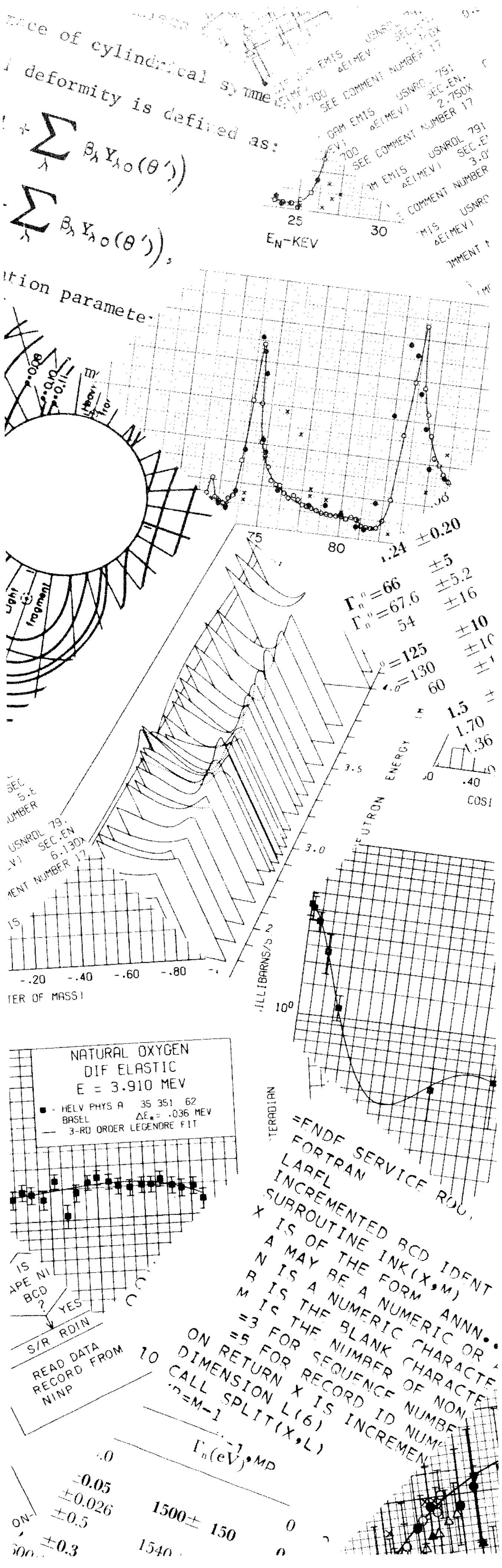

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EVALUATED NEUTRON CROSS SECTIONS FOR ^{107}Ag, ^{109}Ag, AND ^{133}Cs

M.R. BHAT AND A. PRINCE

April 1973

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
UPTON, NEW YORK 11973

national
neutron
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Section
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1. INTRODUCTION

This report describes the evaluation of Ag-107, Ag-109 and Cs-133 for the Evaluated Nuclear Data File, Version III (ENDF/B-III). The choice of the several pieces of experimental data used in the evaluation and the justification for such a choice are discussed in this report. The energy range covered by these evaluations is from 10^{-5}eV to 1.5×10^{7}eV. The experimental data has been supplemented by the results of nuclear model calculations in the energy regions where such data were not available. These codes and the results of their calculations are described in the following pages.

2. LOW ENERGY CROSS SECTIONS

2.1. Resolved Resonance Parameters:

Ag-107, Ag-109

The most extensive measurements of the resonance parameters on the separated isotopes of silver are due to Muradyan and Adamchuk(1). These authors give the resonance parameters of Ag-107 up to 915 eV and for Ag-109 up to 903 eV. We have made use of these parameters as well as those recommended in BNL-325, 2nd Edition.(2) Resonance spins where available are indicated as given in the latter reference. The gamma widths given explicitly in BNL-325 for some resonances have been used; otherwise we have set Γ_{γ} = 0.140 eV. The nuclear radius used for Ag-107 is 0.71365×10^{-12} cm. which gives a σ_p = 6.4 barns; a value obtained in the measurements of Shull and Wollan.(3) This experimental value also agrees with the measurements of Zimmerman and Hughes(4) who obtained σ_p = 6.5±0.5 barns. The nuclear radius used for Ag-109 is

0.63×10^{-12} cm a value given by Chrien[5] from an analysis of the transmission data on low energy resonances. It is quite possible that some of the resonances given are p-wave resonances. However, since none of them has been specifically identified as such all the resonances have been grouped together as s-wave resonances. The resonance parameters for these two silver isotopes are shown in Tables I and II respectively.

