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ANGULAR-DISTRIBUTION NEUTRON-EMISSION SPECTRA OF NIOBIUM FOLLOWING BOMBARDMENT BY FAST NEUTRONS

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Abstract Neutron-emission spectra at ten angles between 20 and 160 degrees and incident neutron energies of 5.9, 7.1 and 8.4 MeV were measured relative to the neutron field emitted after spontaneous fission of ^{252}Cf . The angular distribution of inelastically scattered neutrons appears to be essentially isotropic where it can be separated from the dominant elastic scattering peak. Above an excitation energy of 4 MeV the spectra are well described by a Maxwellian temperature distribution.

INTRODUCTION

The inelastic scattering of fast neutrons is a difficult quantitative problem, both from the experimental and theoretical point of view. Yet the need for a reliable description of these processes persists (1). The present paper presents a method of measuring inelastically scattered neutrons that is both conceptually and experimentally relatively straightforward. The central idea is to determine by the time-of-flight (TOF) method emission-neutron spectra relative to that arising from the spontaneous fission of ^{252}Cf . The latter is reasonably well defined in the emitted-neutron-energy range of 1-8 MeV (2). Preliminary results obtained with this approach are discussed herein for the Nb continuum. A recent evaluation of nuclear cross sections for this nucleus indicates a need for more inelastic-neutron-scattering data (3).

EXPERIMENTAL PROCEDURES

The present measurements were made with the ten-channel TOF neutron spectrometer at the ANL/FNG facility (4). The $\text{D(d,n)}\text{He}^3$ reaction and a gas target assembly were employed as the neutron source, with mean incident-deuteron energy definition of ± 20 keV and neutron energy resolutions of 300-500 keV. Emission-neutron spectra were recorded over the angular range of 20-160° at 5.9,

ytp

Fig. 1. Neutron Emission Spectra. The sample is Nb unless noted otherwise. a. Basic time spectra at 8.4 MeV incident-neutron energy (E_{in}). IN (OUT) refers to the sample position in (out) of the beam line. EC (FC) indicates that the target cell was empty (filled) with deuterium. Reduced spectra follow from the subtractions (IN/FC-OUT/FC)-(IN/EC)-OUT/EC). b. Reduced spectra for selected scattering angles at $E_{in}=8.4$ MeV. c. Reduced spectra at 87 deg. for $E_{in}=5.9, 7.1, 8.4$ MeV. The Cf reference spectrum corresponds to the same detector.

7.1 and 8.4 MeV incident-neutron energies, thus minimizing complications due to the $D(d;n,p)D$ source reaction and the $^{93}\text{Nb}(n,2n)^{92}\text{Nb}$ reaction. The emitted neutrons were detected from $\lesssim 1$ MeV upwards with an energy scale uncertainty of $\lesssim 50$ keV. Fig. 1 characterizes the time spectra obtained in this work. Scattering from carbon accompanied all measurements in order to monitor the "purity" of the spectra. Also shown in this figure is the detector response to the Cf neutron-emission spectrum. In the "off-line" method described in ref. 5, the entire spectrometer is used except that the stop pulse is derived from the detection of the Cf fission fragments. Many of the usual corrections are obviated by the present ratio approach, and for excitation energies above 2 MeV multiple-scattering requires an essentially isotropic reduction of observed count rates by $< 10\%$.

RESULTS AND CONCLUSIONS

An inspection of Fig. 1 suggests several conclusions regarding the inelastic scattering of fast neutrons from Nb. Except for the elastic component, the spectra are essentially isotropic implying a preponderance of compound nuclear process. The

Fig. 2. Experimentally determined Nb/Cf spectrum ratios, R , plotted as $\ln R - 0.5 \ln E_n$ vs. E_n .

spectra suggest a transition to the continuum representation above an excitation energy of about 4 MeV. In the higher emission energy region there is evidence of experimentally unresolved discrete states. The elastic scattering peak tends to dominate much of this part of the spectrum forward of 40° . The continuum portions of the spectra have been analyzed in terms of Maxwellian emission distributions. The Cf spectrum has been shown to be well described in the present energy range by the form $E^{1/2} \exp(-E/T)$ (2), while the form $E \exp(-E/T)$ is assumed for Nb (6). The natural logarithms of the experimentally determined Nb-to-Cf-spectrum ratios were least-squares fitted for each angle and incident energy to the expression $(a+0.5 \ln E - bE)$, where the slope b may be identified with $(1/T_{\text{Nb}} - 1/T_{\text{Cf}})$. As Fig. 2a demonstrates, b is reasonably constant over that part of the angular range which is experimentally well-defined. The energy variation of b is exhibited in Fig. 2b. The nuclear temperatures implied by these fits were evaluated using the Cf temperature suggested by Poenitz and Tamura (2). The results of averaging the individual values are indicated in Fig. 3 together with some recent values from the literature (7).

Fig. 3. Nb temperatures.
This work: ●, ref. 7: ○.

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