

**NUCLEAR DATA AND MEASUREMENTS SERIES**

**ANL/NDM-21**

**Note on the Experimental Determination of  
the Relative Fast-Neutron Sensitivity of a Hydrogenous Scintillator**

by

A. Smith, P. Guenther, and R. Sjoblom

June 1976

**ARGONNE NATIONAL LABORATORY,  
ARGONNE, ILLINOIS 60439, U.S.A.**

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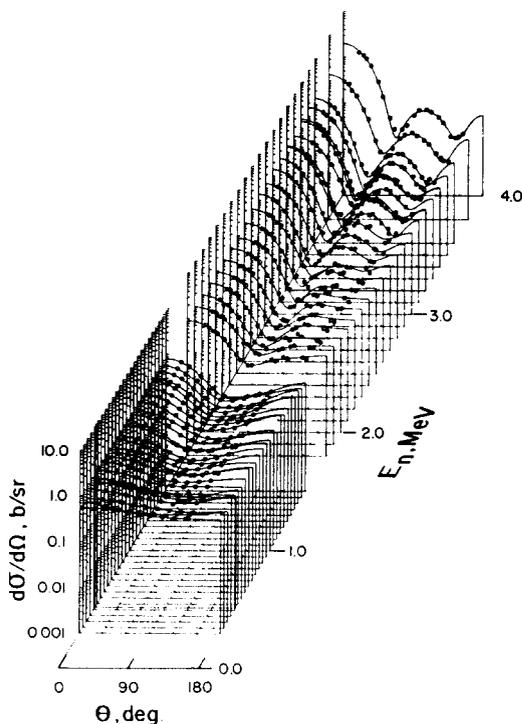
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## NOTE ON THE EXPERIMENTAL DETERMINATION OF THE RELATIVE FAST-NEUTRON SENSITIVITY<sup>Y</sup> OF A HYDROGENOUS SCINTILLATOR<sup>a</sup>

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ABSTRACT

A method for determining the relative fast-neutron sensitivity of a hydrogenous scintillator is outlined. The procedure is based upon the time-of-flight measurement of the prompt-fission-neutron spectrum of <sup>252</sup>Cf. Detailed relative detector sensitivities are experimentally determined to few percent accuracies for neutron energies from a few 100 keV to 10 MeV.

<sup>a</sup> This work supported by the U.S. Energy Research and Development Administration.

## I. INTRODUCTION

Pulsed-beam fast neutron time-of-flight techniques are widely used for the measurement of fast neutron spectra (1, 2). The neutron detector is usually a hydrogenous scintillator and it is often necessary to know its relative energy-dependent response to neutrons from a few hundred keV to 10 or more MeV. This relative response has been calculated or measured (3,4). The measured response has the advantage of including the specific experimental environment. The relative detector response is often determined by observing neutrons scattered from hydrogen at a number of angles with the consequent large changes in scattered-neutron energy (4). This method can give good results and can be free of many monitor-associated problems. However, it is tedious if detail is to be obtained and is sensitive to the exact determination of the scattering angle (particularly scattering angles beyond  $\sim 45$  deg.). Moreover, the "hydrogen sample" is conventionally a hydrocarbon with attendant perturbations due to carbon content requiring careful interpretation. Another method involves the observation of a neutron-source reaction involving a light nuclear target at a number of reaction angles (5). The energy range covered by such a reaction at a single incident energy is limited. Moreover, the result is again sensitive to the exact determination of reaction angle as well as to the uncertainties in angular distribution of neutrons from the particular reaction. The effective range and intensities of the source-reaction method can be improved by varying the incident charged-particle energy. However, this introduces additional problems associated with energy dependent neutron-flux monitoring. Very often uncertainties associated with the determination of relative detector sensitivities are significant contributors to the error associated with the primary measurements.

An ideal calibration would be based upon a well known

isotropic continuum neutron spectrum extending from  $\sim 100$  keV to  $\sim 10$  MeV with a precisely known time of emission. Experimental observation of such a spectrum could provide detailed relative detector responses free of many of the problems associated with the above conventional methods. Recent measurements have well defined the prompt neutron spectrum resulting from the spontaneous fission of  $^{252}\text{Cf}$  (6) making it a "standard neutron field" for energies from several hundred keV to 10 MeV or more. This note outlines the use of this standard  $^{252}\text{Cf}$  fission spectrum for the determination of the relative energy response of a hydrogenous scintillator system routinely employed in fast-neutron scattering measurements (7).

