Measurement of neutron-induced radioactivity in animal tissue

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Introduction

The basis of neutron radiotherapy is to induce the decay of ^{10}B to ^{7}Li, an alpha particle and gamma ray. Emitted particles deposit dose in surrounding cancer cells what lead to their death. Neutron beams can also lead to production of other radioactive isotopes which lives longer than $^{11}B^*$. The main goal of our project is to measure the induced radioactivity in human tissues after the irradiation and identify the produced radioisotopes and estimate the dose from those nuclides. The secondary aim of this work is the validation of simulation calculations in comparison with experimental results.

Motivation

This project is motivated by lack of sufficient knowledge about long-lived radioisotopes which can be produced during therapy. Next to high linear transmission of energy, the high efficiency of boron neutron capture therapy can also be enhanced by induced radioactivity. During radioactive decays, different particles (which deposit energy in surrounding tissues) are emitted and the synergistic effect can occur. The effect of mixed radiation is higher efficiency of tumour cell killing than for separated radiation.

Main goals of the project

1. Identification of isotopes produced during irradiation with gamma spectroscopy with respect of Monte Carlo predictions.
2. Determination of amount of produced radioisotopes.

Materials and Methods

In order to estimate which radioisotopes are produced during the irradiation, the GATE/Geant4 Monte Carlo code was used [1, 2]. For tissue materials, the pig liver and beef bone were chosen. The experiment has been performed at the Faculty of Physics on the University of Warsaw. The neutron beam of the energy spectrum presented in Figure 1 has been provided by PuBe neutron source and samples were irradiated by 1 week. The intensity of the neutron beam is around $1.5 \cdot 10^3 \frac{neutrons}{cm^2}$. To achieve the most noiseless measurement the low-background spectrometer based on NaI and $LaBr_3$ scintillators were used.

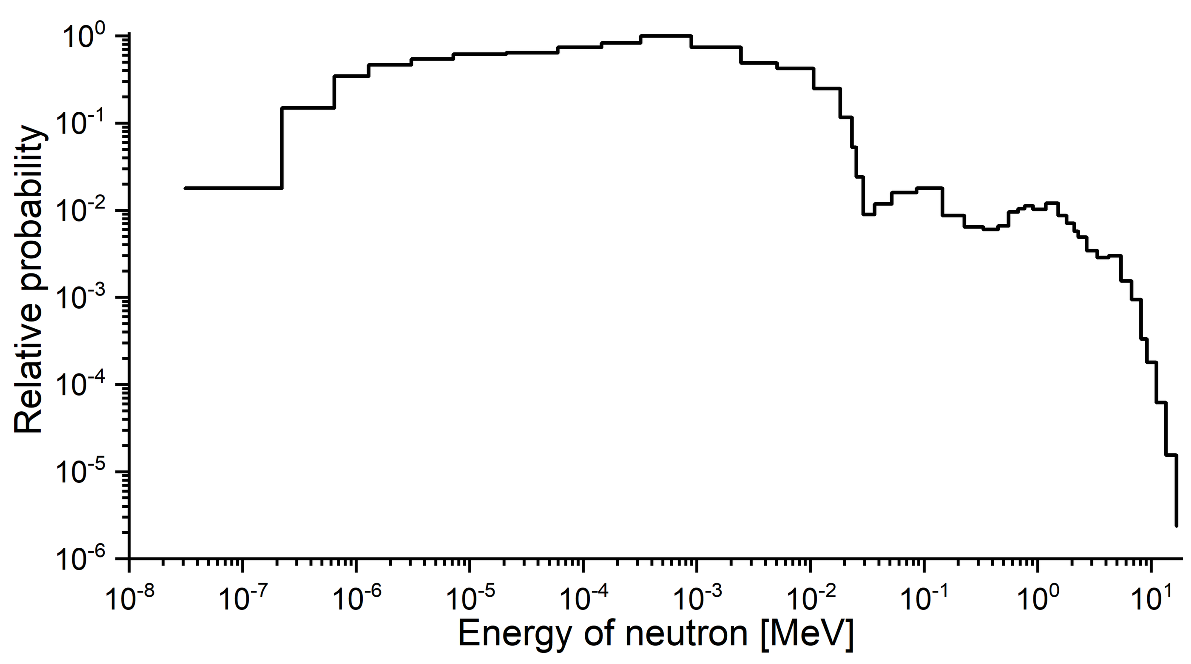

Figure 1: Energy spectrum of neutron beam from PuBe source. This data was also used for GATE simulation of neutron irradiation.

