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CHELSI: A PORTABLE NEUTRON SPECTROMETER FOR THE 20-800 MEV REGION

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Received month date year, amended month date year, accepted month date year

CHELSI is a CsI-based portable spectrometer being developed at Los Alamos National Laboratory for use in high-energy neutron fields. Based on the inherent pulse shape discrimination properties of CsI(Tl), the instrument flags charged particle events produced via neutron-induced spallation events. Scintillation events are processed in real time using digital signal processing and a conservative estimate of neutron dose rate is made based on the charged particle energy distribution. A more accurate dose estimate can be made by unfolding the 2D charged particle versus pulse height distribution to reveal the incident neutron spectrum from which dose is readily obtained. A prototype probe has been assembled and data collected in quasi-monoenergetic fields at the The Svedberg Laboratory (TSL) in Uppsala as well as at the Los Alamos Neutron Science Center (LANSCE). Preliminary efforts at deconvoluting the shape/energy data using empirical response functions derived from time-of-flight measurements are described.

INTRODUCTION

In previous publications(1-2), we have detailed the evolution of a novel neutron spectrometer for use in high-energy neutron fields. It is designed to be lightweight and portable while providing real time dose data to the operator. The culmination of this earlier work is a prototype probe based on a 2”x2” CsI(Tl) scintillator. This probe has been evaluated in quasi-monoenergetic fields at the TSL cyclotron facility at peak energies of 46, 95, 143 and 173 MeV. Data has also been recorded at the Weapons Neutron Research Facility (WNR) located at LANSCE. It has been possible at the WNR facility to use time-of-flight techniques to generate a set of response functions for a 1”x1” CsI(Tl)-based probe. This data has been used to investigate the feasibility of unfolding the 2D plot of pulse shape versus pulse energy data using the unfolding codes MAXED(3-4) and GRAVEL(4).

PROBE DESCRIPTION

Hardware

Figure 1 shows a photograph of prototype version of CHELSI. The probe consists of the scintillator mounted on a photomultiplier tube (PMT) (Electron Tubes # 9266B) coupled to a low power base. The electronics, consisting of a μDXP board (a 16 MHz digital spectrometer designed for embedded applications), a dedicated interface PC board to power the PMT and spectrometer and four rechargeable nickel metal hydride batteries, are enclosed in an aluminum housing. On full charge, the batteries allow seven hours of continuous operation. The total mass of the electronics assembly is 380 grams.

The dedicated PC-board provides RS232 communication to a personal digital assistant (PDA) that displays the charged particle count rate and derived dose rate. This unit also stores the shape and energy data associated with each charged particle event for subsequent deconvolution. To facilitate the setup of the μDXP board, the RS232 signal can also be directed to a laptop running customized software. This allows the proper setting of thresholds, regions of interest and gain. These settings are then downloaded to the μDXP board directly or saved and later transferred to the PDA as appropriate.

The CsI probe assembly can be readily removed from the housing and used in conjunction with Polaris, a bench top digital spectrometer as described previously(1-2).

The external dimensions of the prototype probe are 30 cm x 15 cm x 20 cm with a total mass of 3.3 kg.

Firmware

Based on initial work using the Polaris spectrometer, an algorithm to discriminate between particle types was implemented in the spectrometer field programmable gate array (FPGA) and digital signal processor (DSP) firmware for real time operation. After verifying the consistency of the “online” and the “offline” pulse discrimination, the firmware was migrated to the μDXP for embedded operation.

When a charged particle event is detected and validated, the DSP determines the particle identification index(2) (PID), which describes the shape of the pulse, and calculates the net pulse energy before writing both values to memory. The memory is divided in two 8 kbyte buffers, which are addressed alternately; one buffer is filled, while the host reads the other buffer. Processor live time is recorded on a buffer-by-buffer basis and placed in a header preceding the shape/energy data.

