Development of Helium Measurement System for Neutron Dosimetry

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A system for measurement down to 10^8 atoms of helium contained in a solid sample within the range of mass between 10mg and 1g has been developed for a neutron dosimetry system. The system has an apparatus based on ultra-high vacuum techniques, computer codes to estimate suitable parameters for the given experimental conditions and to control the sequence of data acquisition, and an appropriate routine of the operation of the system. The system apparatus is comprised basically of a gas releaser, a mass spectrometer, and a standard helium supply. Gases in a sample are extracted by evaporating it in the gas releaser and are purified by two titanium getter pumps cooled by liquid nitrogen to decrease background gases. The amount of helium is determined by analyzing the gases with the mass spectrometer in current measurement mode or pulse counting. Several sample measurements are carried out to estimate performance of this apparatus. The apparatus and the results of the performance tests are reported.

1. Introduction

The helium atoms measurement system (HAMS) was developed to measure He production cross sections for several kinds of elements in our previous work[1]. The cross sections are obtained by measuring the amount of He atoms down to 10^{10} in solids[2, 3]. The purpose of this work is to advance the lower helium measurement limit of the HAMS to less than 10^8 He atoms in a solid. The improvement is for applying this system to a new type of area monitoring system employing a He gas accumulation method. The amount of He produced in a dosimeter by neutron irradiation is measured with the absolutely calibrated mass spectrometer in the method. The amount of He is in proportion to neutron fluence at the dosimeter position and is independent of variation in neutron flux. The only He production cross section is required to obtain absolute values of neutron fluence.

Two important points should be considered to advance the lower limit of He measurements. One is to produce a high quality vacuum in the system chambers to decrease the background gas during the sample measurement. The other is to detect a very small output signal from the mass spectrometer. A pulse counting system is applied to achieve high sensitivity in helium measurements. This paper presents the detail description of architecture of the improved HAMS and several results of performance tests.

2. Apparatus

A block diagram and a photograph of the HAMS are shown in Fig.1 and 2 respectively. The HAMS is composed of three blocks, which are a gas releaser, a mass spectrometer, and a standard He supply. The measurement procedure is briefly described. A solid sample containing He is set in the furnace of the gas releaser and is evaporated. The released gases are purified with a trap of the gas releaser and then are introduced into the mass spectrometer to measure the amount of He in the sample. The mass spectrometer has a quadrupole mass spectrometer (QMS), a digital electrometer, a multichannel analyzer and a personal computer that controls the QMS and stores data from the digital electrometer or the multichannel analyzer, and additional information. The sensitivity of the HAMS to He is calibrated by measuring standard He. The standard He is produced by using the standard He supply.

2.1. Vacuum evacuation

Vacuum vessels of the HAMS are redesigned to decrease background gases at the He measurement. Welding at the inside wall are employed to assemble their parts. The inside wall of the vessels are cleaned by emery polishing and electric polishing. The total volume of the vessels is decreased and conductance for pumping is increased. The three blocks (the gas releaser, the QMS, and the standard He supply) have individual turbo-molecular pumps to keep them at the high quality vacuum. The QMS block, especially, has tandem jointed turbo-molecular pumps and is evacuated to lower than 1.2×10^{-8} Pa. The tandem jointed pumps also pump the gas releaser. Two Ti-getter pumps cooled by liquid nitrogen are attached to the gas releaser and the QMS to trap the background gases and purify the released gas. Valves employed in this system are metal seal valves to prevent He permeation.

2.2. Gas releaser

The gas releaser (Fig.3) is composed of a furnace, a sample loader, and a trap. The furnace is a device for releasing He from the solid sample by vaporizing it. The furnace has a pair of electrodes and a shield. An evaporating boat, that is heated electrically, is located between the electrodes that are made of stainless steel 304. The material of the evaporating boat is selected from tungsten, molybdenum, tantalum and graphite and is chosen according to melting point and chemical characteristic of the sample.

2.3. Mass spectrometer

The mass spectrometer is composed of a quadrupole-type mass spectrometer (QMS), a personal computer, a digital electrometer, a multichannel analyzer, and a trap. The QMS is adjusted to be able to measure the mass from 1 to 6 in atomic mass units with the mass analyzing power of 0.025amu(10% valley).

