A Neutron Detector Having Uniform Sensitivity from 10 Kev to 3 Mev

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A neutron detector having approximately uniform sensitivity from 10-kev neutron energy to 3-Mev energy is described. The arrangement, known as a long counter, consists of a paraffin cylinder about 10″ outer diameter ×12″ long surrounding a long boron trifluoride proportional counter. Sensitivity curves are given for two of the best arrangements. The response is flat over the above range to about 10 percent.

A NEUTRON detector which has a uniform efficiency for neutrons of widely different energies has many advantages for certain types of measurements. A large water bath containing slow-neutron detectors in some form fulfills this requirement and has been very useful in determining the number of neutrons emitted by various neutron sources.[1] The examination of the number of slow neutrons as a function of the distance from the source in such a water bath gives additional information regarding the energy of the neutrons.[2] There are many experiments, however, where the use of a large water bath is either awkward or gives erroneous results because of the effect of the degraded neutrons reflected from the bath into the experimental setup.

In order to achieve a high efficiency in a detector of reasonable size an attempt was made to find a suitable arrangement of paraffin surrounding a boron detector. The analogy with the water bath experiment suggested that a long boron counter embedded in a block of paraffin would have a counting rate which would not depend much on the energy of the neutrons. The first detector constructed consisted of a boron-lined ionization chamber 20 cm long surrounded by a cylinder of paraffin 20 cm long and 17 cm in diameter, this was used with its axis pointed toward the neutron source. Preliminary tests on the sensitivity of this counter showed that the sensitivity was very nearly the same for neutron energies of from 0.4 Mev to 2 Mev; these tests served to encourage the development of counters along the same lines. This type of detector will be referred to as a long counter.

The theoretical treatment of the sensitivity of this type of counter is quite complicated and has not been worked out. There are, however, certain qualitative arguments which may help in understanding the behavior of these counters and which may serve to suggest further improvements.

Examine first an arrangement in which a long thermal-neutron detector is embedded in a large (semi-infinite) slab of paraffin and in which neutrons of various energies are incident upon this slab in the direction parallel to the axis of the detector. The neutrons entering the paraffin will be slowed down primarily by the hydrogen atoms to thermal energies and some of these neutrons will be captured by the central thermal-neutron detector and will be recorded as counts in some manner. If the neutrons have a very high energy, the mean free path of these neutrons is initially large and therefore will be slowed down an appreciable distance from the front face of the slab. After a number of collisions, the mean free path will be reduced to such an extent that these neutrons have a very small chance of escaping out of the front face of the slab. This is not the case, however, for neutrons having energies of the order of 100 kev or less, since in this case the mean free path of the neutrons does not change appreciably as the neutrons approach thermal energies.[3] These neutrons would therefore have a much larger probability of escaping out of the surface of the semi-infinite slab as compared to the high energy neutrons. This effect is partially compensated for by the fact that the less energetic neutrons would need to make fewer collisions before becoming thermal-

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[1] E. Amaldi, L. R. Hafstad, and M. A. Tuve, Phys. Rev. **51**, 896 (1937).
[2] R. D. O'Neal, Phys. Rev. **70**, 1 (1946).
[3] C. L. Bailey, W. E. Bennett, T. Bergstralh, R. G. Nuckolls, H. T. Richards, and J. H. Williams, Phys. Rev. **70**, 583 (1946); D. H. Frisch, *ibid.*, 589 (1946).

ized, but the effect would be such that the detection efficiency for high energy neutrons would be several times greater than that for very low energy neutrons.

If the sensitivity for low energy neutrons is to be approximately the same as that for neutrons of high energy, some modification of this idealized arrangement must be made. The success of the first long counter must be ascribed to a fortunate choice of the dimensions of the paraffin block such that the increased probability of escape of high energy neutrons from the sides of the block compensated in some degree for the escape of low energy neutrons from the front face. The effect of the size of the paraffin cylinder has been investigated roughly and is indicated in a later section of this report. The size of the central cavity made by the detector is perhaps important although no systematic investigation of its effect was made. It will be shown, however, that the introduction of additional holes in the front face affected the low energy sensitivity of one of the counters appreciably.