Cs-133

We have used the resonance parameters of Cs-133 as given by Garg, et al.[6] The measured resonances extend up to an energy of 3.5 keV. The assumed value of Γ_γ was 0.110 eV. None of the resonance spins are known. Hence, we have put the resonance spins as 7/2; the spin of the target nucleus. The nuclear radius used here 0.75166×10^{-12} cm. Which corresponds to a σ_p = 7.1 barns as measured by Shull and Wollan[3]. Since none of these resonances has been designated as p-wave resonances we have listed all of them as s-wave resonances. The Cs-133 resonance parameters given in Table III.

2.2. 2200 m/sec Neutron Capture Cross Section

Ag-107, Ag-109

We have used a value of 92 barns for the 2200 m/sec neutron capture cross section for Ag-109 as suggested by Walker.[7] The contribution to the capture cross section from the resonance parameters is 89.96 barns and we have added the difference as a 1/v contribution. For Ag-107 we have used a value of 36.8 barns for the capture cross section. This value was obtained by taking 63.4 barns for the capture cross section of natural silver as measured by Tattersall, et al[8] and calculating the contribution of Ag-107 by assuming 92 barns for Ag-109.

In the case of Ag-107 the resonance parameters contribution 2.56 barns for the capture cross section and the difference has been added on as a 1/v contribution.

Cs-133

The thermal capture cross section recommended by Walker[9] for this nucleus is 29.5 barns. We have used this value in the evaluation; this is made up of 16.06 barns from the resonance parameters and the rest being added on as a 1/v contribution.

3. HIGH ENERGY CROSS SECTIONS

3.1. Optical Model Parameters

The high energy cross section data available for these nuclei consists of capture and total cross section measurements over limited energy ranges with a few values of the (n, particle) reaction cross sections. Hence, the gaps in the experimental data have to be filled by nuclear model calculations. Therefore, one has to decide on a set of optical model parameters suitable for the nuclei under consideration. Such a choice of optical model parameters was made by fitting the total cross section data of Foster[9] for natural silver and cesium between 2.5 - 15.0 MeV. It is found that the optical parameters of Wilmore and Hodgson[10] give total cross sections which agree quite well with the experimental data. The calculations were done with the ABACUS-NBARREX Code.[11] The optical model parameters used are shown in Table IV.

3.2. Capture Cross Sections

Ag-107

The calculations of the capture cross section of Ag-107 were done using the code COMMNUC by C. Dunford.[12] The excited states of Ag-107 used in these calculations are given in Table V along with their spins and parities. One other input data needed by this program is $2\pi \frac{\Gamma_\gamma}{\langle D \rangle}$ = 0.05965 where <D> is the average level spacing as determined from the neutron resonance parameter data for this nucleus. This parameter may also be considered as a normalizing parameter whose value is so adjusted as to get a fit to the experimental capture cross sections. In the case of Ag-107 we obtain a value of $2\pi \frac{\Gamma_\gamma}{\langle D \rangle} = 0.05965$ from the resonance parameters. However, it was found that the experimental capture data could be fitted with a value of 0.04029. The experimental data chosen for the fit was from Obninsk[13] from 29keV to 146keV and from the University of Wisconsin,[14] from 145 keV to 2.45 MeV. These measurements agree quite well with the Duke University [15] capture data above 60 keV or so though the Duke data seems to be consistently lower for lower energies. There is no experimental data on capture cross sections of Ag-107 at higher energies of 14-15 MeV. Hence, one could not estimate the contribution of direct and semi-direct capture at these higher energies. The capture cross section is therefore shown as a monotonically decreasing function of energy and is shown compared with the experimental data in Figure 1.

Ag-109

The experimental capture cross sections used for this isotope is again due to Kononov, et al.[13] from Obninsk. The cross section at 24 keV in this set agrees quite well with the single measurement due to Chaubey, et al.[16] However, all the values of capture cross sections in this set are lower than the Duke values as read off from their published curve. Also, if we combine the Obninsk values for Ag-107 and Ag-109 in the proportion of the natural abundance of these isotopes we get a capture cross section for natural silver which is about 16% lower systematically than the Karlsruhe measurements.[17] These discrepancies indicate need for further accurate measurements on separated isotopes of silver to resolve them. One could obtain a fit for the Obninsk capture data with $2\pi \frac{\Gamma_\gamma}{\langle D \rangle} = 0.02$ though the resonance parameters give a value of 0.0586. The calculated and experimental cross sections for Ag-109 are shown in Figure 2.

