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Characterization of Compact Accelerator DD Neutron Source for *in situ* Calibration Experiment on Neutron Measurement at LHD

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Abstract

A compact Cockcroft-Walton type accelerator DD neutron source has been developed for in situ calibration experiments on neutron measurements at LHD. The equipment mainly consists of three parts; a deuterium (D) reservoir/ion source, a self-loaded deuterium target and a 100 kV high voltage power supply, all of which are contained in a compact cylindrical stainless steel (SUS) tube of 70 mm in diameter and 780 mm in length. About one hour steady operation was performed under the acceleration voltage of 80 keV and the ion beam current of ~60 μA, corresponding to the DD neutron yield of around 10^5 n/s. The neutron emission profile and energy spectrum were measured with an NE213 scintillator and a ^{3}He gas proportional counter.

Preliminary neutronic calculations with a Monte Carlo neutron transport code 'MCNP' were also executed for simulating the *in situ* calibration experiment for neutron detectors that will be installed on LHD.

Through the experiments and the calculations, it is shown that the present DD neutron source is valid for *in situ* calibration on threshold type detectors used for neutron emission profile monitoring and neutron spectrometry at DD plasma experiments.

Keywords:

fusion neutron, neutron measurement, compact accelerator, DD neutron source, neutron source characterization, *in situ* calibration experiment

1. Introduction

Fusion neutron measurements will be one of the most important diagnostic tools for DD/DT plasma experiments in existent fusion devices as well as for control of burning plasmas in future fusion reactors like ITER [1]. The measurement techniques have been developed and refined on total neutron yields for fusion power, neutron emission profiles for plasma ion distribution and neutron energy spectra for ion temperature [2]. An *in situ* calibration experiment with standard neutron sources is essential to check and/or keep their accuracy, when these neutron measurement systems are installed on a fusion device. Up to now, utilization of a ^{252}Cf neutron source is conventionally preferred for this purpose. However, there are some problems on its radiation safety handling, shape of the source spectrum, etc. [3-5].

To improve the *in situ* calibration technique for neutron measurement mainly at LHD [6], we have

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developed a compact accelerator DD neutron source, which can change neutron source strength and has a quasi mono-energetic spectrum of which peak is around the 2.5 MeV similar to that of DD plasma neutrons.

In this paper, the results of performance tests of the neutron source are presented on the neutron yield, the neutron emission profile and the neutron spectrum, including preliminary consideration on its applicability to LHD through the neutronic calculations.

2. Outline of Neutron Source

The compact accelerator DD neutron source we have developed is a Cockcroft-Walton type accelerator [7,8]. The equipment mainly consists of three parts; a deuterium (D) reservoir /ion source, a self-loaded deuterium target and a 100 kV high voltage power supply, all of which are contained in a compact cylindrical stainless steel (SUS) tube of 70 mm in diameter and 780 mm in length. Figure 1 illustrates a part of the accelerator tube, which is connected with a power supply tube of 600 mm in length. The deuterium (D) ions are supplied to an acceleration space from the Penning type ion source with the reservoir consisting of a Zi-V-Fe alloy getter and a molybdenum heater, and are self-loaded into a Titanium target of 6 mm in diameter and 5 μm in thickness to generate neutrons through DD reactions.

We have experienced about one hour steady operation and confirmed that the ion beam current of 60 μA is available under the acceleration voltage of 80 kV.

3. Experiments for Neutron Source Characterization

To experimentally make clear the basic characteristics of the present DD neutron source, we have measured the neutron yields, the neutron emission profiles and the neutron spectra under several operation conditions, such as an acceleration voltage and an ion beam current. Figure 1 shows the experimental arrangement.

