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INFLUENCE OF MATERIALS AND COUNTING-RATE EFFECTS ON ^{3}He NEUTRON SPECTROMETRY

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Abstract

The high energy resolution of the Cuttler-Shalev ^{3}He neutron spectrometer causes spectral measurements with this instrument to be strongly susceptible to artifacts caused by the presence of scattering or absorbing materials in or near the detector or the source, and to false peaks generated by pileup coincidences of the rather long-risetime pulses from the detector. These effects are particularly important when pulse-height distributions vary over several orders of magnitude in count rate versus channel. A commercial pile-up elimination circuit greatly improves but does not eliminate the pileup problem. Previously reported spurious peaks in the pulse-height distributions from monoenergetic neutron sources have been determined to be due to the influence of the iron in the detector wall.

Introduction

High-resolution ^{3}He neutron spectrometers of the gridded ion-chamber type[1] have been used in recent years to measure, in heretofore inaccessible detail, the spectra of delayed neutrons from fission, neutron spectra from separated delayed-neutron-emitting isotopes,[2] and leakage-neutron spectra from fast-critical nuclear assemblies.[3] As the measurement results are studied with increasing thoroughness, it is evident that these detectors are, by virtue of their high energy resolution, capable of bringing out details related to neutron spectra phenomena not commonly observed. Peaks caused by elastic and inelastic scattering of neutrons from materials adjacent to the experiment, as well as irregularities produced by cross-section resonances in material through which the neutrons being measured must pass, become significant in the interpretation of spectra. A second cause of spurious peaks is accidental coincidences, particularly between epithermal neutrons or between epithermal and higher-energy neutrons. This paper results mainly from a study of such phenomena for the purpose of evaluating their applicability to problems of material identification.

Experimental Procedure

A Seforad* model FNS-1 spectrometer tube was used. This spectrometer is a gridded ^{3}He ionization chamber similar to the one developed by Cuttler and Shalev[1] except that the bolted end flanges on the earlier model have been eliminated. The detector was used with its thermal shield of 2 mm of boron nitride and 1 mm of cadmium. A modified Seforad model SR-105 preamplifier was directly coupled to the detector, which was operated at an anode bias of 3000 V. The grid bias of 857 V, obtained from a 1400-MΩ bleeder on the anode supply, is the value set by the manufacturer.

We frequently need to use the detector in environments with significant levels of electromagnetic and acoustical noise, both of which adversely affect the performance of the detector. Suspending the detector and preamplifier in Styrofoam rings inside a 15-cm-diam by 1.6-mm-thick aluminum container reduces noise pickup considerably. This shielded assembly is normally placed on top of an air-cushioned optical table.

The electronics system (Fig. 1) is similar to a previously described system,[4] except that the ORTEC Model 450 amplifier in the older system was replaced by a Model 572 amplifier, which has an internal pileup-inspection circuit. Veto pulses from the pileup circuit are used to gate off the ADC of the multichannel analyzer to pileup-distorted pulses. However, because of the long time constants (6 μs) needed to obtain good energy resolution from this detector, pileup rejection was effective only against partially overlapping pulses; accidental near-coincidence pulses appeared as sum pulses.

Pulse-shape analysis is used principally to separate ^{3}He-recoil pulses from the distribution. Risetime distributions of ^{3}He-recoil pulses and pulses from the ^{3}He(n,p)^{3}H reaction overlap, but if one is willing to sacrifice two-thirds of the ^{3}He(n,p) pulses it is possible to obtain a pulse-height distribution almost free of ^{3}He-recoils. Pulse-shape analysis also improves energy resolution by rejecting pulses distorted by noise or pileup. The pulse-risetime distributions do not shift much in time with neutron energy; therefore use of the risetime gate as shown in Fig. 1 is as effective as a full two-parameter acquisition of risetime versus pulse height, and the data are far easier to reduce.

For the transmission measurements described below, spherical shells of materials surrounded a ^{252}Cf source emitting about 5×10^6 n/s, centered 20 cm from the axis of the spectrometer. Statistically acceptable pulse-height distributions were acquired in 16 h. During previous work the spectrometer was calibrated using monoenergetic ^{7}Li(p,n)^{7}Be neutrons from a Van de Graaff accelerator, and a program was written to reduce pulse-height data to neutron spectra with the TN-4000 data system.* However, since the purpose of this paper is to illustrate effects of materials on pulse-height distributions, most results are presented unreduced.

