THE TIME-OF-FLIGHT TECHNIQUE FOR THE NEUTRON SPECTRUM MEASUREMENT ON VITA-FACILITY

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An innovative accelerator-based neutron source for the boron neutron capture therapy (BNCT) has just started operation at Budker Institute of Nuclear Physics, Novosibirsk. Designed parameters are: proton beam current up to 10 mA and proton energies from 1.915 to 2.5 MeV. One of the main questions is the measurement of the neutron spectrum produced in the ^{7}Li(p, n)^{7}Be reaction by protons with near-threshold energy. The near-threshold operation is supposed to be the most promising for BNCT. To measure the neutron spectrum the special time-of-flight technique based on blinking accelerator method has been proposed. The innovative idea supposes that the accelerator operates in continuous mode with proton energy 1.87 MeV, which is lower then the reaction threshold. The neutron producing target is powered by ~ 50 kV 200 ns high voltage pulses, which cause the rising of proton energy up to 1.92 MeV and neutron pulse generating. The HV pulse generator has been developed and tested. Several specific measures have been taken to reduce the noise caused by generating of high voltage short pulses. The exact neutron production threshold has been measured. First experimental results about neutron spectrum are to be obtained by June 2010.

1. Introduction

Currently, at the Budker Institute of Nuclear Physics the source of epithermal neutrons based on a vacuum insulation tandem accelerator (VITA) for BNCT realization [1] is constructed and launched. The generation of neutrons occurs as a result of the threshold reaction ^{7}Li(p, n)^{7}Be, when the accelerated proton beam hits the lithium target. An important task is to measure the resulting neutron spectrum.

In first experiments on the neutron generation the preliminary conclusion about the character of the neutron spectrum was made using bubble detectors [2]. To obtain more accurate data about the neutron spectrum it is proposed to use the time-of-flight (TOF) technique with an original way of generating short pulses of neutron radiation.

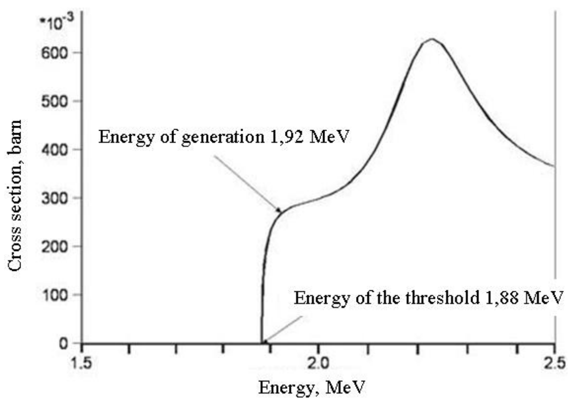

Fig. 1. The cross section of the ^{7}Li(p, n)^{7}Be reaction depending on the proton energy.

The near-threshold operation, when the proton beam energy slightly exceeds the threshold of the reaction ^{7}Li(p, n)^{7}Be (1.882 MeV), appears to be the most promising. In this case, due to the kinematic collimation, the neutrons are emitted mostly forward and have a relatively low energy - 40 keV, so just a very small moderation of these neutrons is required for BNCT. The opportunity of realization of such near-threshold mode (in terms of obtaining the required neutron flux density) arises due to an unusually rapid increase of cross section of the reaction ^{7}Li(p, n)^{7}Be (Fig. 1). In this paper, to measure the spectrum of neutrons using TOF method, it is proposed to implement a pulse neutron generation by applying high voltage short pulses to the lithium target previously isolated from the facility. Thus, when the proton beam energy is 1.87 MeV, neutrons are not generated, but the supply of 200 ns 50 kV pulse to the target leads to the generation of neutrons during these 200 ns. So the spectrum can be obtained measuring the time of flight by a remote detector.

In this paper the method of generation of neutron pulses and the diagnostic system are described, and the results of the first experiments are presented.

