Applied Radiation and Isotopes 69 (2011) 1639–1641

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

New technical solution for using the time-of-flight technique to measure neutron spectra

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ARTICLE INFO

Available online 15 February 2011

Keywords:
Time of flight
Neutron spectra
Epithermal neutrons

ABSTRACT

New technical solution is proposed for using the time-of-flight technique to measure neutron spectra on VITA-facility. During 200 ns the energy of protons increases from 1.865 up to 1.915 MeV by supplying the square pulse of 50 kV on the neutron-generating target, which is isolated from facility body. During these 200 ns the generation of neutrons is performed. The spectrum can be obtained measuring the time of flight by a remote neutron detector.

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 (Bayanov et al., 1998) 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 the initial experiments on neutron generation the preliminary conclusion about the character of the neutron spectrum was made using bubble detectors (Bayanov et al., 2009). To obtain more accurate data about the neutron spectrum it is proposed to use the time-of-flight technique with an original way of generating short pulses of neutron radiation.

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 of –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 the time-of-flight 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 1.865 MeV, neutrons are not generated, but the supply of 50 kV pulse for 200 ns 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 initial 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.

To reach the high repetition rate of the modulator pulses (200 Hz) we applied the pulse feed circuit (see Fig. 2). This circuit provides the pause of charging current of a few microsecond duration needed for plasma recombination in thyratron. Moreover this circuit permits decreasing substantially the required voltage of external rectifier due to doubling of charging voltage on pulse forming line. In the result of applying the pulse feed circuit the repetition rate of the modulator was increased up to 200 Hz at a pulse amplitude of 45 kV. In test experiments the registered shape of the pulses on the equivalent resistive load *R* was not changed in time and met the requirements of the experiment on measuring the neutron spectrum.

To measure and monitor the parameters of the high-voltage pulses directly at the facility where the neutron producing target is placed, a few diagnostics have been created. They include Rogovsky coil for current measurements and the wideband high-voltage divider for registering the pulse voltage directly at the exit unit. The initial measurements have shown that the quasi-rectangular shape of the voltage pulse was distorted by parasitic oscillations, appeared in the circuit due to the capacity of the exit unit and the inductance of the commutation line. To minimize these distortions we optimized the commutation circuit so that these parasitic oscillations do not exceed the 5% of the pulse amplitude.

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doi:10.1016/j.apradiso.2011.02.014

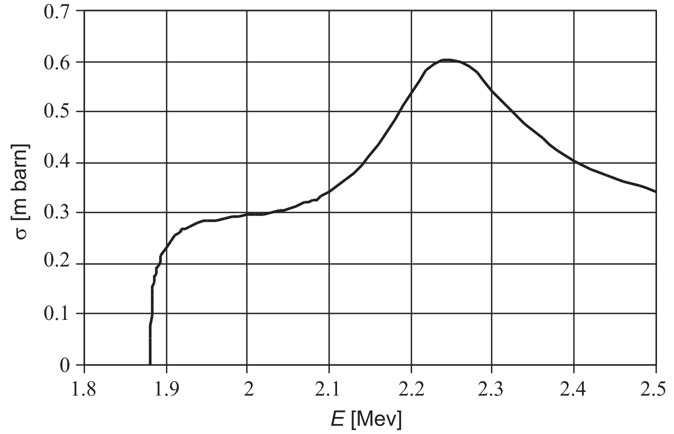

Fig. 1. Cross-section of the ^{7}Li(p,n)^{7}Be reaction depending on the proton energy E.

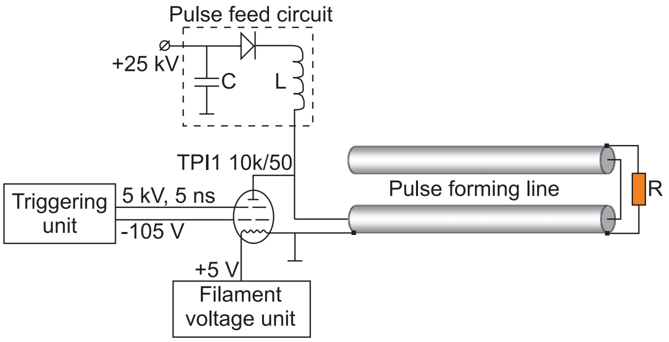

Fig. 2. Schematic drawing of high-voltage pulse modulator with feed circuit.

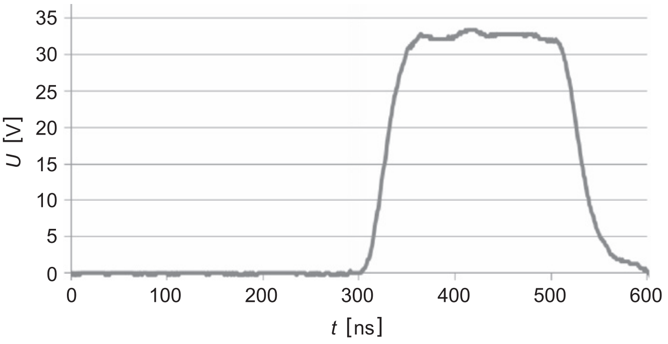

Fig. 3. Signal of the high-voltage divider, proportional to the voltage on the exit unit (the amplitude of the pulse is 40 kV).

