A NEW TECHNIQUE IN ENVIRONMENTAL NEUTRON SPECTROSCOPY

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Abstract

A new phoswich[1] has been developed that permits the measurement of the environmental neutron spectrum using Bonner spheres. The new phoswich consists of an 8 mm diameter, 8 mm long $^{6}LiI(Eu)$ crystal surrounded by plastic scintillator. The use of the fast signals from the plastic scintillator in anticoincidence with the slow signals from the $^{6}LiI(Eu)$ gives a nearly background free $^{6}Li(n,\alpha)$ ^{3}He peak. Thus, the signal to noise ratio in the vicinity of the peak is very high (20-35 to 1). An adequate number of counts is obtainable in one day for most of the spheres.

Typical counting rates for polyethylene spheres of the diameters given below are:

2 inch	2.69 c/hr
3 inch	13.9 c/hr
5 inch	14.0 c/hr
6.87 inch	12.4 c/hr
8 inch	9.07 c/hr
10 inch	6.91 c/hr
12 inch	5.96 c/hr
18 inch	3.77 c/hr

Details of circuitry, phoswich geometry, pulse height analyzer spectra and synthesized spectra will be given.

This paper is an elaboration of the preliminary results presented at an earlier time.[2]

The measurement of the neutron energy spectrum of environmental neutrons is besieged by difficulties caused by the gamma rays, muons, protons and other charged particles which are simultaneously present. The commonly used neutron detection technique which is also applicable to environmental neutron studies is that of a $^{10}BF_3$ counter moderated with a hydrogenous material such as polyethylene or paraffin. The use of various thicknesses of moderator produces a family of different neutron detection efficiencies which are functions of the incident neutron energies. These responses have been studied by some authors,[3] mostly in a direction perpendicular to the axis of the BF_3 counter. Responses versus energy for other polar angles have not been studied in detail to the best of our knowledge. As it is to be expected, there is a significant polar angle dependence in these counters. The popularity of the BF_3 counter is due to the ease with which charged particle events (either gamma ejected electrons or cosmic ray charged particles) are separated from neutron capture events by the exoergic reaction

$$n + {}^{10}_{5}B \rightarrow {}^{7}_{3}Li + {}^{4}_{2}He + 2.8 \text{ MeV}.$$

The separation is made electronically with a simple integral discriminator. The other environmental events deposit typically a few KeV.

Another type of neutron detector is the Bonner Sphere.[4] This is a spherical hydrogenous (polyethylene) moderator with a point like thermal neutron detector at its center. Hence, to a first approximation it has isotropically uniform energy responses. The energy dependence of its detection efficiency has been rather well studied.[5] The most common point like detector is a $^{6}Li(Eu)$ crystal. Here in diameter spheres, 10 inches or greater, but it is questionable if it is meaningful in smaller ones. A second way to reject the charged particle background is to use a phoswich.

The phoswich used in the experiment described in this paper is shown in Figure 3. The pulses from the ^{6}LiI(Eu) have a long decay time (1.4 μsec). The pulses from the plastic scintillator have a very short decay time (2-3 nsec). Due to the monochromaticity of the slow pulses, a very simple passive network was tried. This circuit permitted the separation of the slow and fast components after suitable passive shaping. Figure 4 shows a simplified diagram of the electronics used.

The values first tried and not necessarily optimum are

L = 102 μH, C = 33pF.

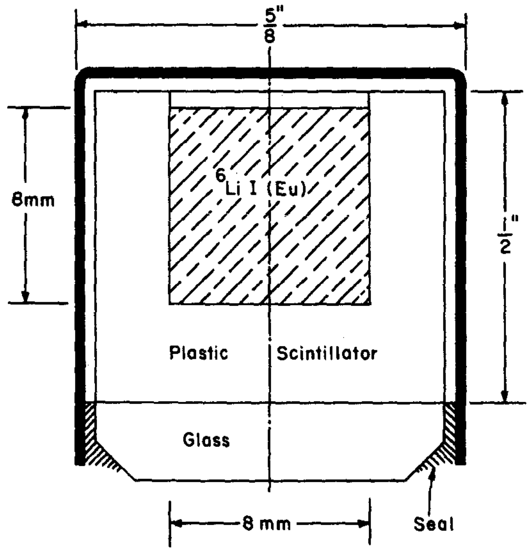

Figure 3. Cross-section of an 8 mm x 8 mm phoswich.