2. Formation of high-voltage pulses

Rectangular high-voltage pulses are created using the 50 kV dc voltage generator on the basis of the double pulse forming line and thyratron TPI-1 10 kA/50 kV serving as a key and operating at the frequency 100-200 Hz. The Fig. 2 demonstrates the oscilloscope traces of the exit unit voltage, registered with high voltage divider. As it is seen, this pulse has practically rectangular shape with duration 200 ns and leading/falling edge durations 20 ns/30 ns respectively, which is acceptable for measurement accuracy. Rectangular pulses with duration 200 ns and amplitude 45 kV have been applied on an isolated target (Fig. 3) with no breakdowns at a frequency up to 200 Hz. To suppress high-frequency noise affecting on the equipment the inductance of the shunt resistors has been reduced, a grounded shield of copper getinaks has been installed. For the diagnostic system the specially designed noise-immune box has been constructed.

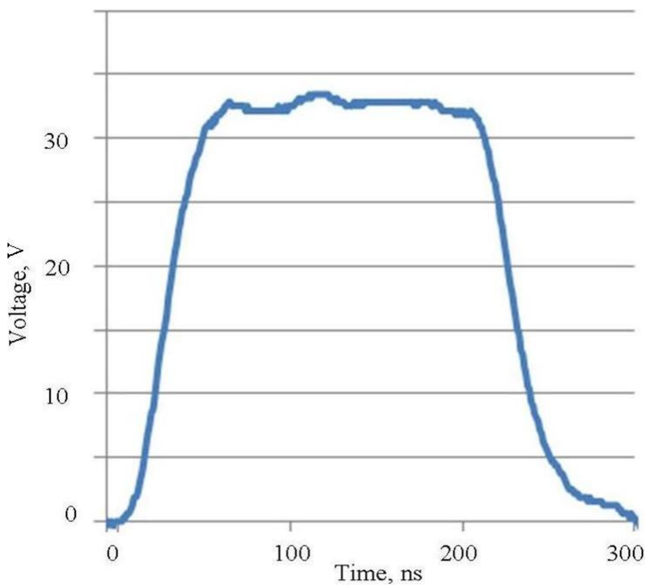

Fig. 2. Signal of the high voltage divider, proportional to the voltage on the exit unit (the amplitude of the pulse is 40kV).

Fig. 3. The photo of the neutron producing target suspended on the ceramic insulator.

3. Registration of neutrons

The registration of neutrons is made with neutron detector Saint-Gobain 709M.157GS20/1.12L, consisting of cerium activated lithium silicate glass scintillator GS20 mounted on photomultiplier Hamamatsy R6095. Registration of neutrons occurs due to the reaction $^{6}Li + n \rightarrow {}^{3}H + \alpha + 4.785$ MeV in the scintillator. Products of the reaction - the α-particles - cause 60 ns scintillation pulses registered by photomultiplier. Using of the special lithium silicate glass GS20 allows extending the region of effective neutron registration up to 500 keV. Calculated detection efficiency as a function of neutron energy for this scintillator [3] is presented in Fig. 4.

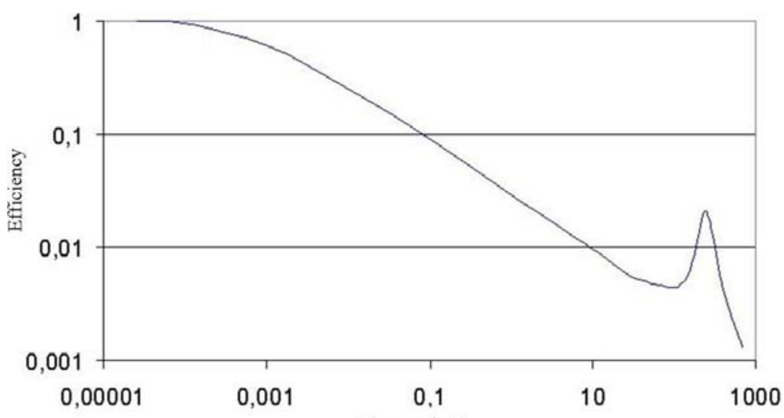

Fig. 4. Calculated detection efficiency as a function of neutron energy for the scintillator GS20.