DESCRIPTION OF COUNTERS

Two counters were used quite extensively and will be described here in detail. The first consisted of a central BF_3 proportional counter 1 inch in diameter, which had an effective length of 8 inches. This tube was surrounded by paraffin cylinders 12 inches long and 6, 8, and 12 inches in diameter. The counter with the 8 inch paraffin cylinder is shown in Fig. 1. The proportional counter protrudes slightly from the front face of the paraffin block but is protected from direct thermal neutrons by means of a cadmium shield. The proportional counter is supported by means of ceresin wax in the center of an aluminum tube which also serves as an electrical shield. The body of the counter was a $\frac{1}{32}$-inch wall brass tube and was soldered to Kovar glass seals. The central electrode consisted of a 10-mil Kovar wire. The $\frac{1}{4}$-inch intermediate electrode was used as a guard ring and was connected to ground. The counter was filled with enriched BF_3 (80 percent B^{10}) to a pressure of 25 cm Hg. With -2700 volts on the outer shell the proportional counter gives a gas amplification of about 10. The signal was further amplified by means of a model 100 linear amplifier[4] with a R-C time constant of 5 microseconds and the pulse was counted by means of a model 200 discriminator and scale-of-64 circuit.[5] Except in the cases where impure BF_3 was used, because of leaks in the tube or filling system, the bias curves (counting rate against minimum pulse height recorded) were such that a change in the bias voltage by a factor of two in either direction would not change the counting rate by more than 5 percent. The counting rate was not affected by the gamma radiation from an unshielded 500-mg radium source used at a distance of 40 cm from the counter.

The other counter, which will be referred to as the shielded long counter, is shown in Fig. 2. The principal modification is that an additional paraffin and boron shield is used so as to make it less sensitive to neutrons which have been scattered about the room. The proportional counter is similar except that it was 10.5 inches long,

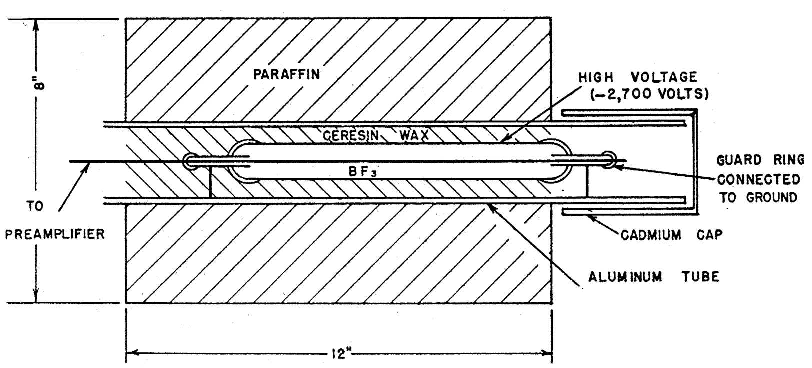


FIG. 1. 8-inch OD long counter.

[4] Designed by M. Sands.
[5] Designed by W. Higinbotham.