Cs-133

The most recent and careful measurements of the capture cross section of cesium in the keV region seem to be those due to Kompe[17] from Karlsruhe. We could fit this data by using $2\pi \frac{\Gamma_\gamma}{D} = 0.03831$; a value obtained from the resonance parameter data. The calculated and experimental cross sections are shown in Figure 3. In the case of this nucleus we do have an (n,γ) cross section measurement due to Qaim[18] at 14.8 MeV. Therefore calculations of the direct and semi-direct capture cross sections were made using FISSPRO Code of Benzi, et al.[19] and normalized to the experimental value of 7.1 mbarn at 14.8 MeV. This contribution to the capture cross section was added on to the capture cross section due to compound nuclear processes above 4.0 MeV.

3.3. Differential Elastic Scattering

Since there is no experimental data on the angular distribution of elastically scattered neutrons from these three nculei we used the ABACUS-NEARREX Code to calculate the angular distribution. The calculated cross sections were then fitted to a number of Legendre polynomials using the Code CHAD[20] to obtain the corresponding coefficients of a Legendre fit.

3.4. Inelastic Scattering

There is no experimental data on inelastic scattering for any of these three nuclei. The relevant cross section were therefore calculated using COMMNUC and the energy level scheme shown in Table V.

3.5. (n, particle) Reactions

Ag-107

Amongst all the measurements of the (n,2n) cross sections on Ag-107, there is only one experiment due to Minetti and Pasquarelli[21] who measure simultaneously the cross sections for populating the 6^+(T1/2 = 8.3 days) metastable state in Ag-106 as well as the 1^+(T1/2 = 24 min) ground state. They find these two cross sections to be 653 ± 30 mb and 870 ± 40 mb respectively at 14.7 MeV. We have chosen then values for normalizing the (n,2n) reaction cross section curve as calculated by Pearlstein[22] using the code THRESH. This code uses the standard evaporation model of a highly excited nucleus to calculate the various (n, particle) reaction cross sections. The cross sections calculated with this code using a Q = 9.531 MeV give a curve which passes through the experimental value of 1523 ± 70 mb at 14.7 MeV; hence we did not have to renormalize the calculated curve. Using the same code and Q = -0.752, -4.354 for the (n,p) and (n,α) reactions respectively the corresponding cross sections were calculated. Since there were no experimental data available on these reactions for Ag-107, the same normalization constants as had been used to normalize the calculated curves of Ag-109 to its experimental points were used here.

Ag-109

Minetti and Pasquarelli[21] obtained a cross section of 797 ± 50 mb for the (n,2n) reaction on Ag-109 leading to the 1^+ ground state of the final nucleus Ag-108. However, they did not measure the cross section leading to the 6^+ metastable state in the final nucleus. In the case of the (n,2n) reaction on Ag-107 we populate a 1^+ ground state and a 6^+ metastable state in Ag-106. The ratio of these two cross sections are 0.751. Since we have states of the same spin in Ag-108 we can assume the same ratio for these two cross sections. Assuming $\sigma^{(g)}$ = 797 we get $\sigma^{(m)}$ = 598 mb giving the total (n,2n) cross section as 1395 mb at 14.7 MeV. The (n,2n) reaction cross section curve as calculated from the THRESH code with Q = 9.182 MeV was normalized to this experimental value. Using the same code we also calculated the (n,p) cross section curve with a Q = 0.538 MeV. This curve was normalized to an experimental value of 15 mbarn at 14.5 MeV. This value was estimated from the measurements of Bayhurst and Prestwood[23] and Coleman.[24] The (n,α) cross section was similarly calculated with Q = -3.403 and the calculated curve normalized to a value due to Mukerjee, et al.[25]

Cs-133

The experimental values for the (n,2n) cross sections used in the evaluation are 1620 ± 150 mb at 14.8 MeV by Qaim[18] and 1598 ± 160 mb by Nagel[26] at 14.6 MeV. Their mean of 1609 mb was used to normalize the curve calculated using THRESH with Q = 9.038. The (n,p) cross section curve was calculated using a Q = 0.121 MeV and normalized to 10.5 mb at 14.8 MeV due to Qaim.[18] The (n,α) cross section values were similarly calculated with Q = -3.695 MeV and normalized to a mean of the experimental values of 1.96 ± .15 mb at 14.4 MeV due to Lu, et al.[27] and 1.14 ± .2 mb at 14.8 MeV due to Qaim.[18]