The stabilized high-voltage power source MHV12-1.5K1300P (TRACO Electronics, Japan) assembled with the accumulator (Figs. 5 - 6) is used to supply the detector. Such assembly avoids the extra wires and induced noise. The detector is located at a distance 2 m from the target.

To measure the time of flight of neutrons a single-channel multistop time-to-digital converter is used. It digitizes the time intervals between signals START and STOP in the range up to 100 ms with 100 ns steps. The error in time measuring is 0.05%. After the signal START converter is able to accept eight signals STOP, which allows registering during the one pulse up to 8 neutrons with energies from 2 eV up to 2 MeV.

Fig. 5. Photo of the detector and power source separately.

Fig. 6. The detector and power source assembled together with the accumulator.

4. Evaluation of the time required to gather statistics

At a proton beam current 10 mA and proton energy 1.915 MeV full neutron flux is $2.88 \cdot 10^{11}$ s^{-1} [4]. Assuming the flux is isotropic in all directions, knowing the pulse duration 200 ns and frequency 100 Hz, we can calculate that the number of neutrons, which will pass through the scintillator per 1 s, is equal to 28.8.

Let's evaluate the time required to gather statistics using our TOF method. If we define 10 intervals in the energy spectrum of neutrons, we should collect about 100 events in each interval for a satisfactory statistical accuracy. Thus, we need about 1000 registered neutrons. Assuming that the average detection efficiency is 10 %, we obtain the time needed to gather statistics ~ 347 s. Given that the detection efficiency of neutron with energy 10 keV is ~ 1 % (see Fig. 4), we will need the TOF diagnostics working about 57 min for good statistical accuracy for high-energy neutrons.

This is a reasonable time, because it is less than the "lifetime" of the lithium target, which is limited by blistering and induced activity [5].

5. Experiments

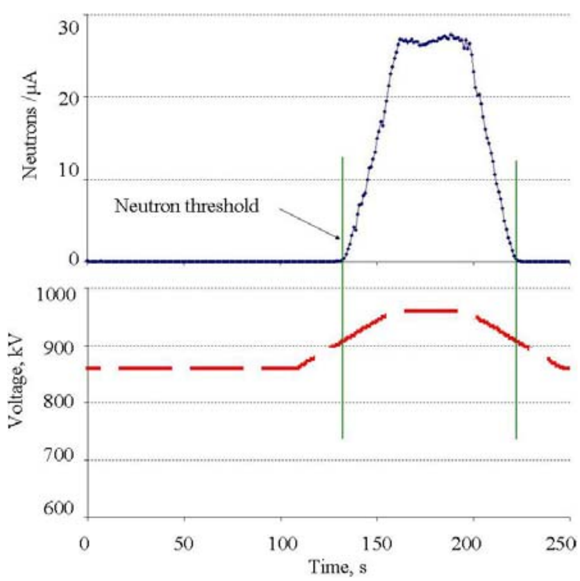

Fig. 7. The exact neutron production threshold. Interrupted line shows the voltage on a tandem depending on the time, solid line - the number of neutrons registered by the detector at this time and divided to the unit of proton beam current.

The above-described diagnostic system was assembled, calibrated and tested using α-Be neutron source. Then the exact threshold of the $^{7}Li(p, n)^{7}Be$ reaction was measured (Fig. 7). To do this, the voltage on the accelerator has been raised from 860 to 960 kV linearly with 1 kV/s rate, while at the same time the count rate of the neutron detector has been noted. After the voltage on the accelerator reached 960 kV it has been lowered at the same rate back to 860 kV.

5. Conclusion

At the Budker Institute of Nuclear Physics the VITA-facility for the boron neutron capture therapy is constructed. To measure the neutron spectrum the unique TOF technique based on the blinking accelerator method is proposed. Neutron pulses are created by applying high voltage pulses on the isolated neutron producing target. The assembled diagnostic system is described, it is calibrated and tested. Preparations for the experiment of measuring the neutron spectrum are made; several steps to reduce noise are taken.

In the near future long-term stable neutron generation and neutron spectrum measurement using TOF technique are planned.

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