Results

Effects of Scattering Materials: Iron

This study was partially motivated by a recent measurement of the neutron spectrum from a replica of the Little Boy device used at Hiroshima.[5] The replica consisted of a physical duplicate of the original assembly with the fissile content reduced and the rapid-assembly mechanism replaced by a vernier actuator. The assembly was then essentially a small fast reactor operating at a power level of a few milliwatts inside a massive iron reflector. A typical neutron spectrum is shown in Fig. 2, together with the ENDF-B-V total neutron cross-section for iron. The peaks, particularly the dominant

*Seforad-Applied Radiation Ltd., Emek Hayarden, Israel.

*Tracor-Northern, Inc., Middleton, Wisconsin.

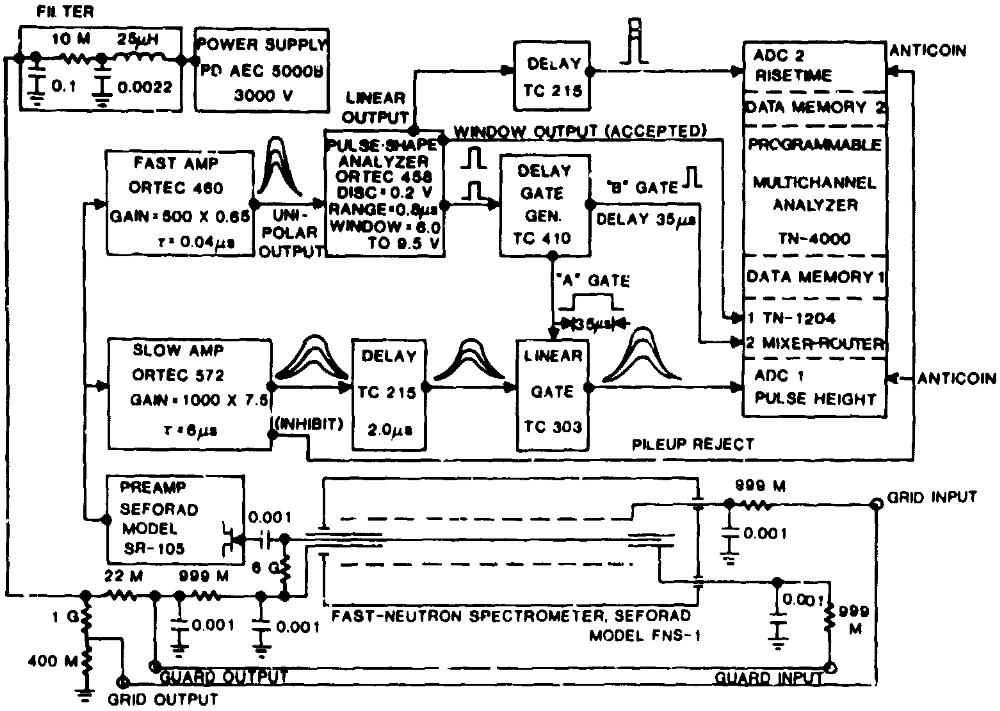

Fig. 1.
Electronics used with the ^3He neutron spectrometer.

one at 24 keV, correlate well with minima in the iron cross-section. Pulse-height distributions from a ^{252}Cf source, bare and surrounded by 1 and 2 in. of iron, are shown in Fig. 3. In this figure, the horizontal axis is the energy absorbed in the detector, i.e., the neutron energy plus 764.5 keV. Of particular interest is the fact that the 72-, 132-, and 180-keV peaks are present in the pulse distribution from the bare source. These peaks have been seen before and their behavior studied for incident monoenergetic neutrons.[5] They are resonant for 390-keV incident neutrons. It is now safe to conclude that the peaks for the bare spectrometer originate in the stainless-steel detector wall.

Effects of Other Materials

Pulse-height spectra are presented in Fig. 4 for transmission of ^{252}Cf neutrons through (a) aluminum, (b) copper, (c) nickel, (d) titanium, (e) tin, and (f) sulfur. In Fig. 5, transmission spectra for (a) cadmium, (b) tungsten, (c) zinc, (d) lead, (e) potassium chloride, and (f) a 5-mm-thick ^{10}B-Al shield about the detector. The repetition in many spectra of pulses in the vicinity of 72, 128, and 180 keV indicates the possibility of interaction of neutrons downscattered by the test materials with scattering minima in the spectrometer wall. Similar measurements have been made using reflecting hemispheres only, with comparable results. No effort has been made to correlate these data to nuclear structure theory; there is no doubt that a good deal of information could be obtained from formal understanding of the work.