Software

In calibration mode, the host software (PC) controls the data read out and plots the PID versus energy values on a scatter plot. A charged particle region of interest (ROI) is then defined by overlaying this plot with a polygon that is further divided into as many as 10 subregions. Once defined, the ROI selection is saved in a PDA calibration file, along with other spectrometer-specific parameter values.

In normal operation, the PDA initially reads the parameter file and determines, for each buffer, the number of counts in each subregion of the ROI. This data and the buffer live time statistics are then used to calculate a conservative estimate of dose rate. The shape/energy data is stored on a compact flash card and uploaded later to a desktop computer for subsequent analysis.

EXPERIMENTAL DETAILS

Quasi-monoenergetic data was obtained at the The Svedberg Laboratory in Uppsala, Sweden using the CHELSI 2”x2” probe assembly as well as a number of other CsI(Tl) scintillators. Four different peak energies (46, 95, 143 and 173 MeV) were generated using the p,Li reaction at the cyclotron-based facility(5).

In order to harden the spectral output, polyethylene filters were placed in the beam path to preferentially attenuate the fluence below 20 MeV. As a result, the filters also had the effect of increasing the fluence fraction in the full energy peak from typical unfiltered values of roughly 40% to about 60%. The optimum filter thickness for each full peak energy, ranging from 30 cm at 46 MeV to 50 cm at 173 MeV, was determined using MCNPX(6). A semi-classical approach(7) was used to calculate the source term

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spectra for these calculations. Later, the calculations were repeated using empirically determined spectra(8), the agreement in the transmitted fluence was within 5% and generally improved with increasing peak energy.

The CsI-based probes were positioned 12.6m from the target while the filters were centered on the beam and located about 3.5m from the Li target.

Beam monitoring was provided using a ^{238}U fission chamber located at the exit of the beam collimator. A $1/r^2$ correction was applied to the spectrum transmitted by the filter to obtain the fluence and ambient dose equivalent(9-10) at the measurement location.

The prototype probe was also evaluated on the 90m flight path at the WNR/LANSCE facility(11) using the measurement methods described earlier(2). In-line beam filters were again employed to harden the beam and reduce the incident gamma and neutron fluence rate. The data of interest to this work was obtained using 10 cm of copper followed by 20 cm of polyethylene and 10 cm of lead, which produced a broadband spectrum extending to 800 MeV with an average energy of about 345 MeV.

DECONVOLUTION

The deconvolution codes MAXED and GRAVEL were used to unfold the 2D pulse shape versus pulse energy plot. Both codes were released by Physikalisch-Technische Bundesanstalt (PTB) as part of the "Unfolding using MAXED and GRAVEL" (UMG) code package(4). To apply these codes, the charged particle region of the plot was sectioned into zones using a grid pattern (see Figure 2). Though encompassing the same plot region as used for the online dose rate estimate, the grid structure will not necessarily be the same. The optimum grid structure has yet to be determined but the example shown in Figure 2 includes 28 separate zones. Time-of-flight data previously collected(2) for a 1"x1" CsI scintillator provided a convenient set of empirical response functions with which to evaluate the feasibility of applying the UMG unfolding codes.

In essence, each zone shown in Figure 2 represents a Bonner sphere-like measurement in that the number of counts per unit fluence varies with neutron energy. This suggests that the few-channel versions of MAXED and GRAVEL might be applicable. The main departure from Bonner sphere unfolding being, as will be shown later, that there are fewer energy bins than number of measurements. This could be advantageous as the solution spectrum may not be as dependent on the *a priori* spectrum as is typically the case with Bonner spheres.

That both unfolding codes require an *a priori* spectrum can be seen as a drawback, especially in situations where the incident spectrum is not known. To address these concerns, we have investigated using a minimum mount of pre-information *i.e.* a flat (constant $d\phi/dE$) spectrum.

