EPJ Web of Conferences **8**, 06001 (2010)
DOI: 10.1051/epjconf/20100806001
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Spectral flux of the p-^{7}Li(C) Q-M neutron source measured by proton recoil telescope

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Abstract. The cyclotron-based fast neutron source at NPI produces mono-energetic neutron fields up to 35 MeV neutron energy using the p + 7Li(carbon backing) reactions. To be applied for activation cross-section measurements, not only the intensity of neutron peak, but also the contribution of low-energy continuum in the spectra must be well determined. Simulations of the spectral flux from present source at a position of irradiated samples were performed using CYRIC TOF-data validated in the present work against LA150h by calculations with the transport Monte Carlo code MCNPX.

Simulated spectra were tested by absolute measurements using a proton-recoil telescope technique. The recoil-proton spectrometer consisted of a shielded scattering chamber with polyethylene and carbon radiators and the ΔE1-ΔE2-E telescope of silicon-surface detectors located to the neutron beam axis at 45° in the laboratory system. Si-detectors were handled by usual data acquisition system. Dead-time – and pulse-overlap losses of events were determined from the count rate of pulse generator registered during duty cycle of accelerator operation. The proton beam charge and data were taken in the list mode for later replay and analysis.

The calculations for ^{7}Li(p,n) and ^{12}C(p,n) reactions reasonably reproduce CYRIC TOF neutron source spectra. The influence of neutron source set-up (proton beam dimensions, ^{7}Li-foil, carbon stopper, cooling medium, target support/chamber and the geometry-arrangement of irradiated sample) on the spectral flux is discussed in details.

1 Introduction

The quasi-monoenergetic p-^{7}Li source with neutron energies between 18 to 36 MeV has been build up at NPI [1]. The proton beam from the NPI isochronous cyclotron U120M strikes the self-supporting ^{7}Li foil backed by carbon disk which serves as a beam stopper. The neutron flux of 6.108 n/cm2/s is calculated for 38 MeV /10 μA proton beam and for the target-to-sample distance of 50 mm. The ^{7}Li(p,n) reaction on thin ^{7}Li foil target is commonly utilized for activation cross sections measurement at higher (20 MeV) neutron energies. To carry out the integral validation- and/or the cross-sections measurements, the neutron spectral flux at sample positions needs to be known.

The spectral neutron yield from the source reaction p +^{7} Li(C backing) was measured by TOF technique at proton energies of 20, 25, 30, 35 and 45 MeV (spectral data measured by the CYRIC group are available from Fig. 2 of the paper [2]). The MCNPX simulation of CYRIC TOF experiment indicates, that MCNPX/LA-150h reasonably reproduces the shape and value of p + Li(C) spectrum and, in particular, the Li(p,n) mono-energy peak with 5% uncertainty (S.P. Simakov., ND 2010 [3]).

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Present work is devoted to the experimental test the MCNPX simulation of flux-density gradient and other geometry aspects of spectral flux at sample positions (in the vicinity of neutron source), using the proton-recoil-telescope method.

2 Experimental arrangement

The standard ^{7}Li(p,n) reaction on thin lithium target induced by 20 to 38 MeV proton beam from isochronous cyclotron U120M was used for the production of quasi-monoenergetic neutron field. The energy of proton beam is justified with an accuracy of 1.5%, standard energy resolution of 1.5% FWHM is achieved. The time profile of the neutron source strength during the irradiation was monitored by the proton beam current measurement on the neutron-source target and recorded on PC (5% uncertainty). The proton beam strikes the self-supporting ^{7}Li-foil of 2 mm thickness having about 2–3 MeV loss of incident proton energy. Li foil is backed with 8 mm thick carbon beam stopper cooled on the back side by 2 mm thick alcohol stream. The ^{7}Li target is metallic plate (40 mm in diameter) of enriched ^{7}Li element ($\leq 0.05\%$ of 6Li) with the thickness uncertainty of 10%.

The proton recoil telescope (PRT) is schematically shown in Fig. 1, where the basic data on the arrangement of experiment are given as well. The PRT detects recoil protons produced by elastic neutron scattering on hydrogen in a high-purity polyethylene radiator foil, mounted on the frame in the evacuated tube by thin gluing belts. By the belts of same weight and dimensions, the carbon foil is mounted on another frame which could be inserted instead of CH_2 radiator without breaking-up the vacuum inside the tube. The thickness of the carbon foil closely simulates the carbon content in the corresponding CH_2 radiator. To subtract the proton component from inelastic neutron interactions with the carbon in the PE radiator and with inner parts of tube, two separate background measurements with carbon (C) radiator and free frame were performed.