3.6. Energy Distributions of Secondary Neutrons

For the nuclei under consideration, energy distributions of secondary neutrons originating from (n,2n) processes and by inelastic scattering to a continuum of levels was also calculated. These energy distributions are expressed as normalized probability distributions. The energy distributions for these nuclei have been specified as an evaporation spectrum of the type

$$f(E \to E') = \frac{E'}{I} e^{-E'/\theta}$$

where I is the normalization constant and

$$I = \vartheta^2 \left[1 - e^{-(E-U)/\theta}\left(1 + \frac{E-U}{\theta}\right)\right]$$

Where ϑ is a temperature tabulated as a function of neutron energy E and U defines the upper limit for the final neutron energy such that $0 \leq E' \leq E - U$. To calculate ϑ as a function of neutron energy, we used the nuclear level density formulation of Gilbert and Cameron[28] with shell corrections. The basic idea of their approach is to match two types of level density formulae:

$$\rho_1 = \frac{1}{T} e^{(E-E_o)/T}$$

which holds true for energies lower than a characteristic energy E_x and

$$\rho_2 = \frac{\sqrt{\pi}}{12} \frac{\exp(2\sqrt{aU})}{a^{1/4} U^{5/4}} \frac{1}{\sqrt{2\pi}\sigma}$$

applicable to energies greater than E_x. E_x may be determined from the nuclear systematics given in this paper and T and E_o are determined by fitting ρ_1 and ρ_2 at $E = E_x$. For energies where the formula ρ_2 is applicable the nuclear temperature τ is

$$\frac{1}{\tau} = \sqrt{\frac{a}{U}} - \frac{3}{2U}$$

where again a and U may be determined from the tables given by Gilbert and Cameron. In the low energy density expression, the nuclear temperature is considered a constant whereas in the high energy expression it is energy dependent as shown by the expression for τ.

References

1. G. V. Muradyan and Yu. V. Adamchuk, IAEA Conf. on Nuclear Data, Paris, Vol. I (1966) 79.
2. Neutron Cross Sections, Vol. II B, Z=41-60, BNL-325, 2nd Edition, Supplement No. 2, M. D. Goldberg, S. F. Mughabghab, S. N. Purohit, B. A. Magurno, and V. M. May, 1966.
3. C. G. Shull and E. O. Wollan, Phys. Rev. 81 (1951) 527.
4. R. L. Zimmerman and D. J. Hughes, Bull. Am. Phys. Soc. 3 (1958) 176.
5. R. E. Chrien, Phys. Rev. 141 (1966) 1129.
6. J. B. Garg, J. Rainwater, and W. W. Havens, Jr., Phys. Rev. 137 B (1965) 547.
7. W. H. Walker, AECL-3037 and Memo to Fission Products Subcommittee, April 8, 1970.
8. R. B. Tattersall, H. Rose, S. K. Pattenden, and D. Jowitt, Journal Nuclear Energy A12 (1960) 32.
9. D. G. Foster, Jr.,and D. W. Glasgow, Phys. Rev. C3 (1971) 576, and SCISRS -I File.
10. D. Wilmore and P. E. Hodgson, Nuc. Phys. 55 (1964) 673. There is an error in Eqn(10), p. 676 of this paper where W = 9.52-0.53E should be W = 9.52-0.053. See P. E. Hodgson, Ann. Rev. Nucl. Sci. 17, 1. Also P. Marmier and E. Sheldon, "Physics of Nuclei and Particles" Vol. II, p. 1107, Academic Press, 1970.
11. P. A. Moldauer and S. A. Zawadzki, Private Communication.
12. C. Dunford, COMMNUC, AI-AEC-12931.
13. V. N. Kononov, Yu. Ya Stavisskii; S. R. Chistozvonov, V. S. Shorin IAEA, Conf. on Nuclear Data, Paris, Vol. I (1966) 469, and SCISRS-I File.
14. A. E. Johnsrud, M. G. Silbert, and H. H. Barschall, Phys. Rev. 116 (1959) 927, and SCISRS-I File.

