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Because the number of neutrons and gamma rays and the energy spectrum of particles from spontaneous fission are well characterized [1–3] for ^{252}Cf, it can be used as a timed source of fission neutrons and gamma rays. The first such usage incorporated a ^{252}Cf source into gas scintillators [4]. This paper describes a timed source of neutrons and gamma rays made by depositing ^{252}Cf on one electrode of a parallel plate ionization chamber [5–7] that can then be used for determining detection-system characteristics. The emission time of neutrons from spontaneous fission has also been determined by recording the emission time of prompt gamma rays from a ^{252}Cf source (not incorporated into a detector) adjacent to the surface of a solid or liquid scintillator [2]. This well characterized source of neutrons can thus be used as a randomly pulsed source for a variety of applications [8–10]. This paper illustrates the use of this type of source to determine the time resolution of detection systems, the efficiency for detection of neutrons between 0.5 and 5 MeV, the effectiveness of pulse shape discrimination systems, and the overall efficiency for detection of prompt fission gamma rays.

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A variety of ionization chambers with ^{252}Cf deposited on their negative electrodes have been fabricated with flat parallel plate, annular, and spherical electrodes [11]. For curved electrodes, the ^{252}Cf deposit must be on an electrode that provides $> 2\pi$ geometric for one of the fission products to ensure that at least one fission product escapes the deposit and enters the chamber gas for each spontaneous fission. The voltage, chamber gas, electrode spacing, and size can be chosen so as to produce pulses from high gain, low impedance, low noise, current amplifiers with pulse widths (full width at 10% of maximum) as narrow as ~5 ns [7]. Because the ratio of the minimum fission product pulse height (track perpendicular to electrode) to maximum alpha pulse height (track near parallel to the electrode) can easily be > 2, alpha disintegrations can readily be discriminated against even though ~30 times more alpha decays occur than do spontaneous fission events. With fast-rise-time current amplifiers and constant-fraction discriminators, the time resolution for determining the time of spontaneous fission events can be <1 ns. With similar time resolution for the detection of neutrons or gamma rays from fission, time of flight (TOF) measurements can be performed to resolve the energy distribution of neutrons with flight paths of ~1 m. Such measurements can be performed with commercially available time to pulse height converters (TPHC) with pulse height analyzers (PHA) or commercially available fast waveform digitizers. The ionization pulse from the spontaneous fission defines $t = o$ and starts the TPHC or digitizer. The event in the detector being evaluated then stops the TPHC, and the TPHC amplitude is stored in the PHA or the time of arrival of the detector pulse is stored in the digitizer.

A measurement of detection efficiency (counts per incident neutron) was performed with a 15.2 × 15.2 × 10.2 cm thick scintillator (BICRON-420) with a flight path of 89 cm. The efficiency, plotted as a function of neutron energy (Fig. 1), has a threshold at ~ 0.4 MeV, rises to a maximum of 65% at 1 MeV, and decreases slightly to 55% at 4.5 MeV.

The detection efficiency of a liquid organic scintillator (NE 213, 11.4 cm diam, 11.4 cm thick) shielded with 0.63 cm of lead adjacent to the front face as a function of energy was also determined with a flight path of 150 cm. This scintillator detection system employed pulse shape discrimination (PSD) techniques to discriminate neutrons from gamma rays. Counts as a function of time after ^{252}Cf fission for the PSD neutron and gamma ray outputs are given in Fig. 2. The time of ^{252}Cf fission has been adjusted to 25 ns so that the dispersion of the prompt gamma-ray peak could be observed. Because all gamma rays travel with the same speed, the width of the gamma-ray peak gives the time resolution of the detection systems. The combined time resolution of the detection systems for the spontaneous fission event and the particle detection event in the scintillator was 1.8 ns, determined from the full width of the prompt gamma ray distribution at half maximum. The efficiency for the detection of prompt gamma rays (counts per incident gamma photon) can be determined from the total number of counts in the gamma peak divided by the product of the total number of ^{252}Cf fissions that trigger the time analysis instrumentation in the TOF measurement, the solid angle subtended by the detector, and the number of prompt gamma rays per fission [2]. The efficiency for detection of prompt fission gamma rays for this scintillator in this measurement is 10.5% per incident gamma ray. Since the energy distribution of gamma rays from ^{252}Cf fission is known, the efficiency as a function of gamma-ray energy can also be determined if pulse height analysis of the gamma-ray signal is employed.