The results indicate a possibility for development of neutron transmission or reflection techniques for bulk material identification and analysis. At this time, however, such techniques do not seem competitive with alternative technologies such as neutron capture-gamma-ray spectrometry. Of more immediate importance is the need that these data

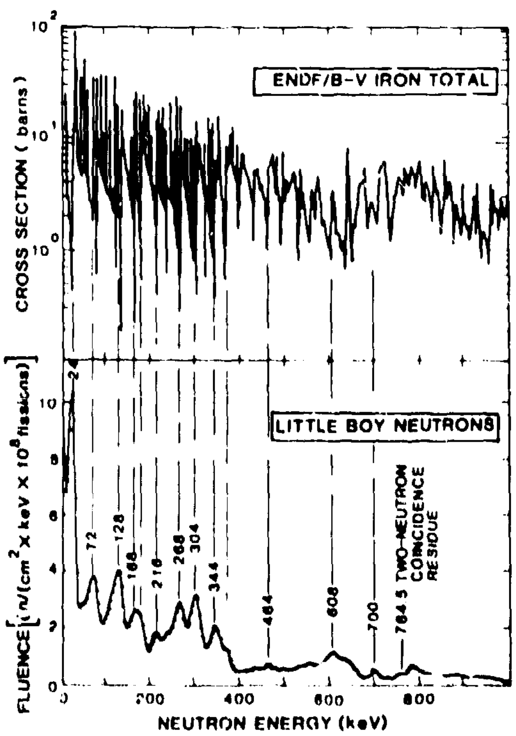

Fig. 2.
Comparison of the neutron spectrum from the Little Boy replica with the total neutron cross-section of iron.

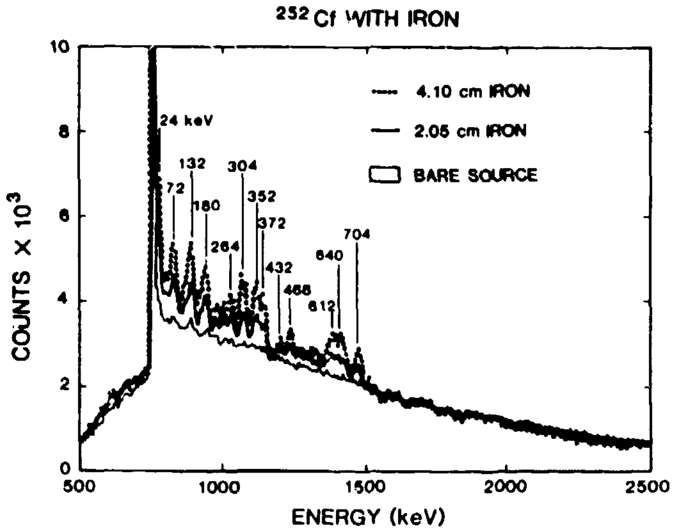

Fig. 3.
Effect of iron on the pulse-height distribution for neutrons from a ^{252}Cf source.

show for care in planning experiments and interpreting results when one uses a high-resolution neutron spectrometer. For example, many of our earlier spectra were measured with the spectrometer mounted on an optical table whose top was made of heavy soapstone [magnesium acid silicate, $H_2Mg_3(SiO_3)_4$]. In Fig. 6, we show the effect of the soapstone on the response to a monoenergetic beam of 1-MeV neutrons. The indicated peaks in the upper curve are consistent with elastic scattering from oxygen, magnesium, and silicon. With the soapstone removed, a small peak remains at 942 keV, probably due to scattering from iron. A peak at 122 keV was greatly reduced when an iron slab under the soapstone was also removed and replaced with aluminum; this same peak was enhanced by placing an iron reflector behind the detector. Also visible in the figure are the full-energy peak from a 500-keV impurity in the incident neutron beam and a proton-recoil continuum caused by the presence of an organic quench gas in the spectrometer tube.

