Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Applied Radiation and Isotopes 61 (2004) 849–852
Applied Radiation and Isotopes
www.elsevier.com/locate/apradiso

Development of equipments for determination of BNCT source spectral parameters

J. Burian[a,*], B. Jansky[a], M. Marek[a], E. Novak[a], L. Viererbl[a], A.C. Fernandes[b], Yu.A. Kaschuck[c], L.A. Trykov[d], V.S. Volkov[d]

[a] *Nuclear Research Institute Rez, plc, Husinec-Rez, Rez near Prague 25068, Czech Republic*
[b] *Nuclear and Technological Institute, Sacavem, Portugal*
[c] *Troitsk Institute for Innovation and Fusion Research, Troitsk, Russia*
[d] *Institute of Physics and Power Engineering, Obninsk, Russia*

Abstract

The knowledge of neutron and gamma ray energy spectra can strongly influence the BNCT information about delivered dose to target volume as well as to the surface healthy tissue region. This region is very often decisive to stay within the recommended healthy tissue limit. Modification of neutron Bonner spectrometer to one block i.e. Bonner spectrometer monoblock (BSM) and gamma ray Si semiconductor spectrometer are being developed and verified in real conditions of LVR-15 reactor beam. Test measurements were also carried out in conditions of known standard spectra. The accepted procedure and the first results documenting the sensitivity BSM to different spectra are presented.

Keywords: BNCT epithermal beam; Spectrometry of neutrons and gamma rays; Bonner spectrometer; Si semiconductor spectrometer

1. Introduction

Most of the facilities where BNCT clinical trials are performed have been using reactor epithermal beam as a source of neutrons (Burian et al., 2002). In these beams thermal, epithermal and fast neutrons as well as gamma rays are present. Integral quantities are determined in prevalent cases (neutron dose, gamma ray dose) where BNCT is clinically practiced. Information for neutron and gamma ray flux as function of energy is important both for correct determination of dose delivered to tumor (effect) and background as often limiting the healthy tissue dose. Providing experimental spectral measurements of epithermal neutron beams should contribute to improvement of the accuracy of integral dose measurements.

Equipments enabling to receive the beam spectral information during a relatively short time were designed in NRI in international cooperation. Modification of neutron Bonner spectrometer to one block, i.e. Bonner spectrometer monoblock (BSM) and gamma ray Si semiconductor spectrometer are being developed and verified in real conditions of LVR-15 reactor beam.

2. Materials and methods

2.1. Importance of spectral information for BNCT

Absorbed dose as a macroscopic quantity is the basic parameter for prescribing, recording and reporting a radiotherapeutic procedure. Neutron absorbed dose is delivered by thermal, epithermal and fast neutrons and their secondary particles (alpha particles, ions, protons). Gamma ray absorbed dose is due to gamma radiation presence in the primary beam and also generated by

*Corresponding author. Tel.: +420-266-172-465; fax: +420-266-172-045.
E-mail address: burian@ujv.cz (J. Burian).

0969-8043/$ - see front matter
doi:10.1016/j.apradiso.2004.05.064

neutron capture reactions. Cross-sections of these reactions are the function of energy. The knowledge of neutron and gamma ray energy spectra can strongly influence the information about delivered dose to target volume as well as to the surface healthy tissue region. This region is very often decisive to stay within the recommended healthy tissue limit.

2.2. Spectrometry

Hydrogen proportional counter, scintillation spectrometer with crystal of stilbene or NE 213 liquid scintillator in connection with Bonner ball spectrometer are very often used as standard methods for determination of neutron spectra. These methods are very sensitive, the flux density of detected neutrons has to be lower than $10^4/\mathrm{cm}^2\,\mathrm{s}$. The real beams are operated with the neutron flux of $10^9\,\mathrm{n/cm}^2\,\mathrm{s}$. Essential decreasing of reactor power is not correct in some conditions. The gamma part can be overestimated when using results from low reactor power to higher levels. It is due to strong influence of gamma ray background from fuel and activation.

To enable the measurement in nominal reactor beam conditions the following measures are applied in principle:

- neutron detectors with low sensitivity are used (activation foils, fission chambers) in direct beam,
- weakened beam is used—only a scattered part of radiation is measured and the primary spectrum is consequently reconstructed. The approach is based on the fact that angular function of scattering can be determined in advance for the same conditions (scattering sample, distance, angle, detector) for an analogical reactor beam.

2.3. Equipments in development

The following equipments are being developed in NRI to receive the source spectral information in conditions of LVR-15 reactor standard operation.