RESULTS

Quasi-monoenergetic data

Figure 3 depicts the charged particle count rate per μSv/hr, for all the CsI scintillators (normalized to the volume of a 2"x2" crystal), plotted against the full peak energy. The count rate was based on the counts in the enclosed area shown in Figure 2 while the dose rate was calculated from the fluence above the 20 MeV arbitrary operating limit of CHELSI. A method of determining the absolute charged particle count rate per unit fluence rate was described earlier(2). Figure 3 also includes data previously obtained at 33 and 60 MeV at the Universite de Catholique Louvain in Louvain-la-Neuve(1), Belgium.

By way of comparison, a background measurement at Los Alamos gave a count rate of 0.02 cps in the same charged particle region for the 2"x2" CsI scintillator.

WNR/LANSCE

An example of a pulse height spectrum recorded using CHELSI with the filter combination described above is shown in Figure 4. Also shown is the 4.43 MeV ^{12}C de-excitation gamma calibration spectrum generated from a PuBe source. These spectra were recorded using the laptop computer.

The corresponding distribution plot of pulse shape with pulse energy is shown in Figure 5. This data was collected in real time. Clearly, the degree of pulse shape discrimination is comparable to that obtained from an off-line analysis of stored waveforms (Figure 2) and represents a major improvement over earlier efforts at real time pulse shape discrimination(2). This improvement is primarily due to a reduction in the timing jitter when gating the PID.

Deconvolution results

Figure 6 compares the MAXED unfolded spectrum with the spectrum obtained using the ^{238}U fission chamber-based spectrometer on the 90m flight path. The fission chamber spectrum has been rebinned to match the MAXED solution spectrum. The input shape/energy data was obtained from one of the six files recorded under identical conditions from which the empirical response functions were determined. A very similar result was obtained using the GRAVEL code. In both cases, the integrated fluence and dose agreed to within 5% of the fission chamber result.

The relatively modest clock speed of the Polaris spectrometer (40 MHz) used in the time-of-flight measurements is the reason for the coarseness (11 energy bins) of the spectra shown in Figure 6. However, for the purposes of dosimetry, high-resolution spectroscopy is not necessary as the H*(10) curve varies by only a factor two between 20 and 800 MeV(10).

SUMMARY

A prototype portable probe has been assembled and shown to provide suitable real time pulse shape discrimination, a prerequisite to proper operation. The 2”x2” CsI scintillator has excellent sensitivity and a low background count rate. Future versions of the probe will use a 1.5”x1.5” scintillator to reduce instrument mass while maintaining adequate sensitivity. Replacing the scintillator and other design changes will allow the instrument to approach the target goal of 2.3 kg.

Preliminary efforts have shown that the UMG codes can be successfully applied to unfold the shape/energy data. Further work is required to optimize the approach and empirical response functions for the 1.5”x1.5” and 2”x2” scintillators must be obtained. The technique will then be validated using the quasi-monoenergetic data.

Field trials with the prototype probe are planned during the next LANSCE beam cycle.

ACKNOWLEDGEMENTS

We would like to thank Nick Fotiadis, John O’Donnell, Steve Wender and Bob Haight for their assistance during the measurements at LANSCE. We also would like to acknowledge the help and expertise of Alexander Prokofiev, Jan Blomgren and the TSL cyclotron operators during our stay in Uppsala..

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Figure 1. Photograph of the prototype CHELSI probe with 2"x2" CsI scintillator

