LA-UR 91-1516

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TITLE NEW EVALUATIONS OF NEUTRON CROSS SECTIONS FOR ^{14}N and ^{16}O

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SUBMITTED TO The International Conference on Nuclear Data for Science and Technology, Julich, Germany, May 13-17, 1991

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NEW EVALUATIONS OF NEUTRON CROSS SECTIONS FOR ^{14}N AND ^{16}O

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Abstract: New evaluations of the neutron cross sections for ^{14}N and ^{16}O have been made for ENDF/B-VI. The evaluations are based at low energies on R-matrix analyses of reactions in the ^{15}N and ^{17}O systems, and at higher energies on GNASH calculations and experimental data evaluations, including covariance analyses. The ^{15}N system R-matrix analysis includes data from reactions among the channels $n+^{14}N$, $p+^{14}C$, and $\alpha+^{11}B$ at energies corresponding to excitations in ^{15}N below E_x=13 MeV. The resonance structure of all cross sections in this energy range is fairly well reproduced. New data indicate a different J-value for the first resonance, however. Sub-threshold S-wave levels required to explain the large $n+^{14}N$ total and elastic cross sections near zero energy give scattering lengths that differ significantly from the previous values. The R-matrix analysis of the ^{17}O system includes many new measurements of the $n+^{16}O$ total cross section, done primarily at Oak Ridge and at Karlsruhe. The resonance structure of all the cross sections [total, (n,n), (n,α), and (α,α)] is well represented by the fit in the region below E_n = 6.5 MeV. The new total cross section information gives different positions for some of the resonances and implies a different normalization for the (n,α) cross sections than that obtained in the ENDF/B-IV analysis. The evaluations at energies above the ranges of the R-matrix analyses incorporate results from a number of experiments performed since the previous ENDF/B evaluations. Especially important are new measurements of the total cross sections and differential elastic, inelastic, and gamma-ray production cross sections.

(^{14}N, ^{16}O, neutron-induced reactions, R-matrix analysis, data evaluation)

Introduction

Because of renewed interest in the transport of neutrons in air, encouraged by a National Academy of Sciences study of radiation effects in the early above-ground nuclear explosions, we have re-evaluated the neutron cross sections for ^{14}N and ^{16}O for ENDF/B-VI. The evaluations are based at low energies on R-matrix analyses of reactions in the ^{15}N and ^{17}O systems, and at higher energies on GNASH calculations and variance-covariance fits to the experimental data. We will first discuss the R-matrix analyses that were used to provide the low-energy cross sections, and then briefly summarize the experimental data evaluations that were used at the higher energies.

R-Matrix Analysis for the ^{15}N System

The ^{15}N system R-matrix analysis includes data from reactions among the channels $n+^{14}N$, $p+^{14}C$, and $\alpha+^{11}B$ at energies corresponding to excitations in ^{15}N below E_x = 13 MeV. The channel configuration for the analysis and a summary of the data included for each reaction are given in Table 1. The $n+^{14}N$ total cross section fitted was a smoothed composite [1] of experimental measurements made in the years 1950-1970, and the elastic angular distributions were those of Fowler *et al.* [2]. $^{14}C(p,n)^{14}N$ angular distributions [3] provided important information about the values of the dominant $n+^{14}N$ channel spins for the resonances, since the doublet-doublet and quartet-doublet transitions give shapes that have opposite sign.

The resonance structure of all the data in this energy region is fairly well reproduced by the analysis, which was started with resonance parameters from the tabulation of Ajzenberg-Selove [4]. Some changes in the level assignments were required in the range E_x = 11.9 - 12.3 MeV, and an additional $1/2^+$ level was found at E_x = 11.96 MeV in order to improve the fit to the total cross section, as is shown in Fig. 1. The first resonance visible in the total cross section at E_n = 0.43 MeV was assumed to have J^π=3/2$^-$. High-resolution measurements of σ_T just completed by Harvey and Larson [5] indicate that it is consistent with J=7/2, however. These new data, along with elastic scattering angular distributions that will be measured at ORELA this summer, undoubtedly will permit further refinement of the ^{15}N resonance parameters. Some results of the ^{15}N R-matrix analysis, and the predicted $n+^{14}N$ cross sections at low energies are therefore likely to change in the near future.

The region below the first resonance is also interesting because of the rapid rise of the elastic and total cross sections with decreasing energy. This behavior could only be explained (and not entirely satisfactorily) by the presence of levels below the $n+^{14}N$ threshold in both the J=1/2 and J=3/2 S-waves. The resulting fit gives nearly equal S-wave scattering lengths, so that the low-energy scattering cross section is only slightly larger than the coherent cross section. The J=1/2 scattering length is quite different from the one obtained by Mughabghab *et al.* [6], having been at one point in the analysis larger than the J=3/2 scattering length.

