

A MICROPROCESSOR-CONTROLLED PORTABLE NEUTRON SPECTROMETER

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Abstract

A neutron spectrometer that acquires and unfolds data in the field has been developed for use in the energy range from 1 to 20 MeV. The system includes an NE213* organic scintillation detector, automatic gain stabilization, automatically stabilized pulse-shape discrimination, an LSI-11 microprocessor for control and data reduction, and a multichannel analyzer for data acquisition. The system, with the exception of the multichannel analyzer, is mounted in a suitcase 47 by 66 by 23.5 cm. The mass is 23.5 kg.

Introduction

A portable neutron spectrometer capable of quantifying the energy and intensity spectrum of fast neutrons in a mixed n- γ field has been developed. A photograph of the spectrometer appears in Fig. 1. The instrument is intended for field use, where neutron field intensities are low and where wide temperature variations may occur while a spectrum is being acquired. Gain stabilization of the linear signal and timing stabilization in the pulse-shape discriminator (PSD) circuit are used. A ^{22}Na gamma-ray source is fastened to the detector to provide a gain- and timing-reference.

A pulse-height spectrum of recoil proton events is acquired on a commercial multichannel pulse-height analyzer (with some modifications). The data are then transferred to a microprocessor (DEC LSI-11), where they are reduced to an absolute differential neutron flux spectrum. The neutron spectrum may be transferred back to the analyzer for viewing or to a cassette for storage. The microprocessor also provides system gain calculations and adjustments, and controls the analyzer during the spectrum accumulation. It automatically performs self-diagnostics and reads-in its program from the cassette. The human/system interface is a panel keyboard and an LED display.

Software development consisted of adapting a neutron spectrum unfolding code¹⁻³ and a gain stabilization method⁴ to this instrument, as well as refining the routines to provide human interface. The resulting system offers several improvements over an earlier instrument⁵⁻⁷:

- (1) a sophisticated unfolding code written in Fortran IV,

- (2) stabilization of both the gain and PSD circuitry by tracking pulse-height and pulse-shape distributions from the internal gamma-ray source,

- (3) the flexibility of using a commercially available pulse-height analyzer, and

- (4) compatibility with any of several NE213 or stilbene detectors in different environments.

System DescriptionGeneral Features

A block diagram of the spectrometer appears in Fig. 2. All electronic parts, except for the multichannel analyzer (MCA), are contained in one 47- by 66- by 23.5-cm suitcase. The total mass is 23.5 kg. This includes all power supplies (175 W, 117 V, 60 Hz) and storage space for the preamp, detector, photomultiplier tube (PMT), and cables. The MCA is 30.2 by 21.3 by 51.8 cm, with a mass of 13.6 kg and a power drain of 100 W. Connectors mounted on the side of the suitcase link the MCA with the spectrometer. After setup, the suitcase may be closed to prevent moisture accumulation. The operating range extends from 0° to 40°C, and cooling fans keep the input-to-output temperature rise at 5°C in a 25°C environment.

Detector and Amplifier

Table 1 lists the available detectors and the range of neutron dose rates for which each is useful. In this instrument, the energy range of these detectors is 1 to 20 MeV with 7% resolution.

The PMT generally used is RCA type 8575. Its tenth dynode supplies the linear output, and its anode provides the negative output for PSD analysis. The linear output is connected to a preamplifier, which is positioned near the PMT. The preamplifier output feeds into an amplifier inside the suitcase. The amplifier has coarse and fine gain adjustments 5X to 300X, and the signal is shaped to 4- μ s rise and fall times. The amplifier contains both a pole zero-adjustment and passive dc-restoration.

Pulse-Shape Discriminator

The negative output from the PMT is the input to the constant-fraction discriminator⁸ (CFD) and the pulse-shape discriminator⁹ (PSD). The CFD provides a fixed-time reference independent of the input signal amplitude. This is accomplished by triggering at a constant fraction of the amplitude of the input signal.