The released gas is introduced into the QMS from the gas releaser and is then analyzed. The output current is amplified by a pulse counting type of secondary electron multiplier (gain: max.$1\text{x}10^{8}$) in the QMS, and is led to the digital electrometer or the multichannel analyzer. The improved HAMS operates in the current measurement mode or the pulse counting mode. The pulse counting with a multichannel analyzer is applied to measure the very small amount of He of less than 10^{10}. The computer code for these procedures controls and computes the timing for measurements. The process of producing the standard He gases are also indicated by the code when we input the operating conditions.

2.4. Standard He supply

Figure 4 shows a block diagram of the standard He supply producing the standard He which is used to calibrate the HAMS absolutely. The standard He supply comprises four vessels: the glass standard volume vessel (V1), the sub-standard vessel (V2), the inlet vessel (V3), and the dilution vessel (V4) and three absolute pressure gauges. The furnace is used as the fifth vessel to produce the standard He, so it is called V5. Standard He in the range of 1×10^{9} to 5×10^{15} He atoms can be produced with dilution method.

3. Performance

Several kinds of tests were carried out to determine performance of the HAMS on helium measurement. The tests were done both in the current measurement mode ($>10^{10}$ He atoms) and in the pulse counting mode ($<10^{10}$ He atoms). The tests are as follows.

Current measurement mode
(1) Standard He gas measurement (1×10^{10} ~1×10^{13} He atoms)
(2) Measurement of chromium samples irradiated by neutron

The amount of He produced in Cr samples by neutron irradiation is measured with the improved HAMS. The measured results are compared with the calculated values with JENDL-3.2 to confirm reliability of He measurement with the improved HAMS.

Pulse counting mode
(3) Standard He gas measurement (8×10^{7} ~1×10^{10} He atoms)
(4) Background measurement of an aluminum-boron alloy sample(dummy)

Actual lower limit of helium measurement of the improved HAMS will be determined by measuring this alloy sample.

4. Conclusion

The results of standard He measurements (test 1 and 3) with a regression curve are shown in Fig.5 and 6 respectively. The curves indicate a good linearity. In the test 2, the calculated values with JENDL-3.2 (Cr(n, α)+Cr(n, nα)) are fairly agree with our measured results (Table1). These results indicate that the HAMS has sensitivity to the amount of He between 10^8 and 10^{13} He atoms. The constituents of the measured Al-Cr alloy sample are written in Table 2. The result of the alloy measurement (test 4) is shown in Table 3. The value indicate that the background is $1.7x10^7$ He atoms on actual dosimeter sample measurements. This background is low enough to measure a sample containing around 10^8 atoms of He.

The HAMS has developed and has an analyzing power from 10^8 to 10^{13} He. It has a possible use in neutron dosimetry from an area monitor to reactor surveillance.

References
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Table 1 Results of neutron irradiated Cr sample measurements.

Sample No.	The amount of produced He (He atoms)	The calculated values with JENDL-3.2 (Cr(n,α)+Cr(n,nα)) (He atoms)
Cr-5	$(1.05 \pm 0.08)x10^{11}$	$1.17x10^{11}$
Cr-9	$(8.70 \pm 0.70)x10^{10}$	$8.84x10^{10}$

Table 2 Constituents of the Al-B alloy sample.

Element	Weight (g)	Chemical purity	Melting point
B	0.065	99.8%	2092°C
Al	0.577	99.99%	660.5°C
Al-B Alloy	0.642	10.1(B Weight %)	1200°C

Table 3 Result of background measurement with the Al-B alloy sample.

The amount of He without a sample	The amount of He with Alloy sample
$3.5x10^7$ He atoms	$5.2x10^7$ He atoms