2.3.1. Bonner spectrometer (BS)

The neutron spectrometer for the first time described by Bramblett et al. (1960) consists of thermal neutron detector at the center of number of different diameter-moderating spheres. The information about the spectrum of neutron field can be derived from the measured readings of a set of spheres. Initially, response functions were determined from measurements with monoenergetic neutrons. Currently, the Monte Carlo method is the most appropriate approach to calculated response functions. The modification of BS to one block, i.e. BSM was designed. The general view is in Fig. 1. It consists of polyethylene (PE) block with Cd and PE with boron shielding. Seven detectors of thermal neutrons (DTN) are inserted in seven measuring channels with different thickness of PE for on-line measurement in geometry of scattered beam. A special insertion with set of foils is used for irradiation in the direct beam.

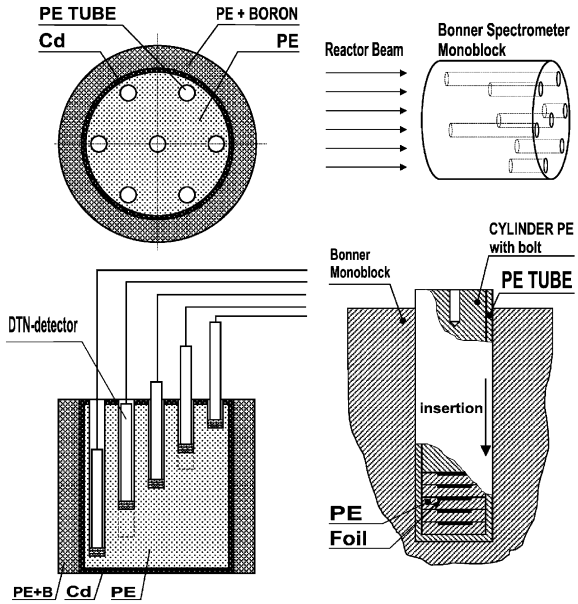

Fig. 1. Designed BSM. The BSM can be equipped either with set of thermal neutron detectors (DTN) for on-line measurement or with insertion containing set of activation foils.

MCNP Monte Carlo code runs sufficiently quickly that large numbers of point responses can be calculated in a reasonable time. It allows detailed geometric modeling of the whole block with detectors. Standard unfolding codes supported by personal experience can be used to derive the final neutron energy spectrum from experimental data.

2.3.2. Si semiconductor gamma ray spectrometer

Gamma–radiation spectrometer–dosimeter SPEDOG (Gamma-radiation spectrometer-dosimeter, 2002) was chosen as a base for development of methodology for scattered gamma ray beam measurement. Silicon detector KX 605 A is sensitive, less then $10^{\,4}$counts/s is permitted input level. The principles of Compton scattering can be applied when materials with low Z (atomic number) are used as scattering sample. Thin layer of aluminum can be used for these purposes. According to Kuhtevich (1970) the procedure of scattering can be completed by application of absorbing filters method for high gamma ray energy.

3. Results

The possibilities of described methods were tested for measurement of neutron and gamma spectra of B2 and

B3 beam of BR-5 reactor in IPPE Obninsk (Kuhtevich, 1970). Iron cylinder of outer diameter 40 mm, inner diameter 20 mm and heights 40 mm was used as neutron scattering sample, for scattering of gammas it was 2 mm layer of aluminum.

The first test measurements for development of spectrometers were implemented in NRI in conditions of known, standard spectra (NRI Laboratory of Spectrometry), as well as in conditions of reactor beam (reactor LVR-15).

3.1. Laboratory of spectrometry

Neutron and gamma spectra escaping the surface of iron spheres of 30, 50 and 100 cm in diameter and water spheres of 30 and 50 cm in diameter were used for that test measurement (Jansky et al., 2002). A neutron source Cf-252 with the emission of 3×10^8 n/s was positioned in the center of a sphere. The leakage neutron and gamma spectra were originally determined by independent neutron and gamma spectrometers of the different laboratories. Neutron spectra were measured with hydrogen proportional counters and scintillation detectors of stilbene type in the energy range of 0.01–20 MeV. Gamma spectra were measured with detectors of stilbene, germanium and silicon types, in the energy range of 0.4–12 MeV.

Typical configuration for measurement in standard fields is shown in Fig. 2. The background determination in real conditions was achieved by using cones for neutron and gamma shielding. Different materials and thickness of cones were used: PE + B (polyethylene with boron) for neutrons, Fe-iron for gamma rays.

3.2. Reactor beam

Epithermal neutron beam was constructed on LVR-15 reactor, the facility has been used for BNCT clinical trials. Today free beam parameters are: $\Phi_{epi} = 7.13 \times 10^8/\mathrm{cm}^2\mathrm{s}$, $\Phi_{fast} = 5.16 \times 10^7/\mathrm{cm}^2\mathrm{s}$, $D_\gamma = 1.98$ Gy/h. The first test measurement for developed equipments was performed in October 2003. Fig. 3 shows the sensitivity

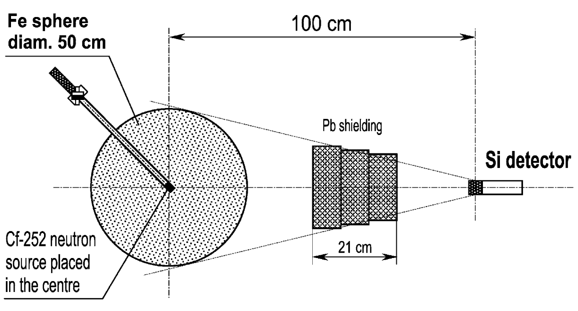

Fig. 2. The configuration for measurement in conditions of standard fields.