Results

The Monte Carlo calculations give an information about the most intense, for gamma spectroscopy, radioisotopes produced within the samples by neutron irradiation. Radioisotopes that are intensively produced within the liver sample during the neutron irradiation are ^{24}Na, ^{28}Al and ^{31}Si. In case of the bone sample the radionuclides like ^{28}Al, ^{31}Si and ^{40}K are produced. Figure 2 presents the theoretical spectrum of gamma radiation emitted by a sample of bone after neutron irradiation obtained by GATE.

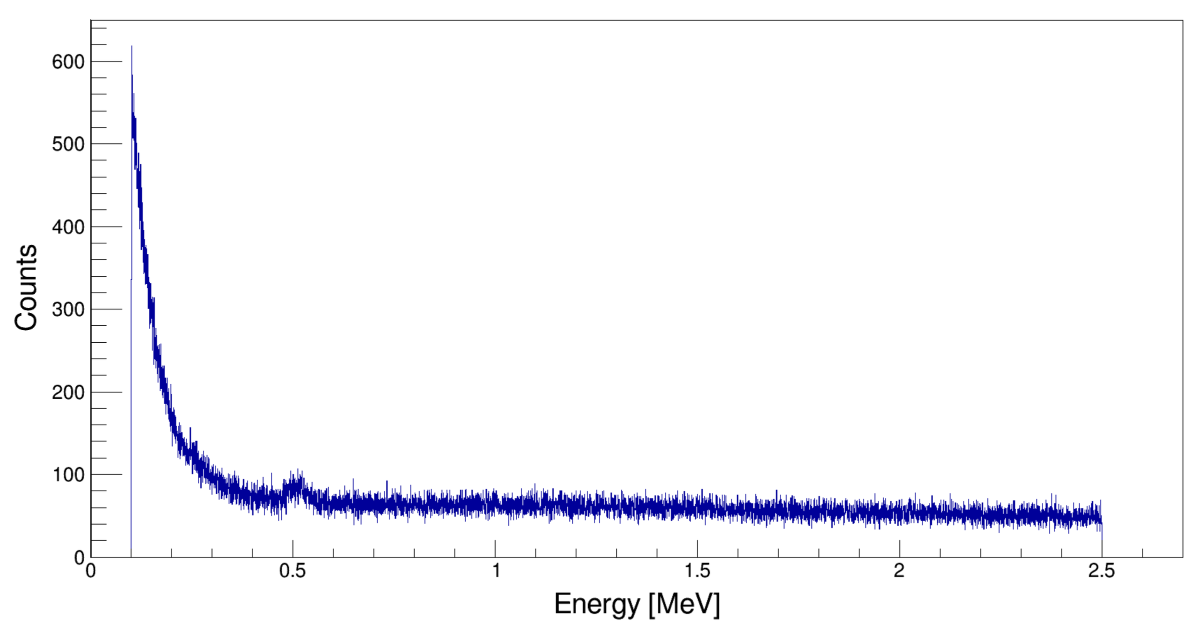

Figure 2: Gamma spectrum of the irradiated bone sample measured by NaI detector obtained by simulation. Irradiation calculated for 2.5 10^6 neutrons. The energy spectrum *measured* by 10^5 seconds.

Figure 3 presents the energy spectrum of irradiated bone obtained by $LaBr_3$ scintillator detector. There are three notable peaks: 470 keV, 1460 keV and in the range 1800-2700 keV. ^{138}La is the source of the peak around 1460 keV and bump starting from 750 keV. Peaks from 1800 keV to 2700 keV are originated by ^{227}Ac and its daughters. Those isotopes produce the intrinsic background of $LaBr_3$ scintillator. The peak around 470 keV is not easily identifiable.

