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NEUTRON DETECTION EFFICIENCY OF SILVER COUNTERS

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A simple inexpensive technique is described for determining the detection efficiency of a silver counter for pulsed neutrons.

The "silver counter"[1,2]) is an uncomplicated fast-neutron detector utilized primarily in controlled thermonuclear research to obtain the total neutron yield from a single intense ($>10^5$ neutrons) short ($<10^{-6}$ s) burst by activation of short-lived beta radioactivity in silver. It is used in a standardized design, configuration and mode of operation[1]) in order to enhance reproducibility of results among different laboratories. A polyethylene block with a square face 30 cm on a side and a thickness of 15 cm is covered with a 0.15 cm thick cadmium sheet which serves to screen out low-energy background neutrons. At the corners of a 10 cm square centered on the back face of the block, holes are drilled normal to the face into which are inserted low-noise cylindrical Geiger tubes, 13 cm long and 1.6 cm in diameter. The KMSF Geiger tubes (specially manyfactured by N. Wood Counter Laboratory, Inc., Chicago, Ill.) have silver walls 0.025 cm thick; this is a variation on the original design[1]) which uses aluminum-walled tubes wrapped in 0.025 cm silver foil. The polyethylene (incompletely) moderates the neutrons which then activate the silver in the reactions

$$^{109}\mathrm{Ag}+\mathrm{n}\rightarrow{}^{110}\mathrm{Ag}\rightarrow{}^{110}\mathrm{Cd}+\beta^-,\quad (2.24 \text{ or } 2.82 \text{ MeV}),$$

(half-life 24.2 s, thermal-neutron cross section 110 b),

$$^{107}\mathrm{Ag}+\mathrm{n}\rightarrow{}^{108}\mathrm{Ag}\rightarrow{}^{108}\mathrm{Cd}+\beta^-,\quad (1.49 \text{ MeV}),$$

(half-life 2.3 min, thermal-neutron cross section 30 b).

The four Geiger tubes are connected in parallel, biased at 1100 V, and capacitatively coupled to a preamplifier; after amplification and pulse-shaping, the signal is sent to a scaler. A timer turns on the Geiger tube circuitry shortly after the neutron burst (to avoid counting X-rays associated with it) for a pre-set 1 min interval. An extensive description of construction details, counting procedure and characteristics of the silver counter can be found in ref. 1. The previously reported calibration measurements for the prototype detector[1]) used neutron bursts from D–T and D–D reactions produced in a Cockcroft–Walton accelerator, and did not unfold the solid-angle and detection-efficiency contributions.

In the experiment described here, the neutrons are provided by a commercial Am–Be source (of strength 2.36×10^6 s^{-1}) whose spectrum is sketched in fig. 2, and has a mean energy of 5.2 MeV, intermediate between the 2.45 and 14.1 MeV fusion energies. A pulse is simulated with this continuous neutron emitter by moving the source smoothly to and from the detector in a prescribed manner, so that the exposure is fully known (rather than incurring errors associated with attempting to "switch" the source on and off abruptly). This is achieved by an improvised device (powered by a drill motor) which carries it on a track along the axis of the counter, traveling a distance of 7.3 m toward the counter face and back again at an approximately constant speed of 2.1 m/s. The measurement was repeated with different distances of closest approach.

If the origin (the source) is a distance x away from

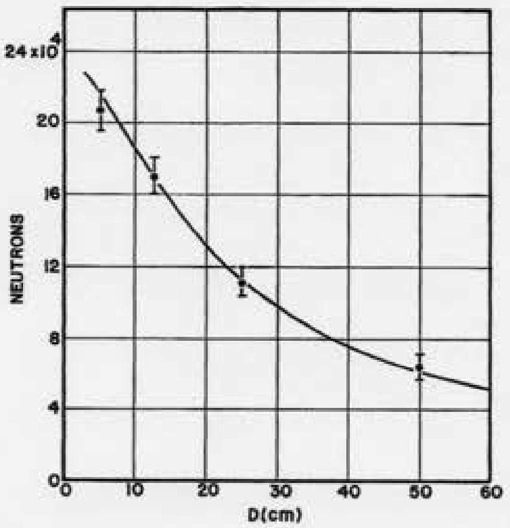

Fig. 1. Neutrons entering detector as a function of distance of closest approach.

