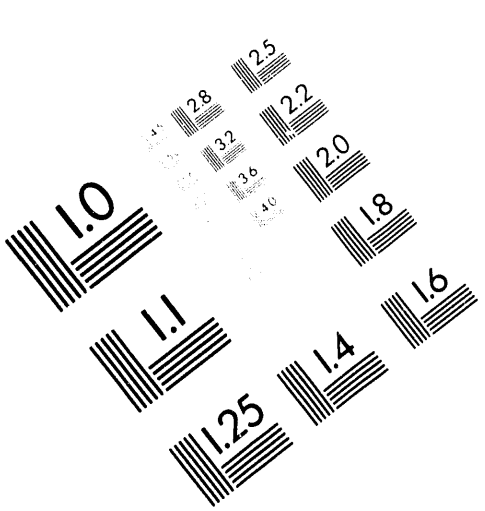


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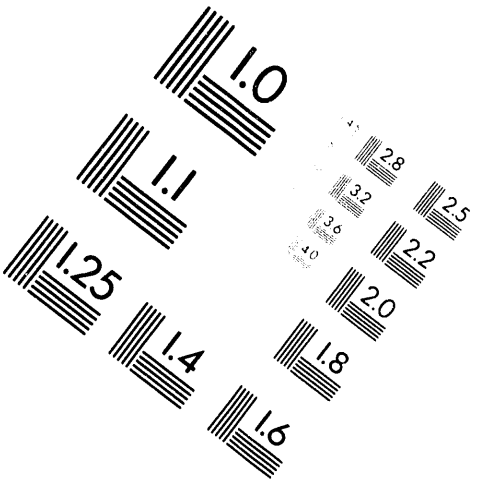


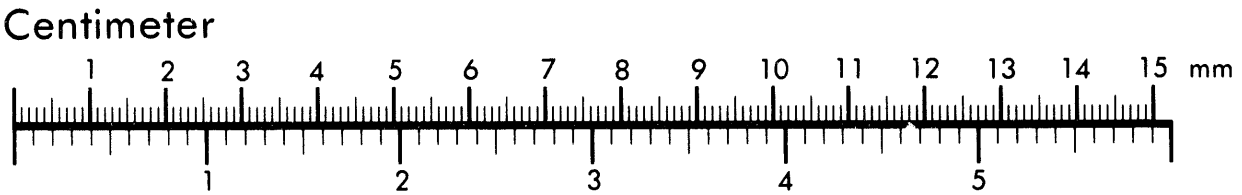


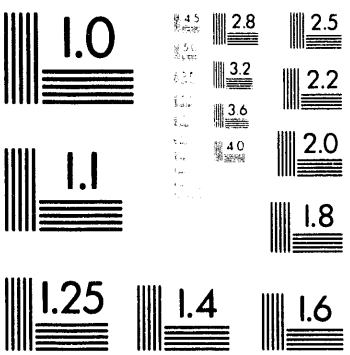


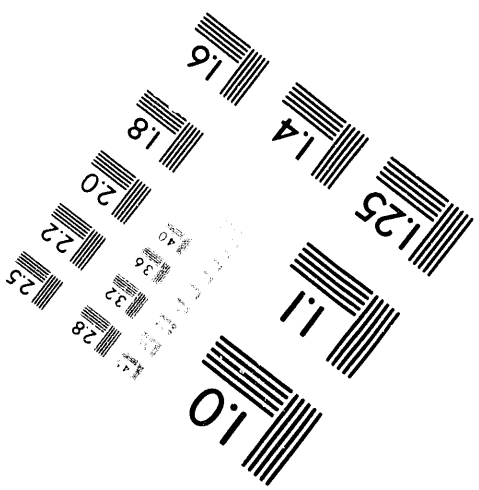


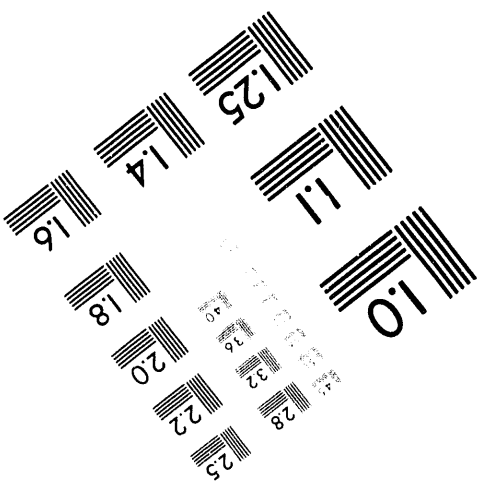


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TITLE: Cross Sections For n+$^{14}$N From An R-Matrix Analysis Of The $^{15}$N System