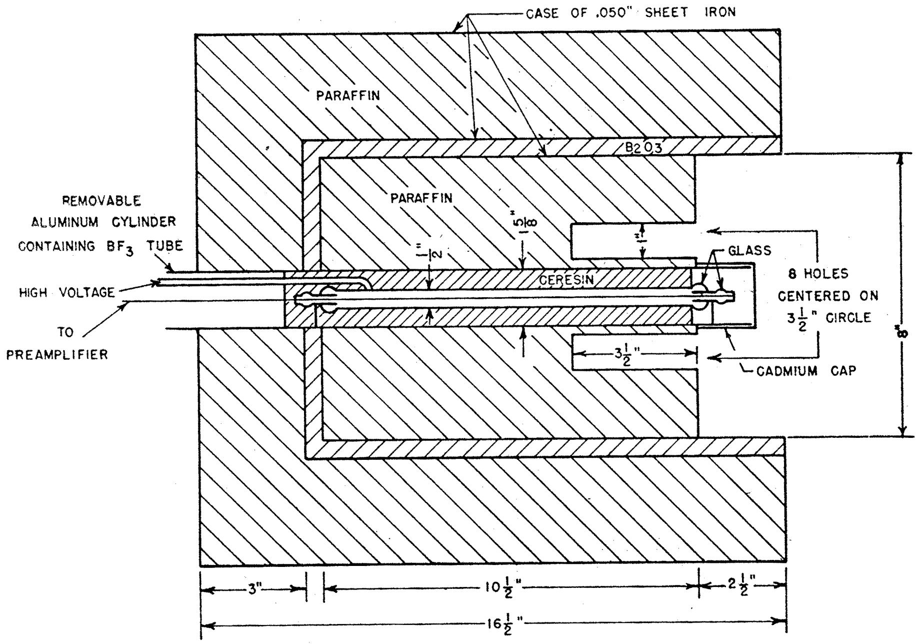


FIG. 2. Shielded long counter.

½ inch in diameter, and was filled with BF_3 to a pressure of 40 cm. For most of the measurements made with these counters it was convenient to use a matched pair of the counters in the arrangement shown in Fig. 3. In addition to increasing the sensitivity of the over-all system, such an arrangement minimizes errors due to exact positioning of sources.

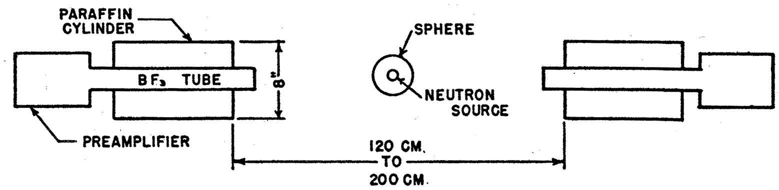
SENSITIVITY CURVES

The data on the sensitivity of the counters to neutrons of various energies were obtained by three methods, namely:

(1) By comparing the counting rates in the counters due to various radioactive neutron sources whose total neutron yield had been compared by some other method such as the water bath technique. Photo neutron sources used were Sb-Be and Y-Be. Alpha neutron sources used were Po-BF_3[6] and Ra-Be. The energies of these sources were taken to be 0.023, 0.16, 2.2 and 5 Mev, respectively. While the energy of the photo neutron sources should be well defined, the alpha neutron sources give a spectrum and the values given represent only average energies. The assignment of an average energy to the neutrons from Ra-Be is especially dubious since the energy spectrum of these neutrons extends out to about 14 Mev. The fraction of neutrons below 0.1 Mev, however, is estimated to be less than 10 percent.[7]

(2) The degradation of the energy of the neutrons from a given source by surrounding the source with spheres of graphite and heavy water. A graphite sphere, 24 cm in diameter, was used which had the effect of reducing the

FIG. 3. Experimental arrangement with a pair of 8-inch OD long counters.



[6] H. T. Richards, LADC—288.
[7] A. A. Yalow, R. S. Yalow and M. Goldhaber, Phys. Rev. **69**, 253A, 1946.

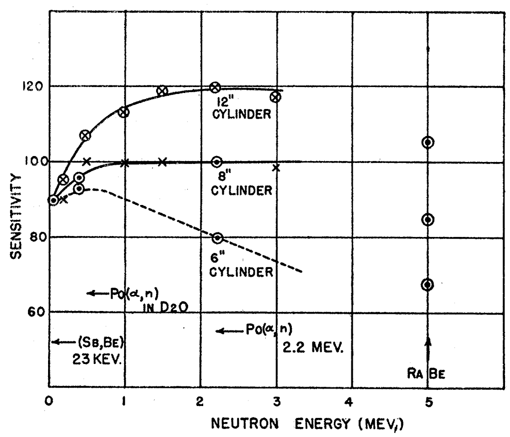


FIG. 4. Sensitivity of 8-inch OD and 12-inch OD long counters. The X's and circled X's represent points obtained with Li^7 (p, n) and D (d, n) neutron sources. Although the curves are not continued beyond 3 Mev the general trends of the curves above this energy are indicated by the points obtained with the Ra-Be source.

average energy of the neutrons by a factor of about 2. A heavy-water sphere, 20 cm in diameter, served to reduce the average energy of the neutrons by a factor of 4 or more. Since neither graphite nor heavy water absorbs neutrons appreciably, the number of neutrons emerging from the sphere would be the same as that emitted from the source. A change in the counting rate with the sphere around the source was therefore taken as a measure of the change in the sensitivity of the counter to the modified spectrum of neutrons. The use of D_2O was, of course, limited by the fact that any source having sufficiently high energy gamma rays would give rise to photo-neutrons from the deuterium. In the case of yttrium it was found that the number of photo-neutrons from deuterium caused by the high energy ray ($\sim$2.8 Mev) was only 3 percent of that due to the Be and hence could be accurately taken into account.

