Integral Test of Niobium Differential Elastic Scattering Cross-Sections of 60 and 120 Degrees for High-Energy Neutrons

by

Saim SELVI*, Kazuo SHIN** and Tomonori HYODO**

(Received December 21, 1983)

Abstract

Spectra of scattered neutrons from a niobium disc were measured at the scattering angles of 60° and 120° by an NE-213 scintillator. Comparison of the experimental data with the point-to-point Monte Carlo calculations, using the evaluated data from the ENDF/B-IV file, showed good agreement at 60°, but considerable discrepancy at 120°.

1. Introduction

Niobium has been recognized as one of the very important materials for fusion reactors. Accumulating and increasing the accuracy of nuclear data of Nb became necessary for the design study of fusion reactors.

Elastic and inelastic cross sections of Nb have been determined by various workers[1~3]. However, in recent years measurement techniques are becoming more sensitive, and the Monte Carlo applications more detailed.

Large scale benchmark experiments have not been carried out because the price of Nb is very expensive. Ingersol et al[4]. measured the penetration of ^{252}Cf neutrons through a Nb sphere, while Shin et al[5]. measured the differential scattering cross section of Nb at 90°.

In this study, scattered neutrons from a Nb disc at 60° and 120° are measured by a NE-213 scintillator, and are calculated by the point-to-point Monte Carlo code JUPITER[6] for the purpose comparing scattering cross-sections.

II. Experimental procedure

Exeriments were made using a ^{252}Cf fission neutron source of approximately

* On leave, Department of Physics, Science Faculty, Ege University, Boronove-Izmir, TURKEY.

** Department of Nuclear Engineering, Faculty of Engineering, Kyoto University.

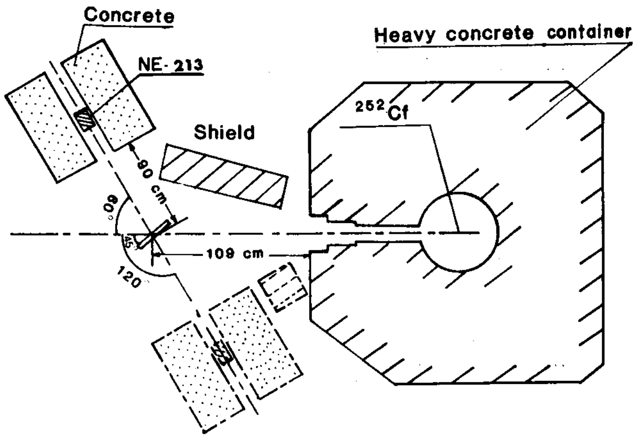

Fig. 1. Experimental arrangement.

0.367 Ci placed in a heavy concrete container, as shown in Fig. 1. The container had a beam collimator, such as a three stepped duct (15 cm diam. ×82.5 cm length, 18 cm diam. ×22.5 cm length, and 20 cm diam. ×15 cm length) penetrating horizontally through the heavy concrete wall. The ^{252}Cf neutron source was placed on the axis of the duct and at the center of a hole in the container.

The center of the disc shaped Nb sample was placed as 109 cm from the wall of the container and on the axis of the duct.

The thickness of the Nb disc is taken as one cm, which is necessary to prevent a multiple neutron scattering in it, since the mean-free-path for 2-MeV neutrons in niobium is 2.5 cm. The angle between the normal line of the Nb disc and the beam line was kept at 45° for the measurements. The scattered neutrons were measured by a 7.6 cm (3 in.) diameter by 7.6 cm (3 in.) long liquid organic scintillator NE-213 spectrometer system. The NE-213 scintillator was placed in a hole of the detector concrete shield at 90 cm from the Nb disc, on the line of the scattering angles of 60° and 120°, as shown in the figure. Heavy concrete and polyethylene shadow shields were placed in order to protect against neutron and gamma rays from the mouth of the beam collimator.

A block diagram of the spectrometer system is shown in Fig. 2. The discrimination of the neutron pulse-height distribution from that of the gamma is made by a RHC pulse-shape-discrimination circuit and a two-dimensional multichannel analyzer. Then, the neutron spectra were unfolded by the FERDO method[7] using the response functions calculated by the Monte Carlo method[8].

