

# Absolute Calibration of Proportional Counter Based Fast Pulsed Neutron Detectors with Resolution Below $10^5$ neutron/pulse

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**Abstract.** A method for absolute calibration of proportional counters for pulsed fast neutrons is presented. The method is based on the use of an isotopic standard source and development of a model for counting detected events from area of a signal compounded by single piled up neutron pulses. Effects of detection counting statistics and electrical background noise are also considered. The method is applied in detectors used for D-D neutron yield measurements in low emission plasma focus devices.

## 1. Introduction.

The measurement of pulsed fast neutron production from plasma focus devices (pulse width  $T \ll 1\mu s$ ) is usually done by foil activation techniques (Ag, In, Be). These techniques allow detection limits down to  $10^5$ - $10^6$  n/pulse. For yields less than  $10^6$  n/pulse (low emission regime) neutron moderation and proportional counters such as  $^3\text{He}$  or  $\text{BF}_3$  tubes could be used [1]. When a moderated proportional counter is irradiated by an extremely short pulse of fast neutrons (10-100 ns pulse width), neutrons are moderated to thermal energies by multiple scattering and thus the pulse is spread over tens of microseconds. Depending on the neutron fluence and the preamplifier RC time constant, neutron signals will be piled up making impossible to count single events. The above notwithstanding the output detector signal area will be proportional to the number of detected events. Two schemes have been proposed to tackle the ensuing pulse pile up: I) Use of high counting rate electronics and control of the count rate by detector-source separation. This technique has been reported to be successful in the  $10^6$  n/pulse range and is not proved in lower emission ranges [2]. II) Cross calibration on the accumulated charge (preamplifier output signal) generated in the tube by the neutron burst using as neutron reference a foil activation detector [3, 4]. As result detection limits are transferred by the calibration process from the reference detector, thus no improvement in the detection resolution is obtained by this method for the low emission regime despite the high efficiency of neutron gaseous proportional counters. At present, there is a lack of an absolute calibration technique for pulsed fast



neutron detectors based on proportional counters. In this work, we propose a calibration method to overcome this deficiency, it is based on the use of isotopic standard sources as neutron reference and a counting model on the net signal area which also accounts for the different sources of fluctuations in our detection system (detection counting statistics, pulse pile up statistics and electrical noise).

## 2. Experimental setup and detection system.

Our detection systems (two units) are based on a paraffin wax moderator ( $45 \times 15 \times 15 \text{ cm}^3$ ) and a  $^3\text{He}$  tube (model LND 2523) sheathed by a 3-mm thick lead sheet to stop x-rays and prevent their subsequent detection. The moderator is surrounded by a cadmium sheet to absorb thermal neutrons. The tube is connected to a preamplifier (CANBERRA 2006) and the high voltage feed is set to 4kV. In order to improve the signal-to-noise ratio, the preamplifier is adjusted with a conversion gain of 235  $\text{mV/M-ion-par}$  which produces a 5x voltage output factor scale. Its RC time constant is set nominally to 50  $\mu\text{s}$ , this is the nominal fall time for individual pulse when risetime is less than hundred nanoseconds. Signal output from the preamplifier is recorded by an oscilloscope (Tektronix model TDS 684) at 1 M $\Omega$  input impedance, AC coupling, and 20MHz band width. Time scale is set to 200  $\mu\text{s/div}$ , and horizontal scale is set in accordance with moderator decay time (governing neutron feeding into the  $^3\text{He}$  tube). Direct measurements of the total signal area are obtained using the internal integration oscilloscope function on a 1500 $\mu\text{s}$  time window, which starts close to the trigger point. The oscilloscope is triggered by the electromagnetic pulse generated from the discharge. In the absence of electrical discharge, there is electrical background noise (EBN), which still contributes to the total signal area. For a specific time window, the EBN depends on oscilloscope horizontal scale; it is affected by changes in laboratory room temperature and should be monitored *in-situ* together with neutron measurements. Its values are well described by a normal distribution. In practical situations, the net signal area ( $X_{T,net}$ ) should be obtained by discounting the EBN mean value from the total signal area. Natural background counting is negligible for the 1500 $\mu\text{s}$  time window ( $r \sim 0.9 \text{ s}^{-1}$ ). Single neutron signal were characterized using non-linear least squares methods, as results it was found that in the detection system neutron signals have an exponential rise and fall with characteristic constants of 1.2 $\mu\text{s}$  and 75 $\mu\text{s}$  respectively [5]. In general a single neutron area signal is then given by  $A = FA \cdot V_0$ , where  $V_0$  is the signal pulse height and  $FA$  a constant which depends on the detection system. Consequently, the pulse area spectrum for the counter is easily obtained from the pulse height spectrum. For the case of our detectors, it was found that  $FA = 91.63 \mu\text{s}$ .