## II. CALIBRATION PROCEDURES AND RESULTS

The neutron time-of-flight system calibrated in this instance was a development of that described in Reference 7, extended to ten detectors distributed over an angular range of  $\sim 135$  deg. and placed at flight paths of five or more meters. The fission source consisted of an essentially weightless deposit of  $^{252}\text{Cf}$  giving  $\sim 3 \times 10^4$  fissions per second. The fission source was contained in a gas scintillator placed at the common focus of the multiple neutron-flight paths. The time of the fission event was determined to within  $\sim 2$  nsec by the response of the gas scintillator. Flight paths were measured to accuracies of  $\leq 0.5$  cm. The uncertainty was largely due to that associated with determining the effective centers of the neutron-detection scintillators. The neutron detectors consisted of glass vials of NE-213 or NE-218 (8) optically coupled to 58 AVP photo-multiplier tubes (9). Neutron flight time was determined using analog electronic circuitry in the manner described in References 4 and 8. This circuitry included a system for the rejection of gamma-ray events on the basis

of pulse shape response. The time scale of the measurement system was determined to within  $< 0.1$  percent using calibrated delay lines which were both fabricated locally and obtained commercially (10). The results obtained with the two sets of delay lines agreed to within the above uncertainty. The details of the instrumental set-up and the calibration procedures are further defined in References 8 and 11.

Fission spectra were simultaneously recorded in all ten detectors for periods of twenty four hours or more, both before and after the use of the instrument system in a cross-section measurement program (in this case fast neutron scattering studies). Representative velocity spectra are shown in Fig. 1. The statistical accuracies at the maximum of the neutron distributions were two to three percent. The time resolution as determined by observation of the prompt fission gamma-ray was in the range 2 to 3 nsec. The time zero of the fission event was determined from the observed position of the prompt fission gamma-ray and the measured time scales and flight paths. The comparison of observed spectra obtained prior to and after the experimental use of the system provided a verification of system stability. The bias point on the gas scintillator was relatively low as illustrated in Reference 11. Thus a very large percentage of the fission events were recorded. However, in order to assure there was not a systematic bias to the neutron spectra due to the orientation of the fission flight paths neutron spectra were obtained with the gas scintillation detector oriented at  $\sim 15$ ,  $\sim 90$  and  $\sim 165$  deg. with respect to a reference flight path. The spectra obtained at the three angles were identical within the statistical precisions of the respective measurements.

The observed neutron velocity spectra were

relativistically converted to energy spectra using the measured flight paths, time zeros and time scales. Backgrounds were subtracted assuming a linear time dependence from before the fission event to well after the time corresponding to a possible detection of a fission neutron. These backgrounds were generally small (several percent of the maximum neutron response). Tests as described in Ref. 11, assured both the linearity of the timing system and the linear and essentially "flat" behavior of the time uncorrelated backgrounds.

The spectral energy-range of interest (nominally from detector threshold to 5 or 10 MeV) was selected from each observed fission neutron spectrum. The spectrum of fission neutrons from  $^{252}\text{Cf}$  was assumed to be Maxwellian in shape with a temperature of  $1.42 \pm 0.02$  MeV as given by the analysis of Grundl and Eisenhauer (6). Thus

$$N(E) \sim \sqrt{E} e^{-E/T} \quad (1)$$

where  $T=1.42$  MeV and  $E$  is in MeV. Using this expression the relative energy dependent detector sensitivities were determined from the observed spectra "before" and "after" the primary experiment runs are involved. In addition there were interim calibration runs made during the primary experiment. These various calibration runs did not always have exactly the same time zero or energy scale thus the resulting energy spectra will not exactly correspond. Therefore the sensitivities deduced from the various calibration measurements for a given detector were sorted in energy bins the width of which was adjusted to correspond to the desired definition of the time scale in the associated neutron scattering velocity measurements. Relative composite sensitivities obtained with this sorting procedure are illustrated in Fig. 2. In addition, comparison of individual measurements for a given detector provides a measure of the stability of the system.

It is evident from Fig. 2 that the above procedures provide a very detailed definition of the relative detector response over a wide energy range to accuracies of  $\approx 5$  percent. The detail is greatest near threshold where the applications can be very sensitive to the exact character of the detector response. This is a valuable experimental advantage. In routine application statistical accuracies of a few percent can be obtained over a wide neutron energy range. Sensitivity curves, such as that illustrated in Fig. 2, characteristically show a small energy dependent fluctuation with a few percent magnitude. This structure is consistent with the neutron scattering from air in the long (e.g., 5 meter) flight paths as discussed in Reference 11. In many applications these small fluctuations can be smoothed and the average effect of the air transmission removed by making ratio measurements (e.g., scattering cross sections relative to H(n,n) scattering). (However, in precise (few percent) measurements at selected energies or using some flux calibration procedures employing varying flight paths, this air transmission effect can be a concern that is not often recognized.)