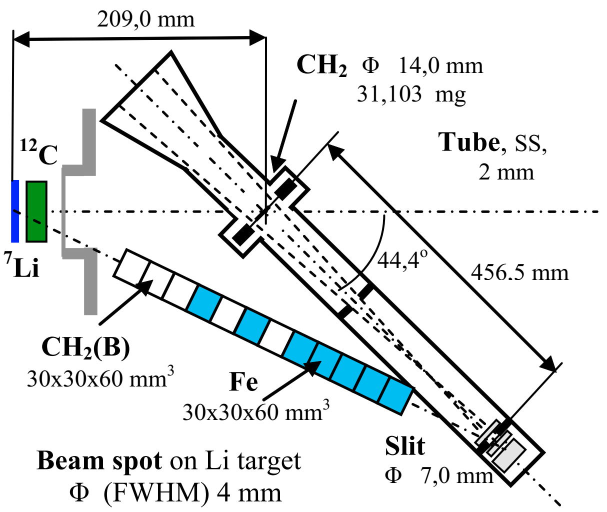

Fig. 1. The experimental arrangement of the proton-recoil-telescope experiment.

By correcting for the energy dependent efficiency, the energy spectrum for the neutrons emitted by the source is determined from the detected proton spectrum, on the kinematics relations basis. Protons are detected at defined angle by telescope of Si detectors. System radiator – telescope lies on one axis and is enclosed in the evacuated tube. The aperture in the middle of PRT tube suppresses detection of parasitic charged particles generated by interaction of neutrons with surrounding material.

Shadow bar composed from steel and borated polyethylene cubes shields telescope away from direct neutrons.

3 Data acquisition and processing

Charged particles from the radiators at laboratory angle of 44.4° are detected by a set of three solid-state silicon detectors: ΔE1, ΔE2 and E, i.e. 0.045, 0.09 and 5 mm thick, respectively (Fig. 2). Each of 3 detector signals was amplified in Ortec 142 preamplifier, amplified in Ortec 572 amplifier, converted in LeCroy 3351 converter and saved on PC hard disc with time labels for time coincidence definition. Quick ΔE2 signal from preamplifier served for converter gate pulses generation.

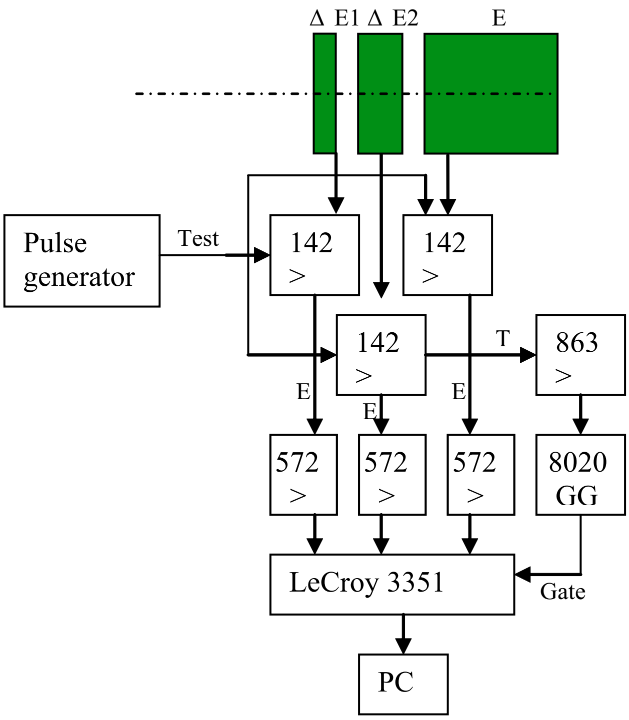

Fig. 2. Registration technique.

Pulses from external generator were detected simultaneously with detector events to estimate precisely the dead time effects. Protons were distinguished from other particles by Bethe formula E.ΔE ≈ AZ^2. During off-line data processing, different two-dimensional matrices of recording events were composed: ΔE1 × (ΔE1 + ΔE2 + E) matrix distinguishing protons with energy from 2.5 MeV (in the case of highest proton energies, the energy losses in ΔE1 may be under detection threshold) and (ΔE1 + ΔE2) × (ΔE1 + ΔE2 + E) matrix distinguishing protons with energy from 4.5 MeV (the proton energy losses are detectable also for highest proton energies). Normalized single spectra that cover different part of proton spectrum were cumulated.

