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Design and commissioning of the exhaust detritiation system for the Large Helical Device

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ABSTRACT

The Large Helical Device (LHD) is the largest helical fusion test device with superconducting magnets. During deuterium plasma experiments using the LHD, tritium and neutrons are produced by the deuterium–deuterium reaction. Thus, an exhaust detritiation system (EDS) using conventional oxidation–adsorption tritium removal was designed and installed to ensure safe tritium handling and public acceptance. The EDS consisted of a vacuum exhaust gas processing system for deuterium plasma experiments and a maintenance purge gas processing system for LHD maintenance. The vacuum exhaust gas processing system used molecular sieves as the dryer unit, whereas the maintenance purge gas processing system used a polymer permeable membrane. The key technique for receiving the complex exhaust gas stream from the LHD was feedback control of the pressure in the piping line to keep the process flow constant. To validate the recovery performance and feedback control system for the EDS prior to using deuterium gas, we used hydrogen gas to simulate tritium gas and actual exhaust gas stream from the LHD. The specified hydrogen recovery rate of more than 95% was satisfied and the actual complex exhaust gas stream was received by the proposed feedback control system in the EDS.

1. Introduction

As part of the nuclear fusion research program at the National Institute for Fusion Science (NIFS) in Japan, deuterium plasma experiments will be conducted to investigate high-temperature plasma physics and the hydrogen isotope effect. In the deuterium plasma experiments, tritium and neutrons will be produced by the deuterium–deuterium reaction. The NIFS has a deuterium plasma experiment schedule using the Large Helical Device (LHD), which is the largest helical fusion test device with superconducting magnets [1]. Although the production rate of tritium in the LHD will be low, tritium is a radioactive material. Thus, careful tritium handling is required to reduce tritium release into the environment in order to ensure public acceptance and conform to regulatory limits on environmental release. The oxidation–adsorption process is an atmospheric detritiation technique that combines an oxidation unit for converting all tritium species to HTO and a dryer unit for HTO adsorption [2]. This candidate system has been tested and used as an atmospheric detritiation system, a glove box gas purification system, an exhaust detritiation system (EDS), and an air clean-up system in tritium handling facilities worldwide and at the Joint European Torus (JET) and Tokamak Fusion Test Reactor (TFTR) fusion test facilities, which have performed deuterium–tritium plasma experiments [2–11]. The EDS in the JET facility consists of a two-stage catalytic recombiner for converting tritium and its compounds to tritiated water vapor, and three molecular sieve driers to recover the tritiated water vapor [3,4]. The system provides a constant air stream to the JET torus vacuum vessel and tritium handling system openings for ventilation during maintenance and detritiates the exhaust gases during an accident [7].

At NIFS, tritium is generated in the LHD vacuum vessel during deuterium plasma experiments and released from the vacuum pumping system; thus, the EDS is installed downstream of the pumping system. The vacuum exhaust gas during plasma experiments has high hydrogen isotope concentrations, is oxygen free, is dry with a dew point of less than −20 °C, and can have a flow rate of several normal cubic meters per hour to more than 10 Nm^3/h during the cryosorption pump regeneration in neutral beam injection (NBI) [12]. Therefore, the EDS for the LHD must be designed to handle various gas stream conditions with a safety processing system for hydrogen oxidation. After plasma experiments, the experimental facilities are inspected, and maintenance

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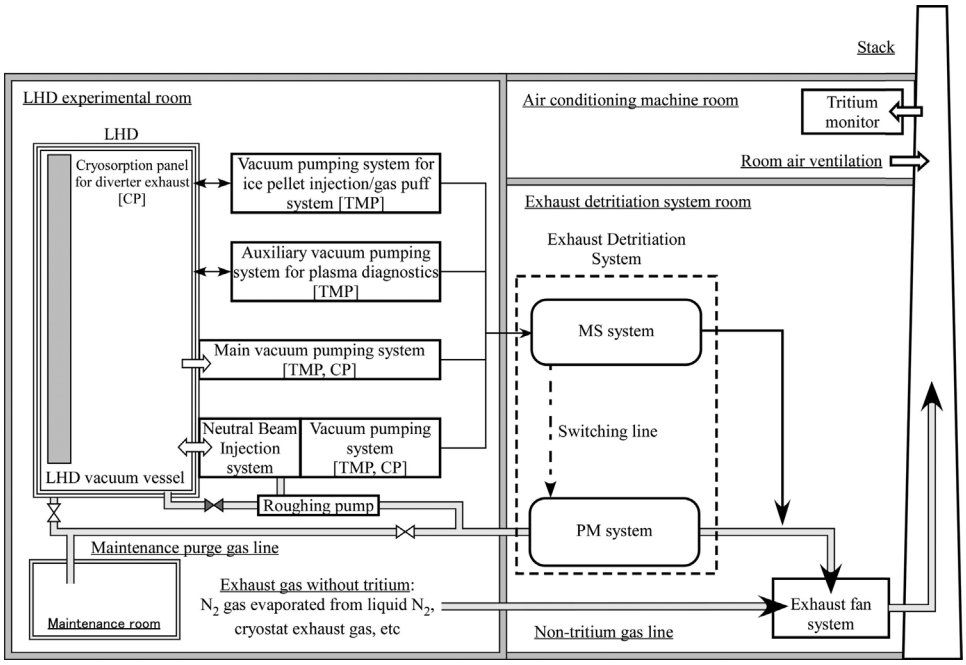

