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Optimization of the proton chopper for ^{7}Li(p,n) neutron spectrometry using a ^{3}He ionization chamber

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ABSTRACT

Thick target ^{7}Li(p,n) neutron spectra were measured with a ^{3}He ion chamber in the proton energy region between 1.95 and 2.3 MeV using the McMaster pulsed accelerator neutron source. The pulsed neutron beam was produced by an electrostatic proton chopper to reject the slow neutron detection events, which seriously limit the fast neutron counting rate of the ^{3}He ion chamber. To collect both arrival time and energy information of ^{3}He detection events, a custom two-dimensional time-energy analyzer was built using a time scaler and a successive approximation peak-sensing ADC. At each proton energy, the optimum chopper operation was determined by taking into account the two competing requirements: high fast-to-slow neutron ratio and reasonable fast neutron counting rate. The proton pulse widths used were 10 μs for 1.95 and 2.1 MeV proton energies, whereas a shorter, 5 μs proton pulse was used for 2.3 MeV acquisition. The raw data were analyzed using three spectral unfolding methods: a simple division by detection efficiency, an iterative algorithm, and a regularized constrained inversion method. The three methods gave consistent neutron fluence spectra within 20% above 30 keV. Thanks to the enhanced fast-to-slow neutron ratio of the pulsed beam, the full detector response function could be employed in unfolding, which led to an extension of the dynamic energy range as well as a better stability of unfolding process in the low energy region.

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1. Introduction

A ^{7}Li(p,n) accelerator neutron source has been conveniently used in research and clinical applications [1–4] due to its high neutron yield, relatively soft neutron spectrum, and proton energy easily achievable by inexpensive low energy proton accelerators. The reaction threshold is 1.86 MeV, and up to 2.4 MeV, ^{7}Li(p,n)^{7}Be is the only channel open for neutron emission. Physical instability of the pure lithium metal due to its low melting temperature makes it challenging to use as a target particularly for high current operations, but this problem can be addressed by extensive cooling of the target assembly [5,6].

Given that optimizing the neutron irradiation field relies heavily on the raw neutron spectra, accurate characterization of the ^{7}Li(p,n) neutron fluence spectra is of great importance for all ^{7}Li(p,n) neutron beam users. However, there has been no experimental verification of neutron spectra from the thick lithium target. Our group had previously measured the spectra in the incident proton energy range 1.95–2.3 MeV and compared them with theoretical calculations as well as Monte Carlo simulations modeling experimental conditions in order to account for room return neutrons [7]. The neutron detector employed to measure the neutron spectrum was the ^{3}He ionization chamber (model FNS-1, Seforad Applied Radiation Ltd., Israel). The ion chamber offers good energy resolution and has been employed in a variety of applications [8–10] but there are a number of difficulties when working with this detector. The maximum counting rate is limited to approximately 1000 s^{-1} due to slow charge carrier collection, with the majority of all counts scored in the epithermal peak. Even though the ion chamber is surrounded with a thermal neutron shield, ^{3}He, the main detection gas, has an extremely high cross-section for slow neutron capture, so that the epithermal peak at 764 keV (the *Q*-value of the ^{3}He(n,p)T reaction) is always a dominant feature of the spectrum even if the slow neutron contamination level is low. The use of the detector response function in the unfolding process is limited only to the part above the epithermal peak due to the fact that, when attempting the unfolding process using the full response, the result of unfolding is mostly governed by the size of the epithermal peak, which makes unfolding unstable.

These fundamental problems are significantly alleviated by active rejection of the epithermal neutron events, which can be done using the proton chopper combined with the time-of-flight (TOF) slow neutron rejection method. Our previous work of Ref. [11] reported development of the proton chopper and proved the concept by showing approximately five-fold reduction of the

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epithermal peak size. In that experiment, the ^{3}He detector was positioned at 3.7 m from the lithium target along the axis of the proton beam line. The proton chopper system was operated at a 2 ms duty cycle producing 20 μs proton pulses. Using a multi-channel time scaler, the experimental threshold for the TOF slow neutron rejection was determined to be 180 eV. That is, neutrons of energy less than 180 eV were rejected.

Following development of the proton chopper, we systematically investigate the dependence of the chopper performance on its operation parameters in this paper. The diagnostics of the pulsing system aims at ensuring that the neutron spectra acquired with the pulsing system are equivalent in neutron yield and spectral content above the slow neutron rejection threshold with neutron spectra acquired in the continuous current mode. Under the optimized proton pulsing condition, neutron spectra were collected and analyzed by three different unfolding methods.

2. The proton chopper

The design of the proton chopper has been described in detail in our previous publication of Ref. [11]. As shown in Fig. 1, the chopper relies on electrostatic deflection of the proton beam. Two aluminum plates (Fig. 1(a)) were inserted in the last section of the proton beam line. The bottom plate is permanently grounded and the top plate is connected to a high voltage switch, which periodically drives the plate potential from zero to 300 V. The maximum voltage is sufficient to create the E-field needed to deflect the proton beam from the opening of the analyzing slit. At the beginning of each duty cycle, the HV switch generates the logic SYNC signal (Fig. 1(b)), which is subsequently used to trigger a custom two-dimensional time-energy acquisition system.