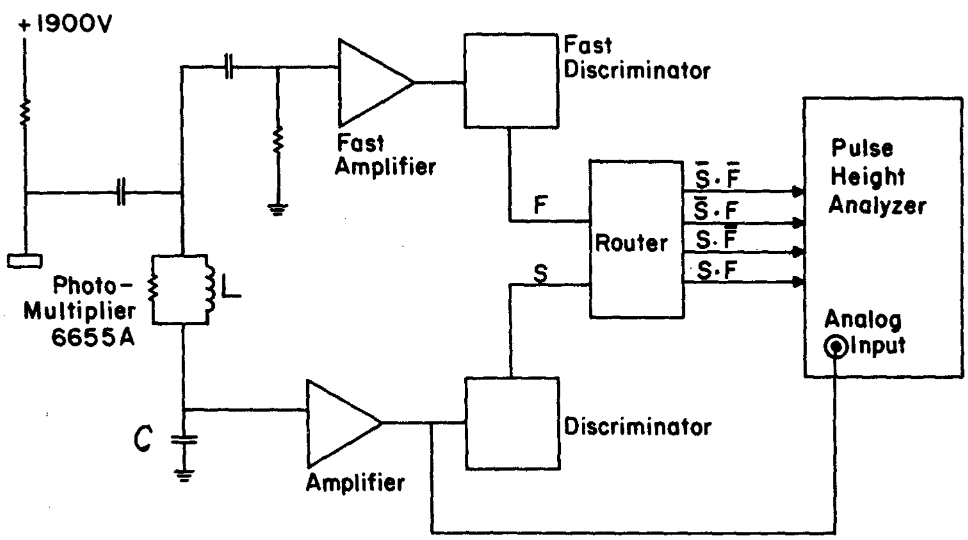

Figure 4. Electronics block diagram.

principle at least, the background charged particles are separated from the neutron capture events by choosing the size of the crystal such that most charged particles traversing it lose less energy than the 4.2 MeV of the reaction

$$n + {}^6_3Li \rightarrow {}^4_2He + {}^3_1H + 4.2\ MeV.$$

Then again, the two types of events should be simply separable by an integral discriminator. In practice when measuring the extremely low environmental neutron flux the separation between neutron captures and other events is not good.

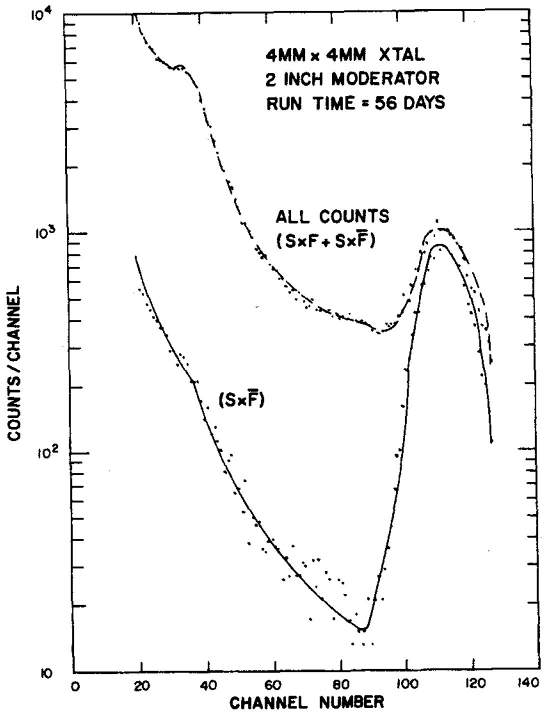

Figure 1. Upper curve is spectrum of all slow pulses. Lower curve is spectrum of slow pulses not accompanied by fast pulses, e.g., "neutrons".

Figure 1, upper curve, is a spectrum of pulses from a 4 mm x 4 mm ^{6}LiI(Eu) crystal in the center of a 2 inch polyethylene spherical moderator while recording environmental neutrons for 56 days. The signal to noise ratio (peak to valley) is not as good as that obtainable while calibrating the system with a PuBe neutron source as shown in Figure 2, for two sizes of crystals.

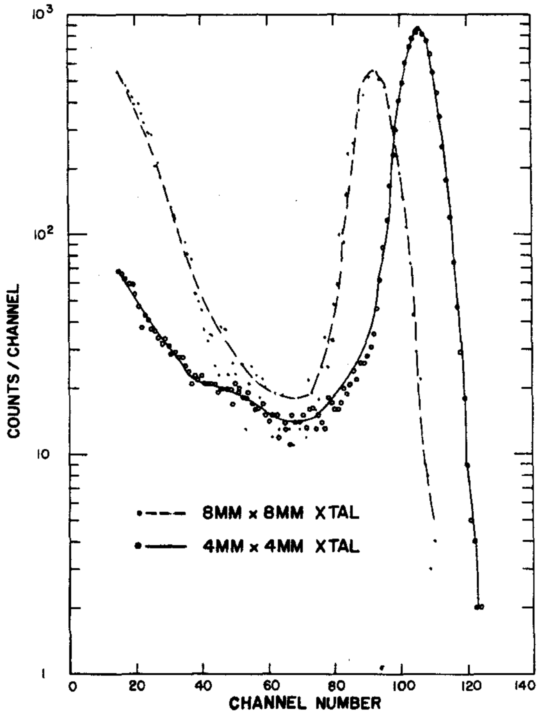

Figure 2. Spectra due to PuBe neutrons from two size ^{6}LiI(Eu) crystals.