For the neutron yield measurement, a high sensitive ^{3}He gas proportional counter (GE REUTER-STOKES, Inc., RS-P4-0840-218) with a polyethylene moderator was used, of which absolute sensitivity had been calibrated with a standard ^{252}Cf neutron source. An NE213 liquid organic scintillation counter (OHYO KOKEN KOGYO CO.LTD., S-2477) with a neutron-gamma ray discrimination circuit was adopted to measure the neutron emission profile and energy spectra around the target. The neutron spectra were derived from the NE213 pulse height data based on a differential method [9,10], and complementarily checked with the pulse height measured with the ^{3}He gas proportional counter.

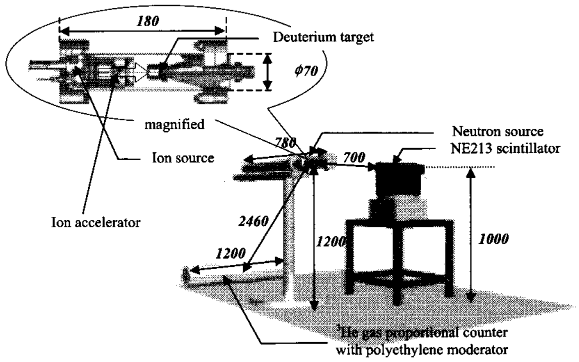

Fig. 1 Structure of a part of accelerator tube and arrangement of experiment.

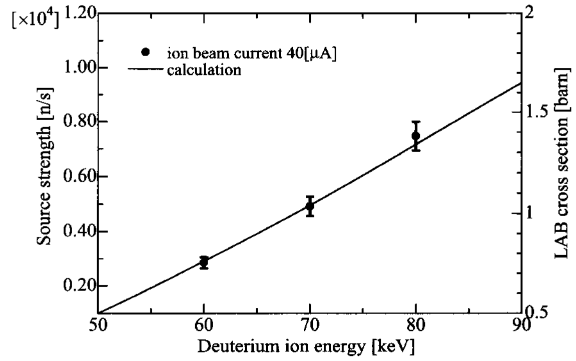

Fig. 2 Dependence of DD neutron yield on acceleration voltage.

4. Results and Discussion

4.1 Neutron yield

Figure 2 gives an example of the measured results of the dependence of DD neutron yield on the acceleration voltage (or deuteron energy), while typical results on the relation between the source strength and the ion beam current are shown in Fig. 3. It has been confirmed that the maximum neutron yield is around 2.0 $\times$ 10^4 n/s under steady operation of about 1000 s and around 8.0 $\times$ 10^4 n/s under transient operation of about 100 s or shorter, at the acceleration voltage of 80 kV and the ion beam current of 60 μA. The result of steady operation correspond to the source strength of about 1/20 less than that of 100 μCi (= 4.3 $\times$ 10^5 n/s) sealed ^{252}Cf source. However, it would be possible to enhance

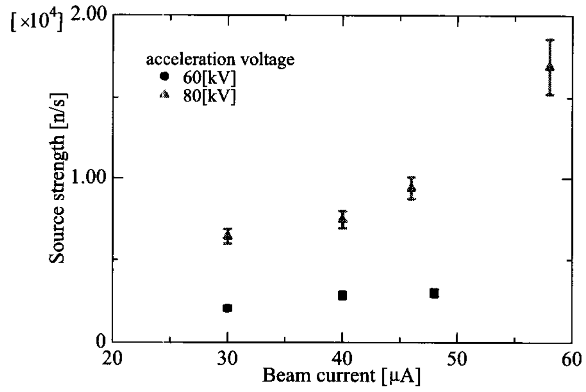

Fig. 3 Relation between source strength and ion beam current.

