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MASTER

STATUS REPORT ON
EVALUATION OF SODIUM
CROSS SECTIONS FOR ENDF/B

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I. INTRODUCTION

Since the evaluation of sodium neutron cross sections^[1] for ENDF/B, significant new measurements have become available for the total, inelastic scattering and capture cross sections, as well as angular distributions for inelastic scattering. These measurements significantly improve the status of cross sections for sodium so that a reevaluation for ENDF/B is warranted. This report presents the status of this reevaluation as of the end of calendar year 1970.

At this time, preliminary reevaluations of the total cross section and inelastic scattering cross section up to 5 MeV have been completed. In general, the new measurements have not disclosed any particularly major deficiencies in the previous sodium evaluation. However, the new data leads to improved definitions of the cross sections, particularly in regard to better resolution of the total cross section and inelastic scattering cross section for the 0.44 MeV level, improved magnitude of the resolved level inelastic scattering up to 8.5 MeV, and better data for elastic angular distributions above 1.5 MeV.

II. EVALUATION OF NEUTRON CROSS SECTIONS

A. Total Cross Sections

The total cross section of sodium has been reevaluated for the ENDF/B library in the neutron energy range from 100 eV to 15 MeV. The total cross sections in Mat. 1059, in the ENDF/B, in the energy range from 400 eV to 30 keV were calculated with the 2.85 keV resonance parameters.

In the new evaluation, the data (obtained at the Nevis Laboratory, Columbia University) below 30 keV are being examined. The data indicate that the width of the 2.85 keV resonance is wider than the earlier measurements by Garg,^[2] but not as wide as those by Lynn.^[3] The peak value at the resonance is within the statistical uncertainty of the theoretical value which is 380 barns for a resonance with $J = 1$. The data as shown in Figure 1 are not corrected for background because aluminum was used for the casings of the sodium samples.

Between 200 keV and 520 keV the measurements of Whalen^[4] and Stelson^[5] have been used because they have the best resolution. In general, these two measurements are in good agreement as is shown in Figure 2. In this energy range, the new evaluation will give the same data as given in Mat. 1059.

Above 520 keV, recent measurements of total cross sections by Stoler and Block^[6] were used in their entirety, because they have high resolution and good statistical precision. These data also join smoothly with the measurements by Whalen^[4] between 500 keV and 640 keV. The measurements by Cierjacks^[7] at Karlsruhe have the same high resolution as those by Stoler and Block,^[6] but there have been some questions with regard to the background corrections on Cierjack's values; therefore, greatest weight has been given to the measurements by Stoler and Block. In fact, the two measurements agree well within a few percents above 1 MeV. Between 500 keV to 640 keV an equal weight

has been given to measurements by Whalen and Stoler. Between 640 keV and 1.2 MeV the new evaluation, based on Stoler, is in agreement with old measurements by Stelson;^[5] whereas the measurements by Langsford^[8] in this energy range were used for Mat. 1059.

Above 1.2 MeV, the new evaluation primarily follows the measurements by Stoler, utilizing the large number of data points by Cierjacks^[7] for the determination of the structure in the cross sections. In this energy range the two sets of measurements agree within a few percent, with primary differences occurring near the valleys of the total cross sections. It has been noted that these high resolution data do not differ much from earlier measurements by Langsford above 1.2 MeV, which were the bases of the earlier evaluation of Mat. 1059. Figures 3 and 4 show the comparisons among the evaluated points, Whalen's data, the RPI data by Stoler, and KFK data by Cierjacks. Figures 5 through 13 show the evaluated total cross sections in comparison with two high resolution data by Stoler and Cierjacks.

