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CHARACTERIZATION AND COMPARSION OF NEUTRON GENERATORS OF IEC AND LINEAR D-T BY THE SPECTROMETRIC SYSTEM NGA-01

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ABSTRACT

This article focuses on description of two different neutron fields from linear and cylindrical Inertial Electrostatic Confinement (IEC) neutron generators. Both of these generators are well defined and commonly used. They use a deuterium-tritium reaction that produces neutrons with energies in the range 13 – 16 MeV, depending on the direction and the energy of the incoming deuterium nucleus. Two-parametric spectrometric system for neutron/gamma mixed fields NGA-01 was used to characterize neutron spectra in the proximity of generators. The cylindrical 45x45 mm stilbene scintillator was connected to this device using an active voltage divider. This way, we were able to measure neutron energies in the range 1 - 15 MeV while filtering out gamma radiation, even when counts per second is high. For the neutron spectrum calculation recoil spectra using deconvolution through maximum likelihood estimation was used. Measured neutron spectra have been compared with simulations realized via MCNP6. According to the theoretical prediction, these two types of generators produce different neutron fields. In case of the linear generator the target is very close to point located tritium bombarded by deuterons. Thus the neutron spectrum varies depending on the angle between the detector axis and the axis of the generator. Both experimental results and simulation show a shift of the neutron energy peak in pulse height histogram. For IEC type generators the neutron spectrum is more complicated. The shape and the position of the neutron energy peak depend heavily on the position of the detector. The most prominent effect is in the position in the plane perpendicular to the generator axis. In this case, the peak splits into two peaks that can be measured and distinguished. These results were verified by the diamond detector which was also used for characterization of the IEC type generator.

KEYWORDS: Linear neutron generator, IEC neutron generator

1. INTRODUCTION

The neutron generators are important tools in physical research. They can be used in many fields of science and technology. Their applications cover defectoscopy, oil logging, material research, cross section measurements, medicine, and many others. In most such applications the correct description of neutron field around such devices is essential. This paper aims to characterize the two different neutron generators, linear neutron generator, IEC neutron generator. The characterization was realized using stilbene scintillation spectroscopy, which results were confirmed using diamond detector.

2. INSTRUMENTS AND METHODS

The neutron field of both linear neutron generator in Ostrava University and IEC neutron generator in Research Center Rez were characterized according to theoretical calculations and measurements. MCNP6 has been used for simulations of neutron spectra. We carried out Neutron-Gamma spectrometer NGA-01 for experimental measurements.

2.1. Linear neutron generator in VSB

Linear neutron generator MP320 (Thermo Scientific, Fig. 1) is located in the shallow underground laboratory of VSB-Technical University of Ostrava in the middle of a shielded concrete room of the inner dimensions 2.4 x 3.75 x 2.7 m (thickness of concrete walls about 1 m) [1,2]. It is a lightweight (12 kg), portable neutron generator (length 57 cm, diameter 12 cm). The initial tritium activity is approximately 70 GBq. It can operate in both continuous and pulsed regimes. Deuteron and/or tritons are accelerated towards a metallic target loaded with deuterium and tritium. The effective target diameter is approximately 1 cm. Neutrons produced in the DT fusion dominate in the spectrum due to the higher cross section of DT fusion compared to those of DD and TT fusions. The reported experiments were performed in the continuous regime at the accelerating voltage of 80 kV and beam current of 60 μA where the total neutron yield into 4π represents approximately 108 neutrons/s. The energy of DT fusion neutrons depends on the neutron emission angle counted relatively to the ion beam direction and spans the interval 13.3 – 14.8 MeV. Widths of the neutron peaks are also angular dependent and do not exceed approximately 0.4 MeV. Neutron flux distribution is not isotropic, maximum deviations are expected for 0o and 180o due to neutron interactions with neutron generator internals.

Figure 1. MP320 neutron generator with stilbene and diamond detectors.