Counting-Rate-Dependent Effects

In Fig. 7, we show the raw pulse-height distribution from a measurement (described above) of the neutron spectrum from Little Boy. We measured the background by placing a shadow shield between the nuclear assembly and the detector. Evident in the background are an epithermal peak, a chance-coincidence peak between epithermal neutrons, wall effect associated with the chance-coincidence peak, and unsuppressed pileup on the high-energy side of the epithermal peak. The first effort at reduction of these data, after subtraction of the background, showed structure between 765 and 1000 keV, which was not consistent with a proton-recoil-counter measurement of the same spectrum (Fig. 8). This structure is due to accidental coincidence between epithermal background neutrons and the first energetic peaks of the spectrum shown in Fig. 2.

A correction for accidental-coincidence pulses is derived as follows. A pulse of amplitude corresponding to channel k is assumed to be generated by coincidence of pulses corresponding to channels (j) and (k-j) with a probability $P_{kj} = \tau N_j N_{k-j}$, where N_j and N_{k-j} are the counting rates in channels (j) and (k-j), respectively, and τ is the effective coincidence resolving time. The total coincidence counting rate P_k in channel k is then given by

$$P_k = \tau \sum_{j=1}^{k} N_j N_{k-j} .$$

Here, partially overlapping pulses, which are mostly eliminated by the pileup-inspection circuit, are ignored.

Where the pulse spectrum is dominated by an epithermal peak, the calculated accidental coincidence spectrum will be an image of the singles spectrum, lower in intensity, shifted upwards in energy by 764 keV, and somewhat broadened in energy resolution. In practice, the constant τ is adjusted to just remove the epithermal coincidence peak from the spectrum.

Figure 9 compares the Little Boy neutron spectrum after correction for accidental coincidences with spectra derived from proton-recoil proportional counters and an NE-213 liquid scintillator. Differences below 600 keV are attributed mainly to resolution differences between the ^{3}He and proton-recoil spectrometers. Above 800 keV, and particularly between 800 and 1000 keV, there is still evidence of a small positive bias in the ^{3}He results, which could come from leakage of partially overlapping pulses into the spectrum or the acceptance of some coincidence events involving ^{3}He recoils and full-energy pulses. Available counting statistics, however, are not adequate for further refinement of the ^{3}He data.

Summary

Mechanisms for generating spurious peaks in high-resolution neutron spectra have been explored. Spectra resulting from transmission of a continuous neutron spectrum through most materials will have peaks and minima that correspond to resonances in the total neutron cross-section of the materials in question and that are potentially useful for material analysis. Peaks can also result from elastic scattering in materials near the source or the spectrometer. The possibility of generating such peaks must be considered in planning an experiment and in interpreting the results.

The effect of gamma-neutron and gamma-gamma pileup on the response of the Cuttler-Shalev detector has been described previously.[6] To these phenomena are now added the effects of chance neutron-neutron coincidences that are prominent when high neutron counting rates are encountered, particularly when the spectrum has a large epithermal component. If a pileup-rejection circuit is used to eliminate the continuum resulting from partially overlapping pulses, a simple calculation can be used to eliminate most, but not all, of the remaining chance coincidence pulses from the spectrum.

