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Characterization of a compact neutron generator with a NE-213 neutron spectrometer for the JET monitoring system calibration

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A calibration of the JET neutron emission monitoring system is in preparation for the second experimental deuterium-tritium campaign planned for 2019. The calibration will utilize a compact DT neutron generator. A target accuracy of <10% is envisaged. The compact neutron generator was extensively characterized at NPL by means of diamond diodes, long counters, silicon diodes, foil activation techniques, and a NE-213 scintillator spectrometer. Here we present the results of the measurement of fast neutron spectra at a distance of 146 cm from the compact neutron generator with an absolutely calibrated NE-213 liquid scintillator spectrometer. An important aim of this measurement was to check the contribution of DD neutrons to the total neutron flux density.

Keywords: JET, neutron diagnostics calibration, deuterium-tritium, fast neutron spectrometer.

1. Introduction

The second experimental deuterium-tritium campaign (DT2) is planned at JET for 2019. In preparation of the campaign, a calibration of the JET neutron emission monitoring system is underway. A compact DT neutron generator (CNG) will be used as a neutron source. A target accuracy of <10% uncertainty at a neutron energy of 14 MeV is aimed for. Due to weight restrictions for remotely handling the CNG inside the JET torus a neutron generator model with a neutron output of approximately $5x10^8$ n/s (in 4π) was selected. The neutron generator is based on accelerating a DT ion mixture unto a solid target. Two CNG fabricated by VNIIA (ROSATOM) were intensively examined at the National Physics Laboratory (NPL) Teddington (UK). Neutron emission spectra and emission intensities were measured at different angles by means of diamond diodes, long counters, silicon diodes, foil activation techniques and a NE-213 scintillation spectrometer. A typical measurement arrangement is shown in Fig. 1.

A MCNP [1] model of the CNG is under development for the planned JET calibration procedure. The model includes the neutronics-affecting geometry of the CNG as well as a neutron source which considers neutron emission from DD, TT, and DT reactions.

In the work presented here we focus on the measurement of fast neutron spectra >1.5 MeV with a NE-213 liquid scintillator based spectrometer. The spectrometer was located approximately 1.5 m away from the CNG, and data were taken at several angles with respect to the neutron generator axis covering a full circle. From these measurements it is expected to get not only values for the angular neutron flux density around DT fusion neutron peak but also the contribution of DD neutrons. The latter is important since DD neutrons will be registered by the Long counters in this CNG characterization but also by the fission chambers of the

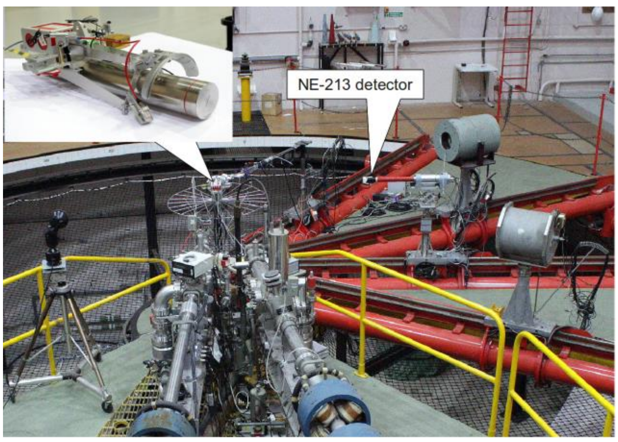

Fig. 1: The compact neutron generator and the set of neutron detectors setting at NPL.

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JET neutron yield monitoring system which will be calibrated with this CNG. Also neutron flux variations due to the internal structure as well as the DT neutron peak anisotropy, an angle-dependency of the energy and width of the DT neutron peak, are of interest. The anisotropy must be taken into consideration when performing the calibration of the JET neutron monitors with the CNG.

2. Measurement

2.1 Neutron spectrometer

The neutron spectrometer used in this work is based on the liquid scintillator NE-213. This scintillator is capable of discriminating between photon and neutron events by pulse shape analysis, neutron-generated light pulses are longer than light pulses due to photon interactions. The measurement method has been widely applied for decades and can be considered well-established.

The signal processing chain was based on an analog electronics set-up. The zero-crossing method was used to discriminate photons and neutrons. Of interest for these measurements are the recoil proton spectra from interactions of neutrons in the scintillator. From the recorded proton recoil spectra and the response matrix of the detector the neutron spectrum is computed with an unfolding procedure applying the MAXED code from the UMG-3.3 [2] package. For the spectrometer used in this work, experimentally qualified response matrices for photons and neutrons up to 16 MeV are available [3].