*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

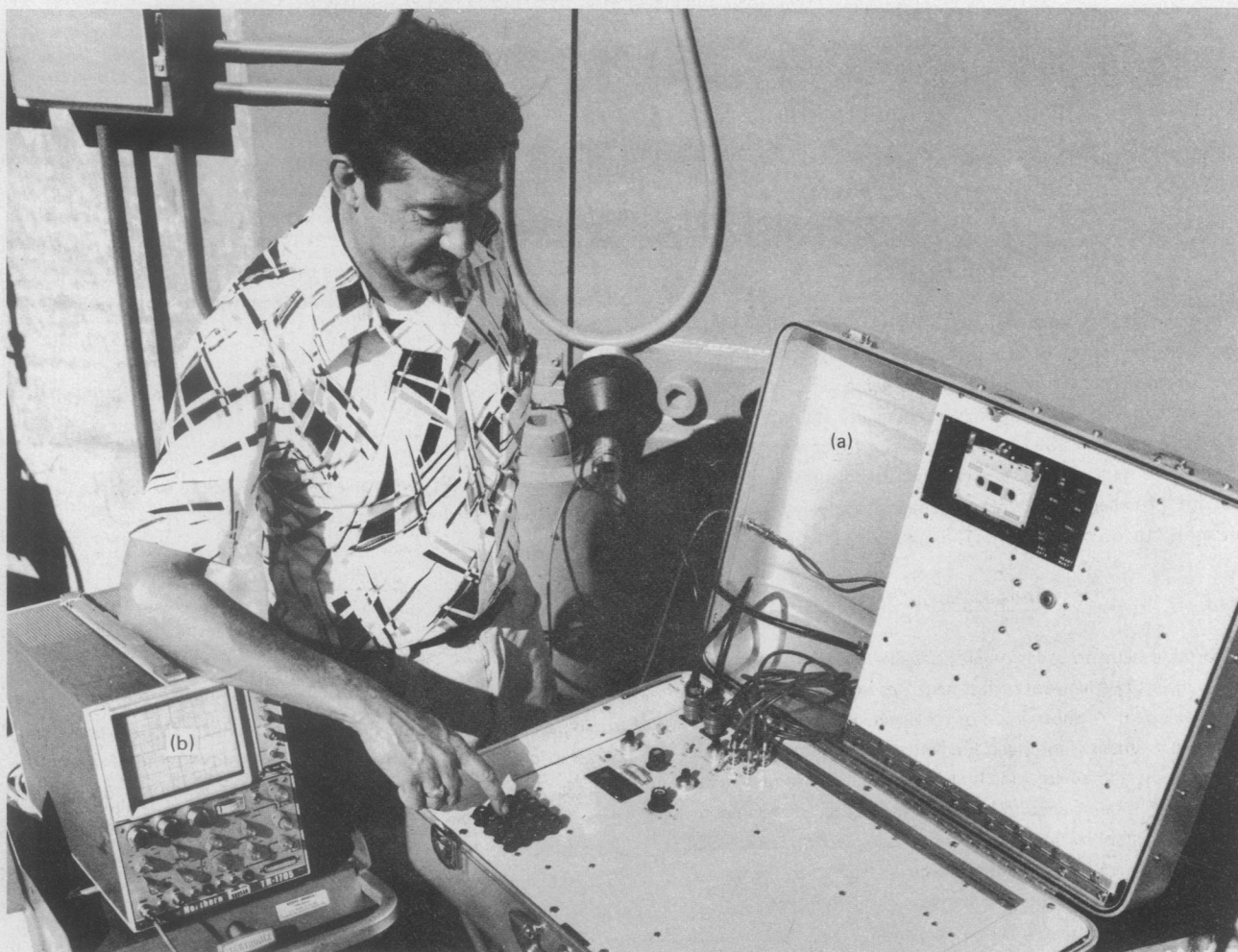


Fig. 1: The portable neutron spectrometer (a) and the multichannel analyzer (b) arranged for use.