The ratio of gamma ray counts in the prompt gamma ray peak for the PSD gamma-ray signal to the counts in the PSD neutron signal gives the effectiveness of the gamma-ray discrimination because the gamma-ray peak in the neutron signal is from gamma rays misidentified as neutrons. This misidentification is likely the result of near simultaneous multiple gamma-ray detections. From the amplitude of the gamma-ray peaks with and without discrimination (Fig. 2), the effectiveness for discrimination can be determined and for this measurement is a reduction in the prompt gamma ray signal by a factor of 1050. The counts appearing in the 50–100 ns time of the gamma ray signal of Fig. 2 are delayed gamma rays from ^{252}Cf fission and neutron signals which have been identified as gamma rays by the PSD discrimination system. Proton recoil tracks near the surface escape the scintillator without producing enough long decay constant light and thus are misidentified as being associated with gamma rays. The fraction identified as delayed gamma rays can be estimated by correcting for the gamma ray decay of the signal ($T_{1/2} \approx 100$ ns) from the time of 40 ns onward. The efficiency for neutron detection as a function of energy with gamma-ray discrimination is given in Fig. 3. With gamma-ray discrimination, the neutron detector efficiency rises at ~1 MeV up to a maximum of ~37% at about 2 MeV and remains constant with energy up to 5 MeV[10]. For these types of determinations, the energy scale can be verified by performing transmission measurements with materials like beryllium, carbon, or others with known resonance structure in the total cross sections in the energy range between 0.5 and 5 MeV. This is done by confirming that the resonances have the correct energy.

These examples illustrate how a well characterized ^{252}Cf source can be used for detection system studies. Such a source provides a means of ensuring that detection efficiencies can be set to prescribed values and periodically checked to verify their stability and is therefore a useful tool for detector calibration and setup. Although the examples given are for fast neutron detectors, this type of source can be used for many other types of detectors because of its well-known characteristics.

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Fig. 1. Detection efficiency vs neutron energy for a 15.2 × 15.2 × 10.2 cm thick organic scintillator (BICRON-420).