Fig. 1. Schematic of the LHD vacuum pumping system and the EDS. TMP: turbo molecular pump. CP: cryosorption pump.

and improvements for new research are carried out. During these operations, people enter the vacuum vessels, which retain tritium in the walls. To prevent oxygen deficiency and reduce the internal radiation exposure from tritium, the working environment is purged with air at a flow rate of 300 Nm^3/h. The air that is released from the vacuum vessel contains a small amount of tritium and must be treated by the EDS to reduce the tritium release from the stack.

The EDS is a key device for conducting deuterium plasma experiments with the LHD because the EDS ensures safe tritium management and public acceptance. In this paper, we describe the design of an EDS based on the gas stream from the LHD vacuum exhaust system, the construction procedure and commissioning test results using hydrogen gas, and the complex exhaust gas stream from the LHD and NBIs.

2. Design of EDS

2.1. LHD vacuum pumping system and requirements specification in the EDS

A schematic of the LHD vacuum pumping system and the exhaust gas line is shown in Fig. 1. The LHD is equipped with various components of the plasma heating system, such as NBI and electron cyclotron resonance heating, an ice hydrogen pellet injection system, a gas puff system, and plasma diagnostics. These components are installed with various independent vacuum pumping systems that are operated continuously or when needed. The main vacuum pump system is the cryosorption pumps for the LHD closed helical divertor and the LHD/NBI vacuum vessels [13–16]. Because these cryosorption pumps are regenerated at certain intervals, the EDS must handle a variable gas flow.

The EDS specifications for LHD are summarized in Table 1. The EDS must treat gas flows from several normal cubic meters per hour containing a high concentration of hydrogen isotope gas to 300 Nm^3/h with no hydrogen isotope gas, depending on the LHD operation mode. Thus, to receive the complex exhaust gas stream (Fig. 1), the EDS requires a vacuum exhaust gas processing (MS) system and a maintenance purge gas processing (PM) system for ventilating the vacuum vessel and other related facilities. The MS system is only operated during the plasma experiments. The operating time is estimated to be about 4000 h. The maximum process gas flow rate is 20 Nm^3/h because dry

Table 1
Specifications of the EDS for the LHD.

Systems	EDS	
	MS system	PM system
Process gas	Vacuum exhaust gas from LHD, NBI, and other experimental apparatus	Purge gas from LHD and NBI vacuum vessel and maintenance room
Max. process flow rate [Nm^3/h]	20	300
Gas composition in process flow	Q_2, Q_2O, C_xQ_y, He, Ne, Ar, N_2 (Q = H, D, T)	Wet air
Detritiation factor (tritium recovery rate)	> 20 (> 95%)	
Annual operating hours [h]	~4300 (24 h × 180 days)	~8400 (24 h × 350 days)

air is added to dilute hydrogen gas in the exhaust gas and to add oxygen to oxidize hydrogen. However, the PM system operates all year, because the related facilities, which are the greenhouse for maintaining contaminated apparatus and the analytical apparatus for researching plasma-facing materials in the maintenance room, are operated continuously. The flow rate of 300 Nm^3/h is determined from the viewpoints of working environment. The number of workers in the LHD vacuum vessel, the maintenance room and greenhouse during the maintenance period is estimated to be about 24. The amount of ventilation per one person considering the CO_2 concentration is calculated to be 12.5 Nm^3/h [17]. Thus a maximum process gas flow rate of 300 Nm^3/h is required.

The maximum amount of tritium produced by the deuterium plasma experiments in the LHD is assumed to be 55.5 GBq annually [18,19]. The tritium gas is released from the vacuum vessel with deuterium gas as the main operation gas, and the gases are passed through the EDS. Then, the gas treated by the EDS is released into the environment via the stack after the room air ventilation gas is diluted. Tritium concentration in the stack is monitored by the active tritium sampler, which has a detection limit of less than 10^{-8} Bq/cm^3 [20], and the real time tritium monitor using an ionization chamber. The annual amount of tritium release from the stack must be less than 3.7 GBq under the agreement with local governments. Thus, the detritiation factor of the