The envisaged measurement procedure was tested at the neutron generator laboratory of the Technical University of Dresden (TUD), see Fig. 2.

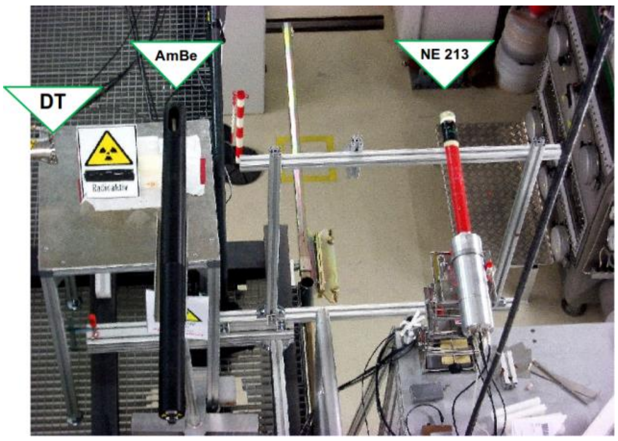

Fig. 2: Test of the envisaged measurement procedure at TUD-NG.

The DT neutron generator of TUD (TUD-NG) was set to its lowest deuteron beam current setting to simulate the CNG to be characterized. The neutron yield here was approximately 10^8 n/s. Additional tests have been done using an AmBe source with a similar neutron source strength. These activities were done to estimate the measurement time required to obtain a recoil proton spectrum with sufficient counting statistics for the unfolding procedure. The uncertainty of the neutron flux measurement in the DT neutron peak energy range was experimentally checked at the Neutron Laboratory of Technical University of Dresden and found to be better than approximately 7 %.

2.2 Neutron spectra measurements of the compact neutron generator

Due to geometrical restrictions, both CNG had to be turned by 180 degrees about their vertical axis after approximately half of the measurements to realize a full 360 degree measurement. In the following we focus on the measurements of neutron fluxes of one of the two CNG with the NE-213 detector at a distance of 146.0±1.0 cm from the source point of the CNG. Fig. 3 shows the measurement points where proton recoil spectra were recorded with the NE-213 spectrometer. Despite the application of a LED-based photomultiplier gain-stabilizing circuit, frequent checks with a ^{22}Na gamma source were done between the neutron measurement.

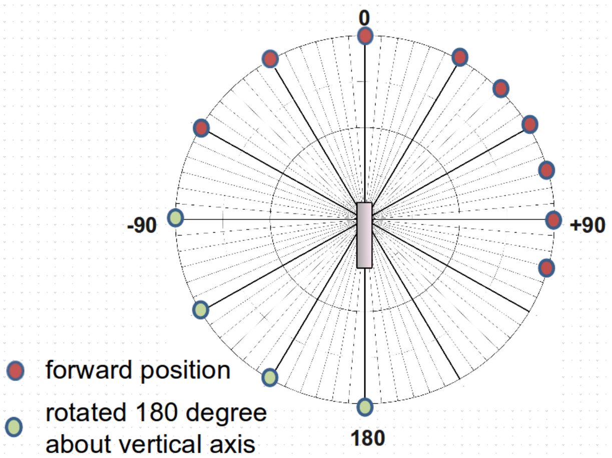

Fig. 3: Measurement positions of the NE-213 detector.

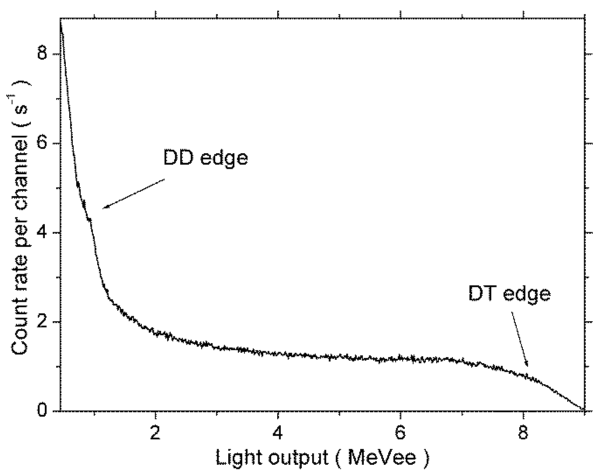

Fig. 4: Typical measured recoil proton spectrum, here for the 0 degree position.

The measurement time in each position was approximately 18 minutes with a short delay after each CNG start to allow the gain stabilizer to settle. This measurement time allowed for a sufficient counting statistics in each channel of the proton recoil spectra. A typical proton recoil spectrum is shown in Fig. 4.

