JUN 6 - 1960

X-422

MASTER

OAK RIDGE NATIONAL LABORATORY

Operated by

UNION CARBIDE NUCLEAR COMPANY

Division of Union Carbide Corporation

Post Office Box X

Oak Ridge, Tennessee

External Transmittal
Authorized

ORNL

CENTRAL FILES NUMBER

CF. 60-5-121

DATE: May 31, 1960

COPY NO. 175

SUBJECT: Use of Silicon Surface-Barrier Counters in Fast-Neutron Detection and Spectroscopy

TO: Distribution

FROM: T. A. Love and R. B. Murray

ABSTRACT

A neutron-sensitive semiconductor counter has been constructed by depositing a thin layer of Li^6F between two silicon surface-barrier counters. Neutrons are detected by observing the $\alpha + \text{T}$ pair resulting from the $\text{Li}^6(\text{n}, \alpha)\text{T}$ reaction; pulses from the two counters are added and the sum pulse is amplified and recorded on a multichannel analyzer. Since the sandwich geometry permits simultaneous detection of both reaction products, the magnitude of the resulting sum pulse is proportional to the energy of the incoming neutron. Pulse-height spectra from slow neutrons and monoenergetic fast neutrons, in the energy region 0.6 to 3.5 Mev, have been recorded from two counters of this type; in both counters the sensitive area was about 0.7 cm^2 , with a Li^6F layer of order $150 \mu\text{g}/\text{cm}^2$ thick. In all cases, a well-defined neutron peak was observed in the pulse-height spectrum. In a typical case the full width at half maximum of the fast-neutron peak was about 300 kev. Counters of this type are relatively insensitive to background effects, notably gamma rays, and thus may prove to be useful in the detection and spectroscopy of fast neutrons.

NOTICE

This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report. The information is not to be abstracted, reprinted or otherwise given public dissemination without the approval of the ORNL patent branch, Legal and Information Control Department.

008 301

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared as on account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights, or

B. Assume any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

100-1000000000
100-1000000000

INTRODUCTION

The development of instrumentation for fast-neutron spectroscopy has received considerable attention in recent years. One of the most fruitful and widely used techniques at the present is time-of-flight spectroscopy, used in conjunction with charged-particle accelerators. A class of problems remains, however, in which it is desired to measure the fast-neutron spectrum of a source which is not amenable to pulsing or fast time measurement, so that time-of-flight spectroscopy is not applicable. As an example, it may be desired to measure the fast-neutron spectrum from an operating reactor, critical assembly, or artificial neutron source. Various techniques have been developed to apply to problems of this nature,¹ including recoil-proton counters, recoil-proton tracks in nuclear emulsions, He^3 proportional counters, and $\text{Li}^6\text{I}(\text{Eu})$ scintillators. None of these techniques is entirely suitable, however, so that improved methods are still of considerable interest.

This paper describes recent experiments directed toward the development of a semiconductor counter which might be suitable for fast-neutron spectral measurements of the type indicated above. A neutron-sensitive semiconductor detector has been constructed by depositing a thin layer of Li^6F between two silicon-gold surface-barrier counters. Neutrons are detected by observing the $\alpha + \text{T}$ pair resulting from the $\text{Li}^6(\text{n},\alpha)\text{T}$ reaction; pulses from the two counters are added and the sum pulse is amplified and recorded on a multichannel analyzer. Since the sandwich geometry permits simultaneous detection of both reaction products, the magnitude of the resulting sum pulse should be proportional to the energy of the incident neutron plus the reaction Q value (4.78 Mev).

Silicon-gold surface-barrier counters have been used as α -particle spectrometers with extremely good energy resolution, approaching a few tenths of a percent for collimated alpha particles with energy of about 5 Mev.² The pulse-height distribution to be expected from monoenergetic neutrons on a sandwich detector of the type described here will exhibit a much broader peak, however, since the $\alpha + T$ reaction products are subject to energy loss in the Li^6F and gold layers before reaching the sensitive volume of silicon. The energy loss in a particular event depends on the angle at which the reaction products are emitted; since the α and T may be emitted at any angle, the energy loss is a variable from some minimum value up to the total energy available. In a practical counter, with a Li^6F layer of finite thickness, this variable energy loss will govern the width of a monoenergetic neutron peak, with a much smaller contribution from the inherent line width of the silicon counter.