2.2. Neutron generator in Research center Rez

Neutron generator NSD-350-24-DT-C-W-S produced NSD Gradel Fusion (Luxembourg) operating in Research Centre (CVR) is based on “sealed tube” system. The diagram of the neutron generator is shown in Fig. 2. The length of the NG tube is 1300 mm and its diameter equals 156 mm. The active volume of the reaction chamber of the length of 350 mm is about 5 dm^3. The activity of tritium hold in “getter” is approximately 500 GBq.

Positive ions of D^+ and T^+, released into the reaction chamber from “getter” by heating to the temperature around 540°C, are accelerated towards the molybdenum cathode. A central hollow cylindrical section defines a zone (cathode) with very low electric field. The cathode walls are grid like and transparent to ions, allowing their movement. The ions are accelerated towards the central cathode and can remain confined to the cathode area (electrostatic confinement) for some time. The fusion reactions can occur when ions accelerated from the reaction chamber towards the anode encounter the volume where the confined ions are present.

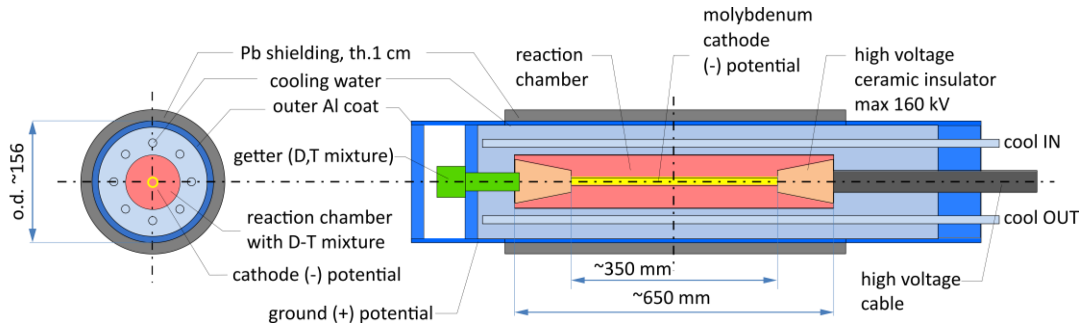

Figure 2. Diagram of the NSD-350-24-DT-C-W-S “sealed tube”.

The yield of D-T reaction (14 MeV) is about 65 times higher than D-D reaction (2.5 MeV) and the yield of T-T reaction (0.5-9.5 MeV) is 3 times higher than D-D. The NG can operate with maximum parameters 160 kV and 150 mA. Neutron emission at the maximum parameters (24 kW) is about 10^{10} neutrons/s. At present time we operate it on 80 kV and 100 mA (8 kW), i.e., neutron emission reaches $5 \, . \, 10^8$ neutrons/s. The neutron generator has been tested at the maximum power of 24 kW but there is a problem with the temperature stability of the neutron generator. Therefore, we reduced the power down to 8 kW that is optimal for temperature stability of the neutron generator.

Due to the design of the HV part optimal insulation and cathode fixing the NG is operated in the vertical position (see Fig. 2). The experimental setup of the NG with stilbene and diamond spectrometers is shown in Fig. 3.

