Lawrence Livermore Laboratory

AN OPERATING MANUAL FOR THE DE PANGHER PRECISION LONG COUNTER (PLC)

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INTRODUCTION

It is difficult to make quantitative measurements of neutron intensity. One of the tools available for such measurements is the de Pangher "precision long counter" (PLC). I have gained some experience with this piece of equipment, and would like to share with the reader the things I've learned.

The ideal flux monitor would be one with constant efficiency for neutrons of all energies, high sensitivity with ability to measure high intensities, and no response to gamma rays or x rays at all. An approximation of this ideal response exists in the form of the PLC. It consists of a long, low-pressure, BF_3 proportional counter imbedded in a rather complex moderator of polyethylene and other materials. Because of the low gas pressure in the BF_3 tube and the energy deposition (2.7 MeV) caused by the $^{10}\text{B}(n,\alpha)$ reaction, it is relatively simple to distinguish the small pulses due to photons from the large pulses due to neutrons. A pulse-height discriminator is used to reduce the gamma-ray response to a negligible level.

Neutron detection efficiency is made relatively constant by: (1) using a long BF_3 tube (and hence the name "long counter"), and (2) through a system of holes bored in the moderator and strategically placed neutron absorbers. A long detector is needed to maintain constant efficiency at high energies where the neutrons penetrate deeply into the moderator ($\lambda \sim 10\text{cm}$ at 14 MeV). At low neutron energies, polyethylene absorbs a significant fraction of the incident neutrons, and so an annular recess is bored into the moderator to admit low-energy neutrons to the front end of the detector. To avoid a peak in the efficiency at energies of a few MeV, a cylindrical shell of boron is placed in the moderator at some distance from the BF_3 tube. All of these things are discussed in more detail in the works of de Pangher.^{1,2} Figure 1 shows a schematic of the PLC construction.

SETTING UP THE PLC

Neutron intensity is measured by determining the count rate due to (n,α) reactions in the BF_3 tube. At present there are three different BF_3 tubes available in the Hazards Control calibration facility at LLL.

Fig. 1. Sketch of PLC showing BF₃ tube and removable internal neutron source.

One of them has a low ^{10}B content for use in very high intensity fields. It is of paramount importance to pay close attention to the proper positioning of the BF_3 tube in the moderator, to proper anode voltage on the BF_3 tube, to the discriminator level which determines which output pulses will be counted, and to the detector count rate.

- The BF_3 tube should be positioned so that the connector extends to the rear of the PLC, and the front end of the tube should be recessed 6.4 mm behind the front plane of the PLC. Variations in this position will cause more or less of the detector active volume to extend outside the moderator, and will cause important changes in the low-energy sensitivity.
- Energy resolution of the BF_3 tube is very sensitive to anode voltage. Improper voltage will result in poor energy resolution, and the result will be a less effective suppression of gamma-ray response. Proper anode voltage for each tube is given in Table 1. Amplifier shaping time should be set to 2 μs and the gain set to give positive, gaussian-shaped output signals of 6-8 volts.
- The lower level discriminator should be set to yield the proper count rate using the standard PLC calibration source #300044. This source consists of a small $^{238}\text{PuBe}$ neutron source mounted in a nylon rod, as shown in Fig. 2. The rod is inserted into the PLC as shown in Fig. 3

Table 1. Characteristics of BF_3 tubes used in the PLC.

BF_3 tube (ID No.)	Gas mixture	Anode volts	Standard source count rate ^a (cps)	Nominal sensitivity $\left(\frac{\text{counts}}{\text{n/cm}^2}\right)$
1. G21973	25 cm $^{10}\text{BF}_3$	1550	111.0	3.10
2. G31585	25 cm $^{10}\text{BF}_3$	1550	111.0	3.10
3. F32106	0.44 cm $^{10}\text{BF}_3$	1050	4.60	0.1285
	4.0 cm $^{11}\text{BF}_3$			
	26.6 cm Ar			

^aAs of 1 January 1976.

Fig. 2. ²³⁸PuBe calibration source is shown at top, mounted in its nylon rod support. The blank nylon rod which replaces the source following calibration is shown at the bottom of the photograph.

Fig. 3. Calibration source as it is inserted into the PLC.

so that the source is centered between the front and rear faces. No other neutron source should be present while the discriminator is being set. The lower level discriminator should be set so that the observed count rate agrees with that shown in Table 1. Generally, at least three separate counts of 10^4 counts each should be made at the final discriminator setting to verify agreement with Table 1 at a 1% error.

- After the lower level discriminator has been set to yield the proper count rate for the standard source, the source should be removed and replaced by the nylon rod provided for that purpose.