The results presented herein are of a preliminary nature and summarize principally construction features of these devices and the results of a first set of experiments with monoenergetic neutrons. Considerably more work remains to be done with higher energy neutron sources, and in the development of improved methods and materials of construction. This paper is intended only as an interim report.

COUNTER CONSTRUCTION

The silicon surface-barrier counters used in this work were kindly supplied by J. L. Blankenship of this Laboratory. The method of preparation of these detectors has been described elsewhere.² The counters used in the present work differ only in that they were not cast in an epoxy resin mold. The edges of the silicon wafer were painted for protection, however, with a

thin coat of polystyrene in toluene, prior to evaporation of the gold layer. The n-type silicon starting material in the counters used in this work was of nominal 3600 ohm-cm resistivity.

A schematic diagram of a sandwich counter is given in Fig. 1. The device consists essentially of two silicon counters seated in thin fluorothene sheets which are in turn mounted in light aluminum rings. A layer of Li^6F , of nominal thickness $150 \mu\text{g}/\text{cm}^2$, is vacuum evaporated on one of the counters prior to assembly. The two counters may be brought close together, adjusted to make the faces parallel, and rigidly clamped, by means of three clamping nuts and three positioning screws, as shown. In practice it is desirable to separate the counters by as small a distance as possible, to avoid losing counts from an "edge effect" to be described below. An attempt is made to achieve a separation of about 0.001 in., at the same time taking extreme care that the counters do not touch and introduce small scratches on the delicate gold face.

A photograph of an assembled sandwich counter is shown in Fig. 2.

A schematic diagram of the electrical connections and pulse-analyzing equipment is shown in Fig. 3. Electrical contact to the gold surface of each counter was made by a narrow streak of silver paint leading from the periphery of the gold surface to the aluminum ring (See Fig. 1). The aluminum rings were then electrically grounded. The reverse bias of 20 volts was applied through a 500,000-ohm resistor, and the signal was fed through a coupling capacitor to a low-noise preamp. In the case of large-area detectors as used here, the associated large counter capacity results in a relatively small signal, necessitating a low-noise preamp to provide an adequate signal-to-noise ratio. Figure 4 shows a schematic diagram of the low-noise preamp used in the present

Fig. 1. Construction Details of a Sandwich Counter. 633 905

UNCLASSIFIED
PHOTO 50199

Fig. 2. Assembled Counter.

000 888

Fig.3. Electrical Connections to Counter and Pulse Circuitry.

Connector
for use with
A-1 Amplifier

NOTES:

1. Rise time is 0.1 μ sec. in Gain 32 pos. & 0.16 μ sec. in Gain 1024 pos.
2. Output can drive 5ma into an external load.
3. Grounded input noise is approx. 3.7 μ v R.M.S. on 2 mc B.W. (eg. with 1 μ sec. delay line clipping), 0.3 μ v on 0.5 mc B.W. & 0.7 μ v on 0.1 mc B.W. The input noise with a 15pf detector load is about 50% higher on 2mc B.W. & much higher on lower B.W.'s.
4. It is necessary to install an interstage shield on the 6922 & the 1801 to reduce miller loading of V1.
5. Wire wound resistors should be used in the input stage to reduce flicker noise.
6. V1 is microphonic & for best performance the amplifier and/or V1 should be shock mounted & protected from high audio frequency noise.

Fig. 4. Low Noise Preamp For Solid State Counters Circuit

work. The signal was then fed to a DD-2 double delay-line amplifier³ with a 1.2- μ sec clipping time. The amplified signal was analyzed in an RIDL 400 channel analyzer. The linearity and zero position of the analyzing equipment were checked between experimental runs with a mercury-relay test-pulse generator whose signal was fed to the preamp input.