The energy calibration was made by gamma rays from ^{137}Cs and ^{60}Co standard sources and by those from an Am-Be neutron source both before and at the end of each experiment. The same procedure was also repeated every 8 hours during the

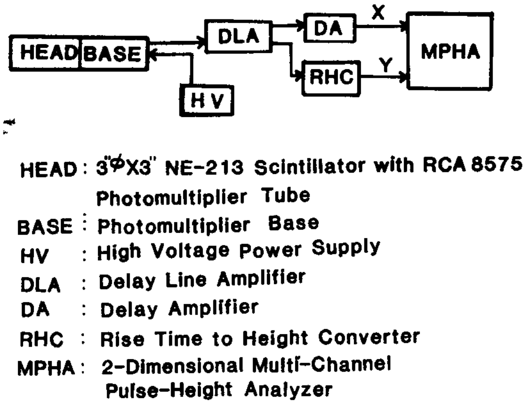

Fig. 2. A block diagram of the spectrometer system.

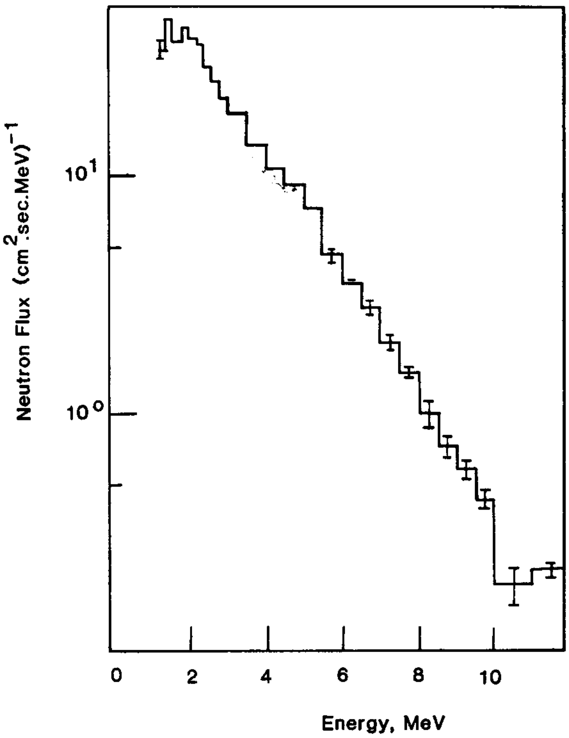

Fig. 3. The source spectrum of the neutrons.

experiments. Therefore, the gain shift is seen to be very small during the experiments.

The profile of the neutron beam at the target position was measured in a previous experiment[8]. The flux distribution on the plane perpendicular to the collimator axis at the detectors center is flat in the circle of 26.6 cm. The distribution of the incident neutrons are, therefore, considered uniform throughout the target. The source spectrum of the neutrons are shown in Fig. 3.

The background neutrons were measured in the geometry removed the Nb disc from the position shown in Fig. 1. The counting rate at each energy channel was subtracted from that of scattered neutrons.

III. Calculations

For the sake of estimating the contribution of the elastic scattering to the measured scattered neutron flux, the neutrons scattered from the Nb in the same experimental geometry for both total and elastic scattering at 60, 90 and 120 degrees were calculated by the point-to-point Monte Carlo code JUPITER. The values of the cross-sections at a neutron energy were obtained by interpolation from a set of 106 energy points of the elastic scattering, and 38 energy points of the other reaction cross sections taken from ENDF/B-IV[9]. The order of the Legendre expansion for the elastic scattering was changed from 14 to 2, according to the 31 incident neutron energy points. The same variation was used for the calculations of the differential elastic cross-sections for all angles.

IV. Result and Discussion

The measured and calculated elastic and total scattering neutron energy distributions scattered from the Nb disc are shown in Fig. 4 and 5. For the sake of comparison, the measured neuron energy distribution at 90° is shown in Fig. 6 from the

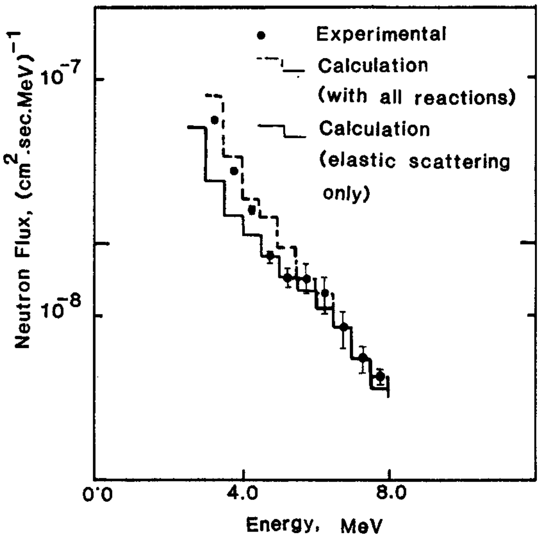

Fig. 4. Comparison of total and elastic cross sections of Nb at 60°.