Table 1. Detectors compatible with the neutron spectrometer.

Detector number	Length (cm)	Scintillator		Useful neutron intensity range (n/cm ² ·s)
		Diameter (cm)	Material	
101	5.08	11.4	NE213	0.1 to 10 ³
103	7.6	3.8	NE213	0.5 to 10 ⁴
105	5.08	5.08	NE213	0.5 to 10 ⁴
104	2.5	2.5	NE213	5 to 10 ⁵
102	1.3	1.3	NE213	50 to 10 ⁶
401	1.0	1.3	stilbene	50 to 10 ⁶

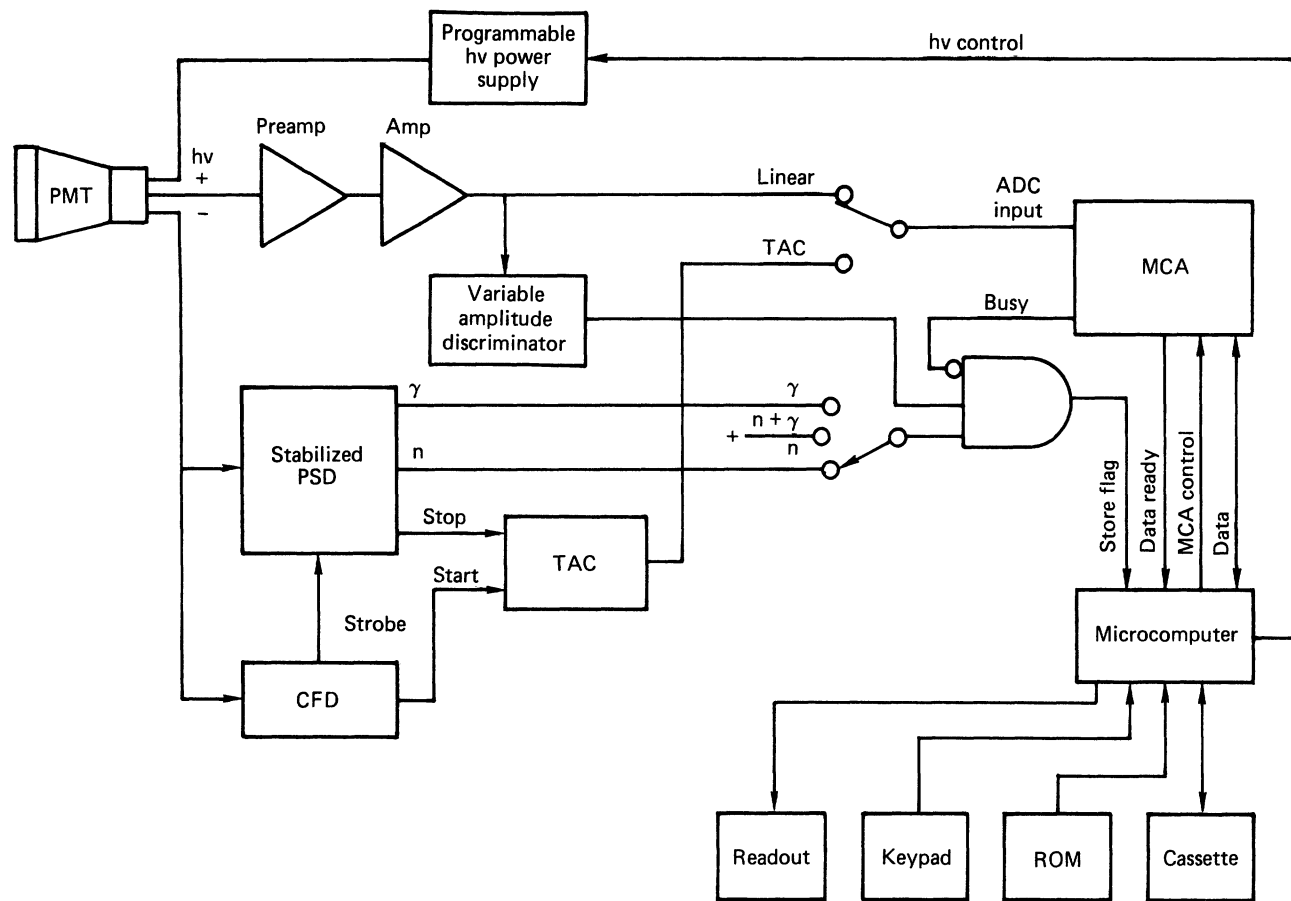


Fig. 2: Block diagram of the portable neutron spectrometer.

The PSD is an expansion of a previously published circuit.⁹ Its purpose is to provide a flag for the computer to indicate whether the detector event was caused by a gamma ray or by a neutron. It is stabilized to prevent any timing drift.

A block diagram of the stabilized PSD circuit appears in Fig. 3. The shaping amplifier consists of an LH0032CG operational amplifier followed by a complementary bipolar output stage. The signal is shaped so that the crossover lags about 200 ns behind the leading edge. This allows for maximum separation between the neutron and gamma signals. The limiting amplifier is three cascaded differential stages of an MC 10216. The limiting-amplifier output is a saturated waveform in which the separation of the zero crossover point for neutron and gamma events is greatly enhanced. Both the shaping and limiting amplifiers are dc-coupled. Also, a feedback loop links the output of the limiting amplifier to the input of the shaping amplifier for dc-stability.

The trigger from the CFD enters two cascaded delays. The first is a variable delay, which is controlled by an analog voltage from a digital-to-analog (D/A) converter. The second, which is adjusted by changing a cable on the front panel, is used to match detector characteristics. The purpose of these delays is to trigger the 30-ns monostable ("one-shot") multivibrator so that the leading edge of its negative going output will occur before the positive trailing edge of the limiting-amplifier output for a neutron event but not for a gamma event. Thus, we get an output from the AND gate for a neutron and not for a gamma event. These two signals (the 30-ns