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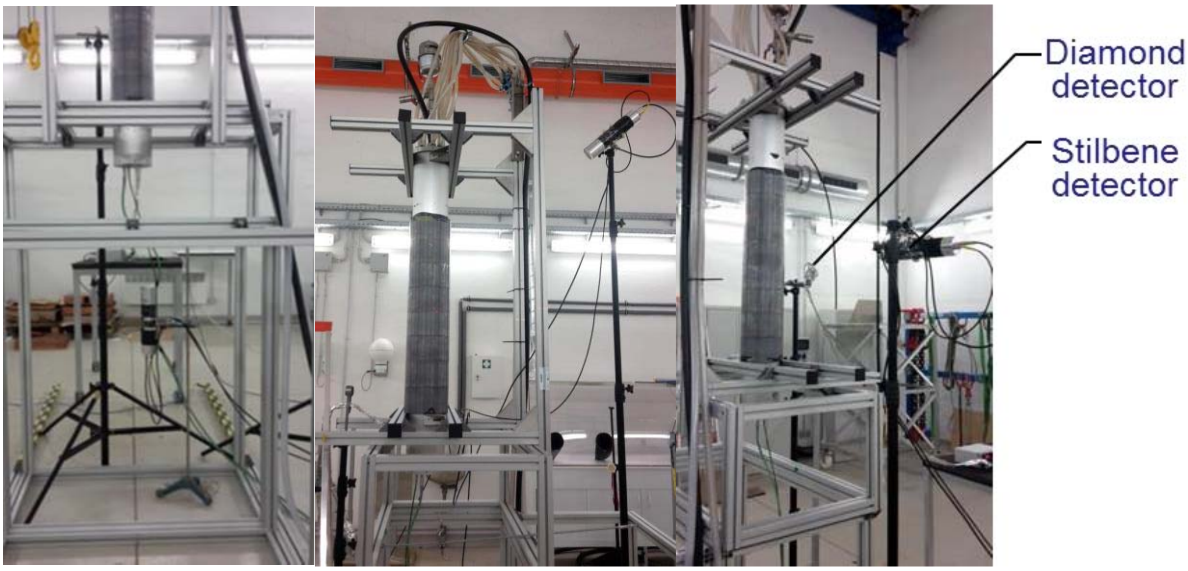

Figure 3. NG with a stilbene detector and a diamond detector placed in several measurement positions.

2.3. Simulations of neutron spectra

Theoretical models of both types of the generators for MCNP simulations have been created according to producer’s documentation. The results of simulations are shown in the graphs of the neutron spectra, see chapter 3.

2.4. NGA-01 Neutron Gamma Spectrometer

The NGA-01 spectrometric system consists of several parts. The first part is a detector, which in this case consists of the stilbene scintillation detector, Hamamatsu photomultiplier, and an active voltage divider. Thanks to the active voltage divider, based on MOS-FET transistors, we achieve excellent linearity parameters even at higher pulse rates per second (> 105) [3]. The second part of the spectrometric system is a preamplifier and digitizing card. The inputs for the selected detectors are matched impedance using the preamplifier, and the input signal is divided into two branches with different amplification (~1:8 ratio). Digitization takes place at a sampling frequency of 500 MHz at a resolution of 12 bits per input. Applied advanced integration method algorithms process single input pulses without death time directly in the gate array (FPGA) [4]. The last part of the system is a computer server with software. This makes it possible to connect to the device remotely and evaluate the measured data for spectral density of neutron fluxes and gamma radiation. The software provides many processing options and provides the user with the appropriate tools to further evaluate or set up the apparatus. It also provides tools for various types of detectors. Acquired recoiled proton spectra (or electron spectra in case of gamma field measurement) are then subjected to deconvolution by the Maximum Likelihood Estimation [5].

3. RESULTS

The measured neutron spectra of the VSB generator are in agreement with theoretical predictions. According to expectation the energy of the emitted neutrons depends on the angle between the deuteron beam and outgoing neutron beam. The results with a notable shift for various angles can be seen in Fig. 4. Due to relatively low energy of accelerated deuterons, a nearly symmetrical manner regarding the target plane can be expected. Such a manner is disturbed by the presence of a massive high voltage source which attenuates primary neutrons.

For validation of the stilbene measured characteristics a confirmatory measurement was realized using a diamond detector. The spectral shift was also studied on apparatus spectra (see Fig.5). It is worth noting that the shift in the diamond response was comparable with the stilbene one.

The calculated neutron spectra (see Fig. 6) are in a relatively good agreement with the experiment in the DT peak region and in the region 4 – 9 MeV while between 10 – 12 MeV and below 4 MeV significant discrepancies occur. The discrepancies below 4 MeV are most probably caused by the fact that calculational model does not take into account some deuterium in the target producing the DD peak in the neutron spectra. The discrepancies in the region 10 – 12 MeV most probably reflect the problems in description of the scattered neutrons.