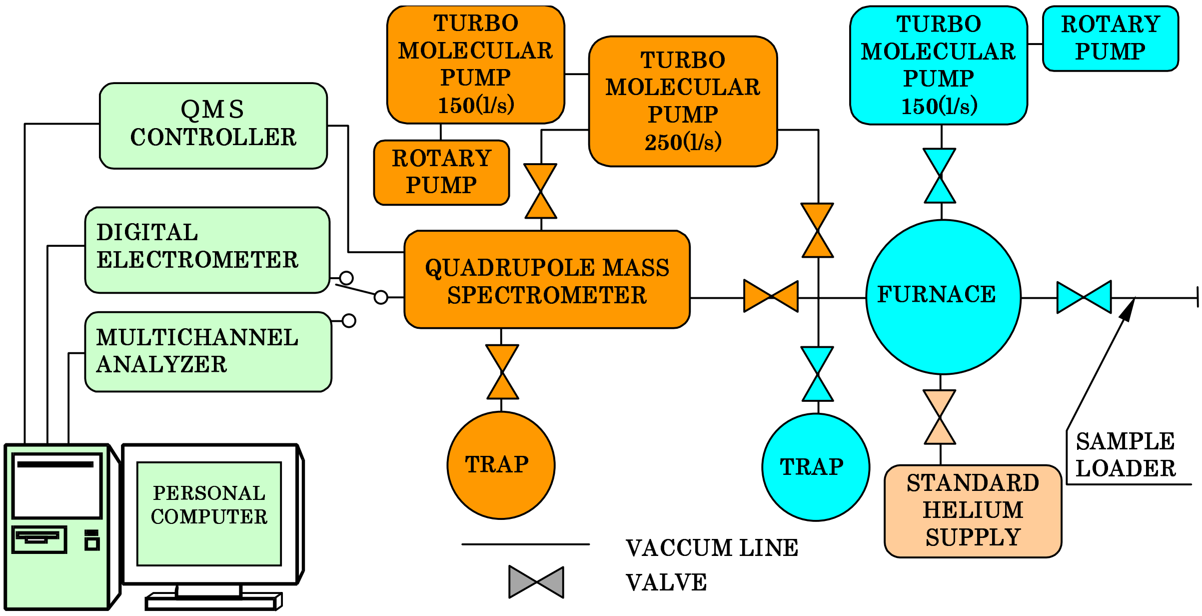

Fig.1 Block diagram of the improved Helium Atoms Measurement System.