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# CROSS SECTIONS FOR n+$^{14}$N FROM AN R-MATRIX ANALYSIS OF THE $^{15}$N SYSTEM

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## ABSTRACT

As part of the Hiroshima-Nagasaki Dose Reevaluation Program, a new evaluation of the neutron cross sections for $^{14}$N was made for ENDF/B-VI, based at energies below 2.5 MeV on a multichannel *R*-matrix analysis of reactions in the $^{15}$N system. The types of data used in the analysis, and the resulting cross sections and resonance structure for $^{15}$N are briefly described. The resonant features of the neutron cross sections were especially well determined by including precise, high-resolution neutron total cross section measurements from ORNL. While the new evaluated cross sections appear to be significant improvements over the earlier ones, they still need to be tested more extensively against recent measurements of the differential elastic cross section from Oak Ridge.

## I. INTRODUCTION

Because of renewed interest in the transport of neutrons in air, encouraged by a joint US-Japanese study[1] of radiation effects in the Hiroshima and Nagasaki explosions, we re-evaluated the neutron cross sections for the major nitrogen and oxygen isotopes, $^{14}$N and $^{16}$O. The evaluations were based at low energies on *R*-matrix analyses of reactions in the $^{15}$N and $^{17}$O systems, which were generally limited to neutron energies below the first excited state of the target nucleus. Above the thresholds for inelastic scattering, the evaluations were based on analyses of the available experimental data, supplemented in regions where data are unavailable by Hauser-Feshbach statistical theory calculations. Both evaluations were included in version VI of the general-purpose Evaluated Nuclear Data File (ENDF/B).

About a year after the release in 1990 of the original ENDF/B-VI evaluation for the n+$^{14}$N cross sections, new, high-resolution measurements[2] of the neutron total cross section were made at the Oak Ridge Electron Linear Accelerator (ORELA) that indicated all previous measurements had been severely resolution-limited in the first resonance visible (at about 433 keV) above threshold, and had suffered some degree of shape distortion even in the broader resonances at higher energies. It was clearly important to include these new data in a revised analysis of the $^{15}$N system, and this was done during the first part of 1992. A revision (mod 1) of the original $^{14}$N ENDF/B evaluation incorporating these new results was released in June of 1992, and processed cross sections based on the updated file were made available to those working on the dosimetry reevaluation program.

We will describe in the following sections the main features of the *R*-matrix analysis of the $^{15}$N system, give comparisons with some of the experimental data, and discuss the resulting level structure of the resonances. Section II concerns the most recent that led to the revised (mod 1) ENDF/B-VI cross sections for $n$+$^{14}$N, and Section III gives the resulting resonance parameters. Section IV contains the summary and conclusions of the paper.

## II. REACTIONS AND DATA INCLUDED

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 data included for each reaction are given in Table 1. The $n$+$^{14}$N total cross section ($\sigma_T$) data fitted were those from the ORELA measurement[2], and the elastic angular distributions ($\sigma_{nn}(\theta)$) were those of Fowler et al.[3] $^{14}$C($p$,$n$)$^{14}$N angular distributions[4] provided important information

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

| Channel | $l_{max}$ | $a_c$ (fm) |
|---|---|---|
| $n+^{14}N$ | 2 | 2.5 |
| $p+^{14}C$ | 3 | 4.3 |
| $\alpha+^{11}B$ | 2 | 5.1 |

| Reaction | Energy Range | Observable Types | # Data Points |
|---|---|---|---|
| $^{14}N(n,n)^{14}N$ | $E_n$=0-2.4 MeV | $\sigma_T$, $\sigma_{nn}(\theta)$ | 932 |
| $^{14}N(n,p)^{14}C$ + inv. | $E_n$=0-2.4 MeV | $\sigma_{np}$, $\sigma_{pn}(\theta)$, $A_p(\theta)$ | 685 |
| $^{14}N(n,\alpha)^{11}B$ | $E_n$=1.3-2.4 MeV | $\sigma_{n\alpha}$ | 104 |
| $^{11}B(\alpha,p)^{14}C$ | $E_\alpha$=1.4-2.6 MeV | $\sigma_{\alpha p}$, $\sigma_{\alpha p}(\theta)$ | 110 |
| Totals: | | 8 obs. | 1831 |

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.

## III. $^{15}N$ RESONANACE PARAMETERS

The resonance structure of all the data in this energy region is well reproduced by the analysis, which was started originally with resonance parameters from the tabulation of Ajzenberg-Selove.[5] Some changes in the level assignments were required in the range $E_x$ = 11.2 - 12.3 MeV, and an additional, broad $3/2^+$ $S$-wave level was found at $E_x$ = 12.0 MeV in order to improve the fit to the total cross section. The $^{15}N$ resonance parameters obtained from the analysis are listed on the left side of Table 2, and are compared with those of Ajzenberg-Selove[5] on the right side of the table.