one-shot output and the limiting-amplifier output) are ANDed together to produce a signal that indicates the event was a neutron.

The output of the variable delay is retarded an additional 8 ns and triggers two cascaded 6-ns one-shots. The variable delay is adjusted so that the trailing edge of the output from the first device and the leading edge of the output from the second both coincide with a pulse triggered by the trailing edge of the limiting-amplifier output for a gamma event. In other words, the two 6-ns pulses are ANDed with a 4-ns pulse generated by the trailing edge of the limiting-amplifier output. If this 4-ns pulse is early, the add-subtract scaler value will advance. If it is late, the scaler value will decrease. Only gamma events will cause the scaler value to change since a neutron event would not generate a 4-ns pulse within the ± 6 -ns window offered by the two cascaded one-shots. The output of the scaler is converted to an analog voltage that controls the delay time of the variable delay. This feedback loop stabilizes the timing of the PSD circuit to allow acquisition of a neutron spectrum over a long period of time, where ambient temperature variations might otherwise cause a shift in timing.

The time-to-amplitude converter (TAC) is used during set-up to enable the operator to adjust the variable delay line. During set-up, a neutron-gamma time spectrum (e.g., Fig. 4) is accumulated. Gamma events cause the left peak, and neutron events cause the right peak. The instrument is then switched to store only neutron events, and the variable delay is adjusted so that the gamma peak disappears while the neutron peak remains.