The spectrum represents a superposition of proton energy distributions from elastic interactions with DD neutrons ($E_P \leq 2.5$ MeV) and DT neutrons ($E_P \leq 15$ MeV).

The NE-213 detector was mounted on one of four platforms of the NPL low-scatter area which can rotate about the CNG. A Long counter (LC) was mounted on the platform next to the NE-213 detector. This LC was covered with a shadow cone for parts of the measurement to determine the contribution of room-returned neutrons to the count rate of the LC. Since the shadow cone was comparably close to the scintillator of the NE-213 detector it was necessary to check if it has an influence on the count rate of the NE-213 detector. Therefore in the following figures measurements are designated with “no cone / with cone” depending on whether the shadow cone was present or not.

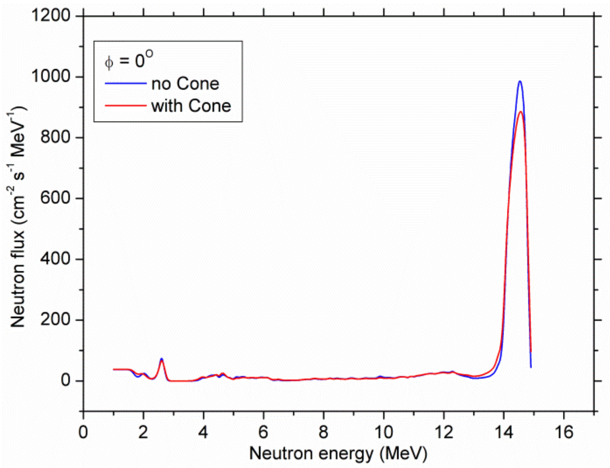

Fig. 5: Neutron spectrum at the 0 degree positions.

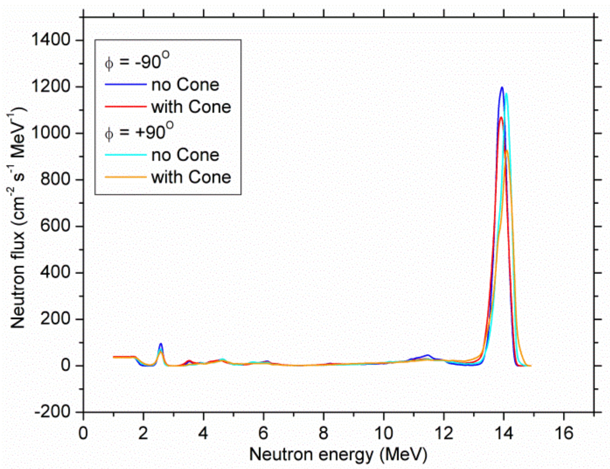

Fig. 6: Neutron spectrum at the 90 degree positions. Note that the DT neutron peak position is shifted towards lower energies as compared to the 0 degree position in Fig. 4.

Each of the measured proton recoil spectra was treated with an unfolding procedure with the MAXED code and the neutron response matrix for the detector. MAXED requires a guess spectrum as further input. A flat spectrum was used for all spectra, and in each case the unfolding parameters such as the upper and lower limits of the proton recoil spectrum were varied to check for stability of the found solution. Examples of the neutron spectra computed in this way for the 0 degree and ±90 degree positions are shown in Figs. 5 and 6. Note that the position of the DT neutron peak indeed changes from higher energies at 0 degrees to slightly lower energies at 90 degrees as one would expect from a neutron generator which is based on a fixed target bombarded with accelerated d/t ions. Each of the unfolded neutron spectra shows also clearly a peak at approximately 2.5 MeV which arises from the DD reaction in the CNG. Neutrons from the TT reaction could not be identified. This reaction takes place in the CNG since a deuterium-tritium ion mixture is bombarding a deuterium-tritium target. TT neutrons show a broad distribution between the energies of the DD and DT peaks. Therefore it is likely that the low

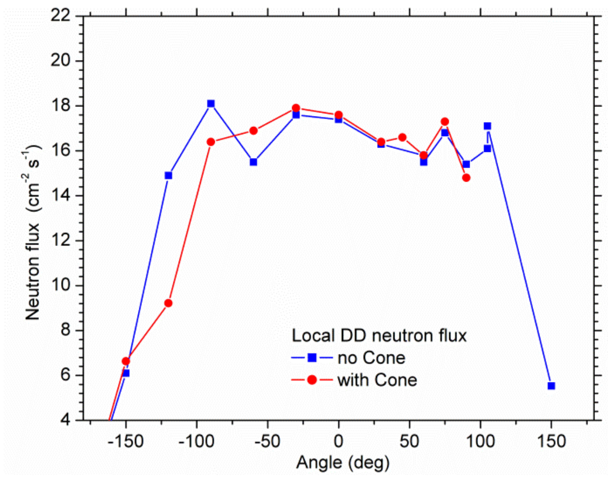

Fig. 7: Neutron flux densities at 2.5 MeV (DD) at different angles with respect to the CNG axis.