There are two ways to improve the rejection of unwanted counts. One is to use small proportional counters.[6] This method almost works for larger

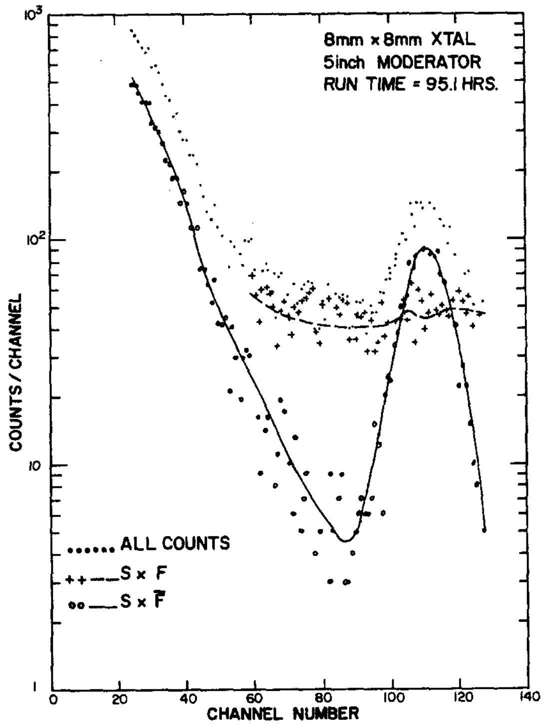

Figure 5. Pulse height spectra from an 8 mm x 8 mm phoswich in a 5 inch polyethylene spherical moderator exposed to environmental radiation for 95.1 hours.

Figure 5 shows the results of an environmental neutron measurement using an 8 mm x 8 mm ^{6}LiI crystal in a 5 inch moderator. This run is 95.1 hours long. The solid curve shows the spectrum of slow pulses not accompanied by fast pulses (S x $\bar{F}$). These event signatures are likely to be due to neutrons. The dashed curve shows the spectrum of slow pulses accompanied by fast pulses (S x F). These events are very likely "noise" or charged particles from the environment. The dotted curve shows all slow pulses (S x $\bar{F}$ + S x F). The peak-to-valley ratio for the (S x $\bar{F}$ + S x F) spectrum is about 2.8, while for the "neutron" pulse only spectrum (S x $\bar{F}$) it is about 22. Therefore, the phoswich has improved the peak-to-valley ratios for neutron detection in environmental measurements by a factor of about five to six.

Figure 1, lower curve, shows the result of using the 4 mm x 4 mm crystal in a phoswich arrangement with background rejection. Another example of the improvement that is obtainable using this technique may be seen from the curve in Figure 5. Consider the neutron data as being in channels 90 to 125. Then we could derive two figures for the number of "neutron events". Case A, use the curve for "all" events. This gives (Signal + Noise)-Noise ~ 3157 - 1440 = 1717 counts ± 68. Case B, use the curve for ($\bar{S}$ x F) type events. The corresponding difference is 1480 - 52 = 1438 ± 39. The fact that two standard deviations do not produce an overlap of the data is a measure of the errors committed in background subtraction in case A.

The dashed line also shows some feed through of neutron events. Hence, improvement in the rejection of the (S x F) events is still possible.

The signal-to-noise ratio is now good enough that a set of Bonner spheres may be used for environmental neutron measurements using a simple integral discriminator for noise rejection. Counting periods of about two days per sphere would be adequate.

Environmental Neutron Flux Measurement

A series of measurements was made inside a light frame house at the NAL site which is at an elevation of 740 feet above mean sea level. The corresponding count rates per hour are given below in Table I.

Table I

Detector Size	Counts Day	Detector Size	Counts Day
2 inch	64	8 inch	218
3 inch	334	10 inch	165
5 inch	336	12 inch	143
6.87 inch	297	18 inch	90

To interpret these results, the spectrum was unfolded using an iterative process.[7]

The absolute detection efficiency of the actual ^{6}LiI(Eu) crystal used was calculated by measuring the neutron flux from a ^{238}PuBe which had been calibrated by the National Bureau of Standards. The correction factor to the data in HASL-267, thus found, was 1.8_8.

Using this value, the cosmic ray neutron flux was calculated as well as the dose and dose equivalent per neutron/cm^2. These quantities are

cosmic ray neutron flux = $63\ n\ cm^{-2}\ hr^{-1}$

flux-to-dose conversion factor = 4.9×10^{-9} rad $n^{-1}\ cm^2$

flux-to-D. E. conversion factor = 2.7×10^{-8} rem $n^{-1}\ cm^2$

Conclusions

A new technique has been developed which permits rapid low resolution environmental neutron spectroscopy using simple electronics.

References

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