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MEASUREMENT OF NEUTRONIC CHARACTERISTICS OF JSNS

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ABSTRACT

JSNS has been in operation since May, 2008. To verify the neutronic performance and check the installation of the beam lines of JSNS, we measured neutron spectral intensities from all the available neutron-beam-lines by the current-mode TOF (CTOF) method and conventional counters in the pulse operation mode. Measured values were in good agreement with the predicted ones for beam lines without a neutron guide tube. While, considerable discrepancies in the spectral intensities were found in some beam lines using a neutron guide tube. The results indicated that the CTOF method was very useful for checking the neutronic performance from the moderators and initial installation of beam lines. We studied the change of the neutronic performance due to the change of the operating conditions of JSNS such as incident proton beam conditions (position and power) and a moderator temperature. The operating parameter dependence on the neutronic performance was compared with the predicted one, and it was found that the agreements between them were very good. This indicated an excellent reliability of neutronics design of JSNS.

1. Introduction

Japan Spallation Neutron Source (JSNS) in the Materials and Life Science Experimental Facility (MLF) is one of major facilities in Japan Proton Accelerator Research Complex (J-PARC). The first neutron beam was generated on May 30, 2008. JSNS is composed of a mercury (Hg) target and three super-critical 100%-para hydrogen moderators surrounded by beryllium and iron reflectors [1-3]. A pulsed proton beam of 3 GeV and 25 Hz hits the Hg target. At the present stage, the proton beam power has reached at 120kW and is now continuously increasing toward the final goal of 1MW.

The design of JSNS has been optimized by extensive neutronics calculations [4-8]. In order to validate the neutronic design, it is very important to measure a neutron spectral intensity at each beam line.

We have developed the current-mode time of flight method (CTOF) [9]. Although the CTOF method is not suitable for precise measurements of neutron spectral intensities due to somewhat larger ambiguity in the measuring data, it is convenient and can stand for measuring high neutron intensity as a direct incident beam. The CTOF method was adopted for measuring neutron beams at the sample position in each beam line.

This paper reports results of the first beam measurements at each beam line to compare with the calculated predictions. In addition, we studied the change of the neutronic performance due to the change of operating conditions of JSNS such as incident proton beam conditions (position and power) and the moderator temperature.

2. Methods of Measurements

For the CTOF method, Lithium (Li) glass scintillators with a photomultiplier-tube (PMT) were used. In this method, scintillation light generated in the Li glass scintillator with neutron interaction was multiplied by the PMT. An anode output of the PMT was connected to a digital signal oscilloscope (DSO). Variation of electric current from the PMT with time that just corresponded to the TOF spectrum is directly recorded by the DSO. In order to eliminate a gamma-ray contribution, two measurements were done by use of Li-6 and Li-7 glass scintillators. The high voltage was properly adjusted to avoid the over-current caused by high intensity neutron beams.

For the cases of more precise measurement, two types of conventional Helium-3 (He-3) gas proportional counters were also used. One was a cylindrical type (He-3: 7 atm) of 1/2” (1.27 cm) in diameter and another was a He-3 beam-monitor of 10 x 10 cm^2 in lateral sizes with an efficiency of 10^{-5} at 25.3 meV.

For all beam lines, to compare measured neutron spectral intensities at a sample position with predicted ones at the moderator viewed surface, the measured values were converted to those on the moderator viewed surface using the transmission data calculated by the McStas [10, 11] with the details of the beam lines, such as neutron guide tubes and collimators. Details of the predicted spectral intensities of each beam lines were reported elsewhere [12, 13].

3. Results and Discussions

3.1 Measurement of the first neutron beam

Figure 1 shows a picture of the setup to measure the first neutron beam on May 30, 2008. The first neutron spectral intensity measured by the CTOF method at BL10 [14, 15] is shown in Fig. 2. Note that the CTOF data was obtained by only the first single proton beam pulse. A peak in the thermal neutron region appears at 13 meV in the figure. This indicates that the almost 100% para-hydrogen is kept in the moderator as expected.