INTERPRETATION OF RESULTS

The manner in which the PLC efficiency varies with energy has been determined.³ The relative efficiency as a function of energy is shown in Fig. 4. It is reasonable to assume that the relative efficiency varies in the same way with energy for all BF_3 tubes described in Table 1. Therefore, for a source of known energy, one multiplies the relative efficiency obtained from Fig. 4 by appropriate sensitivity from Table 1. The result is the neutron sensitivity expressed in counts per neutron/cm² inferred at the PLC effective center. That is, for a point source at a distance R from the front face of the PLC, the count rate will be

$$I = \frac{Sc}{4\pi (R + d)^2} + \text{backscatter rate} \quad (1)$$

where

$$c = \text{sensitivity} \left(\frac{\text{counts}}{\text{n/cm}^2} \right),$$

$$S = \text{source intensity (n/s)},$$

$$d = \text{effective center offset (described earlier),}$$

$$I = \text{measured count rate} \left(\frac{\text{counts}}{\text{s}} \right)$$

Recommended sensitivity figures for several common neutron sources are given in Table 2.

Fig. 4. Relative PLC response vs neutron energy, from Ref. 3. Solid line shows the best estimate of sensitivity.

Table 2. Sensitivity for several unmoderated neutron sources.

Source	E	Sensitivity, $\epsilon \left(\frac{\text{counts}}{\text{n/cm}^2} \right)$	
		No. 1 or 2	No. 3
0.025 MeV			
2.5 MeV	-	3.10	0.128
14 MeV	-	2.48	0.100
$^{238}\text{PuBe}$	4.5 MeV	3.10	0.128
^{252}Cf	2 MeV	3.26	0.134
$^{238}\text{PuLi}$	0.7 MeV	3.35	0.138

THINGS TO WORRY ABOUT

- The effective center is energy dependent. For a point source at least 100 cm from the front face, the effective center of the PLC is located a distance d behind the front face, given by

$$d(\text{cm}) = 7.8 + 1.1 \times E_n (\text{MeV}). \quad (2)$$
 The effective center for a source closer than 100 cm is not well known.
- Dead time in the detector and electronics will result in measurement uncertainty of about 3% at a count rate of 250 counts/s. Higher count rates should not be used for precision measurements.
- The PLC is highly directional. It is a collimated detector so that its response to neutrons scattered by walls and air is reduced. A source should always be aligned on the axis of BF_3 tube for reliable intensity measurements, and should not be so large that it extends more than about $10\text{--}15^\circ$ away from the axis when viewed from the PLC.
- Backscattered neutrons contribute to the count rate. There are at least two ways to determine the count rate due to this background. The most accurate is to measure the count rate at many radii from the source. A plot of $r^2 I$ vs r^2 (where I is the count rate) would yield a horizontal line in the absence of scatter. Scatter introduces a slope to the resulting curve. If the count rate due to scattered neutrons was the same at all radii, the curve would be a straight line whose slope is proportional to the scatter contribution. Extrapolation

of this curve through the $r = 0$ axis yields the source intensity in the absence of scatter. An example is shown in Fig. 5. In the example, Z_0 is the point where a line through the data intercepts the vertical axis. The value of $(R + d)^2 I$ at the point is used to calculate the neutron source strength, S , in the absence of scattered neutrons.

Multiplying Eq. (1) through by $(R + d)^2$ one obtains Eq. (3) below:

$$(R + d)^2 I = \frac{Sc}{4\pi} + (\text{Scatter}) \times (R + d)^2 \quad (3)$$

At the point where $R + d = 0$, the source strength is obtained directly.

$$Z_0 = \frac{Sc}{4\pi} \quad (4)$$

A simpler method is to install a cone-shield between the source and the PLC as shown in Fig. 6. Then most of the neutrons counted by the PLC are scattered and their count rate is an indication of the backscatter contribution. This method suffers from three shortcomings:

1. Some unscattered neutrons penetrate the cone shield and are counted.
2. The cone shield contributes to the intensity of scattered neutrons in the vicinity of the PLC.
3. The shield obscures the PLC from neutrons scattered behind the source.

Good judgment must be exercised in estimating the magnitude of these errors.

Fig. 5. Plot of $r^2 I$ vs r^2 from which scatter rate may be inferred.

Fig. 6. A cone shield may be used to keep all but scattered neutrons from entering the PLC. The scatter contribution is then determined.

REFERENCES

1. J. dePangher, Nucl. Instr. Meth. 5, 61-74 (1959).
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3. D. R. Slaughter and D. W. Rueppel, "Calibration of a dePangher Long Counter from 2 keV to 19 MeV," Nucl. Instr. Meth. 145, 315 (1977).