EXPERIMENTAL PULSE-HEIGHT SPECTRA AND DISCUSSION

Pulse-height spectra have been recorded from neutrons on two sandwich counters. Neutrons of known energy were produced by the $T(p,n)He^3$ reaction, using the ORNL 5-Mv Van de Graaff generator to accelerate the incident protons. The target consisted of a layer of ZrT of nominal thickness 1 mg/cm² which had been evaporated on a platinum backing. The sandwich counter in all cases was placed at 0° with respect to the proton beam, and was located about 1 in. in front of the target. The proton beam was collimated to a spot about 1/8 in. in diameter. The plane of the Li^6F layer was perpendicular to the direction of the proton beam. Neutron energies were calculated from published tables,⁴ taking into account the energy loss of the proton in passing through the ZrT layer. The full energy spread of neutrons incident on the sandwich counter, arising from both the proton energy loss and the angular acceptance of the counter, was small compared to the neutron-peak width in the pulse-height spectra. Neutron energies quoted here correspond to 0° neutrons. Slow neutrons (thermal and epithermal) were obtained by moderating fast neutrons, derived from the $T(p,n)He^3$ reaction or from a Po-Be source, by blocks of paraffin.

A typical pulse-height spectrum from slow neutrons on counter No. 1 is shown in Fig. 5. The full width at half maximum is measured as 0.27 Mev.

UNCLASSIFIED
ORNL-LR-DWG 48687

Fig. 5. Pulse-Height Spectrum from Slow Neutrons on Counter No. 1.

An approximate calculation of the slow-neutron pulse-height spectrum, based on the energy loss of the charged particles in the Li^6F and gold, indicated that the slow-neutron peak should occur at a pulse height corresponding to 4.6 Mev (rather than the Q value of 4.78 Mev). The percent spread in the slow-neutron peak is thus $0.27/4.6 = 5.9\%$. The shape of the slow-neutron (or fast-neutron) peak is expected to be non-Gaussian and assymmetric by virtue of the energy loss processes responsible for the peak width. A low-energy tail is expected in all cases, contributing counts in the spectrum from the peak down to zero pulse height.

Figures 6 through 12 present pulse-height spectra for neutrons ranging from 0.59 to 3.50 Mev, taken with counter No. 1. In every case a well-defined fast-neutron peak is observed, whose full width at half maximum is indicated on the spectrum. A subsidiary slow-neutron peak is also observed in the spectrum and arises from the presence of a small number of degraded, low-energy neutrons. These low-energy neutrons apparently arise from the immediate vicinity of the counter itself, since the relative intensities of the fast- and slow-neutron peaks were essentially unaffected upon surrounding the counter with a cadmium shield. A possible neutron moderator is a blob of Apiezon wax on the back of each counter, securing the pig-tail lead. An additional effect to be noted in the fast-neutron spectra is the presence of a very large and steep background, below the slow-neutron peak. The energy corresponding to the cutoff of this background is very closely correlated with the incident neutron energy, indicating that this effect is due to recoil protons following (n,p) scattering. Additional experiments have confirmed that this is the case, and that the source of recoil protons is the thin peripheral layer of

Fig. 6. Pulse-Height Spectrum from 0.59-Mev Neutrons on Counter No. 1.

UNCLASSIFIED
ORNL-LR-DWG 48795

Fig. 7. Pulse-Height Spectrum from 1.09-Mev Neutrons on Counter No. 1. Small hump at pulse height 104 is probably due to 0.25-Mev resonance in $\text{Li}^6(n, \alpha)\text{T}$ cross section.

UNCLASSIFIED
ORNL-LR-DWG 48796

Fig. 8. Pulse-Height Spectrum from 1.59-Mev Neutrons on Counter No. 1. Small hump at pulse height 104 is probably due to 0.25-Mev resonance in $\text{Li}^6(n, \alpha)\text{T}$ cross section.

UNCLASSIFIED
ORNL-LR-DWG 48797

Fig. 9. Pulse-Height Spectrum from 1.99-Mev Neutrons on Counter No. 1.

UNCLASSIFIED
ORNL-LR-DWG 48798

Fig. 10. Pulse-Height Spectrum from 2.50-Mev Neutrons on Counter No. 1.

UNCLASSIFIED
ORNL-LR-DWG 48799

Fig. 11. Pulse-Height Spectrum from 3.00-Mev Neutrons on Counter No. 1.

