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FAST-NEUTRON INTERACTION WITH NIOBIUM

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Abstract Results of a comprehensive study of the interaction of fast neutrons with niobium are presented, including measurement and interpretation of neutron total, differential-scattering and radiative-capture cross sections. The experimental results are interpreted in the context of the optical-statistical model, with attention to the Fermi-surface anomaly. Experimental results, physical interpretations and rigorous statistical methods are used to provide a comprehensive evaluated nuclear data file suitable for use in a wide range of applied neutronic calculations.

INTRODUCTION

The authors have been responsible for the ENDF/B niobium evaluation for more than a decade. Results of a number of new measurements and the development of rigorous evaluation methods now make possible significant improvements in the file, with particular attention to fusion-energy needs. Concurrently, the analysis of the experimental results provides better understanding of the optical-statistical model, particularly the behavior near the Fermi-surface, and its implication on the nucleon-nucleon force as manifest in the effective nucleon mass in finite nuclei (1,2). The evaluated file was tested using monte-carlo interpretations of the behavior of 14-MeV neutrons emitted at the center of spherical niobium shells (3).

EXPERIMENTAL MEASUREMENTS

Energy-averaged neutron total cross sections were measured from 40 keV to 20 MeV using both monoenergetic and white-source techniques (4), with cross-section uncertainties of the order of 1%. The results are illustrated in Fig. 1. Differential neutron elastic- and inelastic-scattering measurements were made over the range 1.5-10.0 MeV and the angular interval 20-160 deg, using the

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PHYSICAL INTERPRETATION

The experimental results were interpreted in the context of the spherical optical-statistical model. Discrete levels were included in the calculations to excitations of 2.0 MeV and the Gilbert and Cameron (5) statistical representation was used at higher energies. The six OM parameters (real and imaginary strengths, radii and diffusenesses) were determined by chi-square fitting the measured differential elastic-scattering distributions. The fitting procedures properly accounted for the inelastic excitation of the first (30 keV) level (not experimentally resolved), as described in ref. 4. The neutron total and the inelastic-scattering cross sections were well described by the resulting model parameters. The model was suitable for both evaluation and physical considerations. The real and imaginary potential strengths (expressed as volume-integral per nucleon) are related to the effective reduced nucleon mass in finite nuclei as discussed by Brown et al. (2) and Mahaux and Ngo (1). The reduced mass peaks at the Fermi surface with a consequent energy dependence of the potential strengths. Near Pb-208, Mahaux and Ngo predict a significantly non-linear energy dependence as the binding energy is approached. The present experiments do not support such a behavior for niobium. Brown et al. suggest a nearly linear energy dependence throughout the positive energy region, with significant deviations only below the binding energy. Such a behavior is indicated by the present experiments (see Fig. 4). At positive energies the real and imaginary strengths are essentially linear with energy. Consideration of Sr particle and hole states, as reported from pickup reactions, indicates nonlinearity at the Fermi energy and below (see Fig. 4). The estimates may be conservative as the experimental bound strengths upon which they were based may be too small. From the practical standpoint, the conventional linear energy dependencies of the potential are suitable, though the absorption strength is mass dependent.

EVALUATION AND INTEGRAL TESTS

The above experimental data (and that available in the literature) and the model, were used to derive a comprehensive evaluated neutronic data file. The details of the derivation are given in ref 4. The file is in the ENDF format and uncertainties are specified. The resonance parameters are taken from ref. 6. The evaluated energy-averaged total cross section is rigorously derived and very well known. Scattering cross sections are better defined than in existing files, particularly with respect to the continuum-inelastic component.

time-of-flight technique (4). The scattering cross sections were relative to the $H(n,n)$ or independently-measured carbon-total cross sections. Incident-

Fig. 1. Measured (symbols) and evaluated, (curve) neutron total cross sections of niobium.

energy resolutions were relatively large so as to assure an energy-averaged behavior consistent with the concept of the optical model. All scattering results were corrected for multiple-event, angular-resolution and beam-attenuation effects. The differential-elastic-scattering results are generally known to 3-5% (see Fig. 2) (4). Differential inelastic-scattering cross sections were measured to excitation energies of more than 2.0 MeV. These are generally "effective" inelastic cross sections for the cumulative excitation of several levels within the experimental resolution. They are given in ref. 6. Energy-differential radiative-capture cross sections were measured from 0.1 to 2.0 MeV using the liquid-scintillation-tank technique (4) with accuracies of the order of 10%. The experimental results are compared with values given in the literature and with the present evaluation in Fig. 3.

Fig. 2. Measured (symbols) and calculated (curves) elastic cross sections.

Fig. 3. Measured (symbols) and evaluated (curve) capture cross sections.

Fig. 4. Energy-dependence of the real potential strength.

There is a significant increase in the (n,2n) cross section relative to ENDF/B-V. All prominent charged-particle-emission cross sections are given. The activation cross section due to the inelastic excitation of the 30 keV metastable state (frequently used for dosimetry) is given in detail, including uncertainties. A qualitative impression of the file content is given in Fig. 5.

Fig. 5. Illustrative evaluated cross sections.

The file was tested using the 14-MeV pulsed-sphere measurements of Wong et al. (3) and monte-carlo transport calculations using the TART code (7). The agreement between measured and calculated integral spectral is good. Full documentation of the evaluation is given in ref. 4.

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