Table 1. Channel configuration and data summary for ^{15}N system analysis.

Channel	l_{max}	a_c (fm)
$n+^{14}N$	2	2.6
$p+^{14}C$	3	4.3
$\alpha+^{11}B$	2	5.1

Reaction	Energy Range	Observable Types	# Data Points
$^{14}N(n,n)^{14}N$	E_n=0-2.3 MeV	σ_T, $J_{el}(\theta)$	701
$^{14}N(n,p)^{14}C$ + inv	E_n=0-2.3 MeV	σ_{np}, $\sigma_{pn}(\theta)$, $A_p(\theta)$	711
$^{14}N(n,\alpha)^{11}B$	E_n=1.3-2.3 MeV	$\sigma_{n\alpha}$	112
$^{11}B(\alpha,p)^{14}C$	E_α=1.4-2.6 MeV	$\sigma_{\alpha p}$, $\sigma_{p\alpha}(\theta)$	110
Totals:		8 obs	1630

R-Matrix Analysis for the ^{17}O System

The R-matrix analysis of the ^{17}O system is an extensive update of the one used to provide cross sections at energies up to 6 MeV for the ENDF/B-IV evaluation. The channel configuration for the analysis and a summary of the data included for each reaction are given in Table 2. Many new measurements of the $n+^{16}O$ total cross section, done primarily at Oak Ridge [7] and at Karlsruhe [8], were included, as well as new measurements [9] of the differential

elastic cross section and polarization at neutron energies between 2 and 4 MeV. The resonance structure of all the cross sections is well represented by the 45 R-matrix levels included in the fit at energies below E_n = 6.5 MeV, as is illustrated in Fig. 2. The level structure found agrees for the most part with the recommended data, [10] but with different parity assignments for some of the resonances and minor differences in positions and widths for the others. The new total cross section information gives a different position, especially, for the first resonance at E_n = 435 keV, and implies a different normalization for the (n,α) cross sections than that obtained in the ENDF/B-IV analysis.

Table 2. Channel configuration and data summary for ^{17}O system analysis.

Channel	l_{max}	a_c (fm)
n-^{16}O	4	4.44
α-^{13}C	4	5.69

Reaction	Energy Range	Observable Types	# Data Points
$^{16}O(n,n)^{16}O$	E_n=0-6.5 MeV	σ_T, $\sigma_{nn}(\theta)$, $A_n(\theta)$	2421
$^{16}O(n,\alpha)^{13}C$	E_n=0-6.0 MeV	$\sigma_{n\alpha}$, $\sigma_{n\alpha}(\theta)$, $A_n(\theta)$	904
$^{13}C(\alpha,\alpha)^{13}C$	E_α=0-4.6 MeV	$\sigma_{\alpha\alpha}(\theta)$	207
Totals:		7 obs.	3532