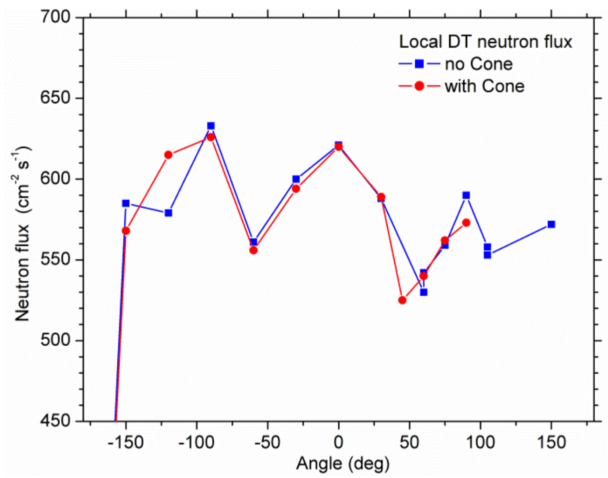

Fig. 8: Neutron flux densities at 14 MeV (DT) at different angles with respect to the CNG axis.

count rate per channel in the proton recoil spectra of the NE-213 scintillator does not allow for their registration.

The neutron flux density of the primary DT and DD neutrons was obtained by integration over the corresponding peak. It is shown graphically in Fig. 7 for the DD neutrons and in Fig. 8 for the DT neutrons.

The steep decrease at angles >150 degrees is due to shadow effects of the internal CNG structure. Note also the drops in neutron flux at ±60 degree.

The contribution of DD neutrons to the total fast neutron flux is approximately 2.8 %. Fig. 9 shows the ratio of the neutron fluxes from the areas of the DD and DT neutron peaks. Note that the angle-dependence of the ratio is nearly independent for "clean" directions, i.e. angles where not much shadowing structure would be expected inside the CNG while at larger angles the DD neutron flux is considerably reduced.

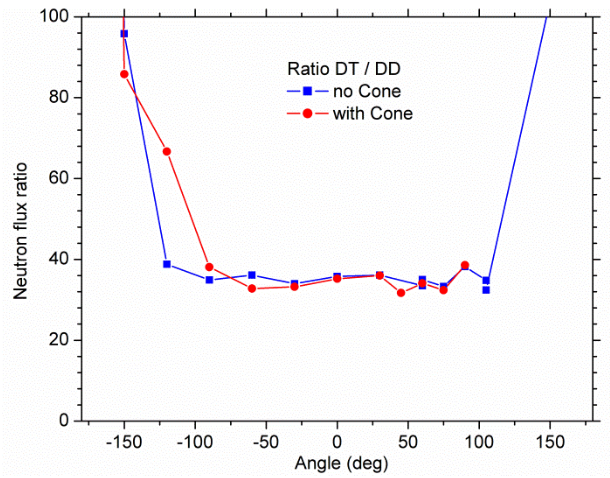

Fig. 9: Ratio of the neutron fluxes at DD and DT peak energies.

3. Discussion and Summary

A characterization activity for two compact fast neutron generators is underway with the aim to use them for calibration of the neutron yield monitoring system of JET to an accuracy <10% at 14 MeV. As a part of this campaign, neutron flux densities on a full circle around the compact neutron generator were measured at a distance of 146 cm with a scintillator-based fast neutron spectrometer. The neutron spectrometer registered contributions from the DD and DT neutron reaction in the CNG. The contribution of DD neutrons was quantified with 2.8%. This value needs to be taken into consideration when normalizing all measurements in this campaign to the Long counters of NPL which serve as a standard, since these Long counters are sensitive to both neutron energy ranges. The applied NE-213 neutron spectrometer's energy resolution is also sufficiently high to resolve the DT fusion peak energy dependence on the angle with respect to the CNG axis (=the axis of the internal deuterium-tritium ion beam). This angle dependence of the DT fusion peak as well as the DD neutron contribution will affect the calibration of the JET monitoring system in several ways. Both determine the neutron field at the place of the JET diagnostics at the time of calibration and both must be described correctly by the MCNP model of the CNG in order to be able to link the point-like calibration neutron source to the later neutron emission from the extended DT fusion plasma in JET.

Acknowledgments

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