UNCLASSIFIED
ORNL-LR-DWG 48800

Fig. 12. Pulse-Height Spectrum from 3.50-Mev Neutrons on Counter No. 1.

polystyrene, previously described. Both the wax and polystyrene layer will be eliminated in future counters by the use of fluorocarbon materials, hopefully eliminating or reducing these background effects.

Both slow-neutron and fast-neutron spectra were recorded with counter No. 2, with very similar results to those presented for counter No. 1. The primary purpose in assembly and testing counter No. 2 was to determine whether the methods of preparation were dependable and reproducible. The results indicate very little difference between the counters. Figure 13 presents the spectrum from 1.99-Mev neutrons on counter No. 2, which may be compared with Fig. 9.

In Fig. 5 a clearly defined hump occurs below the slow-neutron peak, and is labelled "single-particle events." Similar maxima may be observed in the fast-neutron spectra. These maxima arise from events predominantly occurring near the edge of the Li^6F layer. As a result of the finite separation distance between the two counters, there is a certain probability that an event will occur in which the alpha and triton are emitted at a small angle to the plane of the Li^6F layer such that one of the particles will be counted while the other escapes entirely. Thus the pulse-height spectrum from monoenergetic neutrons should in principle display three peaks: one due to the simultaneous capture of both alpha and triton to give the full-energy peak, one due to capture of the alpha with escape of the triton, and one due to capture of the triton with escape of the alpha. In practice, however, the peak due to alpha capture with escape of the triton is expected to occur at a low pulse height and to be very broad and smeared; this arises from the large energy loss of the alpha in penetrating the Li^6F and gold at small angles. In a practical

UNCLASSIFIED
ORNL-LR-DWG 48801

Fig. 13. Pulse-Height Spectrum from 1.99-Mev Neutrons on Counter No. 2.

case, then, one would expect to observe only two distinct peaks, as in Fig. 6. It can be seen in Fig. 5 that the slow-neutron peak, equivalent to 4.6 Mev deposited, occurs at pulse height 97; the triton-capture peak, equivalent to slightly less than 2.73 Mev, should occur just below pulse height 58, in agreement with experiment. The alpha-capture peak is not observed.

The "edge effect" discussed here can be minimized in two ways: (1) by minimizing the separation distance of the two counters, and (2) by evaporating the Li^6F layer over an area less than that of the silicon counter, leaving a blank strip around the border. Both of these techniques were employed with the counters used in the present study. As previously indicated, the separation distance was of order 0.001 to 0.002 in. Prior to evaporation of the Li^6F , each counter was covered with a plastic mask containing a rectangular aperture which defined the area of the gold face to be covered. The dimensions of the aperture were about 0.9 times the dimensions of the silicon counter.

Referring now to Figs. 6 through 12, it is seen that the full width at half maximum ranges from 0.28 to 0.42 Mev. These figures should not be taken exactly, as they are derived from only one set of runs with relatively few total counts in each spectrum. The important points to note are that the neutron-energy spread is relatively constant, of order 300 kev, and that the neutron-energy resolution improves rapidly with increasing energy. The fractional width $\Delta E_n/E_n$ decreases from $\sim 30\%$ at 1 Mev to $\sim 10\%$ at 3 Mev. A calculation of the shape and width of the fast-neutron peak as a function of neutron energy presents a rather complicated problem by virtue of the center-of-mass motion and the nonisotropic angular distribution of the reaction products. It is not possible, a priori, to predict the behavior of the fast-neutron peak at higher energies.

Qualitatively, however, one expects the fractional width $\Delta E_n/E_n$ to decrease with increasing energy. It is hoped to focus attention on this point in future studies.

The pulse height vs. energy relationship, based on the present results with counter No. 1, is apparently linear or very nearly so, as expected. It is not possible to determine this relationship precisely on the basis of the present work, since the total energy deposited in the counters by a neutron of energy E_n is not simply $E_n + Q$, but is less than this by an amount which depends on the thickness of the Li^6F and gold layers, and on the angular distribution of the reaction products. As indicated previously, thermal neutrons result in the deposition of about 4.6 Mev. In the absence of detailed calculations for fast-neutron cases, one does not know accurately the energy deposited in a fast-neutron event. As a first approximation, however, a plot of pulse height vs. $(E_n + 4.6 \text{ Mev})$, Fig. 14, can be reasonably fitted with a straight line through the origin.