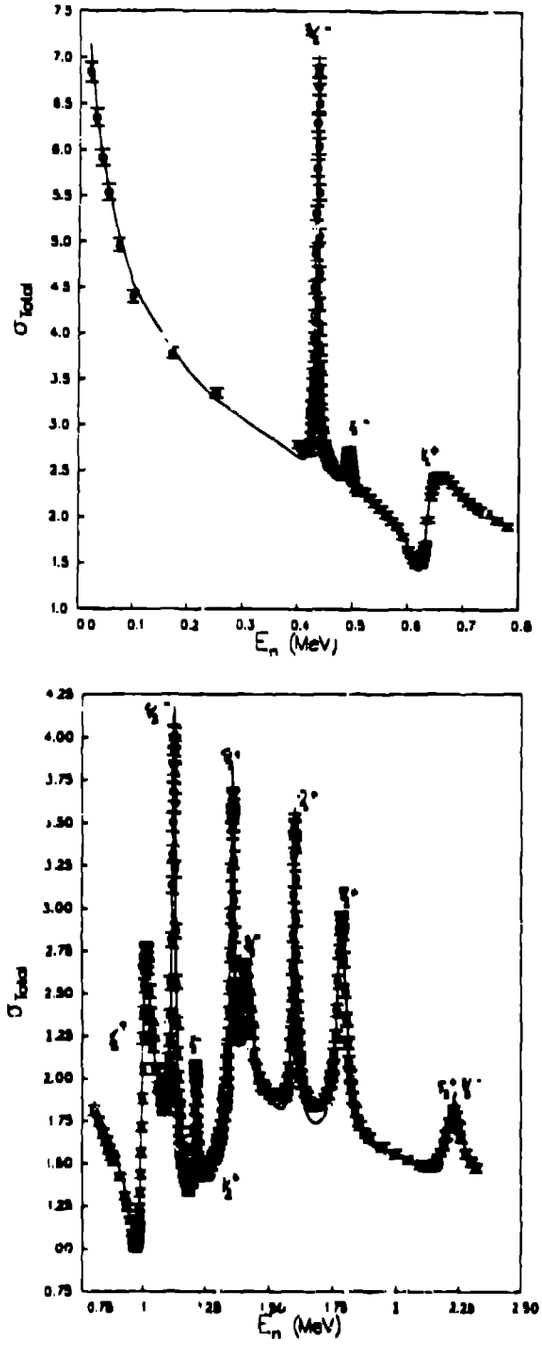

Fig. 1 Neutron elastic scattering cross section for ^{14}N at energies up to 0.8 MeV (top) and at energies between 0.8 and 2.3 MeV (bottom). The solid curve is the R-matrix fit, and the points are experimental data. [11]

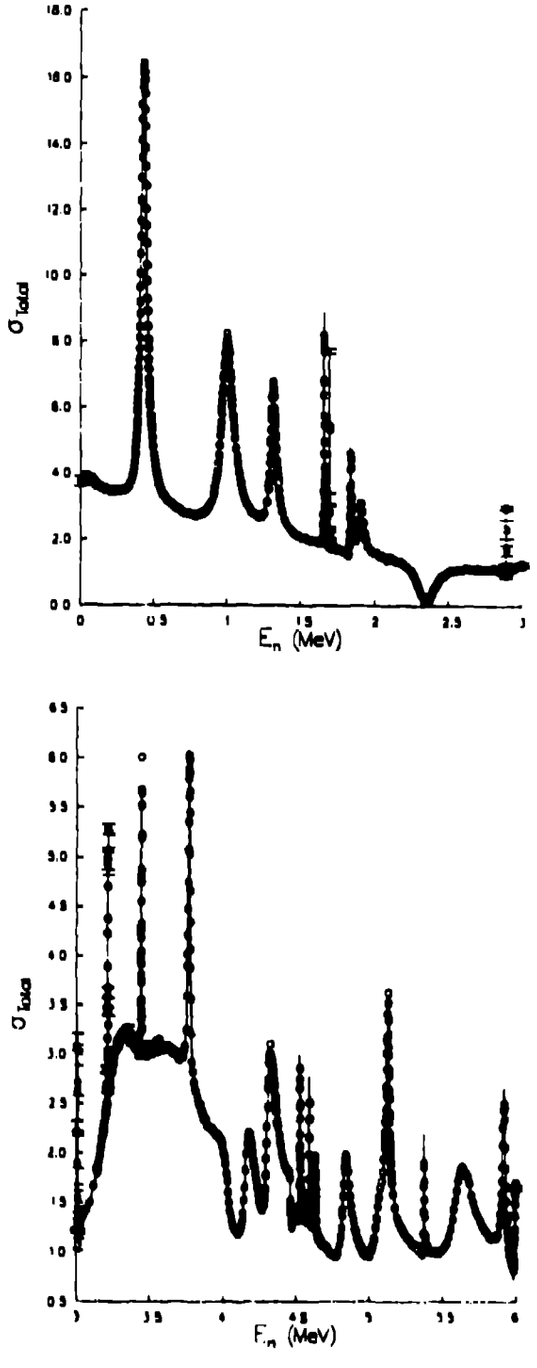

Fig. 2. Neutron total cross section for ^{16}O at energies up to 3 MeV (top) and at energies between 3 and 6 MeV (bottom). The solid curve is the R-matrix fit, and the points are experimental data. [12]

Experimental Data Evaluations

Above the thresholds for inelastic scattering, the ^{14}N ($E_n \geq 2.30$ MeV) and ^{16}O ($E_n \geq 6.25$ MeV) evaluations are based on analyses of the available experimental data, supplemented in regions where data are unavailable by Hauser-Feshbach statistical theory calculations. For both isotopes important new differential elastic and inelastic scattering data as well as gamma-ray production measurements were included in the evaluations. Hauser-Feshbach statistical theory (GNASH) calculations were used to interpolate and extrapolate the data at higher energies.

