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FAST-NEUTRON SPECTROMETER DEVELOPMENT

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The program which is reviewed here is directed toward the development of a more efficient and versatile fast-neutron spectrometer which would be suitable for the measurement of fission neutron spectra, continuous spectra in the energy region 1 to 12 Mev. Previous measurements of this type have been carried out with proton-recoil spectrometers which have the twofold disadvantage of extremely low sensitivity and the requirement of either a point source or neutron collimation. The construction of an improved proton-recoil spectrometer is described in the current Applied Nuclear Physics Division Annual Progress Report for the period ending Sept. 10, 1956 (ORNL-2081). This instrument is currently being aligned and tested as time permits. The major effort, however, is now a study of the scintillation response of $\text{LiI}(\text{Eu})$ crystals, with the hope of developing a crystal scintillation spectrometer.

The scintillation response of $\text{LiI}(\text{Eu})$ crystals to neutrons is due to the $\text{Li}^6 (n, \alpha) \text{T}$ reaction ($Q = 4.78$ Mev); the reaction products in slowing down and stopping excite the crystal to radiate light which can be detected by a conventional photomultiplier arrangement. Analysis of the photomultiplier pulse height spectrum provides a measure of the total energy released in the crystal, hence the energy of the incoming neutron.

The advantages offered by a $\text{LiI}(\text{Eu})$ crystal as the detecting element in a fast-neutron spectrometer are several: (1) the crystal is an isotropic detector so that a neutron collimator need not be used to define the direction of the incident neutron; (2) the crystal is small (for example, 1 in. in diameter and 1/8 in. thick), making possible spectral measurements at a "point"; (3) the detection efficiency is orders of magnitude greater than

that afforded by proton-recoil spectrometers; and (4) pulses from gamma rays below about 4.7 Mev fall below the thermal peak, and can thus be biased out. The difficulties which may be encountered are: (1) the crystals may respond to high energy gamma rays; (2) the energy resolution for fast neutrons is rather broad; and (3) the crystals are hygroscopic and must be maintained in a moisture free environment.

The detection efficiency for crystals of Li^6I as a function of neutron energy is shown in Fig. 1. The shape of the curve is determined entirely by the energy dependence of the $\text{Li}^6(n,\alpha)\text{T}$ cross section. Thin crystals (2 mm in thickness) are normally used in this work to minimize the gamma-ray detection efficiency; the pulse height spectra obtained from 10-mm crystals are quite similar to those from 2-mm crystals.

In order to examine the properties of $\text{LiI}(\text{Eu})$ as a fast-neutron spectrometer, it is necessary to bombard a crystal with fast neutrons of a single energy and observe the resulting pulse height spectrum. Monoenergetic neutrons in the energy region from 0.63 to 14.9 Mev were obtained from the (p,t), (d,d), and (d,t) reactions using gas targets. The incident particle was accelerated by the ORNL 2.5-Mev Van de Graaff generator. The pulse height spectra shown in Figs. 2, 3, and 4 are from a 2-mm thick crystal of Li^6I with 0.025 mol % europium activator, with incident neutrons of energies 0.63, 1.57, and 5.79 Mev, respectively. These spectra were obtained with the crystal at room temperature. In every case the large thermal-neutron peak arises from neutrons degraded in energy by scattering from the walls, floor, etc. The magnitude of this peak is due to the very large cross section for the (n, α) reaction at thermal energies. In these spectra it is seen that the fast-neutron peak appears as a broad and "rectangular" band, rather than the

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FIGURE 1

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FIGURE 2

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FIGURE 3

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FIGURE 4

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sharp Gaussian shape of the thermal-neutron peak. This behavior is tentatively ascribed to a difference in the scintillation efficiency of $\text{LiI}(\text{Eu})$ for the alpha and triton at room temperature. For the fast-neutron induced reaction both the alpha and triton have a range of energies available to them, since the energy division between the reaction products depends upon their angular distribution. For very slow (thermal) neutrons, however, the energy distribution between the alpha and triton is uniquely specified.

Figure 5 shows the pulse height spectrum from 5.79-Mev neutrons on an 8-mm-thick crystal of $\text{Li}^7\text{I}(\text{Eu})$. This may be compared with Fig. 4 [5.79-Mev neutrons on $\text{Li}^6\text{I}(\text{Eu})$] in which a large fast-neutron peak occurs. No evidence of a fast-neutron peak was observed in the Li^7 crystal. The small thermal-neutron peak in Fig. 5 is due to a trace of Li^6 impurity. The continuous background in both Figs. 4 and 5 arises from the penetration of the deuteron beam through a thin nickel foil in the gas target which is used for the (d,d) reaction. This background can be isolated (and subtracted) from the fast-neutron spectrum simply by removing the deuterium gas from the target. It should be noted that this continuum is not the result of 5.79-Mev neutrons on the crystal.