3.2 Confirmation of reliability of the CTOF method

To confirm a reliability of the CTOF method, we measured neutron spectral intensities at BL10 with the CTOF method and the 1/2” He-3 counter. In case of the measurement by the conventional 1/2” He-3 counter, the incident beam of reduced intensity by a proper beam collimator was used with repetitive proton pulses to make a pulse pile-up and a dead time effect negligible. The results are shown in Fig. 3 with the predicted ones. The measured data by the CTOF method are in good agreement with those by the 1/2” He-3 counter. At 20 kW in the proton beam power, it took 6 minutes and 1 hour for the measurements by the CTOF method and the 1/2” He-3 counter, respectively. The discrepancy between the CTOF method and the 1/2” He-3 counter is at most 20%. The experimental error of the CTOF method is evaluated at 25% due to 5% in the experimental error of the 1/2” He-3 counter. These measured data are also in good agreement with the predicted ones not only in the spectral shape but also in the absolute intensity. It is rather surprising to recognize that the predicted spectral intensities were obtained with given proton beam pulses, the configuration of the target-moderator-reflector assembly in the design and the neutron beam line details without any parameter adjustment or normalization.

3.3 Measurement at each beam line

Figure 4 shows measured spectral intensity at the sample position in each beam line measured by the CTOF method. In this figure, these measured data are not converted to those on the moderator viewed surface. From the intensities, beam lines are classified into three groups; group 1 (BL01 and 16), group 2 (BL10, 12 and 21) and group 3 (BL08, 19 and 20). The grouping corresponds to the moderator types (coupled (CM), decoupled (DM) and poisoned (PM) moderators, respectively).

Figures 5, 6 and 7 show the comparisons of measured spectral intensities with the calculated ones at CM, DM and PM beam lines, respectively. The small bump below 5 meV in Fig. 5 was observed due to a neuron reflection of a steel collimator (such as the guide-tube effect). However, except it the agreements with the calculation for CM and DM beam lines are fairly good. There is a discrepancy between the measured and the predicted intensities in PM beam line (BL19). The BL19 has a steel collimator section, a straight and a curved guide tube sections in series from the moderator. Therefore, the measurements of the intensities at the entrance of the guide section were also done (indicated as @7.5m in the figure). The result may indicate a certain neutron beam loss in the guide section due to misalignment.

3.4 Moderator temperature dependence

Figure 8 shows measured neutron spectral intensities at two different moderator temperatures (17.7K and 19.7K). These measurements were done with the 1/2” He-3 counter in BL10. For an easy comparison, the ratios (the 19.7K data/ the 17.7K data) are also shown with the predicted ones. The increase of the moderator temperature brings about the decrease of the neutron intensity below 20 meV. One of the reason is that hydrogen density decreases with increasing temperature, and another is in the total cross section of the para-hydrogen below 20 meV. Mean free paths of neutrons (inverse number of the total cross section, MFP) are about 1.2 cm at 100 meV and about 16 cm at 10 meV. The moderator thickness (MT) is 6.2cm. When the MFP is larger than the MT, neutrons are likely to penetrate the moderator with reducing chances to be scattered with the hydrogen. Hence the decrease in the hydrogen density results in less neutron beam intensity. On the other hand, when the MFP is smaller than the MT, neutrons are likely to be scattered by the hydrogen at least once in the moderator. Hence the neutron intensity is mostly insensitive to the hydrogen density. As the temperature increases, though the neutron intensity above 20 meV is unchanged, those below 20 meV decreases. The measured decrease below 20 meV is about 2% in maximum (The experimental error is within the 0.5% in this case). While, the predicted one is 4% in maximum. To understand the discrepancy, further studies at more different temperatures, for example 18K and 22K, are necessary.

3.5 Proton beam condition dependence

Figure 9 shows the ratio of neutron intensities at the sample position in BL10 against the change of proton beam vertical position at the target. As the vertical position of the proton beam rises, the neutron intensity increases since the proton beam position approaches to DM. The relation between the measured intensity and the beam position is almost the same as that of the calculated one.