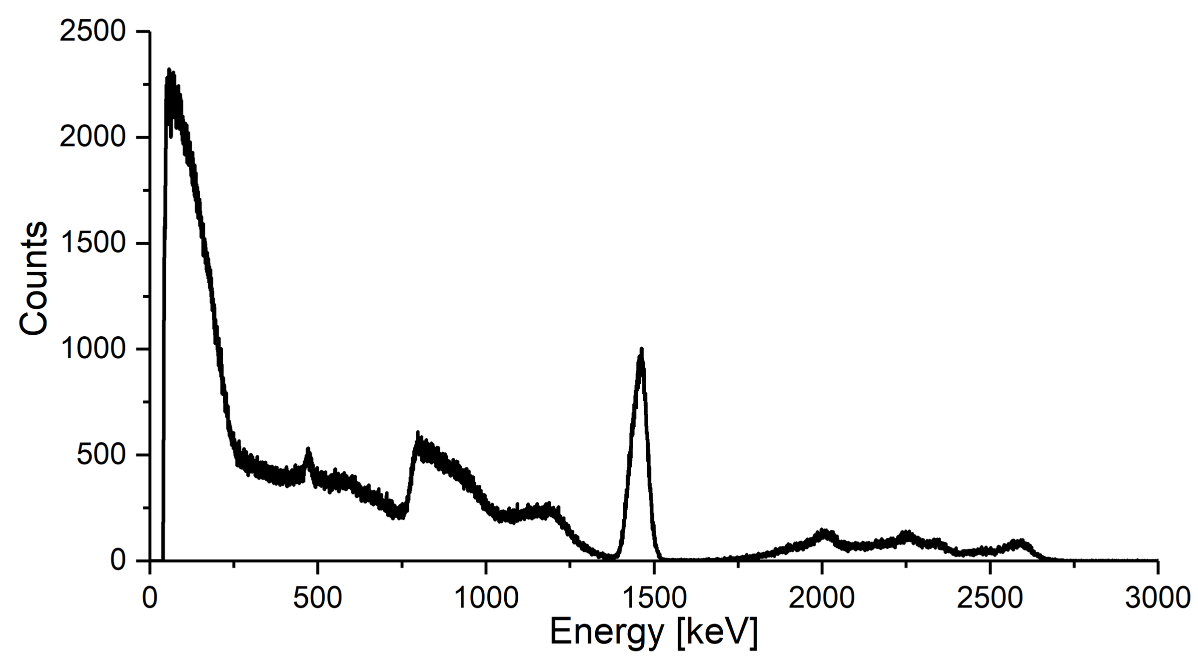

Figure 3: The energy spectrum of irradiated bone obtained by $LaBr_3$ detector measuered by 1 week.

For better distinguish the produced isotopes, from the spectrum in Figure 3 the background was substracted. The obtained spectrum (Figure 4) is similar to present one in Figure 2, but the energy and shape of the peak near 500 keV are slightly different.

