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Method for locating and characterizing neutron sources

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Counting neutron-induced tracks in plastics as a function of the orientation relative to the arrival direction of incident neutrons makes possible a rugged method of measuring the direction, fluence, and average energy of a directional flux of fast neutrons and the distance and strength of the source.

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It is occasionally useful to be able to infer what direction a burst of fast neutrons comes from and what the number and energy of the neutrons are. Such measurements could be of importance in monitoring fusion or fission reactions.

A result of experiments in fast neutron dosimetry suggests a simple rugged device that could be used. Track-containing polycarbonate films have survived free fall from an altitude of 40 km with the tracks unaffected. Such detectors are therefore suitable for exposure under reasonably violent conditions.

The experiments consisted of irradiations with fast neutrons of two track-detecting[1] materials, allyl diglycol carbonate (CR-39) and polycarbonate (Landauer "Neutrak" dosimeters). Pairs of samples were irradiated at a 3-MV High Voltage Engineering Co. positive-ion accelerator in a special low-scatter neutron-irradiation facility. Two orientations were used, 90° (perpendicular to the beam of neutrons) and 0° (parallel to the beam). Sources of the neutrons at 0.57, 2.1, 5.3, and 15.1 MeV were, respectively, the following reactions: 1.5 MeV P on ^{3}H, 2.9 MeV P on ^{3}H, 2.3 MeV ^{2}H on ^{2}H, and 0.4 MeV ^{2}H on ^{3}H. The effective target source diameters were < 1.0 cm, as compared with a source-to-sample distance of typically 50 cm, so that the angular divergence at the sample did not exceed 1°. The character of the angular dispersion of recoiling nuclei is such that this divergence is expected to be unimportant. The 1.6-mm thick CR-39 detectors from Welcast Plastics Co., Inc. (1045 Eagon St., Barberton, Ohio 44203) were etched for 1.35×10^4 s in 60 °C 6.54 N KOH solutions, and read out by scanning at 1000×. The established criteria for track identification (clean recognizable elliptical or circular pits) are described in detail in Ref. 1, (Chapter 4). The "Neutrack" polycarbonate dosimeters were supplied and read out by R. S. Landauer, Jr. and Co. (Glenwood Science Park, Glenwood, Illinois 60425) using their standard commercial procedures for electrochemical track revelation.

Table I shows the observed ratios of track densities in the two orientations as function of the energy of the neutrons. The source of these tracks is mainly the spectrum of nuclei in the polymer itself or nuclei in the front covering layer that recoil from elastic neutron collisions. The angular distribution of these recoil particles (mainly protons) are known to be anisotropic in the laboratory system. The trivial correlation between neutron energy, recoil particle energy, and recoil angle in an elastic collision on one hand and the recoil particle registration probability with its dependence on particle energy and angle of incidence (because of the existence of a critical registration angle) implies that a neutron-energy dependence of these angular track-density ratios will exist.

The angular ratio observed in this experiment was found to be a sensitive function of neutron energy (varying as $E^{0.8}$ for CR-39 over the range tested and for the experimental conditions used), and it is enough different from unity that it can readily be measured.

Thus, a spherical detector, a set of cylindrical detectors, or an array of plane detectors at many different orientations could be used to determine a line through the source, by finding the orientation of surfaces with the maximum track densities. The maximum-to-minimum ratio would give a measure for the average fast-neutron energy, and the track density measures the fluence. The direction along the line is uncertain, but if two spatially separated measurements are made, triangulation will give the direction and also the distance to the source. It follows that the source strength is also then determined.

The measurements were made at neutron fluences of 1.5 to $4.0 \times 10^9/\mathrm{cm}^2$, but the track densities are high enough so that they can be extended to considerably lower levels by at least a factor of 50.

Actual irradiation and detector evaluation methods will influence the absolute values obtained for fluence, energy, and direction sensitivity. Therefore, calibration runs

TABLE I. Examples of ratios of track densities at 0° to those at 90° for two detectors and four neutron energies.

Material	Neutron energy (MeV) 0.57	2.1	5.3	15.1
CR-39	0.043	0.13	0.23	0.58
Polycarbonate	···	0.03	0.16	0.43

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have to be made for a particular experimental design. The principle, however, of the method indicated in this paper can be expected to be useful in most neutron-measurement situations.

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[1]R. L. Fleischer, P. B. Price, and R. M. Walker, *Nuclear Tracks in Solids* (University of California, Berkeley, 1975).