Figure 10 shows the ratios of measured neutron intensity at the sample position in BL10 to the change of the proton beam power. The neutron intensity is well proportional to the proton beam power. It is supposed that increasing proton beam power causes increasing moderator temperature and accelerating conversion of para to ortho of the hydrogen, resulting in any influence of the neutronic performance. However, this result indicates that increasing proton beam power until 300 kW is not serious as far as the neutron intensity is concerned.

4. Conclusion

By the CTOF method and the conventional He-3 counters, we measured the neutron intensities in each beam line. From the result, we could confirm the neutronic performance and check the installation of the beam lines by the comparison with the calculated one.

For the next stage of the measurement, we will perform precise measurements on the moderator temperature dependence, the ortho-para-hydrogen ratio dependence, and so on.

Acknowledgements

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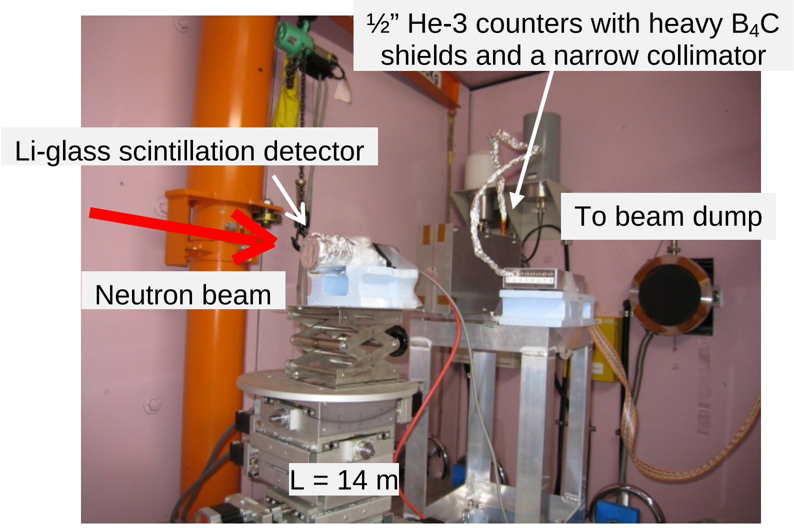

