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NEUTRON FLUX MEASUREMENT AT RTNS FACILITY

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ABSTRACT

Procedures and instrumentation for measuring neutron fluences and doses at the Lawrence Livermore Laboratory RTNS facility are described, primarily for information to outside users of this facility. The results of an intercomparison of the dosimeters are given, and the accuracy of the fluence determination is discussed.

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INTRODUCTION

When the Rotating Target Neutron Source (RTNS) facility is used as a source of 14-MeV neutrons, a Ti-T target is bombarded by 400-keV atomic deuterons. Because the neutron output depends on the condition of the target, measurement of the incident deuteron current does not yield reliable information about neutron flux.

The performance of the neutron generator is expressed in terms of the source strength, i.e., the total number of D-T neutrons produced per second. For a calculation of the flux per unit solid angle, the slight anisotropy of the D-T reaction must be taken into account. Values for the variation of neutron intensity with angle may be found in Ref. 1.

Users are usually interested in the dose at the sample position. Calculation of the dose from the source strength is not always reliable. If the sample is close to the source (less than 5 cm), errors are introduced by the finite source size (about 1 cm) and the lack of knowledge of its effective center. If the sample is far from the source, errors are introduced by neutrons scattered into the sample from equipment in the room, the walls, shields, etc.

NEUTRON FLUX MEASUREMENT

The following monitors are available for determining neutron flux:

1. Proton recoil counter. This device measures neutron source strength. It is insensitive to the exact source position and to scattered neutrons and serves as the routine source strength monitor.

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2. Tissue equivalent ionization chamber. This device measures dose in tissue, including dose from scattered neutrons and gamma rays. Its diameter of 2 cm limits its usefulness to measurements at distances greater than about 10 cm from the source. Because the chamber is designed to measure dose in tissue, its reading is not necessarily useful for physical measurements. This chamber has been calibrated against the proton recoil counter and in a gamma-ray field.
3. Foil dosimeters. When samples are irradiated close to the source, the most reliable fluence (or dose) measurements use small foils placed next to the sample. The activity of the foil induced by the 14-MeV neutrons is determined after the end of the irradiation. Facilities for determining the activity are available at Lawrence Livermore Laboratory in the Radiochemistry and Hazards Control departments, if the user does not wish to perform this measurement himself. The dosimeter reaction should result in an activity whose half-life is long compared to the irradiation time, and the reaction should have a threshold so that the dosimeter does not detect slow neutrons. $\text{Nb}(n,2n)$ is a frequently used reaction, but Al, Cu, or Zr foils and S pellets are also often employed as dosimeters. The foil dosimetry, especially with the $\text{Nb}(n,2n)$ reaction, is described in Ref. 2.

PROTON RECOIL COUNTERS

Two kinds of proton recoil counters are available. Both detect protons ejected from a polyethylene foil. The first is a "counter telescope" in which coincidences are counted between a proportional counter through which

the recoils pass and scintillations in a CsI crystal viewed by a photomultiplier tube. Although this device has a readily calculated efficiency, it has counting losses which are difficult to determine when high neutron source strengths are used. In the following only the second type of proton recoil counter will be discussed. In this counter proton recoils are detected in a single small, thin CsI crystal, which is mounted on a photomultiplier tube. The hydrogenous foil and the scintillator are mounted parallel to each other in a gold-lined evacuated chamber in the configuration shown in Fig. 1.

Two counters, referred to as A and B, are in current use. Table I lists the parameters and efficiencies of these two counters. The detector efficiency ϵ , labeled Johnson, is calculated according to Eq. (8) of Ref. 3. This calculation is in good agreement with a Monte Carlo calculation⁴ carried out at LLL. The latter calculation takes into account edge effects in the CsI scintillator. All efficiencies are in units of counts per neutron per steradian. The efficiency calculations were performed for both counters at 100 cm from the source at 14° with respect to the deuteron beam line. The countrate of the recoil counter for a given source strength and for a given distance is within a few percent independent of angle with respect to the incident deuterons. This is due to the fact that the effect of the anisotropy in the neutron emission probability almost exactly cancels the effect of the energy dependence of the neutron-proton scattering cross section. Figure 2 shows, based on Ref. 1, for 400 keV deuterons incident on a thick Ti-T target the average energy of the neutrons emitted in various directions, the variation of the neutron-proton total cross section with the calculated neutron energy, and the relative neutron yield as a function of angle. As may be seen, the product of cross section and yield varies very little with angle.

Samples are usually irradiated at 0° while the proton recoil counter is usually placed at 130° , 100 cm from the source. The total number of neutrons produced by the source is given by $4\pi/\epsilon$ times the counts at 130° , and this quantity is shown in Table I. Attention must be given to any difference between the amount of material between the counter and the source, and the material between the sample and the source. Such materials include the target backing, the cooling water, the water spreader, and air. The quantity "neutrons per count" of Table I is derived from the Monte Carlo calculations after corrections for edge effects in the CsI crystal (6%) and background counts (3%). Figure 3 compares the Monte Carlo calculations with measurements of the recoil spectrum at 10° with respect to the deuteron beam. The calculated tail at low pulse heights is due to edge effects in the CsI crystal. The 6% correction means that at the bias setting shown, the counts in the tail below bias is 6% of the total counts above bias. The 3% background correction is that measured with the radiator removed. Figure 3 shows that the measured background is 9% if we assume the shape to be identical to that measured with radiator removed. Of this 9%, 3% is attributed to radiator out background, and 3% to edge effects. The remaining 3% is probably due to proton recoils from high energy neutrons inelastically scattered from the target and detector assembly. The background therefore has the uncertainty 3^{+3}_{-0} %. The discriminator of the counting circuit should be set at 50 % of the pulse height corresponding to the peak in the pulse-height distribution, i.e., to the energy of the incident neutrons. Because there are some pulses of the height corresponding to the discriminator setting, the setting of the discriminator affects the countrate and introduces another 2% uncertainty into the efficiency. The overall uncertainty in the efficiency determination due to background, crystal edge effects and discriminator setting is estimated to be $\pm 5\%$.