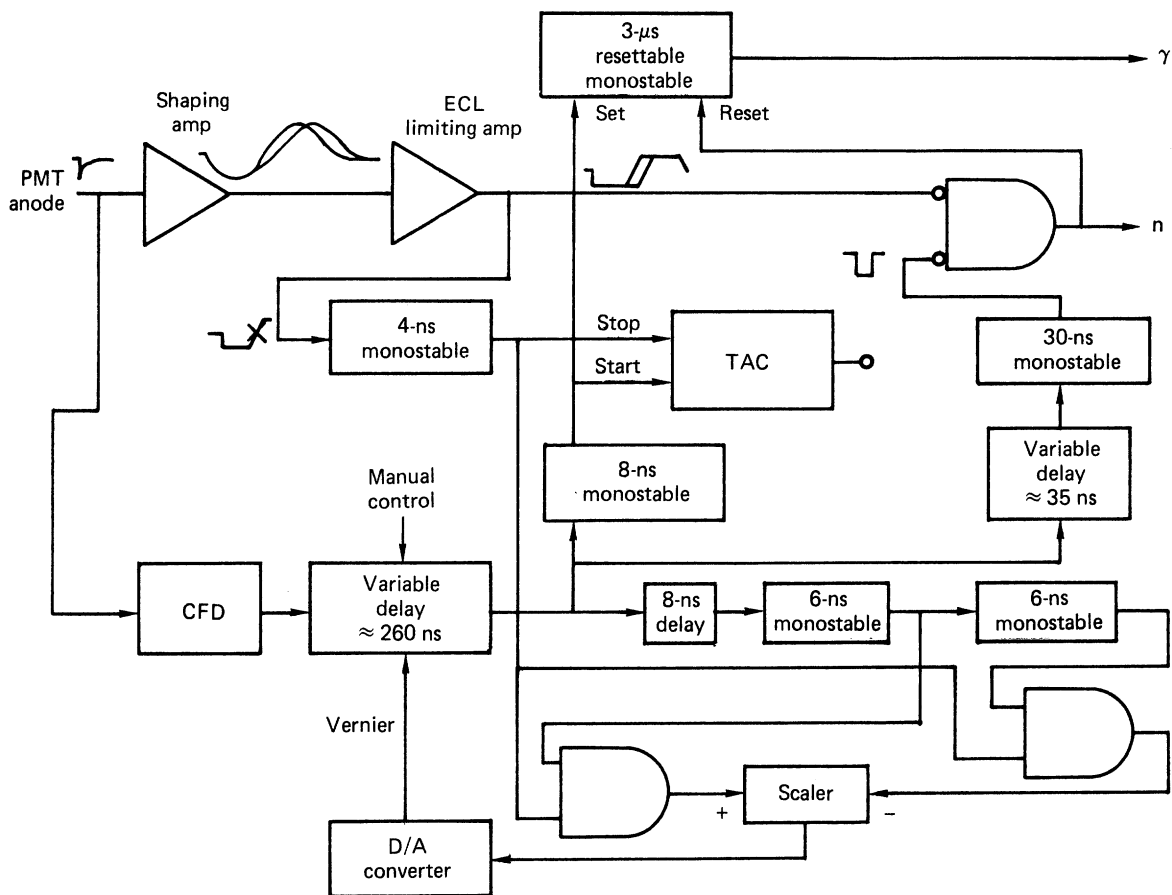


Fig. 3: Block diagram of the pulse-shape discriminator circuit.