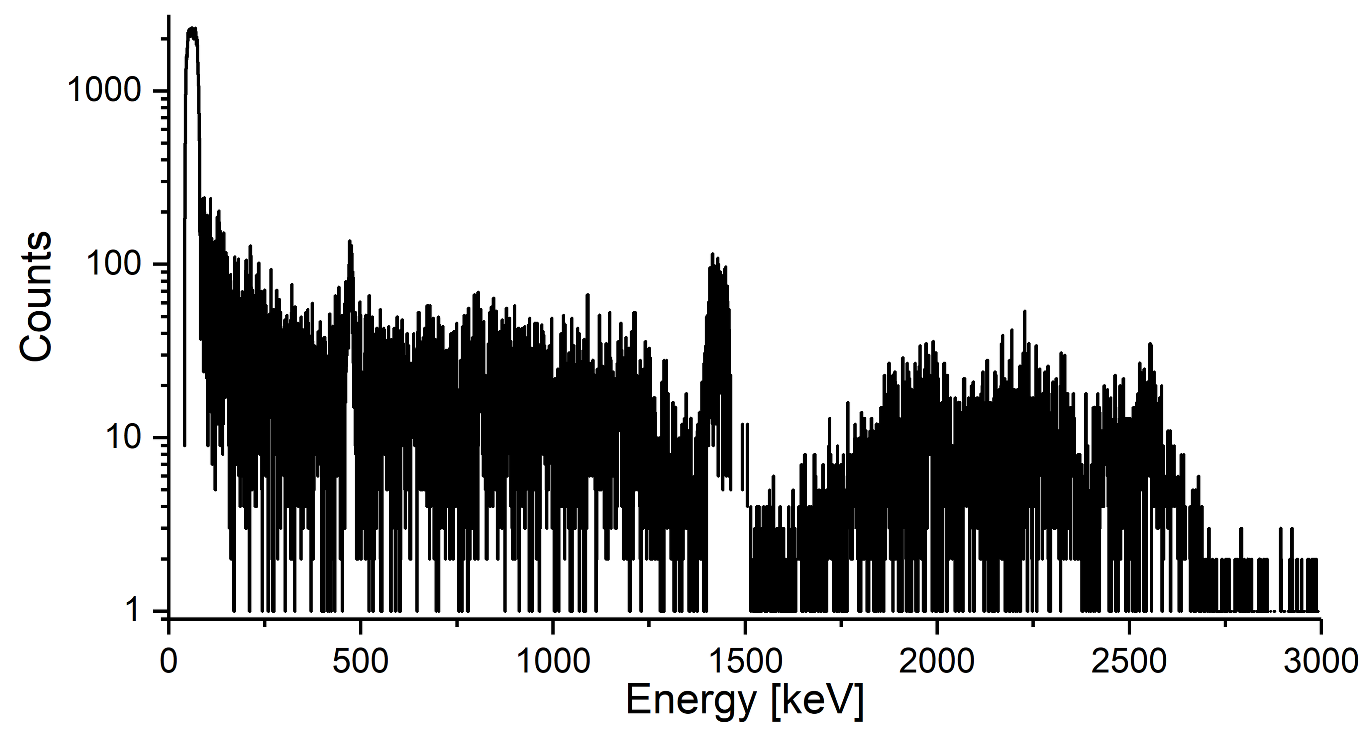

Figure 4: The energy spectrum of irradiated bone obtained by $LaBr_3$ detector with substracted background radiation.

Conclusions

In contrary to the proton-induced, the neutron-induced radioactivity is very difficult to measure, especially because of the lack the annihilation gammas and beta decaying isotopes without emitting gamma photons. Still, there is need to estimate the risk from the radioactivity induced by neutrons on which BNCT treatment patients are exposed to.
Based on the theoretical calculations, one can conclude that a lot of radioisotopes are created in human tissues. For example, the ^{24}Na can wash out from the irradiated volume and circulate through patients body with blood [3]. That is why the dose from induced radioactivity cannot be omitted in calculations of received total dose. In addition, some of the mentioned above nuclides (because of high cross-section for production) can be useful for off-line measurements of fast neutron fluence.

Forthcoming Research

The next step of this project is to use the beta spectrometers to estimate the amount of gamma-less beta-emitters. During Boron Neutron Capture Therapy the beam of neutrons is more intense and less energetic than in PuBe neutron source. That is why simultaneously with beta spectroscopy measurement the experiment will be extended for the *medical* neutrons.

References

[1] S. Jan et al. Gate: a simulation toolkit for pet and spect. *Physics in Medicine and Biology*, 49(19):4543, 2004.

[2] S. Agostinelli et al. Geant4 - a simulation toolkit. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 506(3):250, 2003.

[3] Keiko Fujiwara et al. Induced radioactivity in the blood of cancer patients following boron neutron capture therapy. *Journal of Radiation Research*, 54(4):769, 2013.