3. Tests and results

3.1. Diagnostics of the proton chopper

To collect both energy and time information simultaneously, a 2-D time-energy analyzing system was built. Fig. 2 shows the detailed block diagram of the acquisition system. The input of the 2-D system accepts a shaped linear signal. The peak-sensing ADC (model 8715, Canberra) carries out the pulse height analysis and indicates the end of conversion time by the DATA READY logic signal. Since the ADC is a successive approximation type and the conversion time is constant, the DATA READY signal can be used as a simple way of picking up the detected pulse arrival time. The time scaler is triggered by the SYNC signal sent by the proton chopper and records the pulse arrival time. The dwell time of the time scaler was set at 1 μs in the first 40 time channels and above the channel 40 the dwell time progressively increased to approximate linearity between channel number and neutron energy as well as to cover the 2 ms time interval between subsequent duty cycles with the available number of channels. Both pulse height and arrival time values are read directly by a digital signal processor (DSP) (model DSP56F807PY80, Freescale Semiconductor) and recorded in its 64 kB memory, which is allocated to form a matrix of 64 columns by 1024 rows to store pulse arrival time and amplitude, respectively. This matrix can be requested anytime during the acquisition or after the acquisition is completed and transferred via USB connection to the PC.

Since the 2-D system picks up the leading edge time of the ADC DATA READY signal rather than deriving the time from the rising edge of the preamp output, the recorded time is delayed by both the shaping amp and the ADC. In particular, the peaking time of the shaping amp is subject to the shaping time constant, so that the amount of time delay changes when the shaping time setting is altered.

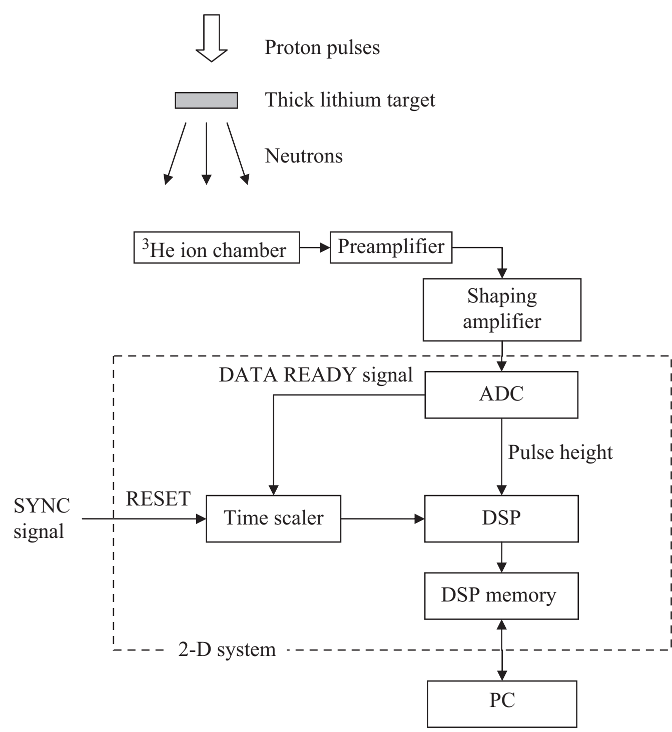

Fig. 2. Diagram of the acquisition system. The SYNC signal is generated by the proton chopper at the beginning of each proton pulse.

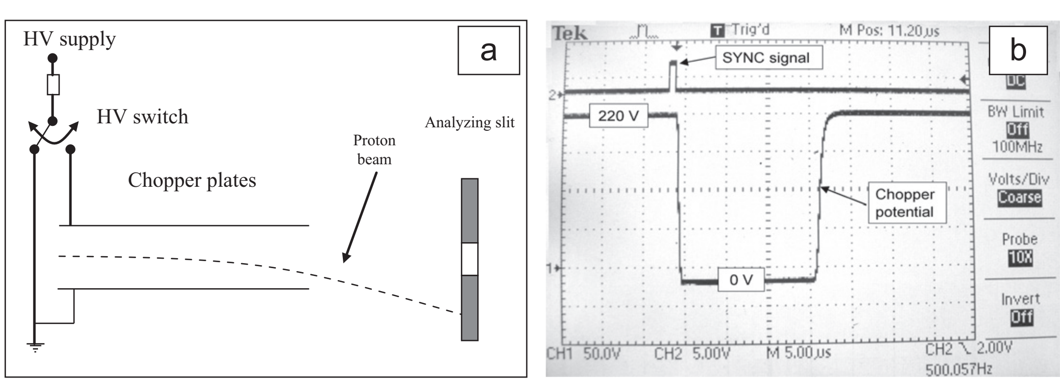

Fig. 1. Diagram of the electrostatic chopper system (a) and experimentally measured output potential of the top chopper plate (b).

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