The DT generator is placed in a relatively small lab, thus the quantification of the room effect becomes important. The background contribution in the DT reaction peak is negligible, while in lower energies plays a major role (Figs. 4 and 5). Very important seems the fact that the background rate is nearly constant for various orientations of the DT source. This effect reflects the small dimensions of the lab (Fig. 9).

In the case of the CVR generator an unconventional shape of the neutron spectra was measured. Also this shape was confirmed using the diamond detector. The physical explanation of such shape roots in geometry of the accelerating tube. The two peaks reflect two major cases where the accelerated particle can interact either in center in aperture or pass through it and interact with particles aiming to aperture. The maxima in these two cases differ because in the first case the incident particle hits the stationary particle, while in the second case the particle hits the particle with similar energy but opposite momentum (Fig. 8).

The result of simulation is shown in Fig. 7. A single neutron source is used for the simulation, i.e. a cathode such as a target, DT, a centered electric field with a potential of 80 kV, and in the case of a chamber, it contains accidentally simulated deuterons and tritons in a 1: 1 ratio [6].

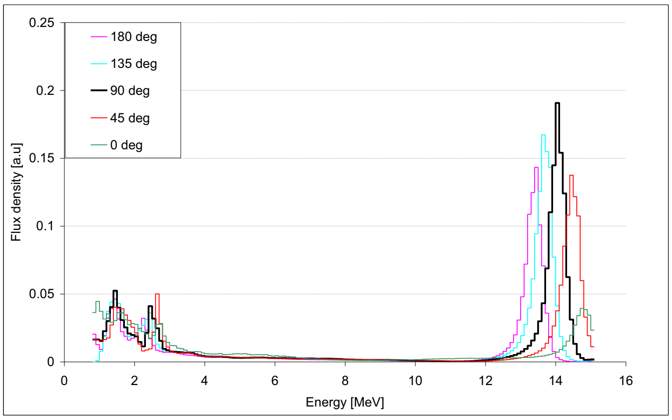

Figure 4. Neutron spectra in various angles from the Ostrava D-T generator.

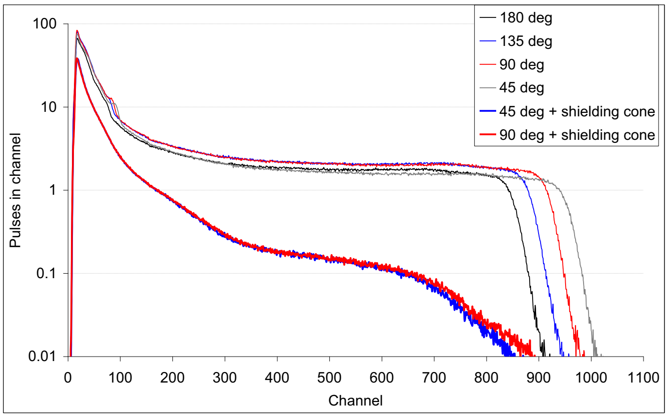

Figure 5. Apparatus spectra in various angles from the Ostrava D-T generator.

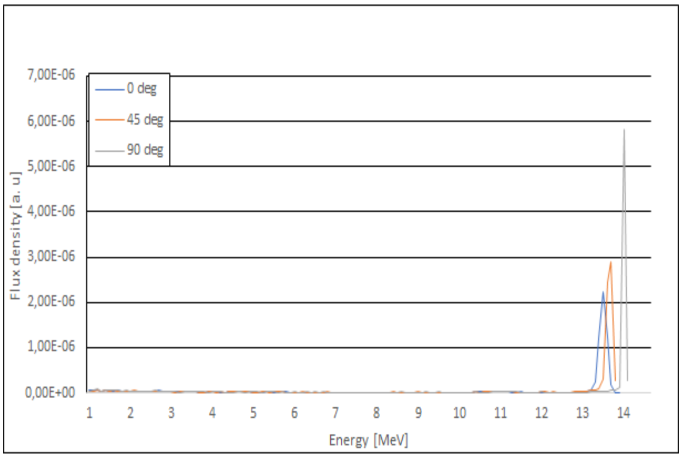

Figure 6. Simulated neutron spectra of the VSB neutron generator for various emission angles