Fig.1 Picture of setup for the first neutron beam measurement at BL10

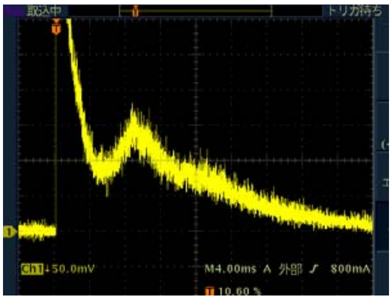

Fig. 2 Observed first neutron spectrum on the display of the oscilloscope

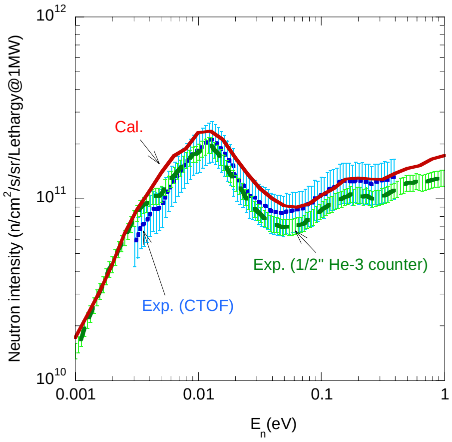

Fig. 3 Comparison of measured neutron spectral intensity with calculated ones

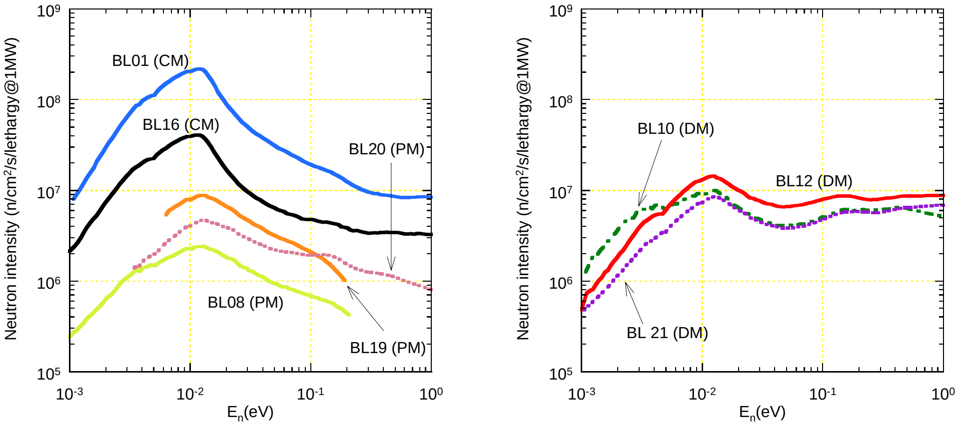

Fig. 4 Measured neutron spectral intensities at sample position in each beam line

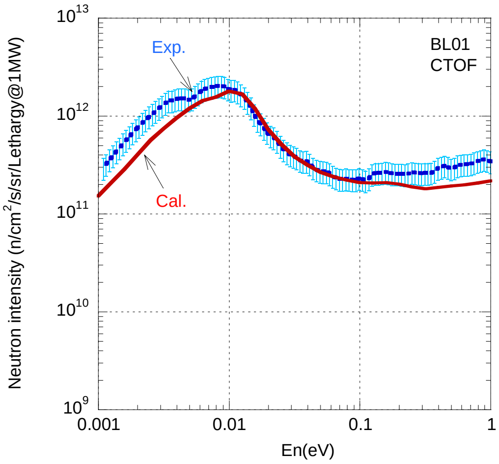

Fig. 5 Comparison of measured neutron spectral intensity with calculated one at BL01 (CM beam line)

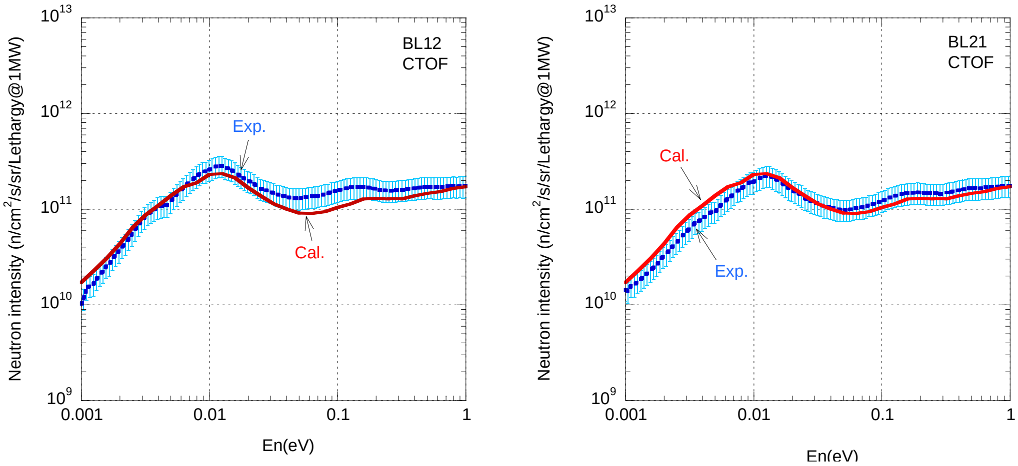

Fig. 6 Comparison of measured neutron spectral intensities with calculated one at BL12 and 21 (DM beam line)