ACCURACY OF FLUX MEASUREMENTS

Absolute fast neutron flux measurements are difficult to perform with an accuracy better than 10%. Absolute flux measurements are usually based on proton recoil counters. The accuracy attainable with proton recoil counters just described is $\pm 5\%$ in routine operations, and somewhat better if special care is taken. The calculation of dose on small samples is subject to the additional uncertainties mentioned in the Introduction.

TISSUE EQUIVALENT CHAMBER

The walls of the tissue equivalent (T.E.) ionization chamber consist of T.E. plastic A-150, which has the composition $C_{6.35} H_{10.2} O_{0.325} N_{0.25}$, and smaller amounts of F and Ca.

The chamber is normally open to air, but provisions are available to flow T.E. gas through the chamber (use $2 \text{ cm}^3/\text{min}$ of N_2 , CO_2 , CH_4 mixture). For most applications the air filling is satisfactory. Tissue equivalent gas must be used, however, when an appreciable number of slow neutrons is present. The calibration in R/C is proportional to the absolute pressure. According to the manufacturer and confirmed at Lawrence Livermore Laboratory the calibration at 760 mm Hg and $22^\circ C$ is 3.36 R/nC for air and 2.93 R/nC for T.E. gas.

The conversion from roentgens to absorbed dose in rads is different for absorbed dose in air and absorbed dose in tissue because of the difference in stopping powers. The conversion is also different for neutrons and gamma rays because the energy to produce an ion pair is different for the electrons produced by gamma rays and for the heavier particles produced by neutrons.

In addition, T.E. plastic is not really tissue equivalent for neutrons (it was designed for gamma-ray dosimeters). The effects of the difference in energy per ion pair and the nonequivalence of C and O for neutrons almost cancel for 15-MeV neutrons: each is about 5%, but in opposite directions. As a consequence, the usual conversion factor of 0.96 from roentgens to rads in tissue can be used for both gamma rays and 15-MeV neutrons, i.e., multiply the reading in roentgens by 0.96 to obtain absorbed dose in tissue in rads. A direct measurement of this conversion factor at Lawrence Livermore Laboratory⁵ for 15-MeV neutrons gave 0.95.

COMPARISON BETWEEN PROTON-RECOIL COUNTER AND ACTIVATION MEASUREMENT

The reaction cross section which is reported to be most accurately known around 14-MeV and which leads to an easily observed radioactivity is the reaction $\text{Al}(n,\alpha)^{24}\text{Na}$ which leads to a 15-hr β -activity. The cross section for this reaction was assumed to 111.7 mb at 15 MeV, halfway between the value recommended by Young and Foster⁶ and the measurement by Vonach, et al.⁷ The β activity was measured independently in different geometries by D. R. Nethaway at the LLL Radiochemistry Division (Foils N) and by R. V. Griffith at the Hazards Control Department (Foils G). The Al Foils G were placed at 0° and 100 cm, while the foils N were placed on top of recoil counter B which was at 14° with respect to the incident deuterons and at 100 cm. The foils N were at a distance of 99.7 cm. The results of two fluence measurements on different days are given in Table II. The difference between the fluences at 0° and 14° is less than 1% and was neglected. As may be seen, the agreement between the independent measurements is well within the uncertainty of the individual determinations.

TABLE I

Parameters and Efficiencies of Proton Recoil Counters

	<u>Counter A</u>	<u>Counter B</u>
Radiator Thickness (mg/cm^2)	72.85	70.45
Radiator radius, R (cm)	1.910	1.917
Crystal radius, r (cm)	0.3175	0.3188
Scintillator Thickness (cm)	0.127	0.127
Radiator-crystal distance, D (cm)	5.016	4.968
Source to radiator distance, L (cm)	100	100
ϵ , Detection efficiency (Johnson)	1.693×10^{-8}	1.693×10^{-8}
ϵ , Detection efficiency (Monte Carlo)	1.699×10^{-8}	1.699×10^{-8}
Background (%)	3	3
ϵ (Monte Carlo + Background)	1.75×10^{-8}	1.75×10^{-8}
Neutrons per count ($4\pi/\epsilon$) (Monte Carlo)	7.18×10^8	7.18×10^8

TABLE II

Comparison of Fluences (cm^{-2}) Measured with
Proton Recoil Counter and with Al Foils

<u>Date</u>	<u>Counter B</u>	<u>Foils N</u>	<u>Foils G</u>
29 July 1975	5.71×10^{10}	5.39×10^{10}	5.70×10^{10}
30 July 1975	1.14×10^{11}	1.11×10^{11}	1.14×10^{11}

Fig. 1. Schematic of proton recoil counter.

Figure 2 - Neutron energy and yield for 400-keV deuterons on thick Ti-T target.

Figure 3 - Calculated and measured pulse height distribution for hydrogen recoils in the counter shown in Figure 1.

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