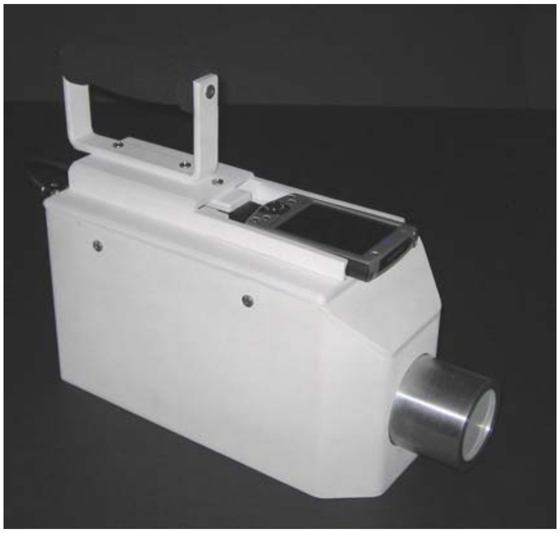

Figure 2. Offline pulse shape/energy plot of WNR data collected using a 1"x1" CsI detector. Superimposed on the plot is a grid defining 28 zones used in unfolding the data.

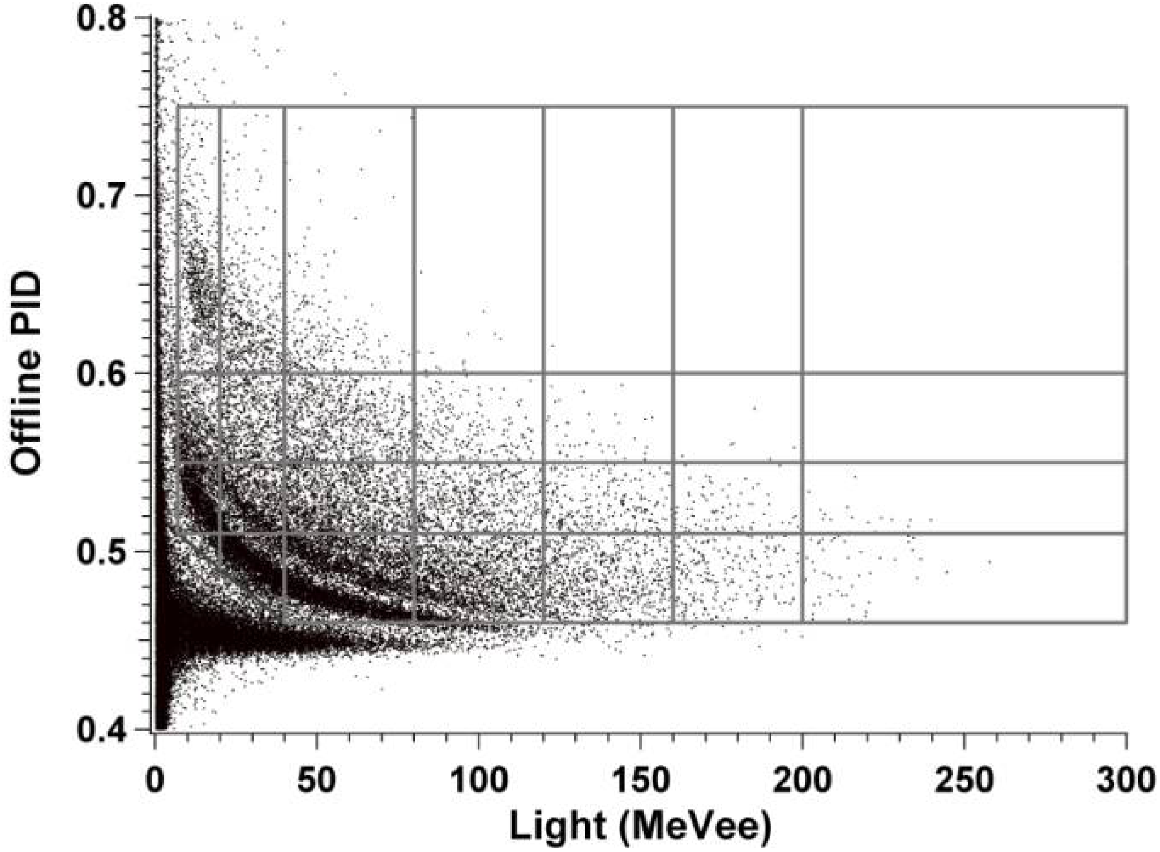

Figure 3. Charged particle count rate per μSv/hr (H*(10) as a function of peak energy of the quasi-monoenergetic beam. Ambient dose equivalent calculated from fluence above 20MeV. Data have been normalized to the volume of a 2"x2" scintillator.