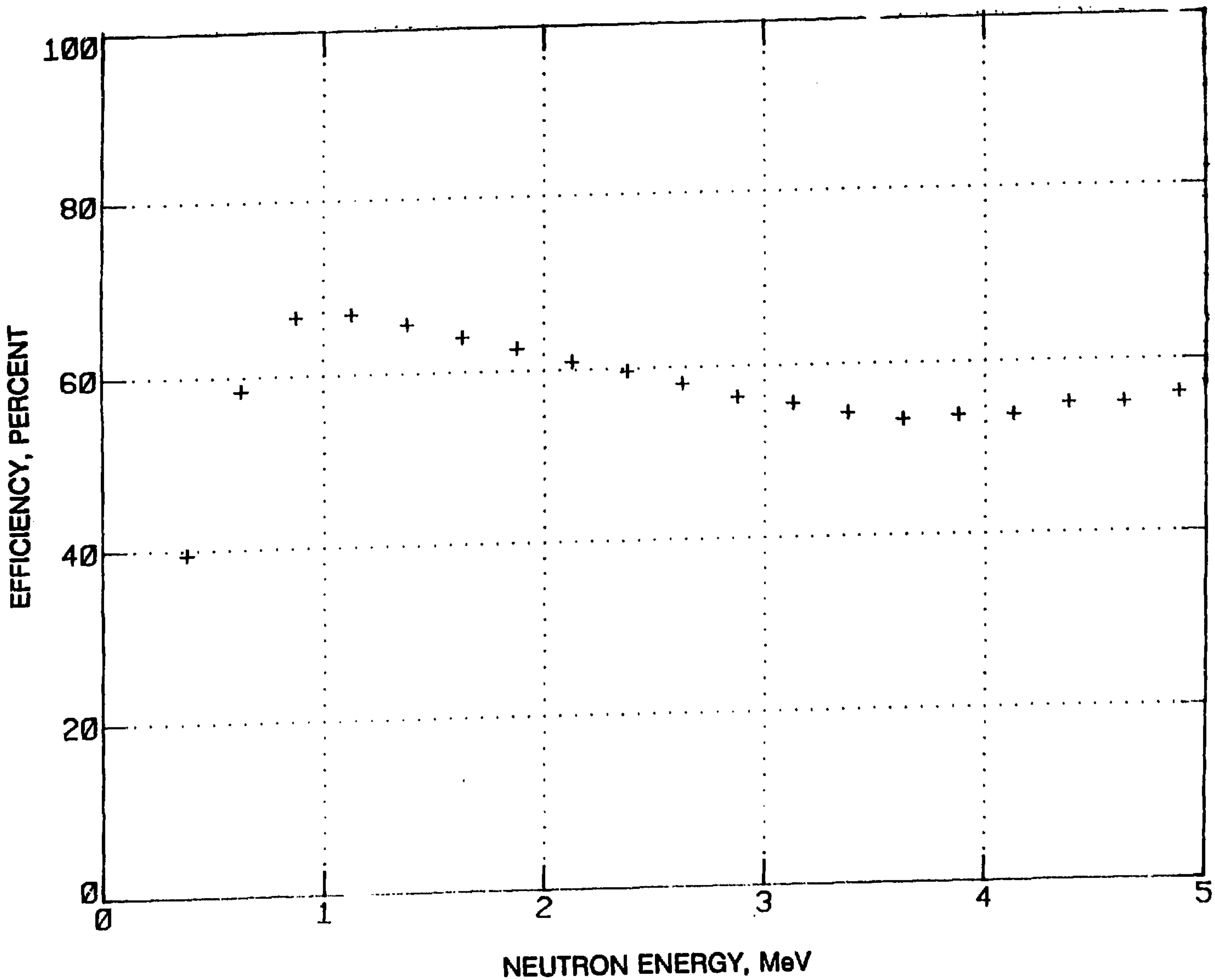
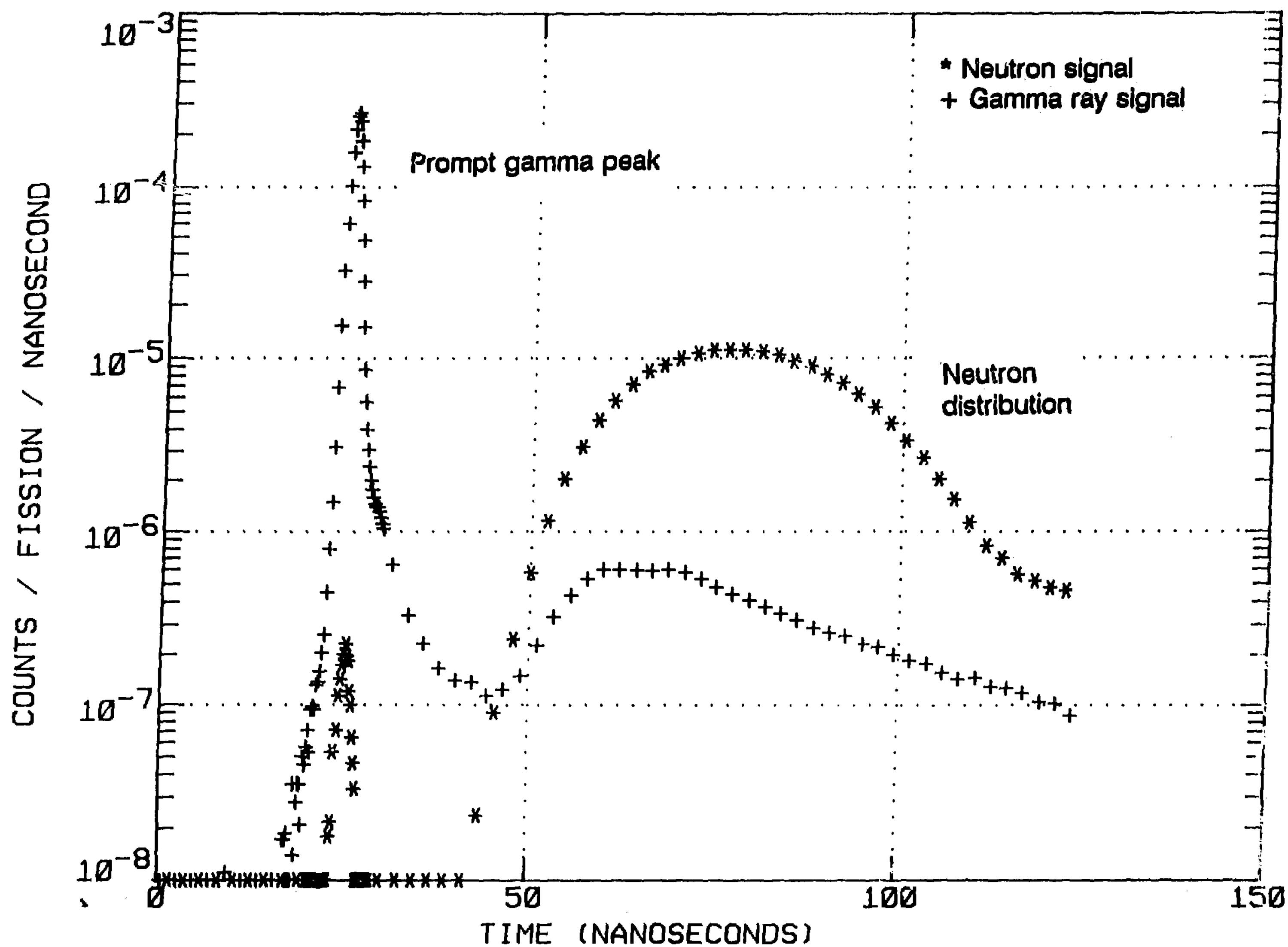
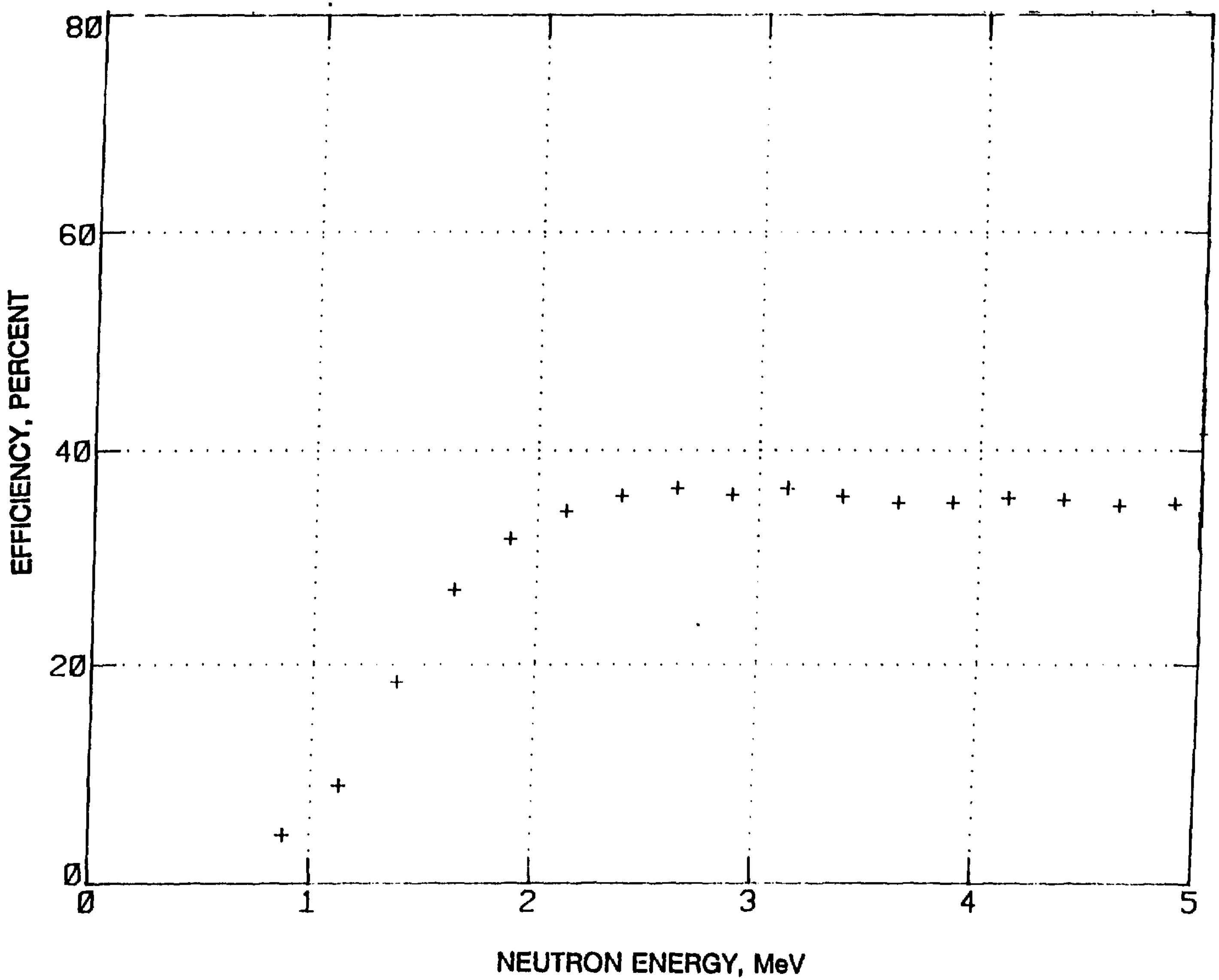

EFFICIENCY, PERCENT
100
80
60
40
20
0
0
1
2
3
4
5
NEUTRON ENERGY, MeV

Fig. 2. Time-of-flight data for evaluation of a pulse-shape discrimination system with NE 213 liquid organic scintillator.



10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
COUNTS / FISSION / NANOSECOND
0
50
100
150
TIME (NANOSECONDS)
* Neutron signal
+ Gamma ray signal
Prompt gamma peak
Neutron distribution

Fig. 3. Detection efficiency vs neutron energy for NE 213 liquid organic scintillator with pulse-shape discrimination.



80
60
40
20
0
0
1
2
3
4
5
EFFICIENCY, PERCENT
NEUTRON ENERGY, MeV