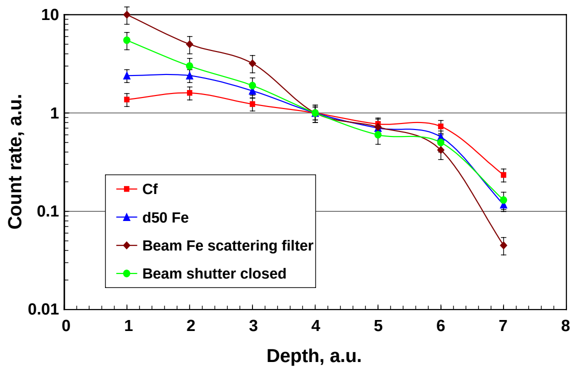

Fig. 3. The sensitivity of BSM readings in different spectra. The DTN responses in 7 channels of BSM. Channels are sorted according to the thickness of moderator. The measurements were performed in four different neutron spectra: Cf-bare Cf spectrum, d50Fe–Cf spectrum leaking from 50 cm Fe sphere, scattered reactor beam, closed reactor beam.

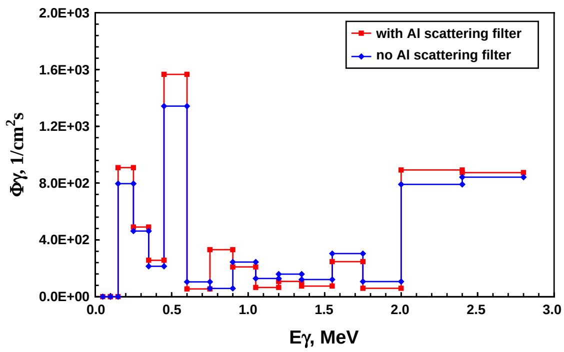

Fig. 4. Gamma spectra with and without scattering sample.

of BSM readings in different spectra. In Fig. 4 gamma spectra with and without scattering sample are demonstrated in group structure.

4. Discussion

First results of measurement with BSM (Fig. 3) shows that the responses are sensitive to spectrum change. The most hard Cf spectrum gives less response in lower depth and higher one in greater depth which results from the neutron moderation. For the softer spectrum (beam-Fe scattering filter) the results are opposite—higher detector responses in lower depth and considerably less in greater depth. The differences in gamma spectrum (Fig. 4) measured with and without Al scattering sample are quite low. The reason is that gamma background is high in comparison with effect of gamma scattering on the sample. Additional shielding is necessary to investigate.

The measurement verifying the final procedure of developed spectrometers is planned for June 2004. The present time activity concentrates on MCNP calculation of BSM response functions.

Developed BSM and Si semiconductor spectrometers and methodology used will be effective tools for determination of spectral parameters of beams used for BNCT.

Acknowledgements

This work was supported by Grant MPO FD-K/048 and IAEA TC Project CZR/4/009 Part2.

References

Bramblett, R.L., Ewing, R.I., Bonner, T.W., 1960. Nuclear Instrum. Methods 9, 1.

Burian, J., Marek, M., Rataj, J., Flibor, S., Rejchrt, J., Viererbl, L., Sus, F., Honova, H., Petruzelka, L., Prokes, K., Tovarys, F., Dbaly, V., Benes, V., Kozler, P., Honzatko, J., Tomandl, I., Mares, V., Marek, J., Syrucek, M., 2002. Report on the first patient group of the Phase I BNCT trial at the LVR-15 reactor, research and development in neutron capture therapy. In: Sauerwein, W., Moss, R., Wittig A., (Eds.), Proceedings of 10th International Congress on NCT for Cancer. Essen, Germany, September 2002.

Gamma-radiation spectrometer-dosimeter "SPEDOG", 2002. Simulation Systems Ltd., http://www.ssl.obninsk.ru.

Jansky, B., Novák, E., Turzik, Z., Kyncl, J., Cvachovec, F., Kluson, J., Trykov, L.A., Volkov, V.S., Cuda, P., 2002. Comparison of measured and calculated mixed neutron and gamma fields in iron and water benchmark assemblies driven by Cf-252 neutron source. International Symposium on Reactor Dosimetry, Brussel, August 2002.

Kuhtevich, V.I., Trykov, L.A., Trykov, O.A., 1970. Single Crystal Scintillation Spectrometer (with Organic Scintillator). Atomizdat, Moscow (in Russian).