization chamber exhibits reduced tritium absorption and lower memory effects. Furthermore, tritium gas can diffuse directly into the chamber' s sensitive region without requiring a sampling system or ion trap, which are typically installed at the front end of conventional flow-through ionization chambers. The background signal of this monitoring system is approximately 3.7×10^5 Bq/m^3, and after exposure to tritium concentrations of about 10^{11} Bq/m^3 for 4 hours, the background can be restored by purging the chamber several times with dry air. The system is suitable for long-term tritium monitoring in both gloveboxes and workplace environments.

Keywords: Ionization chamber, Monitor system, Tritium measurement
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Introduction

Tritium, the only radioactive isotope of hydrogen and a crucial fuel in fusion research, will be handled in large quantities in the ITER (International Thermonuclear Experimental Reactor) fuel recycling system [1, 2]. Its β-rays have an average energy of 5.7 keV and a maximum energy of 18.6 keV. Due to its radioactivity, tritium operations are typically confined within stainless steel tubing, gloveboxes, and concrete walls [3]. Monitoring tritium concentration at each confinement level is essential for providing early warning of tritium leakage [4].

Flow-through ionization chambers are widely used for real-time tritium measurements because of their fast response and simple structure [5–7]. However, they require a sampling system to pump gas into the chamber’ s sensitive region [8], which increases the risk of tritium leakage and generates additional radioactive waste. Furthermore, gas samples must be de-ionized using ion traps before entering the ionization chamber. Memory effect is another critical issue that can compromise measurement accuracy [9, 10].

In this work, we developed a tritium monitoring system featuring an open-walled ionization chamber to meet the requirements for gaseous tritium measurements in both gloveboxes and workplace environments. In this design, gaseous tritium diffuses into the chamber’ s sensitive region without pumping. The dual mesh wall structure helps de-ionize ions generated by tritium β-rays before they enter the sensitive region, while also reducing memory effects. Ions are collected by an electrometer, and custom software was developed for data reception and storage.

Basic Principles

Ionization chambers for tritium measurements operate in saturation mode, where all ions generated by tritium β-rays are collected. The signal output (I_s) can be described by Eq. (1):

$$I_s = \frac{EeCV}{W} + \frac{eDs}{W} + \frac{en_{out}}{W}$$

where E is the average energy (eV) of β-rays emitted by tritium, e is the electron charge (C), W is the average energy (eV) required to generate an ion pair in gas, C is the tritium concentration (Bq/m^3) in the chamber’ s sensitive region, V is the chamber volume (m^3), D is the radioactive contamination level of the chamber walls (Bq/cm^2), s is the total inner surface area (cm^2), and n_{out} is the number of ions generated outside the sensitive region.

The chamber's signal output is contributed by tritium in the sensitive region, tritium adsorbed on the inner walls, and tritium outside the sensitive region. The second term in Eq. (1) represents the memory effect. Therefore, minimizing the influence of the second and third terms is essential for improving monitor performance, which motivated the development of this novel open-walled ionization chamber system.

Design of the Monitor System

General Design

As shown schematically in Fig. 1 [Figure 1: see original paper], the monitoring system consists of three components: a detector, an electrometer, and an industrial personal computer (IPC). Signals generated in the chamber are transmitted to the electrometer, and specialized software installed on the IPC handles data acquisition, processing (conversion, display, and storage).

Saturation Characteristics

The saturation characteristics of the monitor system were tested at tritium concentrations of 7.0×10^9 Bq/m^3 and 6.9×10^{11} Bq/m^3 by varying the negative cathode bias voltage from 0 V to 1000 V. As shown in Fig. 5 [Figure 5: see original paper], the signal output initially increased with absolute voltage before saturating at a certain threshold. Higher voltages are required to ensure saturation at higher tritium concentrations, primarily due to ion loss from recombination and diffusion within the chamber. For tritium concentrations of 7.0×10^9 Bq/m^3 and 6.9×10^{11} Bq/m^3, the chamber operated in saturation mode at approximately 100 V and 150 V, respectively. Therefore, 300 V is recommended as the operating voltage to ensure consistent saturation mode operation.

Linear Response

The linear response was examined by exposing the open-walled ionization chamber to a point γ-ray source positioned at various distances, producing dose rates ranging from 0.045 mGy/h to 2.57 mGy/h (equivalent to 1.8×10^7–1.03×10^9 Bq/m^3). The results, presented in Fig. 6 [Figure 6: see original paper], demonstrate excellent linear response across the tested range.

Memory Effect

Memory effects were evaluated by exposing the monitor system to a tritium concentration of 6.9×10^{11} Bq/m^3 in a sealed container for approximately 4 hours. After removing the tritium and purging the container with dry air, the monitor' s background recovered to 3.7×10^5 Bq/m^3 within about 10 minutes. In contrast, a sealed-wall chamber exhibited background levels exceeding 1.0×10^7 Bq/m^3 after similar exposure due to tritium adsorption on the walls.

Conclusion

A novel tritium monitoring system has been developed for gaseous tritium measurements, particularly suitable for glovebox and workplace applications. The open-walled ionization chamber design significantly simplifies the structure of conventional tritium measurement systems while reducing memory effects. All operations can be controlled through the IPC using specially designed software. With a 1.0 L ionization chamber, the system achieves a background level of 3.7×10^5 Bq/m^3, making it suitable for long-term tritium monitoring in both gloveboxes and workplace environments.

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Note: Figure translations are in progress. See original paper for figures.