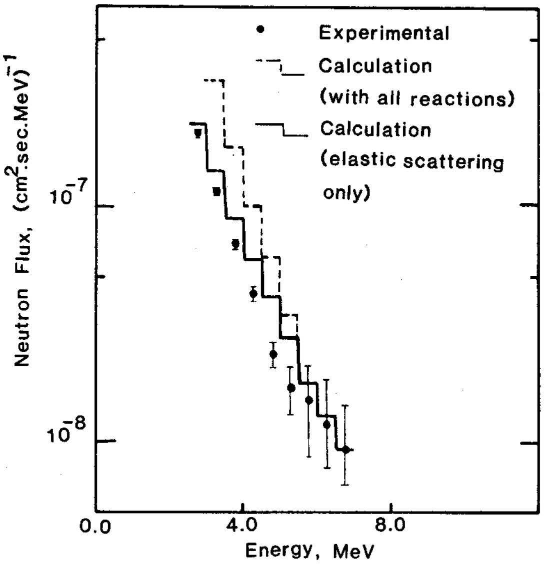

Fig. 5. Comparison of total and elastic cross sections of Nb at 120°.

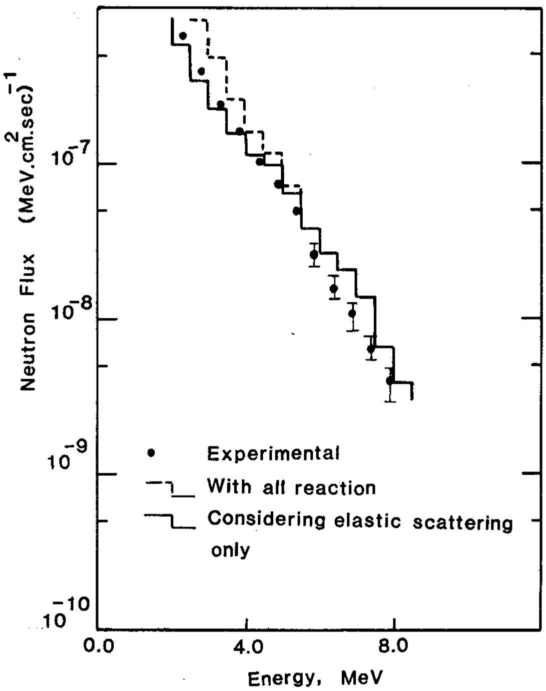

Fig. 6. Comparison of total and elastic cross sections of Nb at 90°.

reference[5].

The essential normalization was made presuming that one incident neutron was on the target.

The errors estimated by the modified FERDO code and the statistical errors calculated by the JUPITER code are shown on the experimental and calculated data, respectively.

The neutron fluxes obtained by the experiment as well as those considering all reactions show good agreement at the scattering angle 60°, as shown in Fig. 4. The neutron fluxes of elastic scattering show only discrepancies between the experiments and those considering all reactions in the energy range less than 4 MeV. This shows that most of the scattered neutrons in the energy range over 5 MeV may be caused by the elastic scattering.

The results obtained at 120° show considerable discrepancies between the experimental results and the calculated consideration of all the reactions. The cause of the discrepancy is not yet known. The data at 90° in Fig. 6 shows a tendency of disagreement between curves. One cause of the discrepancy might be an overestimation of the inelastic cross-section by the isotropic assumption.

Acknowledgement

The present work has been supported by the special Grantin-Aid (fusion) Scientific Research Promotion from the Ministry of Education, Science and Culture (Monbusho).

References

1) J. C. Hopkins et al., Nucl. Sci. Eng., **36**, 275 (1969).
2) J. Whalen et al., Trans. Amer. Nucl. Soc., **16**, 311 (1973).
3) D. B. Thomson, Phys. Rev., **129**, 1649 (1963).
4) D. T. Ingersoll, Proc. 5th Int. Conf. on Reactor Shielding, Knoxville, p. 841 (1977).
5) K. Shin et al., This Memoirs, **45**, 17 (1883).
6) K. Shin et al., J. Nucl. Sci. Tech., **17**, 668 (1980).
7) W. R. Burrus and V. V. Verbinski, ANS-SD-2, p. 148 (1965).
8) K. Shin et al., This Memoirs, **41**, 116 (1979).
9) ENDF/B-IV, Brookhaven National Laboratory (1975).