A typical oscillogram of the high-voltage pulse is shown in Fig. 3. As it is seen, this pulse has practically rectangular shape with duration 200 ns and leading/falling edge durations 20/30 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 with no breakdowns at a frequency up to 250 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 a specially designed noise-immune box has been constructed.

3. Registration of neutrons

The registration of neutrons is made with neutron detector Saint-Gobain, consisting of cerium activated lithium silicate glass scintillator GS20 with diameter 18 mm and thickness 4 mm mounted on photomultiplier Hamamatsu R6095. Registration of neutrons occurs due to the reaction $^6\text{Li}+\text{n}\rightarrow{}^3\text{H}+\alpha+4.785$ MeV in the scintillator. Products of the reaction – the α-particles – cause 60 ns scintillation pulses registered by photomultiplier. Usage 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 (Zetterström et al., 1966) is presented in Fig. 4.

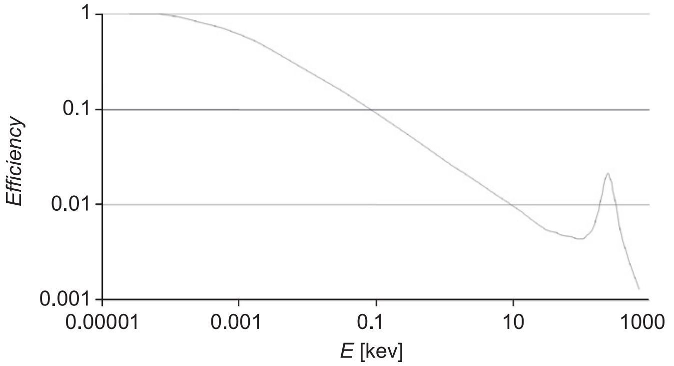

Fig. 4. Calculated detection efficiency as a function of neutron energy for the scintillator.

The stabilized high-voltage power source MHV12-1.5K1300P (TRACO Electronics, Japan) assembled with the accumulator (Fig. 5) is used for the detector supply. Such assembly avoids the extra wires and induced noise. The detector is located at a distance of 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 in the range up to 100 ms with 100 ns steps between START signal (which is synchronized with the leading edge of high-voltage pulse on target) and STOP signal from the neutron detector. The error in time measuring is 0.05%. The START signal converter is able to accept eight STOP signals, which allows registering during the one pulse up to 8 neutrons with energies from 2 eV up to 2 MeV.

4. Evaluation of the time required to gather statistics

At a proton beam current of 10 mA and proton energy of 1.920 MeV, the calculated total neutron yield is $3.66\times10^{11}\,\text{s}^{-1}$ (Bayanov et al., 1998). Assuming the flux is isotropic in all directions, knowing the pulse duration 200 ns, distance 2 m from the target and scintillator diameter 18 mm, we can calculate that the number of neutrons that will pass through the scintillator per pulse is equal to 0.37.

Let us 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 ~270 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 45 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 (Bayanov et al., 2010).

5. Experiments

The above-described diagnostic system was assembled, calibrated and tested using α-Be neutron source. Then the exact

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

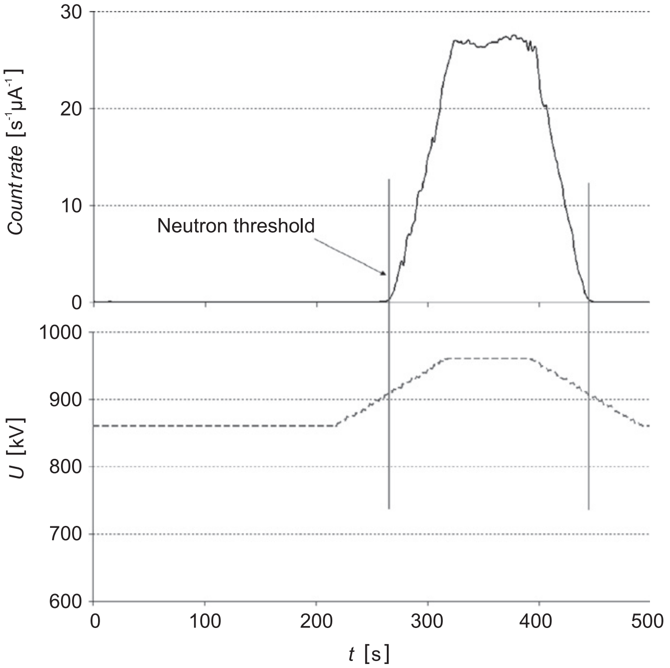

Fig. 6. Exact neutron production threshold. Interrupted line shows the voltage on a tandem depending on the time; solid line shows the number of neutrons registered by the detector at this time and divided to the unit of proton beam current.

threshold of the ^{7}Li(p,n)^{7}Be reaction was measured (Fig. 6). 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. This experiment means that voltage 910 kV of the accelerator corresponds to the proton energy 1.882 MeV, and this voltage will be used to measure the neutron spectrum with proposed TOF technique.

6. Conclusion

At the Budker Institute of Nuclear Physics the VITA-facility for the boron neutron capture therapy is constructed. To measure the neutron spectra 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 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.

Acknowledgment

This work was supported by the Ministry of Education and Science of Russian Federation (federal program “Scientific and scientific-pedagogical personnel of innovation Russia”).

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