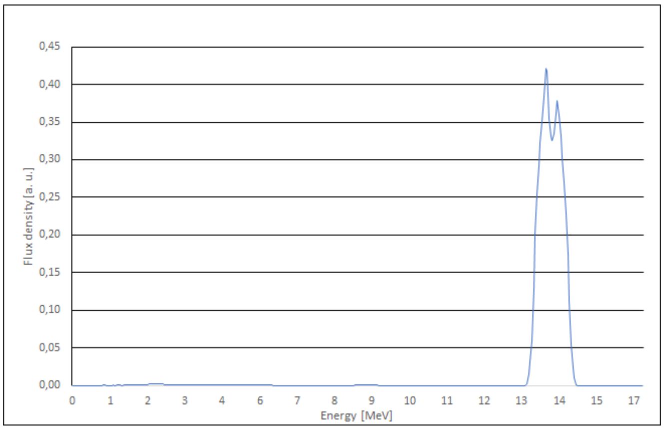

Figure 7. Results of the simulated neutron spectra for the IEC neutron generator.

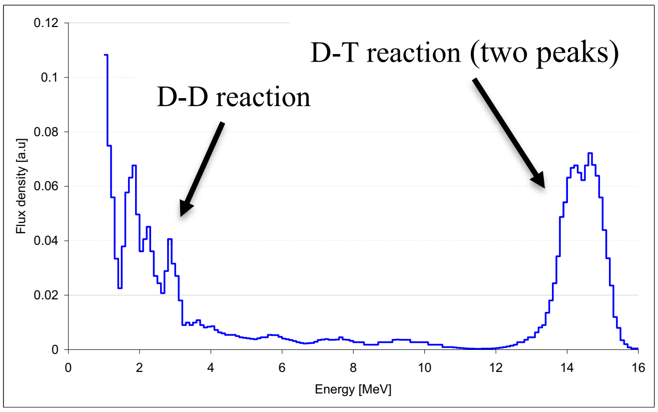

Figure 8. Neutron spectra of the Research Center Rez neutron generator

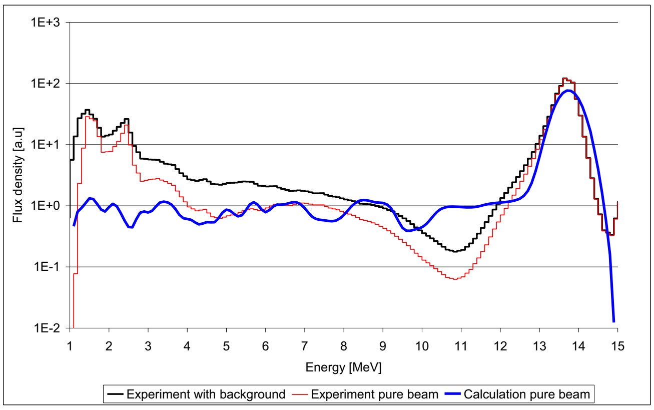

Figure 9. The room effect in the VSB lab

4. CONCLUSIONS

The neutron spectra from VSB and CVR neutron generators were characterized using spectroscopy system (NGA-01) with stilbene scintillation detector. Simulated neutron spectra for two types of the generators have been compared with experimental measurements. The measured spectra are in good agreement with theoretical simulations. In the case of solid target, the realized experiments confirm the shift in the neutron peak. The maximal energy is along the axis of the accelerated deuterons, the lowest in the opposite direction. In the volume source generator in CVR the spectra have two peaks confirmed by independent measurement by the diamond detector. The two peaks are reflecting the kinematics in the accelerator tube.

In case of the VSB neutron generator the room effect was qualified. It is worth noting that the contribution of scattered neutrons to the DT peak is negligible, while in lower energies their contribution is much higher than that of primary neutrons. Very important is the fact that the background rate is nearly constant in various orientations of the DT source. This effect reflects the small dimensions of the lab.

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