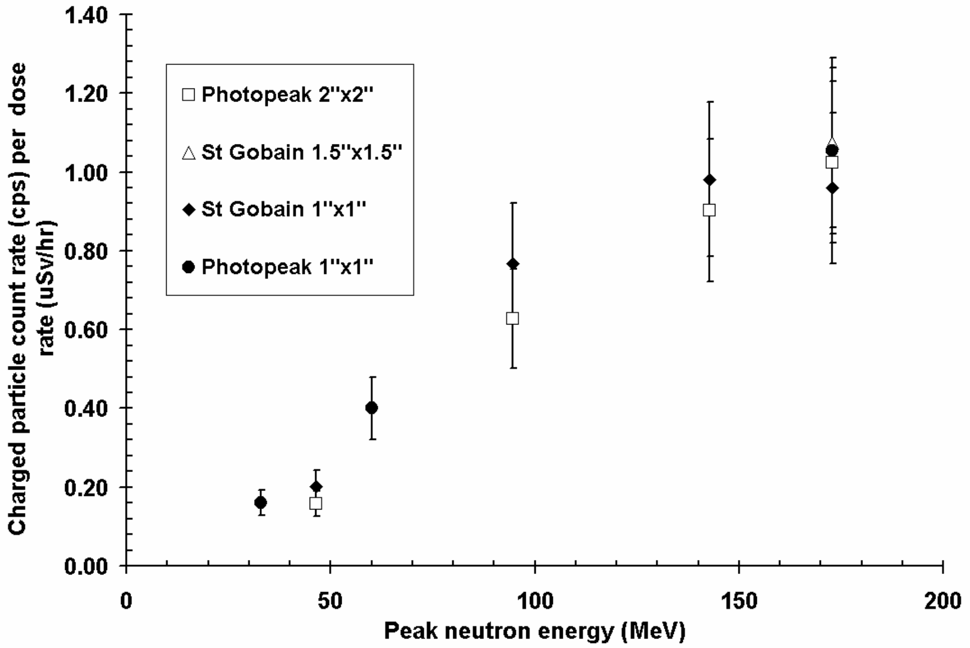

Figure 4. WNR pulse height spectrum (bold line) obtained using the CHELSI probe. Also shown is the calibration spectrum collected using a PuBe source