B. Inelastic and Elastic Scattering Cross Sections

At the time of an earlier evaluation of the sodium cross sections,^[1] no experimental measurements of elastic and inelastic scattering cross sections were available for neutron energies above 4 MeV. Recently, elastic and inelastic scattering cross sections of sodium and the related angular distributions have been measured by Fasoli^[9] at the neutron energies 1.51, 2.47, 4.04 and 6.40 MeV, and by Perey and Kinney^[10] in the energy range from 5.4 MeV to 8.5 MeV. The total inelastic scattering cross sections from the first excited level at 440 keV have been measured from gamma ray investigations by Smith,^[11] Tucker,^[12] and Perey.^[13]

A comparison of the angular distributions of elastically scattered neutrons at 6.4 MeV has been made between Fasoli's data and Perey's data. Data by Fasoli at this energy, which include inelastically scattered neutrons from the 0.44 MeV excitation level, are in good agreement with the sum of angular distributions of elastic neutron scattering and inelastic neutron scattering from the same level measured by Perey and Kinney at 6.37 MeV.

The differential cross sections of inelastically scattered neutrons from the excitation levels at 4.43 and 4.77 MeV, respectively, are also in agreement within uncertainties of measurements. The total error in experimental values increases with the incident neutron energy and with the excitation energy; this error varies from 10 to 20 percent in the Fasoli's data. The review of these data shows that inelastic scattering differential cross sections from various excitation levels seem to be roughly isotropic in the center-of-mass system.

The reevaluation of sodium elastic scattering differential data includes distributions measured by Chien and Smith^[14] for the energy range from 0.3 to 1.5 MeV; above 1.5 MeV, Fasoli's data at 1.5, 2.47, 4.04 and 6.40 MeV are used; in the energy region above 4 MeV the elastic differential cross sections by Perey^[10] at 5.44, 6.37, and 8.52 MeV are included in the reevaluation.

In this reevaluation the high resolution total inelastic scattering cross section measured by Perey^[13] are adopted below 2.2 MeV. It is not clear

at this time why the new data by D. L. Smith^[11] are significantly lower than Perey's data in the energy range between 1 MeV and 1.5 MeV.

C. Recent Experimental Data for Other Cross Sections

New measurements on sodium capture cross sections have been made at Rensselaer LINAC Laboratory.^[15] Neutron radiative capture in sodium were measured with a large (1.25 in diameter) liquid scintillator detector. For resonances with well-known neutron widths, radiation widths have been determined, while the resonance capture areas were determined for most of the other resonances. The resonance parameters for the 2.85 keV resonance and other resonances will be reexamined. The preliminary evaluation of these parameters indicates that the parameters in Mat. 1059 are satisfactory and consistent with both measurements made at Nevis Laboratory and RPI LINAC Laboratory. The spin assignments, neutron widths, and capture widths look satisfactory as they are in the present version of ENDF/B. In the reevaluation, there could be some minor adjustments on resonance energies and radiation widths for two well-known resonances of sodium (2.85 keV and near 53 keV).

The threshold cross sections (n,2n), (n,p) and (n, α) will be briefly examined, since there have been no major experimental data of significance on these threshold cross sections. The measurement of (n,2n) by Menlove will be normalized consistent with the new evaluated fission cross sections of ²³⁵U in Version III of the ENDF/B.

D. Summary

Reevaluation of sodium neutron cross section data for ENDF/B has shown the following differences from ENDF/B Version I (Mat. 1059):

1. Total cross sections in the new evaluation based on the high resolution data by Cierjacks (Karlsruhe), and Block (RPI) differs as much as 10 percent from Mat. 1059 above 0.5 MeV and below 1.20 MeV. Above 1.2 MeV, the new evaluation does not differ much from the old evaluation.
2. Although the magnitude of elastic scattering cross sections in Mat. 1059 were found satisfactory, the angular distributions were a little deficient. The first two Legendre coefficients in Mat. 1059 were 10 percent low at 4.04 MeV compared with the recent measurement by Fasoli (CNEN, Italy, 1968).
3. Inelastic scattering cross sections in Mat. 1059 were found to be satisfactory up to the neutron energy of 4 MeV. Above 4 MeV, the cross section in Mat. 1059 will be replaced with new measurements by Perey and Kinney (ORNL, 1970).