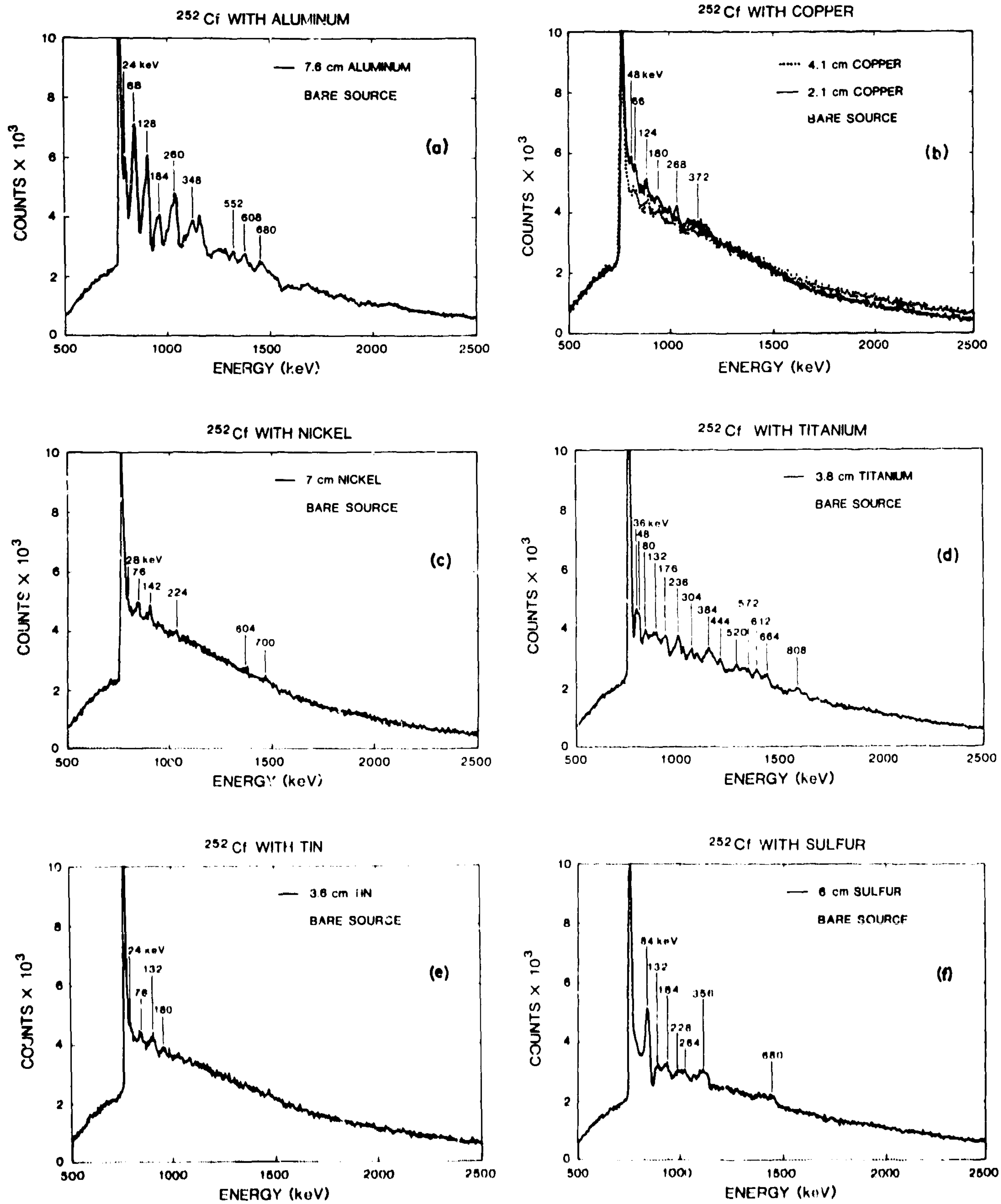

Fig. 4.
Pulse-height distributions for ^{252}Cf neutrons transmitted through aluminum, copper, nickel, titanium, tin, and sulfur.