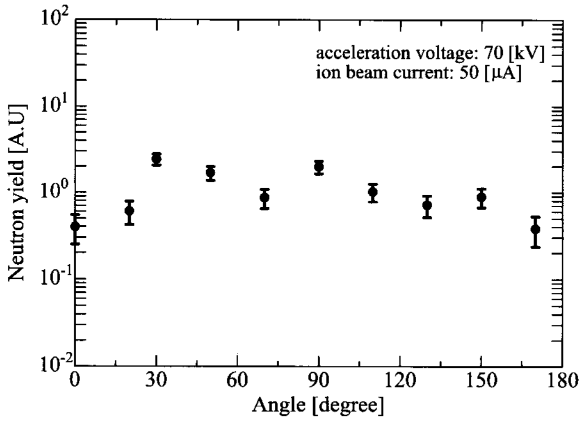

Fig. 4 Neutron emission profile around the source.

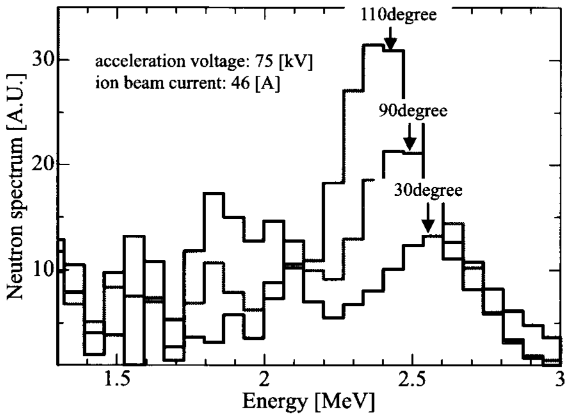

Fig. 5 Neutron spectra obtained from NE213 data unfolding.

the neutron source strength up to 10^6 n/s by installing a high density deuterium pre-loaded target and keeping the acceleration voltage at 90 kV.

4.2 Neutron emission profile

Figure 4 shows some results of the neutron emission profile around the source target in directions from 0 to 180 degrees to the beam axis on the horizontal plane, where the neutrons with energy higher than 1.5 MeV are adopted. In this operation, at the acceleration voltage of 70 kV and the ion beam current of 50 μA. The DD neutron source has a roughly isotropic emission profile. This emission is signified by kinematic collision. However, these results are from initial data, so we should get more data and consider again.

4.3 Neutron energy spectrum

Figure 5 shows a typical example of neutron spectra that depend on the emission angle. These neutron spectra were obtained with unfolding of the NE213 data. The neutron spectrum at each emission angle is found to be quasi mono-energetic of around 2.5 ± 0.5 MeV, of which peak energy changes with kinematics of DD reaction. However, some peaks of lower energy region are caused by scattered components and the data unfolding with the differential method.

We have made the detailed analysis on the neutron peaks at the emission angle of 90 degrees, together with supplemental measurements with the ^{3}He gas proportional counter. Figure 6 shows the neutron spectra obtained with the NE213 detector and the 3He gas proportional counter, at the acceleration voltage of 75 kV and the ion beam current of 46 μA. In the pulse height spectrum of the ^{3}He gas proportional counter in Fig. 6, it should be noted that the DD neutron peak appears on the energy added to 0.764 MeV because the pulse height signals are proportional to the total energy deposited in the counter gas through ^{3}He(n,p)t exothermic reaction (Q-value = 0.764 MeV), and the sharp peak around 0.764 MeV is caused by thermal neutrons.

5. Applicability to *in situ* Calibration Experiment at LHD

To check an applicability of the present DD neutron source to *in situ* calibration experiments at LHD, we made a preliminary model of the MCNP [11] calculation for LHD, which mainly consists of the vacuum vessel, simplified helical coils and a part of the experimental building, as shown in Fig. 7. The responses of neutron detectors placed outside the device