The first visible positive-energy resonance at $E_n$ = 433 keV is the one mentioned earlier for which the peak value of all previous measurements had been consistent with $J$ = 3/2. The peak value of the new ORELA measurement[2] clearly indicates $J$ = 7/2, with a shape that is somewhat more consistent with positive parity ($l$=2) than with negative parity ($l$=3). Our preliminary assignment of $7/2^+$ for this level has recently been confirmed by new measurements[6] of the neutron elastic scattering angular distributions for $^{14}N$, also made at ORELA. In fact, all of the assignments found in this multichannel analysis for levels that cause visible structure in neutron elastic scattering have been tentatively confirmed by an independent analysis[6] of the new data done at Oak Ridge National Laboratory.

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 by the presence of levels below the $n+^{14}N$ threshold in both the $J$ = 1/2 and $J$ = 3/2 $S$-waves. Because of these levels and the broad, new $3/2^+$ state at higher energies, the $S$-wave scattering length for $J$ = 3/2 is larger than the one for $J$ = 1/2, in agreement with the solution obtained by Mughabghab et al. [7] We also find the sub-threshold $3/2^-$ level in about the right position, although in our analysis, it corresponds to a virtual, rather than bound, state in the closed particle-channels.

Table 2. Resonance parameters for $^{15}N$.

| $E_x$ (MeV) | $J^\pi$ [a] | $\Gamma$ (keV) | $E_x$ [c] (MeV) | $J^\pi$ [a,c] | $\Gamma$ [c] (keV) |
|---|---|---|---|---|---|
| 10.711 | $3/2^-$ | 0.00 | 10.702 | $3/2^-$ | 0.2 |
| 11.238 | $7/2^+$ | 2.35 | 11.235 | $\geq 3/2$ | 3.3 |
| 11.291 | $1/2^-$ | 7.03 | 11.293 | $1/2^-$ | 8 |
| 11.403 | $1/2^+$ [b] | 253 | 11.615 | $1/2^+$ [b] | 253 |
| 11.424 | $1/2^+$ | 35.7 | 11.438 | $1/2^+$ | 41.4 |
| 11.766 | $3/2^+$ | 37.6 | 11.763 | $3/2^+$ | 40 |
| 11.875 | $5/2^-$ | 15.8 | 11.876 | $3/2^-$ | 25 |
| 11.938 | $5/2^+$ | 1.36 | 11.942 | $9/2^-$ | $\leq 3$ |
| 11.962 | $1/2^-$ | 12.0 | 11.965 | $1/2^-$ | 17 |
| 12.004 | $3/2^+$ | 387 | - | - | - |
| 12.093 | $5/2^+$ | 17.8 | 12.095 | $5/2^+$ | 14 |
| 12.145 | $3/2^-$ | 43.9 | 12.145 | $3/2^-$ | 41 |
| 12.324 | $5/2^-$ | 15.4 | 12.327 | $5/2^{(+)}$ | 22 |
| 12.368 | $5/2^+$ [b] | 271 | 12.522 | $5/2^+$ [b] | 58 |
| 12.499 | $5/2^+$ | 41.7 | 12.493 | $5/2^+$ | 40 |
| 12.906 | $3/2^-$ | 63.9 | 12.920 | $3/2^-$ | 56 |

[a] All levels are $T$ = 1/2, unless otherwise noted.
[b] $T$ = 3/2 level.
[c] Taken from Ajzenberg-Selove.[5]

## IV. CONCLUSION

The multichannel $R$-matrix calculations for the resonance region below the first excited state of the target give significantly improved representations of the data for all reactions, and especially of the new measurement[2] for the neutron total cross section. When such measurements are made with the resolution and precision of the data from Oak Ridge, they provide critical information about the positions, $J$-values, and sometimes even the parities, of the resonances, and determine the overall energy and normalization scales for all the reactions in the system. Therefore, even the $^{14}N(n,n)$ differential cross sections at energies below 800 keV where they had never been measured were better determined by having the improved total cross section measurement.

More extensive comparisons of the elastic angular distributions need to be made with the new ORELA measurements, however. There is still the possibility that some of the level assignments (especially the parities) have not been well-determined by the existing neutron elastic angular-distribution data at excitation energies above 11.8 MeV. We will continue to work closely with the experimental group at Oak Ridge to compare with their data, most likely by folding the instrumental effects into our $^{15}N$ $R$-matrix calculations.

## ACKNOWLEDGMENT

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