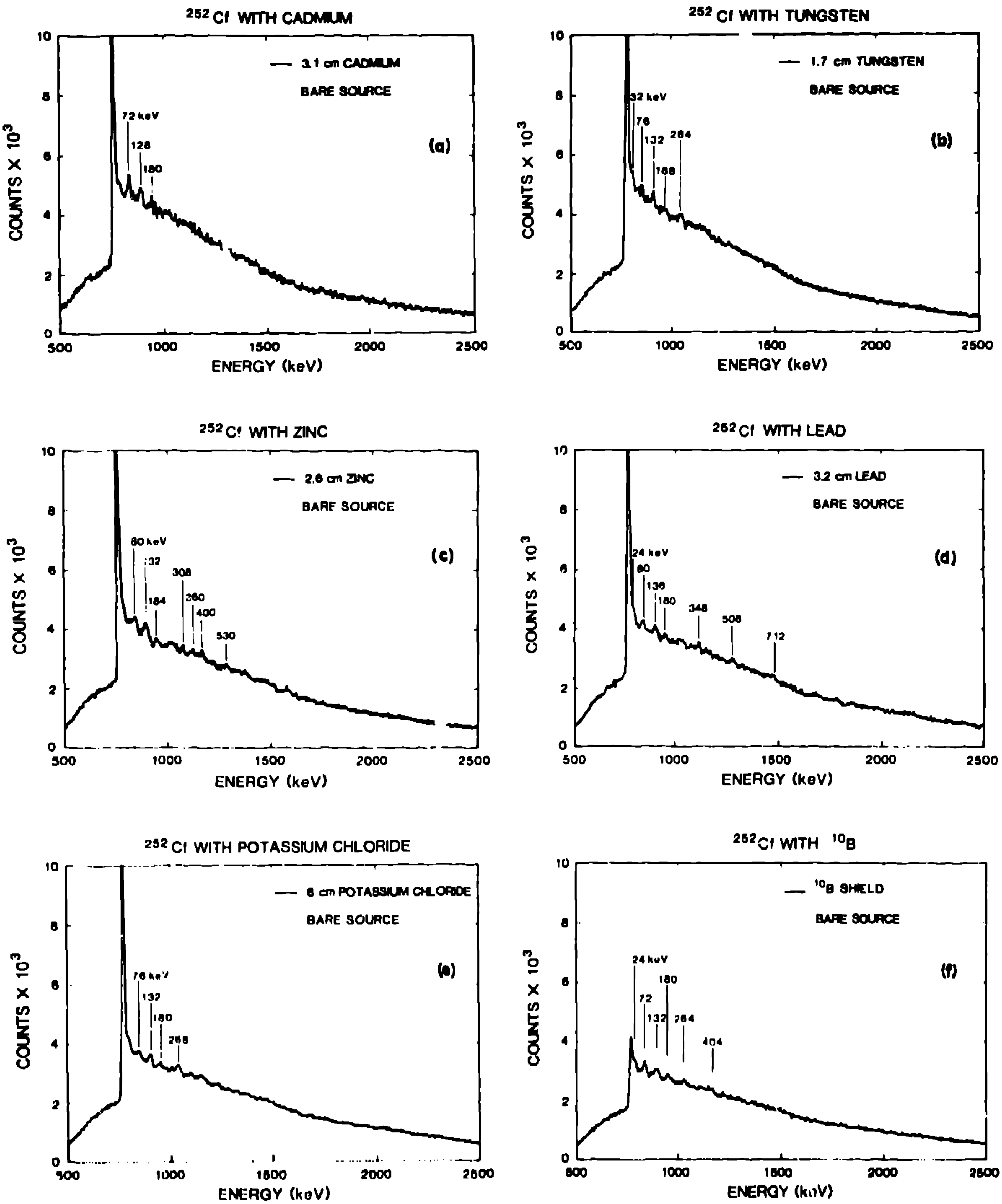

Fig. 5.
Pulse-height distributions for ^{252}Cf neutrons transmitted through cadmium, tungsten, zinc, lead, potassium chloride, and ^{10}B-Al.

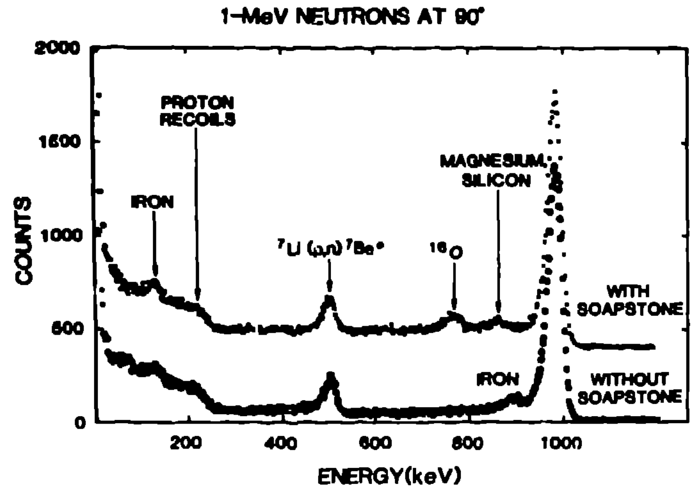

Fig. 6.
Effect of a nearby soapstone table top on the response to 1-MeV neutrons.

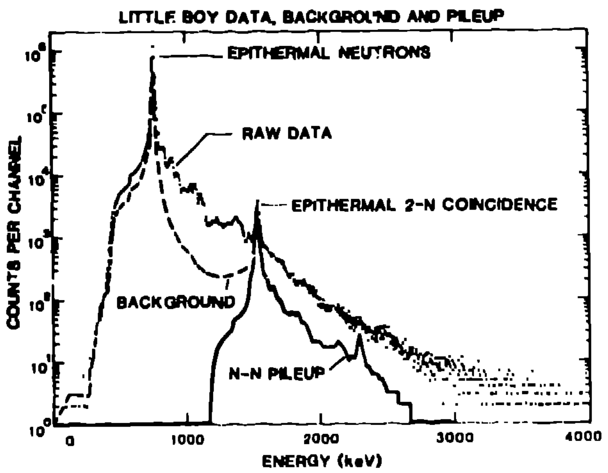

Fig. 7.
Pulse-height distribution for the Little Boy spectrum showing background, pileup, and chance-coincidence effects.

