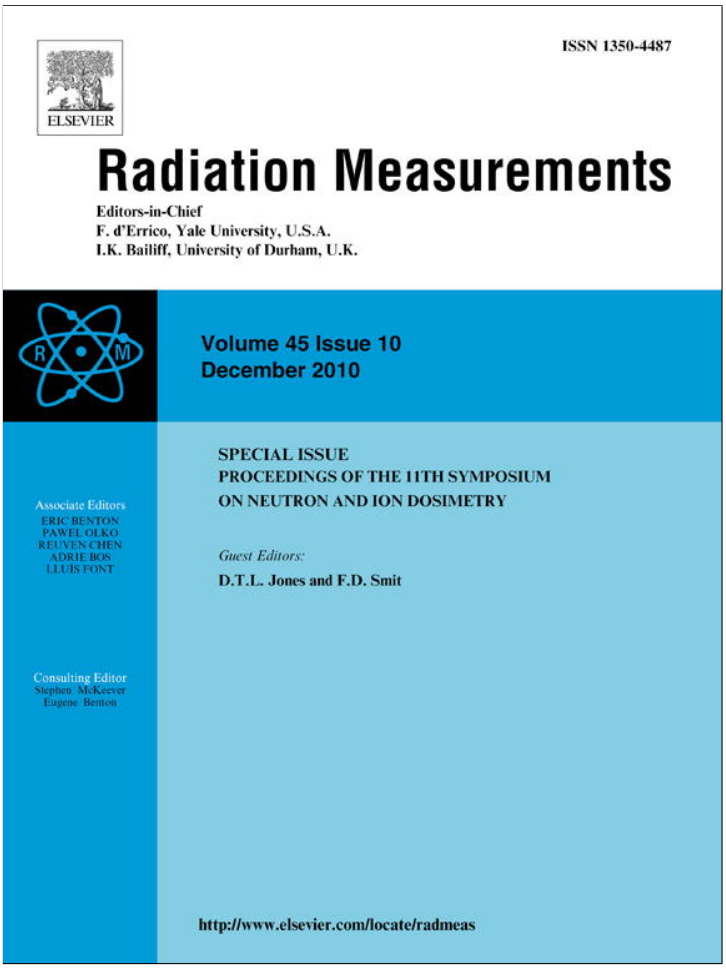

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Dosimetry and spectrometry at accelerator based neutron source for boron neutron capture therapy

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ABSTRACT

An innovative accelerator-based neutron source for boron neutron capture therapy has started operation at the Budker Institute of Nuclear Physics, Novosibirsk. This facility is based on a compact vacuum insulation tandem accelerator designed to produce proton current up to 10 mA. Epithermal neutrons are proposed to be generated by 1.915 MeV protons bombarding a lithium target using ^{7}Li(p,n)^{7}Be threshold reaction.

In the article, techniques to detect neutron and gamma-rays at the facility are described. Gamma radiation is measured with NaI and BGO gamma-spectrometers. The total yield of neutrons is determined by measuring the 477 keV γ-quanta from beryllium decay. For the rough analysis of the generated neutron spectrum we used bubble detectors. As the epithermal neutrons are of interest for neutron capture therapy the NaI detector is used as activation detector. We plan to use a time-of-flight technique for neutron spectra measurement. To realize this technique a new solution of short time neutron generation is proposed.

Introduction

Presently, boron neutron capture therapy (BNCT) (Locher, 1936) is considered to be a promising method for the selective treatment of malignant tumors. The results of clinical tests, which were carried out using nuclear reactors as neutron sources, showed the possibility of treating brain glioblastoma and melanoma metastases not subject to treatment by other methods (Hatanaka, 1990, Hatanaka and Nakagawa, 1994). The broad implementation of the BNCT in clinics requires compact inexpensive sources of epithermal neutrons. In 1998 the source of epithermal neutrons based on an electrostatic tandem accelerator with vacuum insulation was proposed (Bayanov et al., 1998). In this source, a 10-mA beam of 1.915 MeV protons bombarding a lithium target produces neutrons via ^{7}Li(p,n)^{7}Be reaction (with a threshold at 1.882 MeV). The resulting flux of neutrons with an average energy of 40 keV can be used, after slight moderation, for BNCT purposes.