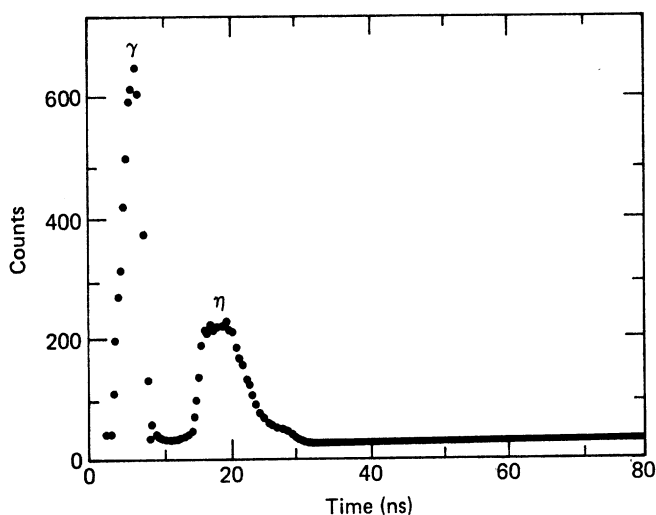


Fig. 4: Spectrum of neutrons (right peak) and gamma rays (left peak) as a function of time for ^{22}Na and $^{238}\text{Pu-Be}$ sources.

Multichannel Analyzer

The pulse-height analyzer is a Northern Scientific model NS 1705, modified for microprocessor control (Fig. 2). When the analog-to-digital (A/D) converter has completed a conversion, this analyzer signals the processor that data are ready. The processor then checks the

store flag, which can be enabled by a neutron, a gamma-ray, or both, as selected by the front panel switch. If the flag is present, the processor issues a store pulse that files the event in the analyzer's memory. Regardless of the condition of the store flag, every gamma flag increases the appropriate channel count in the processor's gain stabilization spectrum. After a fixed number of gamma events are stored in this spectrum, the processor looks for the spectrum's Compton edge to see if the system gain has drifted.⁴ If so, the processor adjusts the system gain using a D/A converter that controls a programmable high-voltage power supply. The high-voltage control circuit appears in Fig. 5. The high-voltage adjustment range is from +800 V to +2 kV, and the processor has an additional control of ± 180 V. After the flags have been checked and the event serviced, the processor issues a clear pulse to the analyzer and spectrometer, and the A/D converter will be ready for the next event.

System Control

The system/user interface is provided by a hexadecimal keyboard and a four-digit readout, both on the front panel. The keyboard is used to initiate spectrum unfolding, gain stabilization, and spectral data transfer to or from the analyzer and cassette. On it one can also enter tag numbers, the energy scale for unfolding and stabilization, and the detector-sensitive volume for unfolding. Three of the digits on the readout echo the numbers entered by the operator. The fourth indicates the machine status, including these conditions: idle

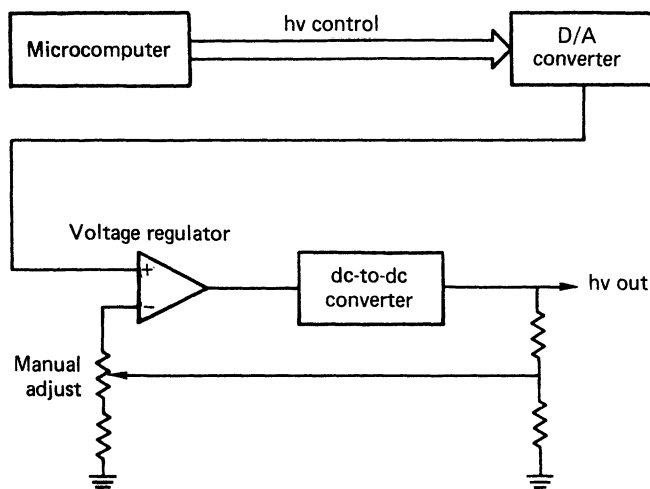


Fig. 5: Block diagram of the high-voltage power supply.

(analyzer may be used as if it were stand-alone), diagnostic or absolute loader error, gain stabilization, unfolding in progress, and successful completion of diagnostics.

The software is functionally divided into four main groups: the user interface and peripheral handlers, the spectrum unfolding routine, the gain stabilization routine, and the diagnostics and absolute loader. The user interface is written in assembly language and includes the handler for the keyboard and panel readout, the handler for data transfer to and from the analyzer and cassette, and system control. The cassette handler assigns tag numbers to spectra recorded on the cassette and permits tag searches to find a specific spectrum.