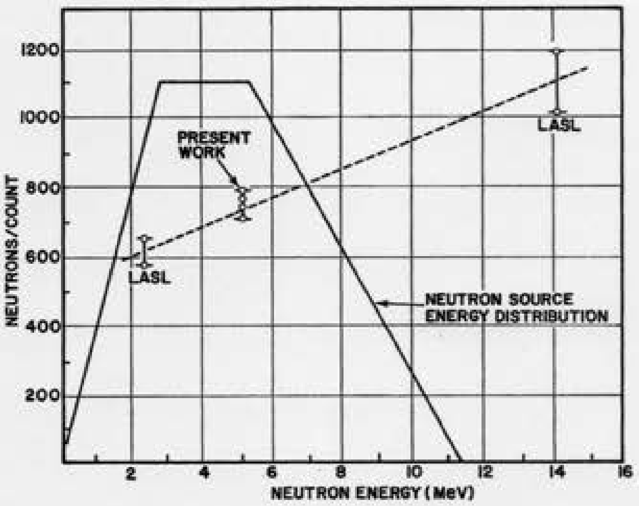

Fig. 2. Neutrons entering detector per count as a function of neutron energy.

a square of side L (the detector face), and lies on the axis of symmetry normal to the square, the solid angle subtended from the origin to the square is derived to be:

$$\Omega(x) = 4\arcsin\left[L^2/(L^2+4x^2)\right]. \quad (1)$$

The number of neutrons entering the detector, as the source is moved up to a distance D from it, starting further away by D', and back again, is obtained by integration over the trip:

$$N = (\mathrm{d}N/\mathrm{d}t)(4\pi)^{-1}\int \Omega\,\mathrm{d}t$$
$$= (2\pi v)^{-1}(\mathrm{d}N/\mathrm{d}t)\int_D^{D+D'} \Omega(x)\,\mathrm{d}x, \quad (2)$$

with v the (constant) speed of the source motion, and $\mathrm{d}N/\mathrm{d}t$ the source strength. The integration has been performed analytically. In the experiment D' is much larger than D and L (as indeed it should be in order to avoid excess counts from the source at both ends of the trip) so that the infinite D' limit can be applied with minimal error. The simplified expression for the integral then yields:

$$N = (2L/\pi v)(\mathrm{d}N/\mathrm{d}t)\log\left[1+L(L^2+4D^2)^{-\frac{1}{2}}\right]. \quad (3)$$

Fig. 1 is a plot of eq. (3) for the parameters of the experiment, together with the measurements (counts above background renormalized by a least-squares fit). Since the 7 s pulse duration in this experiment is not negligible compared with the 24.2 s half-life (unlike the thermonuclear burst), there is some decay of the induced activity before the Geiger tubes are turned on; this effect is easily calculated and corrected for (it amounts to a 10% increase over the observed counts). The detector performance is then deduced from the normalization as 750 neutrons/count.

The Los Alamos data[1]) were reduced from "source neutrons per count" at various source-to-detector distances to "neutrons entering the detector per count" by application of eq. (1). In fig. 2, the detector response is plotted as a function of neutron energy for the LASL results at 2.45 and 14.1 MeV, and for the KMSF results for a spectrum of mean energy 5.2 MeV. The error bars in this case indicate the scatter in the data. A roughly linear rise of neutrons/count with energy is noted, qualitatively corresponding to less efficient moderation of the neutrons at higher energies.

The silver counter and a fast plastic scintillator–photomultiplier counter have been used to detect neutrons in laser-plasma experiments[3,4]) at KMSF. The measurements of the two counters are in agreement to within the statistics.

References

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