One of the major difficulties in measuring the fast-neutron spectrum from a fission source or reactor is the large background of high-energy gamma rays. The availability of the separated isotopes Li^6 and Li^7 leads to the possibility of a simple technique for eliminating the gamma-ray contribution to an observed fast-neutron pulse height spectrum. This might be done by recording the spectrum from both an Li^6 and an Li^7 crystal; since gamma rays interact with the electrons of the crystal, the gamma-ray response of both crystals should be the same. The Li^7 pulse height spectrum, however, will not

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FIGURE 5

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demonstrate a direct effect from fast neutrons. Taking the difference between the Li^6 and the Li^7 pulse height spectra should then subtract out the gamma-ray contribution. There are, of course, other neutron events in Li^6 and Li^7 which must be considered, such as inelastic scattering, radiative capture, and other charged particle reactions. Inelastic scattering and radiative capture give rise to relatively low-energy gamma rays which will fall below the thermal-neutron peak and thus be eliminated. Charged particle reactions such as (n,p) and (n,d) are endothermic and occur with small cross sections;¹ they will be observed only for neutrons above about 8 Mev. At the present time, this scheme of monitoring the gamma-ray background appears to be feasible. It will be necessary to examine the response of the crystals to high-energy gamma rays and neutrons in greater detail, however, before this technique can be adopted.

The pulse height spectrum from 14.9-Mev neutrons on $\text{Li}^6\text{I}(\text{Eu})$ is shown in Fig. 6. Two qualitative differences between this spectrum and those at lower energies are observed. First, the fast-neutron peak has a nearly Gaussian shape with a full width at half maximum of about 9%. Second, the continuum is quite large compared to the 14.9-Mev neutron peak and rises sharply to a plateau just below the (n, α) peak. In the case of 14.9-Mev neutrons, competing reactions may contribute to the background. This does not necessarily mean, however, that neutrons in the 1- to 8-Mev region of the fission spectrum will be obscured by the background from the higher energy component; the fission spectrum falls off rapidly in energy so that the continuum from high-energy neutrons will still be small.

1. G. M. Frye, Phys. Rev. 93, 1086 (1954).

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FIGURE 6

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Figure 7 shows a plot of pulse height vs total energy released for the Li^6I (0.025% Eu) crystal. The data are plotted as full-width of the peak at half-maximum. It is seen that the midpoints of the peaks can be joined by a straight line, indicating that the relationship is essentially linear throughout the range of interest.

Measurements of fast-neutron pulse height spectra have been carried out on other crystals of $\text{LiI}(\text{Eu})$ with various concentrations of europium activator and Li^6 isotope. The spectra observed have all been basically similar to those shown in Figs. 2, 3, 4, and 6. Pulse height spectra from fast neutrons on a 10-mm thick crystal of $\text{LiI}(0.1\% \text{Eu})$, with the natural concentration of Li^6 , have been reported previously.²

Another variable which can affect the scintillation properties of a crystal is its temperature. In order to examine the effect of varying the temperature, pulse height spectra from 5.3-Mev neutrons on $\text{Li}^6\text{I}(\text{Eu})$ have been recorded at several temperatures. The apparatus used for cooling the crystals is shown schematically in Fig. 8; the design of this equipment was dictated by the fact that conventional photomultipliers do not function below about -140°C . With the scheme shown here the photocathode is maintained near room temperature, while the crystal temperature is continuously variable down to -196°C . The crystal temperature, which is measured by a copper-constantan thermocouple, is set by adjusting the flow rate of the cooling gas.

Two effects are observed upon cooling the crystals. First, the scintillation efficiency increases with decreasing temperature. The thermal-neutron pulse height as a function of temperature, for a normal $\text{LiI}(0.1\% \text{Eu})$ crystal,

2. Physics Division Semiannual Progress Report for Period Ending Sept. 10, 1954, ORNL-1798, p. 32 (Nov. 24, 1954).

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FIGURE 7

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FIGURE 8

is shown in Fig. 9. Second, the fast-neutron peak assumes a nearly Gaussian shape at about -140°C , with a marked improvement in resolution. This behavior is shown as a function of temperature for two different crystals in Figs. 10 and 11. The resolution indicated in these spectra is somewhat deceptive, in that it is the full-width at half-maximum divided by the pulse height of the maximum, following the usual convention. From the standpoint of neutron energy, however, the zero of energy occurs at the position of the thermal-neutron peak, so that the neutron energy resolution is greater than that shown. For example, the neutron energy resolution at -142°C (Fig. 11) is 17.7%. Only one experiment has been carried out at temperatures lower than -142°C , using the Li^6I (0.06% Eu) crystal. The pulse height spectrum at -196°C , from 5.3-Mev neutrons, was similar to that observed at -142°C , Fig. 11. The continuous background in Figs. 10 and 11 is from the gas target.

The considerable improvement in fast-neutron response observed in these crystals upon cooling has provided the motivation for a continued study of pulse height spectra at low temperatures. A new cooling apparatus is being constructed to replace that shown in Fig. 8, since the gas flow requires almost constant attention to maintain a steady temperature. It is hoped that it will be possible to eliminate the long light pipe, separating the crystal from the photomultiplier, by the use of special photomultipliers which will operate at liquid nitrogen temperatures. As soon as these experimental details are worked out, it will be of immediate interest to examine fast-neutron pulse height spectra, at various temperatures, for neutrons throughout the energy region from 1 to 15 Mev.

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FIGURE 9

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Fig. 10.

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Fig. 11.

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