Recently, a pilot variant of the accelerator-based neutron source for boron neutron capture therapy has started operation at the Budker Institute of Nuclear Physics, Novosibirsk (Kuznetsov et al., 2009), which produces a stationary beam of protons with an energy of 1.92 MeV and a current of up to 3 mA. This article presents the dosimetry and spectrometry techniques used and results obtained at experiments on neutron generation.

Dosimetry and spectrometry techniques

Gamma radiation arising in the proton-bombarded target was registered by a detector based on a NaI crystal (Ø6 × 6 cm) and a Photonis XP3312B photoelectron multiplier, which was equipped with a collimator, a high-speed spectrometric analog-to-digital converter, and a processor with special software for analysis of the spectrum of γ-quanta. The detector was usually arranged at a distance of 222 cm behind the neutron-generating target and protected by a lead shield with a wall thickness of ~10 cm and, in some cases, with a boron-doped polyethylene screen. The dimensions of the input hole of the collimator were 10 × 15 mm. The gamma spectrometer was calibrated with respect to a ^{40}K spectral line registered in the background radiation and with respect to radioisotope sources of ^{60}Co and ^{137}Cs. Fig 1a, b shows respectively the spectra of γ-quanta measured at a proton energy of 1.7 MeV (i.e., below the threshold of reaction with a neutron yield) and 1.92 MeV. The spectrum obtained in the subthreshold regime exhibits a pronounced line at 477 keV, which is related to the

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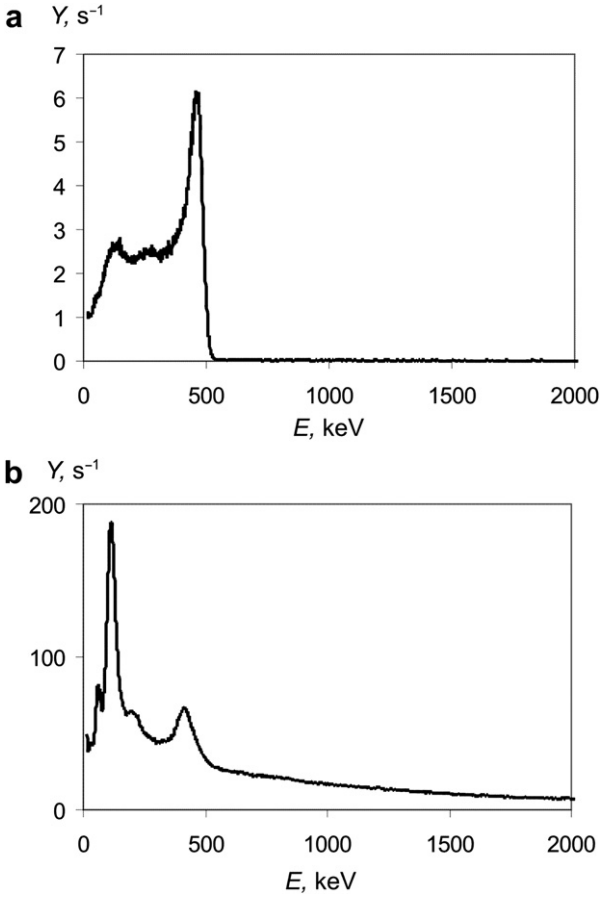

Fig. 1. Typical γ-spectra measured at a proton energy of (a) 1.7 MeV and (b) 1.92 MeV.

excitation of lithium nuclei by protons. In the regime of neutron production, additional γ-quanta appear due to the capture of neutrons by structural materials of the facility and (predominantly) by iodine nuclei in the scintillator crystal, which was checked by additional screening of the detector with boron-doped polyethylene that significantly attenuated neutron flux.