The proton beam energy was 27.6 MeV. The typical beam current on the Li target was about 3–5 μA. The induced ^{7}Be activity in Li foil was measured after irradiation to test the ^{7}Li foil thickness

Three expositions were performed: CH_2 radiator, C radiator and radiator-free mode. The normalized C- and free-mode expositions were subtracted from CH2 to obtain the net n-H recoil spectrum. Resulting spectrum of process was obtained with good statistics. The two-dimensional CH_2 proton

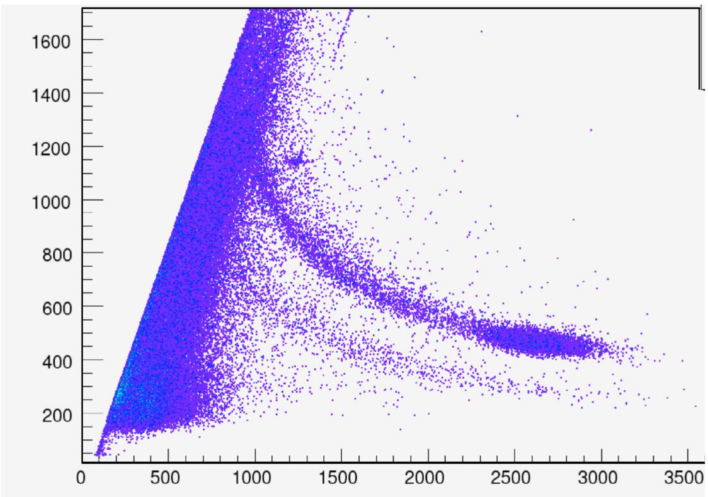

Fig. 3. The (ΔE1 + ΔE2) × (ΔE1 + ΔE2 + E) pulse-height matrix from the CH2 exposition.

spectrum in the (ΔE1 + ΔE2) × (ΔE1 + ΔE2 + E) matrix is shown on the Fig. 3. Events of protons passing through all three detectors lie on the strong hyperbole. A weaker hyperbole under three detectors hyperbole originates from protons passing only through second and third detectors.

The events on the proton kinematic locus were separated by the acquisition software and the single proton spectrum was obtained. Similarly, the single proton spectrum from the ΔE1 × (ΔE1 + ΔE2 + E) matrix mode was obtained. Both single proton spectra were sewn and the background was subtracted from them. Thus the proton spectrum originated only from (n,p) scattering was obtained (Fig. 5). Low energy part of the E detector spectrum was strongly influenced by the noise, therefore this part was displaced by linear interpolation.

4 Simplified response function

Beside the MCNPX simulation, to obtain the neutron spectrum from measured proton recoil spectrum – the analogous code for the reconstruction was developed as well. In the code, for all relevant E_n, the response function, i.e. proton spectrum caused by one neutron with energy E_n, was calculated. For all E_n, the response functions were superposed by optimization procedure to fit experimental proton-recoil neutron spectrum. Multiplication factors pertaining to response functions create resulting n spectrum.

In the code, the response function is based on the n + p differential cross section knowledge and the scattering kinematics. The n+p differential cross section data were obtained from LA-150h library. The response function energies model was calculated including the realistic geometry arrangement of the Li foil-radiator-detector set. The response function spreading due the protons energy losses in the CH_2 foil and also due recoil angle spreading is considered. As a simplified approach to the reconstruction procedure, the effects of secondary scattered neutrons were neglected. The typical response function shape for our experimental arrangement (Fig. 1) is shown in Fig. 4.

The specific response function property is the relatively narrow proton energy range, in which the response function has non zero values. This fact allows employ more effective optimization procedure than that based on the Monte Carlo method. The optimization procedure is based on the neutron spectrum iteration. The iteration procedure converges in a relatively low step number.

5 Results and conclusions

In the Fig. 5, the experimental proton-recoil spectrum is compared with result of MCNPX simulation [3] for proton energies above 2.5 MeV (the lower limit of present acquisition system).

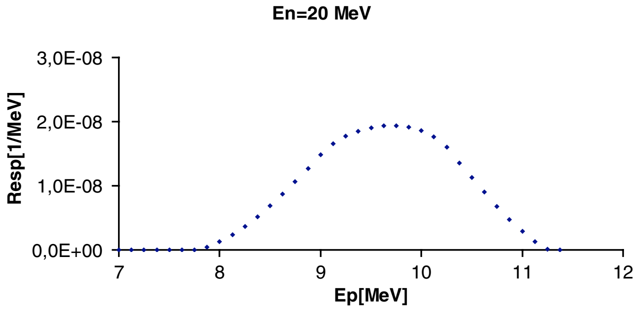

Fig. 4. Typical response function shape.

The MCNPX calculations included all events caused by tracks of neutrons (coming from the Li-carbon target assembly and from target chamber massive due to secondary scattering) across the radiator and consequent recoil of protons to the solid angle of detector telescope. Good overall agreement is indicated: simulated and experimental mono-energetic peaks are consistent within high statistical accuracy of experiment (0.5%) and the integrated continuum within 6% - see Tab. 1. Nevertheless, small systematical deviation of the form of measured spectrum from simulated one seems to be evident.