Detail, such as shown in Fig. 2, is often not warranted in the present application thus there is statistical merit in bin-sorting the distributions within a selected energy mesh. Several examples of such bin-sorts are given in Fig. 3. In addition it is often useful to express the observed detector sensitivities in an analytical manner suitable for interpolation between measured values. It has been empirically found that the expression

$$EH(E) = \sum A_n E^{-n} \quad (2)$$

reasonably fits the typical recoil-scintillator efficiency curve over a wide energy range with a limited number of terms. This is illustrated by the least square fits shown

in Fig. 3. Of course, this fitting procedure will not describe the small fluctuations due to air scattering, noted above. (Where important, these small fluctuations must be treated in detail.) It is interesting to note that the relative sensitivity distributions determined in the above manner closely follow the  $H(n,n)$  cross section at energies well above threshold as would be expected from a simple "thin radiator" approximation (11).

### III. VERIFICATION OF THE METHOD

The above relative detector sensitivities were tested by observing neutrons scattered from the hydrogen of a  $CH_2$  sample. (An incident neutron energy was selected approximately 25% above the maximum energy of interest (about 3.5 MeV in the present example)). The detectors were then set at a number of scattering angles distributed in such a manner that the scattered neutron energies varied over the range of interest. The relative detector sensitivities were deduced from the observed response rates and the known  $H(n;n)$  cross section (12). This procedure did not require a knowledge of monitor performance other than stability or a flux measurement. The  $H(n;n)$  scattering results were corrected for multiple-event effects, incident beam attenuation, contributions from the carbon of the sample and angular resolutions (13). This hydrogen calibration procedure is essentially identical to that described in Reference 14.

The results of a typical  $H(n;n)$  measurement of the above type were normalized to the fission-spectrum-based relative sensitivities. The two types of results are compared in Fig. 3. The  $H(n;n)$  values are less detailed and extend over a smaller energy range than those obtained from the fission neutron spectrum but the two sets of values relatively agree to well within the respective

uncertainties of the measurements and associated correction procedures.

Application of the above fission-based calibration procedures in neutron scattering measurements has been generally successful. Relative scattered-neutron distributions are obtained using the fission-based relative sensitivities and then normalized to the  $H(n;n)$  cross section values using a few careful  $H(n;n)$  measurements at angles and energies selected for optimum response. The resulting differential cross sections compare favorably with those obtained using other relative calibration procedures and, in such simple cases as  $C(n;n)$  scattering, the angle-integrated elastic scattering cross sections are in good agreement with the reported total neutron cross sections at energies where other processes are not significant.

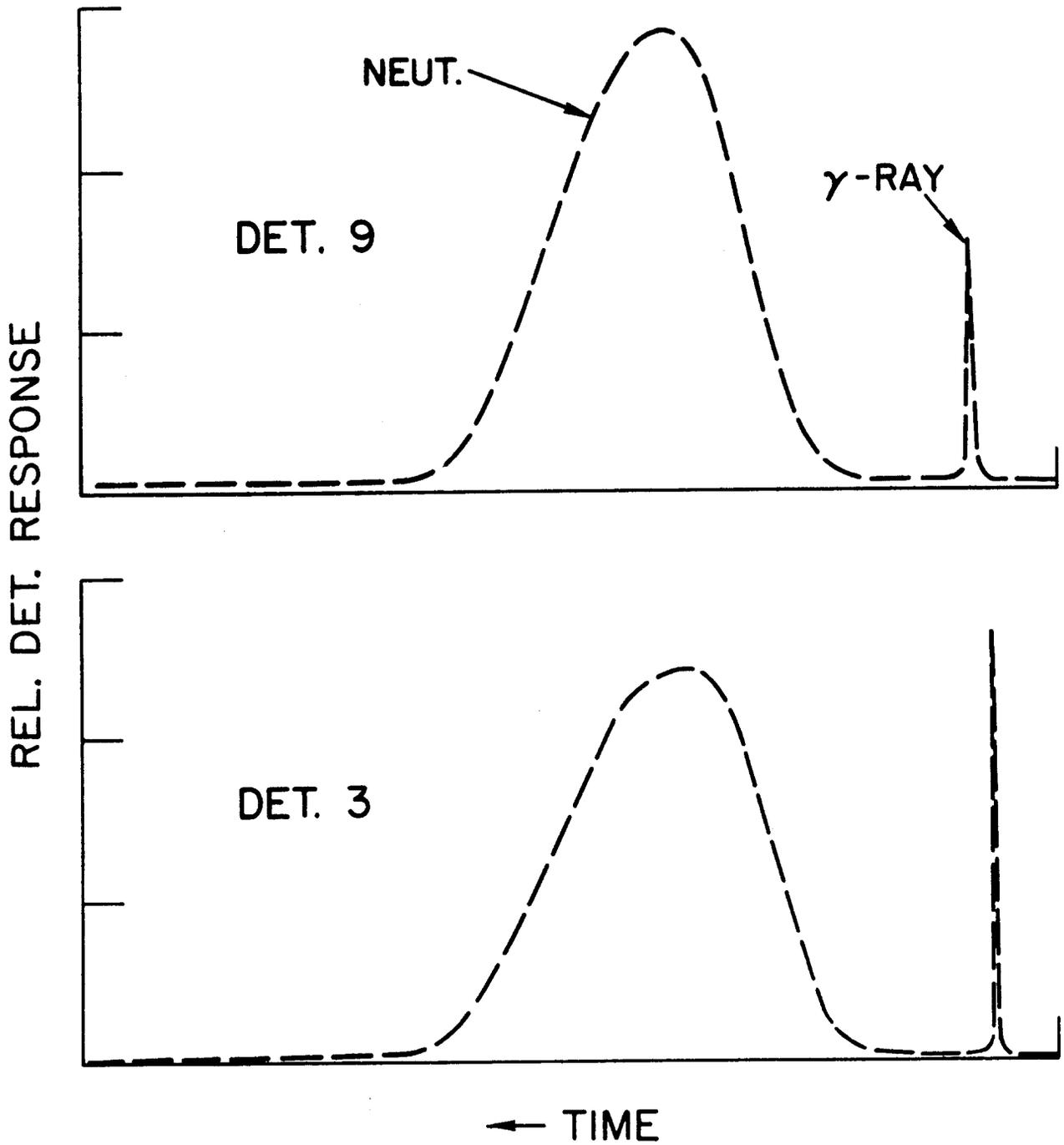
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## FIGURE CAPTIONS