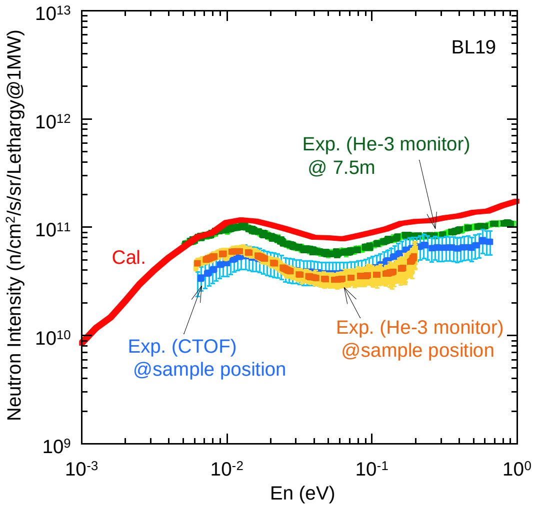

Fig. 7 Comparison of measured neutron spectral intensities
with calculated one at BL 19 (PM beam line)

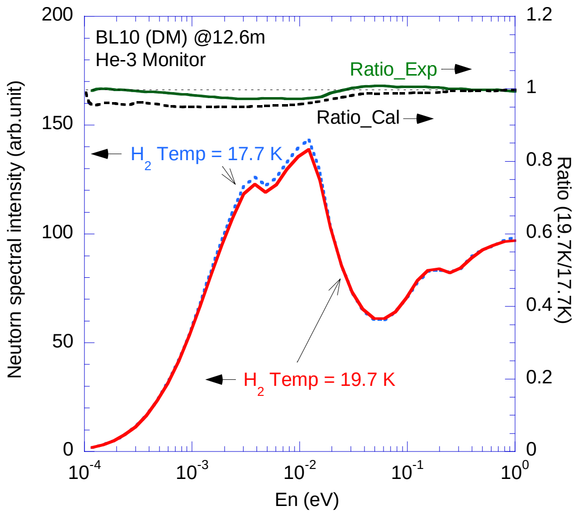

Fig. 8 Dependence of neutron spectral intensity to hydrogen temperature

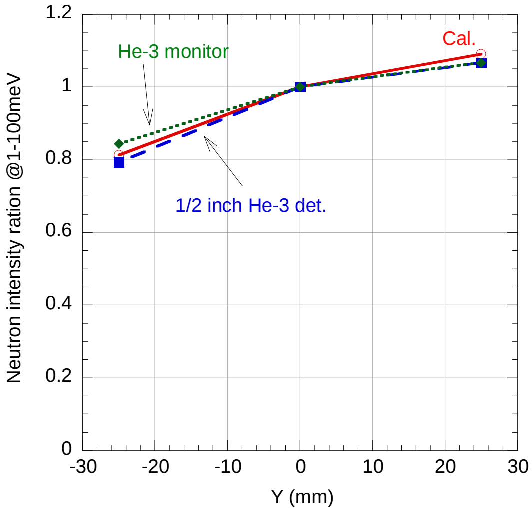

Fig. 9 Dependence of neutron intensity to proton beam vertical position
These data are integrated in energy region from 1 to 100 meV
and are normalized to those at the center position (Y=0 cm).

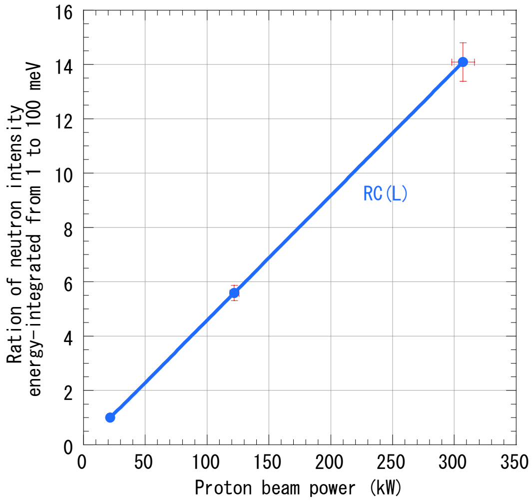

Fig. 10 Dependence of neutron intensity to proton beam power.
These data are integrated in energy region from 1 to 100 meV
and are normalized to those at 20 kW in proton beam power