Possessing high sensitivity with respect to neutrons, the NaI detector could be used in the activation mode. The ^{128}I isotope

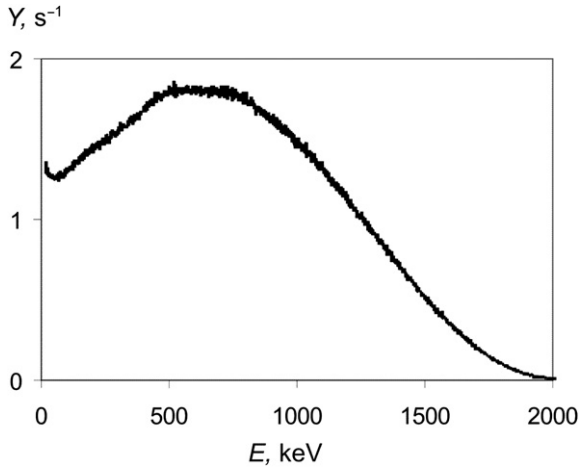

Fig. 2. Typical γ-spectrum of the activated NaI detector.

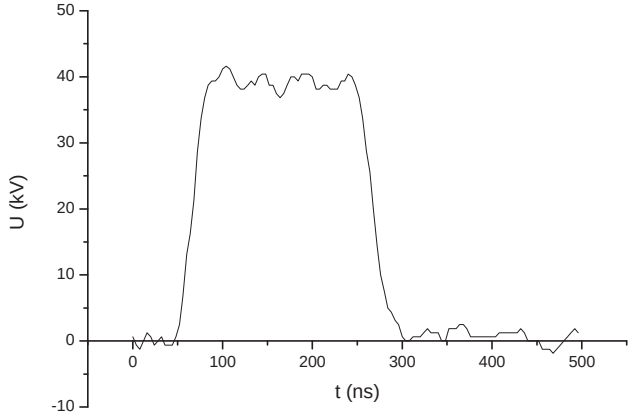

Fig. 3. Signal of the voltage on the matched load.

formed upon capturing a neutron has the half-decay time of 25 min. The decay proceeds in 6.4% cases with electron trapping via a non-radiative channel and in 93.6% cases with electron emission (β^- decay) with energies up to 2.12 MeV. In addition to ^{128}I, there also appears the ^{24}Na isotope at a rate of about 2% of that for ^{128}I. Fig. 2 shows the spectrum measured using the activated detector upon neutron generation, which is typical of the β^- decay. Using the neutron count rate and generation time, it was possible to determine neutron flux.

Since the production of every neutron via ^{7}Li(p,n)^{7}Be reaction is accompanied by the formation of a radioactive ^{7}Be isotope with the half-decay time of 53 days, the residual activity of a lithium target is used to determine the total neutron yield.

The rough analysis of the spectrum of generated neutrons was performed using bubble detectors of the BDT and BD100R types (Bubble Technology Industries, Canada). The BDT device comprised of a transparent vessel with a polymer containing dispersed overheated liquid. The liquid composition is selected so as to achieve maximum sensitivity for thermal neutrons. In contrast, BD100R is most sensitive to neutrons with the energies above 100 keV.

The time-of-flight technique is proposed for neutron spectra measurement. For a short interval of time the energy of proton increases from 1.865 MeV (lower than the threshold of the ^{7}Li(p,n)^{7}Be reaction i.e. 1.882 MeV) up to 1.915 MeV. The energy increase is performed by supplying the square pulse of 50 kV for 200 ns on the neutron-generating target that is isolated from the facility body. During these 200 ns the generation of neutrons is performed. The registration of neutrons is made with a Saint-Gobain neutron detector, consisting of cerium activated lithium silicate glass scintillator GS20. This detector prolongs the region of effective neutron registration up to 500 keV. The neutron spectrum is detected according to the time of delay in its registration. The high voltage modulator for time-of-flight technique has been created. It consists of: the high-voltage pulse commutator on the base of industrial thyratron with hollow cathode TPI-1 10 kA/50 kV; the unit for creation of heater voltage; the triggering unit and the double pulse forming line. The result of measuring the high-voltage pulse of the modulator on matched load of pulse forming line $R = 150$ Ohm at the test frequency 50 Hz is shown in Fig. 3. As seen this pulse possesses practically rectangular shape with the duration 200 ns at the leading and falling edges durations 18 ns and 25 ns respectively. The amplitude of the pulse in this testing experiment was 40 kV.

Conclusion

Dosimetry and spectrometry techniques are proposed and developed for neutron generation at accelerator based epithermal neutron source.

Acknowledgements

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