- Fig. 1. Illustrative fission-neutron velocity spectra measured with independent neutron detectors.
- Fig. 2. Detailed relative detector sensitivity. Measured values are indicated by data points the vertical extent of which indicate statistical uncertainties.
- Fig. 3. Representative relative detector sensitivities. Crosses indicate bin-sorted fission spectrum results. Circles note results obtained by observation of the  $H(n;n)$  process. The statistical uncertainties associated with the data points are  $\sim 3\%$ . The curve is the result of fitting the expression of Eq. 2 to the measured fission-spectrum results. The straight line is a linear section extrapolating the curve to the cut-off point. The two illustrated results were obtained with independent detectors having somewhat different responses.

Fig. 1.



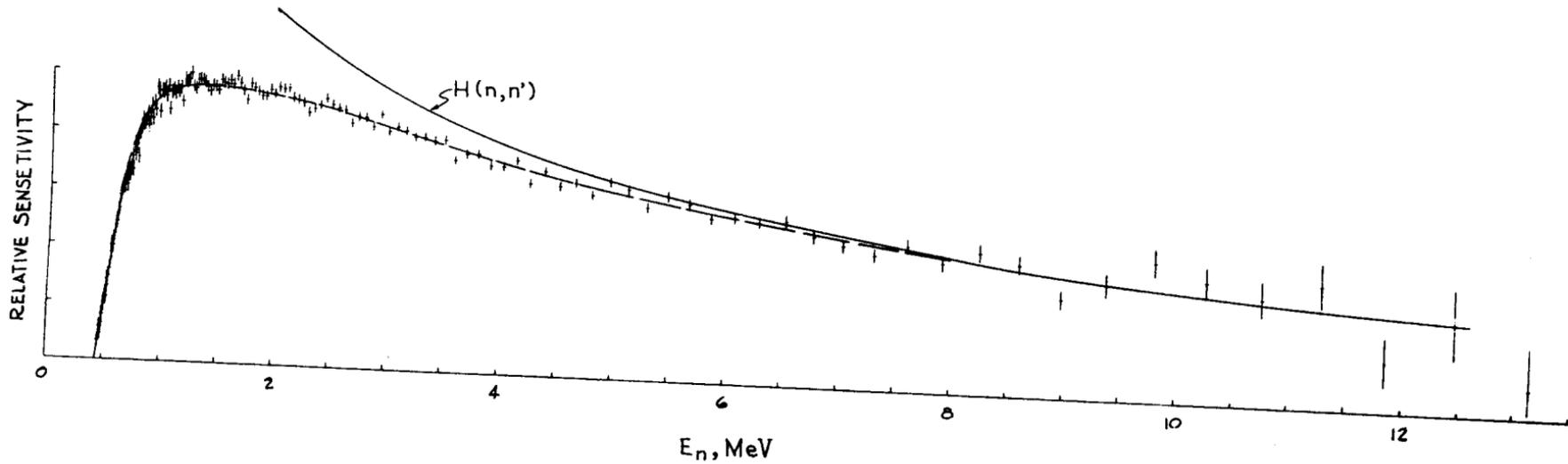


FIG. 2.

Fig. 3.