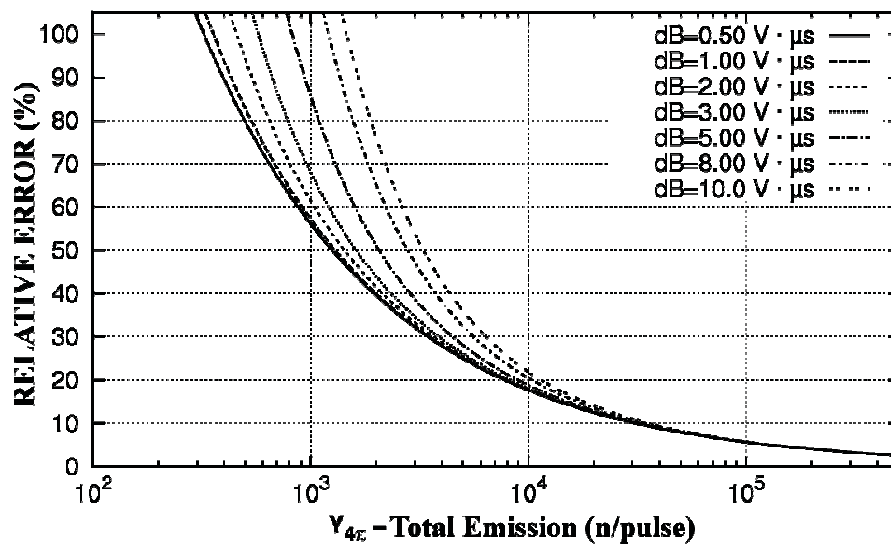
## 3. Counting model and measurement of neutron production.

The expected number of detected events in the counter is given the model

$$m(X_{T,net}, dB) = [a \cdot X_{T,net}] \pm \sqrt{f_0 \cdot [a \cdot X_{T,net}] + a^2 \cdot dB^2}, \quad (1)$$

where  $dB$  is the standard deviation of the observed distribution for the electrical background noise, and  $a$  and  $f_0$  are constants which depend on the detector system. The values of these constants are obtained from numerical calculations. From the experimental probability density function and using the Monte Carlo method is possible to reproduce the random detector system response including fluctuations by counting statistics, piling up statistics and electrical background noise. From these calculations, the value for  $a$  and  $f_0$  were carefully selected to ensure the predictability power of the model [6]. The constant  $a$  is related with the convergence to the central limit in the piling up statistics, while  $f_0$  includes effects of counting statistics and piling up statistics in the fluctuations of the counting model. The term  $a^2 \cdot dB^2$  in eq. (1) includes the effect of the EBN in the uncertainties of the model.

The absolute calibration of our detection system is given by the fact that counting efficiency and thus the detector calibration factor ( $j_c$ ) is obtained using an isotopic source as neutron reference. The last is valid in the approximation that source and fusion neutron spectra produce identical results after undergoing multiple scattering moderation inside the detector.



**Figure 1.** Relative standard error for our detection systems at distances from the source in the range  $14\text{cm} \leq r \leq 40\text{cm}$ .

Using the counting model, the neutron yield from the source by solid angle is obtained from

$$Y = j_c \cdot m \left( 1 \pm \sqrt{\left( \frac{dj_c}{j_c} \right)^2 + \frac{f_0}{m} + \frac{a^2 \cdot dB^2}{m^2}} \right). \quad (2)$$

For our detection systems characteristics values  $f_0 = 1.0658$  and  $a = 0.44617$  were found. When detectors are placed at distances from the source in the range  $14\text{cm} \leq r \leq 40\text{cm}$ , a mean value  $j_c = 14.2$  is obtained. In figure 1 are shown different plots of the relative standard error for measurements in the low range emission. It is seen that reasonable uncertainties are obtained with the methodology presented in this work for emissions lower of  $10^4$  n/pulse, which means an improvement in the detection limit of almost two order of magnitude in comparison with state of art measurement techniques.

#### 4. Acknowledgments.

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