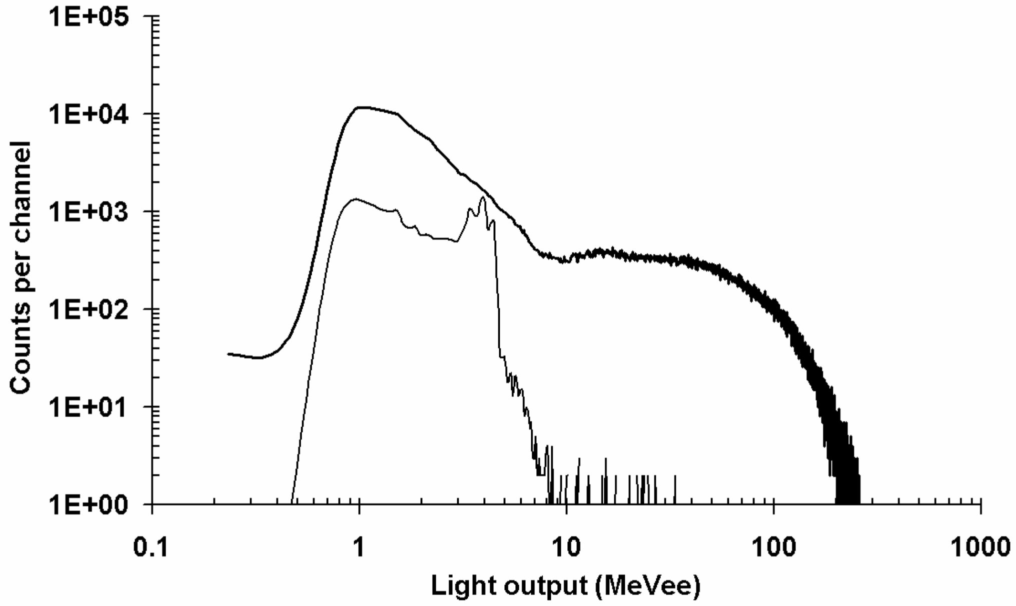

Figure 5. On line pulse shape discrimination at WNR using CHELSI.

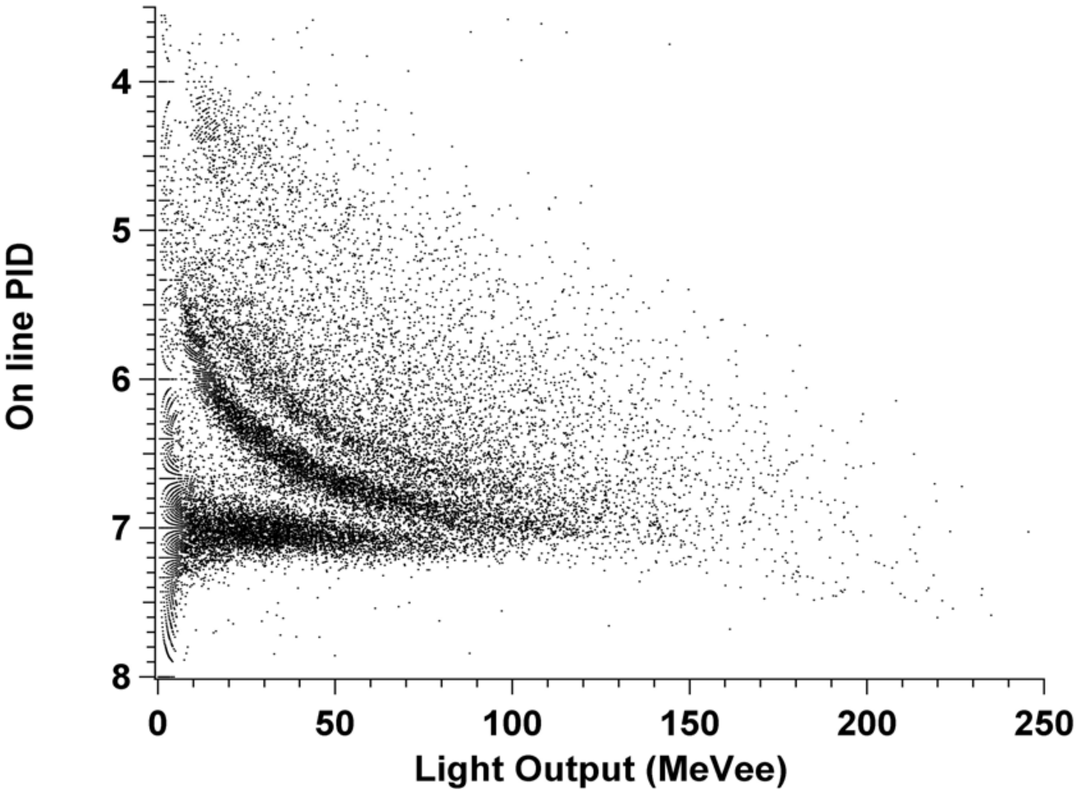

Figure 6. Comparison of unfolded spectrum (solid line) using MAXED and fission chamber spectrum (dotted line). A flat default spectrum was used to unfold the pulse shape/energy data.