Finally, preliminary experiments were carried out to examine the effect of gamma-ray backgrounds on the neutron-counting properties of a sandwich detector. A sandwich counter was placed adjacent to a paraffin block in which a Po-Be source had been placed, and the pulse-height spectrum from slow neutrons was recorded. The slow-neutron peak was centered at channel 100, with a fractional width of about 6%. A 0.6-curie Co^{60} gamma-ray source was then placed 5 in. from the detector, and the spectrum was rerun. No significant change was observed in the pulse height, width, or count rate in the slow-neutron peak. A steep background occurred, however, at low

UNCLASSIFIED
ORNL-LR-DWG 48802

Fig. 14. Pulse Height vs. Total Energy Deposited, for Neutrons on Counter No. 1. Abscissa values are approximate, as discussed in text.

pulse heights, cutting off at about channel 20. On the basis of this experiment, it is tentatively concluded that these counters offer rather strong discrimination against gamma-ray backgrounds even in quite high gamma-ray fields. The large positive Q value of the $\text{Li}^6(n,\alpha)\text{T}$ reaction, of course, provides a built-in bias against any background event up to 4.6 Mev.

CONCLUSIONS

The experiments summarized here indicate possible future application of sandwich counters of this type for certain problems involving the detection and spectroscopy of fast neutrons. The principal advantages of such a counter appear to be its simplicity of construction and operation, and its relative insensitivity to gamma rays. A further advantage lies in the fact that the counter accepts neutrons from any direction, eliminating the need for neutron collimation. The detection efficiency is limited by the thickness of the Li^6F layer. A layer $150 \mu\text{g}/\text{cm}^2$ thick, as used in the present counters, offers a detection efficiency of 3.4×10^{-3} for thermal neutrons and 0.94×10^{-6} for 2-Mev neutrons, assuming normal incidence of the incoming neutron. These efficiencies are, of course, rather low and limit the use of this technique to those experiments with sufficiently high neutron intensities. The efficiency can be increased by the use of thicker Li^6F layers at the expense of broadening the peak width. Another possibility for increasing efficiency is that of stacking, say, 5 or 10 counters together.

REFERENCES

1. For a review of various neutron detection methods, see J. B. Marion and J. L. Fowler, Fast Neutron Physics, Part I, Interscience Publishers, Inc., New York (1960).
2. J. L. Blankenship and C. J. Borkowski, paper presented at Seventh Scintillation Counter Symposium, Washington, D. C., February, 1960. To be published in IRE Transactions on Nuclear Science, 1960.
3. E. Fairstein, Rev. Sci. Instr. 27, 475 (1956).
4. J. L. Fowler and J. E. Brolley, Jr., Revs. Modern Phys. 28, 103 (1956).

DISTRIBUTION

1. F. S. Alsmiller
2. J. L. Blankenship
3. E. P. Blizard
4. T. V. Blosser
5. C. J. Borkowski
6. V. R. Cain
7. A. D. Callihan
8. G. T. Chapman
9. G. deSaussure
10. J. L. Fowler
11. R. M. Freestone
12. W. M. Good
13. K. M. Henry
14. L. B. Holland
15. G. S. Hurst
16. W. H. Jordan
17. L. Jung
18. J. Lewin
- 19-79. T. A. Love
80. F. C. Maienschein
81. J. J. Manning
82. A. Meyer
83. F. J. Muckenthaler
- 84-144. R. B. Murray
145. V. Paré
146. R. W. Peele
147. E. R. Rohrer
148. E. G. Silver
149. A. H. Snell
150. H. A. Todd
151. V. V. Verbinski
152. D. R. Ward
153. A. M. Weinberg
154. R. E. Zedler
155. W. Zobel
156. M. J. Skinner
157. Document Reference Section
- 158-159. Central Research Library
- 160-171. Laboratory Records
172. ORNL-RC
- 173-187. TISE, AEC

DO NOT REPRODUCE