REFERENCES

1. T. A. Pitterle, "Evaluated Neutron Cross Sections of ^{23}Na for the ENDF/B File," APDA-217, June 1968.
2. J. B. Garg, J. Rainwater, S. Winchank, and W. W. Hazens, Jr., "Total Cross Section of Elements With Widely Spaced Levels in the Energy Interval of 200 eV-600 keV," in Nuclear Structure Study With Neutrons, Proceedings of the International Conference on the Study of Nuclear Structure With Neutrons, Antwerp, Belgium, July 19-23, 1965, p. 256, North-Holland Publishing Company, Amsterdam, 1966.
3. J. E. Lynn, F. W. K. Firk, and M. C. Moxon, "The 2.85 keV Neutron Resonance of Sodium," Nucl. Phys. 5, pp. 603-614, 1957.
4. "Reactor Physics Division Annual Report, July 1, 1964-June 30, 1965," ANL-7110, December 1965.
5. P. H. Stelson and W. M. Preston, "Total Neutron Cross Section of Sodium," Phys. Rev. 88, pp. 1354-1357, 1952.
6. P. Stoler and R. C. Block, Private Communication.
7. S. Cierjacks, P. Forti, D. Kopsch, L. Kropp, J. Nebe, and H. Unseld, "High Resolution Total Neutron Cross Sections Between 0.5 to 30 MeV," KFK-1000, June 1968.
8. A. Langsford, P. H. Bowen, G. C. Cox, F. W. K. Firk, D. W. McConnell, and B. Rose, "High Resolution Neutron Time-of-Flight Measurements on Na and C from 0.2 to 140 MeV," in Nuclear Structure Study With Neutrons, Proceedings of the International Conference on the Study of Nuclear Structure With Neutrons, Antwerp, Belgium, July 19-23, 1965, p. 562, North-Holland Publishing Company, Amsterdam, 1966.
9. U. Fasoli, D. Toniolo, G. Zago, and V. Benzi, "Elastic and Inelastic Scattering of Neutrons by Na at 1.51, 2.47, 4.04, and 6.40 MeV," Nucl. Phys. A125, pp. 227-240, 1969.
10. F. G. Perey and W. E. Kinney, "Neutron Elastic and Inelastic Scattering Cross Sections for Na in the Range of 5.4 to 8.4 MeV," ORNL-4518, August 1970.
11. D. L. Smith, Argonne National Laboratory, Private Communication.
12. W. E. Tucker, ORO-2791-28, Texas Nuclear Corporation Report, 1965.
13. F. G. Perey and W. E. Kinney, Private Communication.

REFERENCES (CONTINUED)

14. J. P. Chien and A. B. Smith, "Fast Neutron Scattering from Beryllium, Sodium, and Aluminum," Nucl. Sci. Eng. 26, pp. 500-510, 1966.
15. R. W. Hockenbury, Z. M. Bartolome, J. R. Tatarczuk, W. R. Moyer, and R. C. Block, "Neutron Radiative Capture in Na, Al, Fe, and Ni from 1 to 200 keV," Phys. Rev. 178, pp. 1746-1769, 1969.

Figure 1. Total Neutron Cross Section -
100 eV to 30 keV

Figure 2. Total Neutron Cross Section -
100 keV to 500 keV

Figure 3. Total Neutron Cross Section -
500 keV to 600 keV

Figure 4. Total Neutron Cross Section -
600 keV to 700 keV

Figure 5. Total Neutron Cross Section -
0.7 MeV to 0.9 MeV

Figure 6. Total Neutron Cross Section -
0.9 MeV to 1.2 MeV

Figure 7. Total Neutron Cross Section -
1.2 MeV to 1.5 MeV

Figure 8. Total Neutron Cross Section -
1.5 MeV to 2.0 MeV

Figure 9. Total Neutron Cross Section -
2.0 MeV to 3.0 MeV

Figure 10. Total Neutron Cross Section -
3.0 MeV to 5.0 MeV

Figure 11. Total Neutron Cross Section -
5.0 MeV to 7.0 MeV

Figure 12. Total Neutron Cross Section -
7.0 MeV to 10.0 MeV

Figure 13. Total Neutron Cross Section -
10.0 MeV to 15.0 MeV