(3) The use of homogeneous neutrons of known energy from the Li (p, n) and D (d, n) reactions. In these experiments the flux of neutrons into the counters was determined by counting the fissions occurring in a standardized sample of uranium 235. The energies of these neutrons are accurately known, and the flux measurement are considered to be reliable so that these points should be quite significant.

The summary of the data on the first counter with 6-, 8- and 12-inch cylinders are shown in Fig. 4. Since very few data were obtained with the 6-inch cylinder, the curve is sketched in only to indicate the general trend of the sensitivity curve as the size of the paraffin cylinder is reduced. It is seen that the 8-inch cylinder gives the best approximation to a uniform sensitivity over the region shown. Other tests with neutrons absorbable by cadmium indicated that the sensitivity of the counter to thermal neutrons was about 70 on the scale used in Fig. 4. The sensitivity of this counter would be somewhat affected by the arrangement in which it is used. For most of the tests described here the counters were used as a matched pair in the arrangement shown in Fig. 3 so as to reduce errors caused by the location of the sources. This pair of counters was used in the center of a room approximately 15 by 20 feet at a height of about 50 inches above the floor. In spite of precautions to keep all other material as far from the counters as possible about 15 percent of the counting rate in the counters was due to scattered neutrons when a Ra-Be source was placed at a distance of 1 meter from the front face of the counters. The absolute sensitivity of this counter was such that it would give about 1 count for every 10^5 neutrons emitted from a source placed at a distance of 1 meter from the front face.

The shielded counter is less sensitive to scattered neutrons by a factor of about 3 and hence largely eliminates this objectionable feature of the 8-inch long counter. The sensitivity of this counter to high energy neutrons is considerably

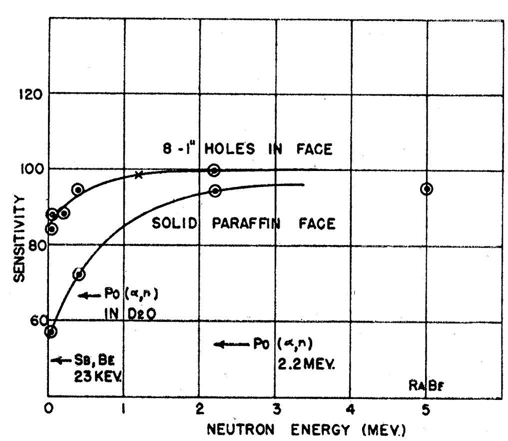


FIG. 5. Sensitivity of shielded long counters.

increased due to the larger mass of paraffin in the shield, and the sensitivity to low energy neutrons is therefore relatively low. The use of holes in the front face, however, increases the sensitivity to low energy neutrons to a sufficient extent so that the response curve of the counter is about as good as that of the previous counter. The effect of these holes is clearly indicated in the sensitivity curves shown in Fig. 5. It seems probable that the sensitivity of this counter would remain fairly constant up to energies of about 5 Mev, but there has been no work done to indicate the trend of the sensitivity curve in this range of energies.[8] No doubt further improvement in the response curve for both high energy neutrons and low energy neutrons can be accomplished by using more suitable paraffin arrangements.

The detectors described here have been found useful in many problems requiring a high and approximately uniform sensitivity to neutrons of various energies. Some of the applications have been the determination of the yield and angular distribution of neutrons from various (p, n) and (d, n) sources as a function of energy, the preliminary measurement of neutron yield from various radioactive sources, and the determination of the number of delayed neutrons accompanying fission.

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[8] Preliminary measurements with 16.5-Mev neutrons indicate that the sensitivity of the shielded counter for these neutrons is approximately 40 on the scale used in Fig. 5 (R. F. Taschek, private communication).