

Bennett E F. Fast neutron spectroscopy by proton-recoil proportional counting.
Nucl. Sci. Eng. 27:16-27, 1967.
[Argonne National Laboratory, Argonne, IL]

Cylindrical proportional counters containing hydrogen have been used to measure reactor neutron spectra from about 1 keV to about 2 MeV. Discrimination based upon changes in the counter pulse induction effect was used to eliminate the background of pulses induced by gamma rays from the spectrum of pulses arising from recoil protons. [The *SCI*[®] indicates that this paper has been cited in over 80 publications, making it one of the ten most-cited papers for this journal to date.]

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"The neutron spectrum is fundamental to any detailed understanding of how a fission reactor works. The spectrum distinguishes between thermal reactors, where many neutrons exist at energies in thermal equilibrium with the moderator in the core, and fast reactors, where most neutrons are not very far below the energy they possess when emitted in fission.

"When I began to work on reactor experiments at the Argonne National Laboratory in the late 1950s, there were few experimental techniques in existence for carrying out in-core measurements of the neutron spectrum, and these were severely restricted in energy range. From graduate school, I had gained some experience with gas-filled proportional counters for ionization measurements. Hydrogen contained in counters of this type will recoil and ionize when struck by a sufficiently energetic neutron. The problem with these gas-filled recoil counters is that reactor environments contain gamma rays as well as neutrons. Fast-electron events from the gamma rays induce pulses of the same amplitude as those

from proton recoils. The interesting region of pulse amplitudes contains, therefore, both the desired (proton recoil) events and the undesired (gamma induced) events. A simple pulse amplitude distribution cannot distinguish between them.

"The two types of events are readily discernible just by looking at a broad-band oscilloscope trace of pulses from proportional counters having a mix of densely ionizing events (from recoil protons) and weakly ionizing events (from fast electrons). The proton recoil events rise much more rapidly. A measure of this rate-of-rise could then be used to distinguish the gamma background. Although the principle was clear, there was little available in about 1960 to allow its implementation. What was required, in effect, was an added dimension to the pulse acquisition system. Rather than just the amplitude of the event, one needed also the rate-of-rise, and this required an expansion of the data acquisition system from one to two dimensions. Although this is very easy with even the simplest of today's computers, it was difficult in the early 1960s. By 1963, I had access to an early model two-parameter pulse amplitude analyzer, and within about two years most of the studies contained in the paper had been carried out. A more detailed account of the measurement technique and related analysis required for neutron spectrum measurements can be found in reference 1.

"Frequent citation of the paper is probably due to the extensive reactor-oriented research programs which existed in the 1960s and 1970s, both in the US and abroad. Measurements of the neutron spectrum using the technique described in the paper have been done at most laboratories where experimental reactor physics studies are carried out."

1. Bennett E F & Yale T J. *Techniques and analyses of fast-reactor neutron spectroscopy with proton-recoil proportional counters*. Argonne, IL: Argonne National Laboratory, 1971. 67 p. ANL-7763.