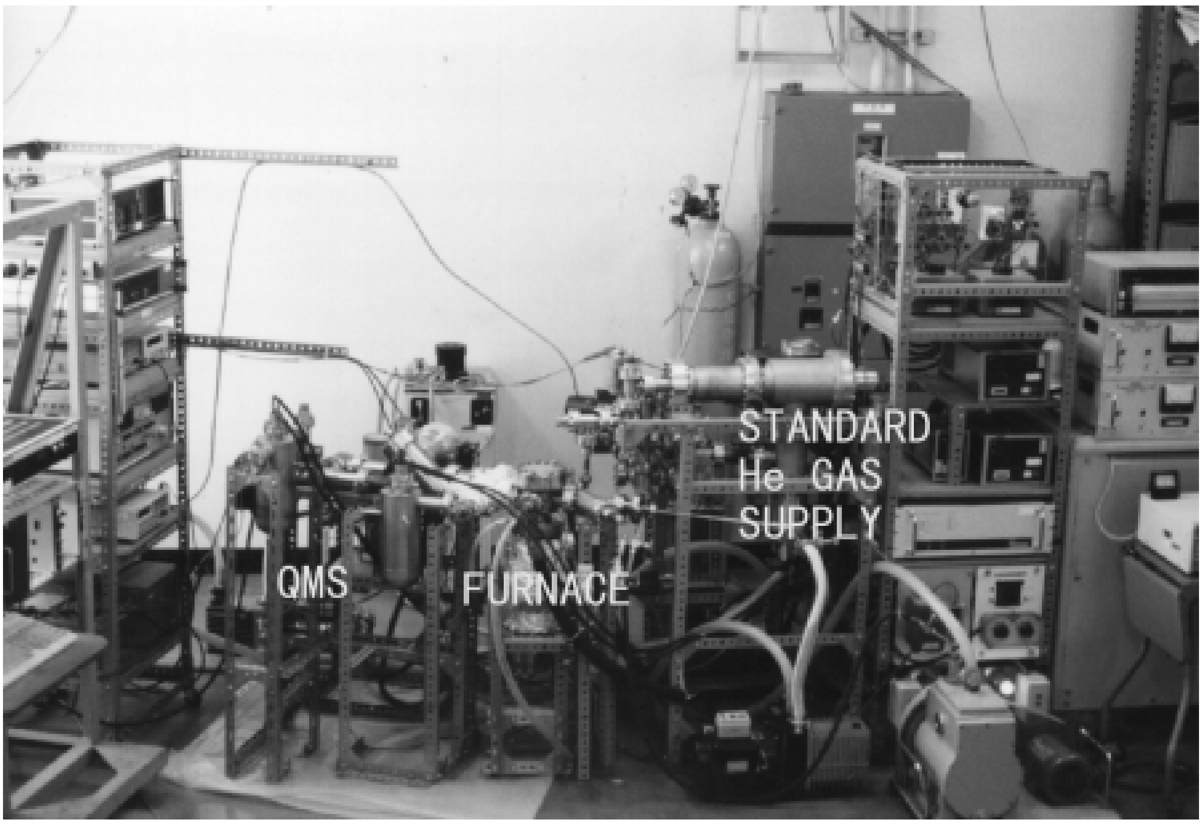

Fig.2 Photograph of the improved Helium Atoms Measurement System.

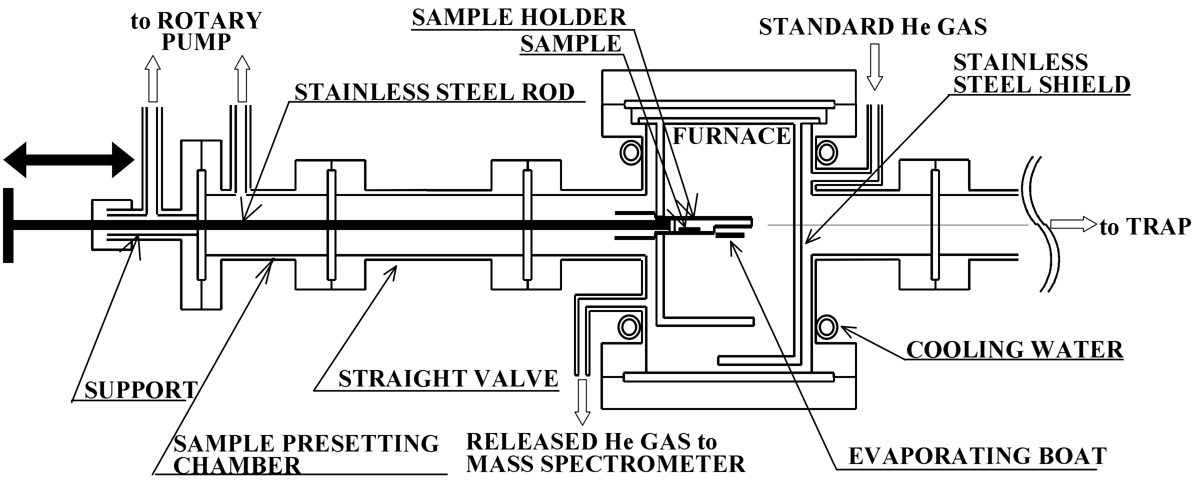

Fig.3 Schematic diagram of the gas releaser.