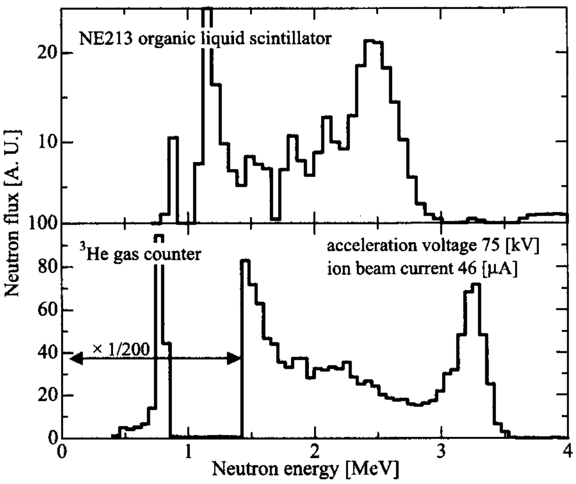

Fig. 6 Results of neutron spectra obtained from NE213 detector and ^{3}He gas counter.

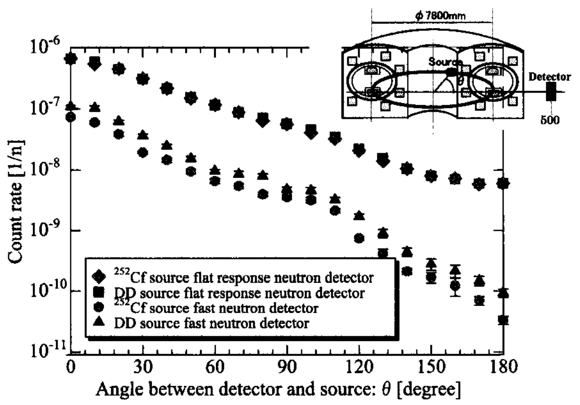

Fig. 7 Simulation result on toroidal angle dependence of neutron detector responses when DD and ^{252}Cf neutron point source are rotated in the toroidal direciton.

were calculated when the mono-energetic (2.45 MeV) DD source or ^{252}Cf neutron point source were rotated in the toroidal direction on the center axis inside the vacuum vessel. Two kinds of detectors were considered; one is a flat response neutron detector mainly used for neutron yield monitoring such as a ^{235}U fission chamber, the other is a fast (or the threshold type) neutron detector used as a neutron emission profile monitor and a neutron spectrometer such as a scintillator. Figure 7 shows the simulation results on toroidal angle dependence of these neutron detector responses. For the flat response neutron detector, almost no difference is found between the responses for the DD and the ^{252}Cf neutron sources, while significant difference is seen in the result of fast neutron detector. From another calculation done in poloidal cross section geometry of the 4.5-L port of LHD, where a multi-channel neutron collimator made of polyethylene will be installed under the floor for neutron emission profile measurement. It is also shown that the measured neutron spectra of the present DD neutron source would be a good approximation for the typical neutron spectra at the end of the neutron collimator. This means that the present DD neutron source is especially useful for the *in situ* calibration on neutron emission profile monitors and neutron spectrometers for DD plasma experiments.

6. Summary

We have developed and characterized the compact accelerator DD neutron source to improve the *in situ* calibration experiment on neutron measurement at magnetic confinement fusion devices like LHD. In the system start-up within 100 hours operation, main results on the neutron source characterization are summarized as follows;

(1) The maximum neutron yield is around 2.0×10^4 n/s under steady operation over 1000 s and around 8.0×10^4 n/s under transient operation of about 100 s or shorter.

(2) The neutron emission profile is roughly isotropic. However because of these are initial data, it is necessary for us to be more measurements and consideration.

(3) The neutron energy spectrum is quasi mono-energetic around 2.5 ± 0.5 MeV.

Comparing with a conventional ^{252}Cf neutron source, it is necessary to improve the source strength and the operational stability of the present DD neutron source. However, from the viewpoint of neutron spectral shape and radiation safety handling, the DD neutron source would be quite useful for *in situ* calibration on threshold type detectors used for neutron emission profile monitoring and neutron spectrometry at DD plasma experiments.

As further works, we are making more detail analysis of the neutron source characteristic under well conditioned and continuous or turned operation, including great efforts to enhance the neutron source strength by installing high density pre-loaded deuterium target and keeping as high as acceleration voltage as possible.

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