In the case of n+^{14}N, major experiments completed since 1973 include measurements by Chardine *et al.* [11] of neutron elastic and inelastic scattering angular distributions to the lowest 5 excited states of ^{14}N for incident neutron energies between 7.7 and 13.5 MeV, plus several other measurements spanning the energy range from 4.3 to 25 MeV.[12] New information on neutron inelastic scattering up to E_n = 20 MeV is provided by the measurements of Nelson *et al.* [13] and Auchampaugh and Wender, [14] as well as extensive double-differential neutron emission measurements for E_n = 14 MeV. [12] A comprehensive new measurement of $^{14}N(n,p)$ and $^{14}N(n,\alpha)$ cross sections to discrete states by Morgan *et al.* [15] up to E_n = 14 MeV is useful for the experimental data evaluation as well as the R-matrix studies.

The only major new total cross section measurement, [16] covering the energy range E_n = 0.97 to 5.3 MeV, is in substantial disagreement (~14%) with older, precision measurements and was not included in the ENDF/B-VI evaluation. Consequently, only minor changes were made in the evaluated total cross section above 2.5 MeV. However, the new ORELA measurement of the ^{14}N total cross section [5] will be incorporated into the present analysis as an update to the ENDF/B-VI evaluation.

The n+^{14}N elastic scattering cross section between 2 and 20 MeV is illustrated in Fig. 3, where a comparison is given between the experimental data base and the ENDF/B-V and ENDF/B-VI evaluations. Note that the cross section has increased by some 9% near E_n = 14 MeV.

Several new neutron total cross section measurements for ^{16}O [12] have become available since the previous ENDF/B evaluation. Most important for the present experimental (and R-matrix) evaluations is the measurement of Cierjacks *et al.* [8] To obtain average total cross sections, we performed a variance-covariance analysis of all the available data, and then relied on the higher resolution measurements (*e.g.*, Ref. 9) to define local structure. Important new differential elastic and inelastic scattering measurements have also become available, [12] especially the precision data of Börker *et al.* [17] Finally, several n + ^{16}O gamma-ray production measurements have been completed since the last ENDF/B evaluation, and one very recent one [13] contributed significantly to the present work.

Conclusion

The new ENDF/B-VI evaluations of neutron-induced reactions on ^{14}N and ^{16}O at energies between 10^{-11} and 20 MeV are overall improvements on the previous evaluations. We believe the results for ^{16}O to be significantly better over the whole energy range, where the new total cross-section information has given firmer positions and shapes for the resonances and improved consistency with the reaction data. The shift in position of the first oxygen resonance and revised normalization scale of the (n,α) reaction cross section may have important bearing in nuclear data applications.

The results for the low-energy ($\leq$ 2.5 MeV) nitrogen cross sections are relatively more uncertain in the light of the new total cross-section measurement [5] at Oak Ridge. We know already that the J-value of the first resonance differs from that used in the evaluation. Refinements of the n+^{14}N cross sections based on these data and new measurements of the differential elastic scattering cross section will be incorporated in an updated evaluation in the near future.

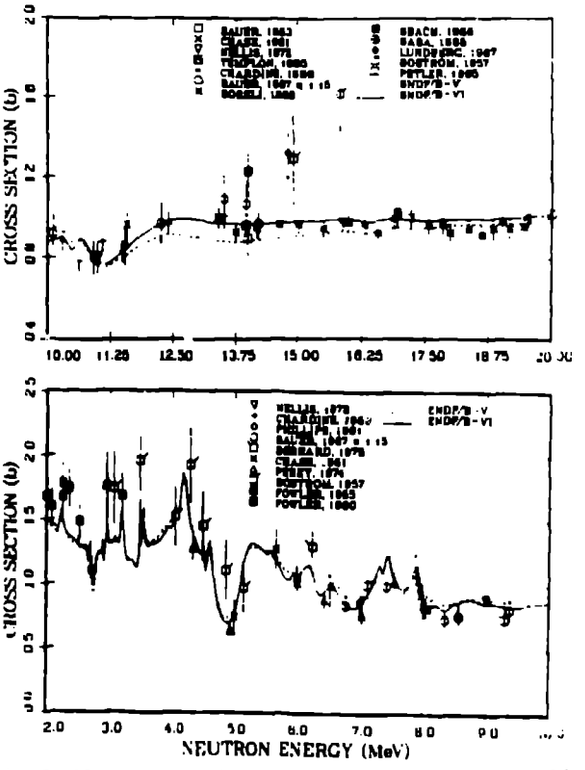

Fig. 3. Neutron elastic scattering cross section for ^{14}N between 2 and 20 MeV.

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