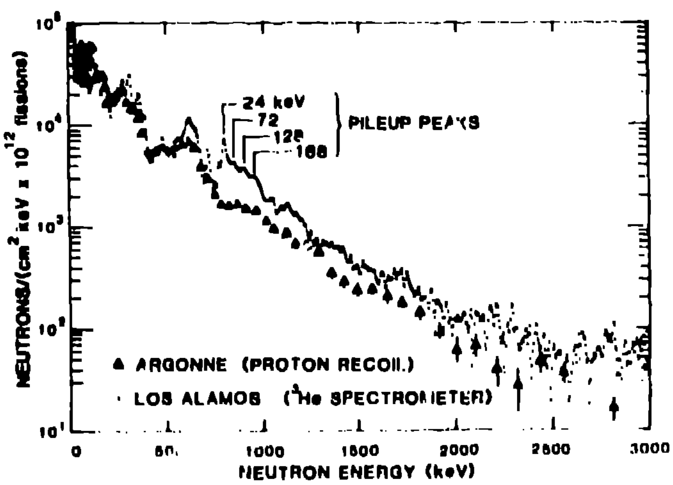

Fig. 8.
Little-Boy neutron spectrum before removal of accidental coincidences.

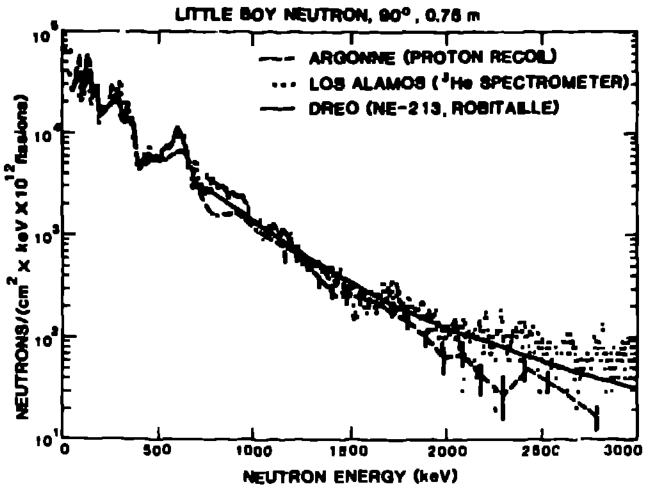

Fig. 9.
Little-Boy neutron spectrum after removal of accidental coincidences in the ^{3}He pulse spectrum.

References

1. J. M. Cuttler, S. Shalev, and Y. Dagan, "A High-Resolution Fast-Neutron Spectrometer," Trans. Am. Nucl. Soc. (1) 12, 63 (1969).

2. K. L. Kratz, "Review of Delayed Neutron Energy Spectra," Proceedings of the Consultants' Meeting on Delayed Neutron Properties, Vienna, Austria, 26-30 March 1979. International Atomic Agency Report INDC (NDS)-107/G+ Special (August 1979), pp. 103-182 and references therein.

3. A. E. Evans, E. F. Bennett, and T. J. Yule, "Little Boy Neutron Spectrum Below 3 MeV," presented at the Annual Meeting of the Health Physics Society, New Orleans, Louisiana, June 5, 1984. Los Alamos National Laboratory Preprint No. LA-UR-84-1523 (1984).

4. A. E. Evans and J. D. Brandenberger, "High Resolution Fast Neutron Spectrometery Without Time-of-Flight," IEEE Trans. Nucl. Sci. (1) NS-26, 1484-1486 (1979).

5. A. E. Evans, "^{3}He Ion-Chamber Performance from 0.1 to 3.2 MeV," presented at the Symposium on Beta-Delayed Neutron Emission at the 183rd National Meeting of the American Chemical Society, Las Vegas, Nevada, March 28-April 2, 1982. Los Alamos National Laboratory Preprint No. LA-UR-82-09 (1982).

6. S. Shalev and J. M. Cuttler, "The Energy Distribution of Delayed Fission Neutrons," Nucl. Sci. Eng. 51, 52-66 (1973).