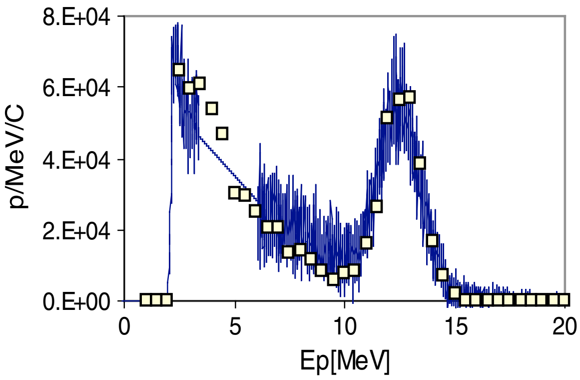

Fig. 5. The measured proton recoil spectrum (line) compared with the MCNPX simulation (squares).

Table 1. The comparison of measured and simulated proton recoil yield in the proton-recoil spectrometer.

	EXP	MCNPX
	p/C	
Total 2,5–15 MeV	3,63E + 05	3,48E + 05
Peak 10,5–15 MeV	1,37E + 05	1,35E + 05
Continuum	2,26E + 05	2,13E + 05

In Fig. 6, the MCNPX simulated neutron spectrum calculated for the radiator position is compared with the curve, calculated by simple extrapolation procedure from TOF data of Uwamino [3].

Here, the neutron spectrum calculated from measured PRT spectra by simplified response functions is given as well. Due to the non-stability of deconvolution procedure this spectrum could be evaluated for neutron energies above 10 MeV only.

The quantitative comparison of different approach to the determination of neutron spectrum is given in Tab. 2. Again, the integrated spectra from PRT-data deconvolution agree with MCNPX simulation within 10%. However, the discrepancy is seen for the continuum. The reason could

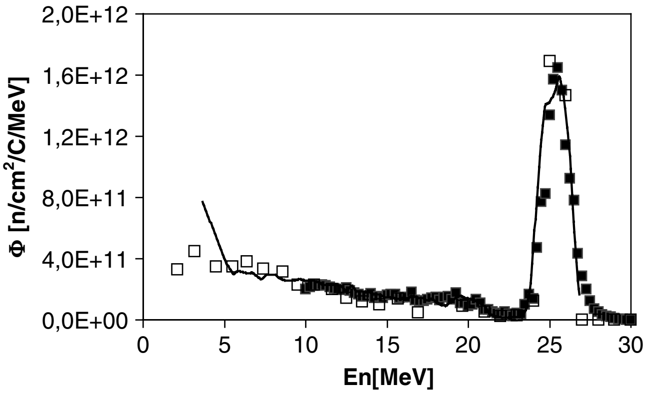

Fig. 6. Simulated neutron spectrum (empty squares) with TOF data (line) and simplified deconvolution of proton-recoil spectrum (full squares).

consist in misinterpretation of parasitic neutrons, which are neglected in the formalism of simplified deconvolution.

Table 2. The comparison of spectral neutron yield above 10 MeV.

	MCNPX prediction	Simplified deconvolution	TOF data extrapolated
	n/cm2/C		
Total 10–29 MeV	4,60E + 12	5,05E + 12	5,24E + 12
Peak 23–29 MeV	3,31E + 12	3,18E + 12	3,35E + 12
Continuum	1,29E + 12	1,87E + 12	1,89E + 12

The spectrum calculated by simple extrapolation procedure from TOF data [2] is also included in present comparison. Note, that the claimed accuracy of these data (10%) together with possible errors in taking the quantitative data from the Fig. 3 of this report make the comparison less reliable.

We conclude, that the MCNPX simulation with the MCNPX/LA-150h library well reproduces measured data from proton-recoil-telescope method. Further investigation need to be done to get more reliable interpretation of measured data to explain observed discrepancies between simulated continuum of p-^{7}Li(C) neutron spectrum and data from TOF measurement [2].

The work was carried out under partial support by the European Communities within F4E project. The views and opinions expressed herein do not necessarily reflect those of the European Commission. The authors are indebted to the operating crew of the U-120M cyclotron for the ready assistance.

References

1. P. Bém, V. Burjan, M. Götz, M. Honusek, U. Fischer, V. Kroha, J. Novák, S.P. Simakov and E. Šimečková, The NPI Cyclotron-based Fast neutron Facility, Int. Conf. on Nucl. Data for Sci. & Techn., Nice, Apr. 2007.
2. Y. Uwamino et al., Nucl. Instr. Meth., A389, 463 (1997).
3. S.P. Simakov, P. Bém et al., “Analysis of the Dosimetry Cross Sections Measurements up to 35 MeV with a 7Li(p,xn) Quasi-monoenergetic Neutron Source”, ND 2010.