The spectrum unfolding routine is written in Fortran IV and reduces the 256-channel pulse-height spectrum to an absolute-differential neutron-flux spectrum of 120 channels. Unfolding requires about 30 s. The gain stabilization routine is also written in Fortran IV and is entered after n (typically 10^5) gamma-ray events have been stored in the region of interest of the stabilization spectrum. The gain is checked by integrating the area under a Compton edge and then seeing if it is greater than or less than a standard value.

The diagnostics and the absolute loader are modifications of those found on the DEC REV-11 board, and they are contained on ROM. The diagnostics test the instruction set and the memory. If an error occurs during these tests, the operator is notified through the status digit. The diagnostics normally are automatically entered on power-up. Upon their successful completion, the processor jumps to the absolute loader and notifies the operator, via the status digit, that it is waiting for a program read-in from a cassette.

Application

The neutron spectrometer accumulates data in a mixed neutron-gamma field and unfolds the data to obtain an absolute-differential neutron-flux spectrum. Figure 6 shows the raw pulse-height data and unfolded spectrum from a ^{238}Pu -Be source, using a 2.54- by 2.54-cm NE213 detector. The energies of the peaks are indicated on the unfolded spectrum. These results compare favorably with those ob-

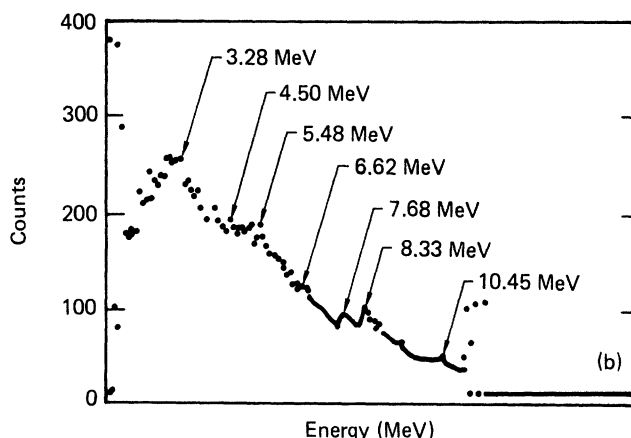
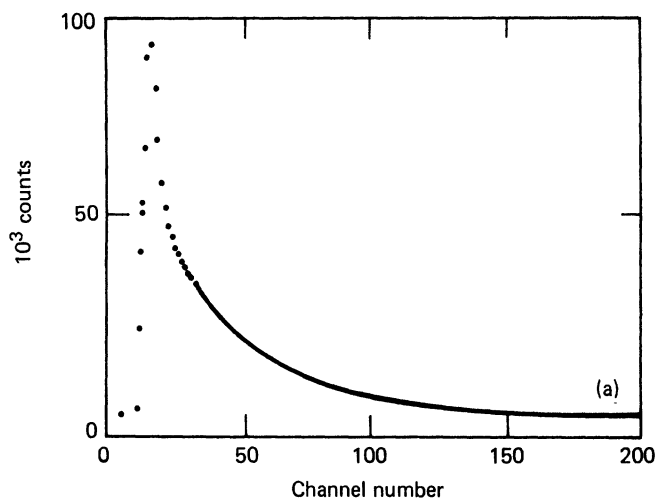


Fig. 6: Data from the neutron spectrometer for a ^{238}Pu -Be source. (a) Raw pulse-height data. (b) The unfolded spectrum, showing the energy of each peak (nonlinear scale).

tained by others.¹⁰⁻¹² The spectrum fills 120 data channels (channel 0 through 119). Channels 120 through 126 contain the data exponent (vertical scale), the channel-0 energy and exponent, and the energy per channel and exponent. This spectrum results from a 210-mrem exposure. We have already seen a time spectrum for ^{22}Na and ^{238}Pu -Be sources in Fig. 4, where there is less than 1% gamma-to-neutron crossover.

Acknowledgment

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