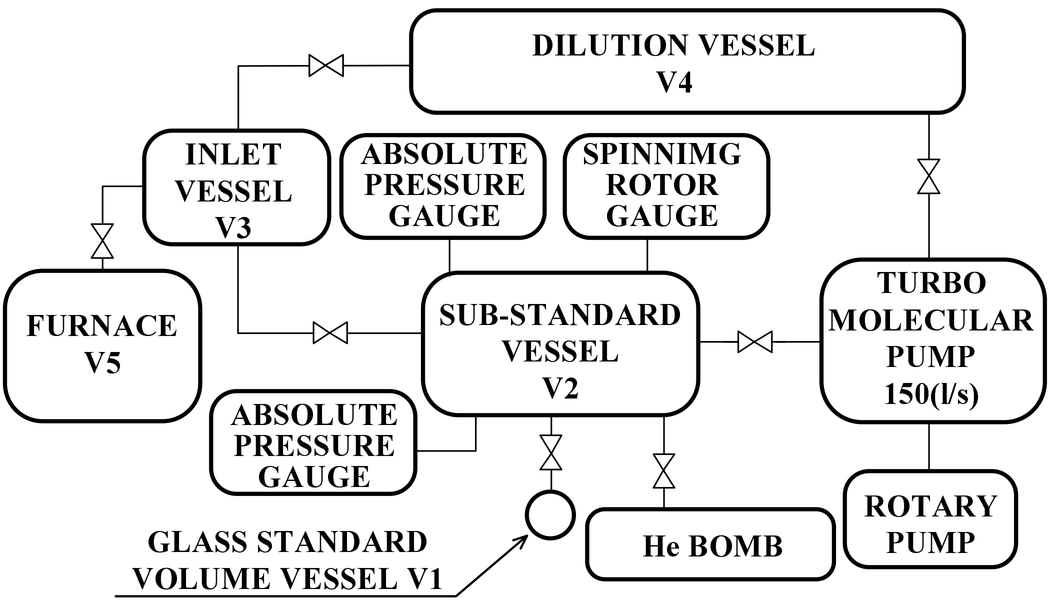

Fig.4 Block diagram of the standard He supply.

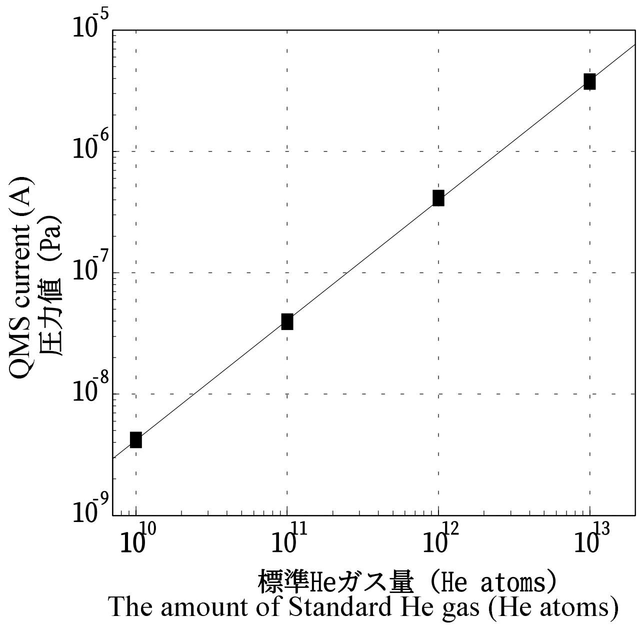

Fig.5 The results of standard He gas measurement (1×10^{10} ~1×10^{13} He atoms) in current measurement mode.

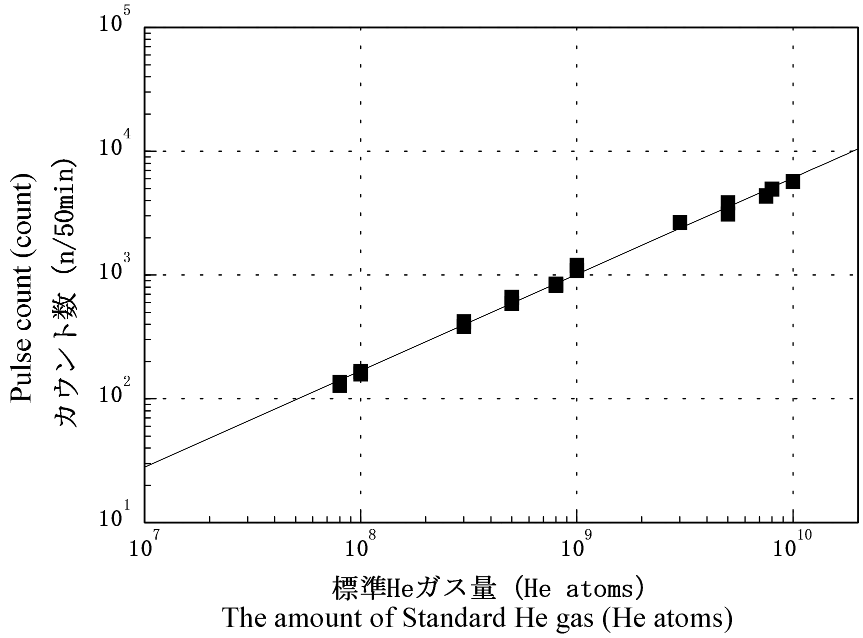

Fig.6 The results of standard He gas measurement (8x10^{7}~1x10^{10} He atoms) in pulse counting mode.