15. L. W. Weston, K. K. Seth, E. G. Bilpuch, and H. W. Newson, Annals of Physics 10 (1960) 477.

16. A. K. Chaubey and M. L. Sehgal, Phys. Rev 152 (1966) 1055.

17. D. Kompe, Nucl. Phys. A133 (1969) 513, and SCISRS-I File.

18. S. M. Qaim, Jour. Inorg. and Nucl. Chem. 32 (1970) 1799.

19. V. Benzi, G. C. Panini, and G. Reffo, GEC(69)24.

20. R. F. Berland, CHAD, (NAA-SR-11231).

21. B. Minetti and A. Pasquarelli, Nucl. Phys. A118 (1968) 449.

22. S. Pearlstein, Neutron-Induced Reactions in Medium Mass Nuclei, J. Nucl. Energy 27 (1973) 81.

23. B. P. Bayhurst and R. J. Prestwood, Jour. Inorg. and Nucl. Chem. 23 (1961) 173.

24. R. F. Coleman, B. E. Hawker, L. P. O'Connor, and J. L. Perkin, Proc. Phys. Soc. 73 (1959) 215.

25. S. K. Mukherjee, A. K. Ganguly and N. K. Majumdar, Proc. Phys. Soc. 77 (1961) 508.

26. W. Nagel and A. H. W. Aten, Jr. Physica 31 (1965) 1097.

27. W. Lu, N. Ranakumar, and R. W. Fink, Phys. Rev. 1C (1970) 358.

28. A. Gilbert and A. G. W. Cameron, Can. Jour. Phys. 43 (1965) 1446.

Table I Resonance Parameters for Ag-107

E_R	J	Γ	Γ_n	Γ_γ
1,63000+ 1	0,00000+ 0	1,57590- 1	1,15870- 2	1,46000- 1
4,15000+ 1	1,00000+ 0	1,42930- 1	5,92670- 3	1,37000- 1
4,48000+ 1	0,00000+ 0	1,50610- 1	3,61440- 3	1,47000- 1
5,13000+ 1	1,00000+ 0	1,57350- 1	2,43520- 2	1,33000- 1
8,35000+ 1	5,00000- 1	1,40027- 1	2,74135- 5	1,40000- 1
1,07600+ 2	5,00000- 1	1,40020- 1	1,97090- 5	1,40000- 1
1,10880+ 2	5,00000- 1	1,40084- 1	8,42397- 5	1,40000- 1
1,28040+ 2	5,00000- 1	1,40090- 1	9,05240- 5	1,40000- 1
1,44200+ 2	0,00000+ 0	1,49210- 1	1,92130- 2	1,30000- 1
1,54700+ 2	5,00000- 1	1,40060- 1	5,59700- 5	1,40000- 1
1,62400+ 2	5,00000- 1	1,40250- 1	2,54870- 4	1,40000- 1
1,67100+ 2	5,00000- 1	1,40210- 1	2,06830- 4	1,40000- 1
1,71200+ 2	5,00000- 1	1,40090- 1	8,50480- 5	1,40000- 1
1,73100+ 2	5,00000- 1	2,05780- 1	6,57840- 2	1,40000- 1
1,83600+ 2	5,00000- 1	1,40162- 1	1,62599- 4	1,40000- 1
2,02500+ 2	1,00000+ 0	1,66950- 1	1,29500- 2	1,54000- 1
2,18200+ 2	5,00000- 1	1,40180- 1	1,77260- 4	1,40000- 1
2,51290+ 2	5,00000- 1	1,49510- 1	9,51130- 3	1,40000- 1
2,60000+ 2	5,00000- 1	1,40270- 1	2,70890- 4	1,40000- 1
2,64470+ 2	5,00000- 1	1,43900- 1	3,90300- 3	1,40000- 1
2,70500+ 2	5,00000- 1	1,40120- 1	1,25000- 4	1,40000- 1
3,10900+ 2	1,00000+ 0	2,50200- 1	1,16200- 1	1,34000- 1
3,29000+ 2	5,00000- 1	1,40330- 1	3,26490- 4	1,40000- 1
3,47340+ 2	5,00000- 1	1,40370- 1	3,72740- 4	1,40000- 1
3,56200+ 2	5,00000- 1	1,40380- 1	3,77470- 4	1,40000- 1
3,61800+ 2	1,00000+ 0	1,97060- 1	2,20640- 2	1,75000- 1
3,72000+ 2	5,00000- 1	1,40280- 1	2,79670- 4	1,40000- 1
3,82100+ 2	5,00000- 1	1,40390- 1	3,90950- 4	1,40000- 1
4,01700+ 2	5,00000- 1	1,40480- 1	4,81020- 4	1,40000- 1
4,10010+ 2	5,00000- 1	1,40320- 1	3,24010- 4	1,40000- 1
4,24000+ 2	5,00000- 1	1,40150- 1	1,50320- 4	1,40000- 1
4,44600+ 2	5,00000- 1	1,77950- 1	3,79540- 2	1,40000- 1
4,61400+ 2	5,00000- 1	1,63200- 1	2,31990- 2	1,40000- 1
4,66800+ 2	5,00000- 1	2,39390- 1	9,93860- 2	1,40000- 1
4,72200+ 2	5,00000- 1	1,55650- 1	1,56460- 2	1,40000- 1
4,76100+ 2	5,00000- 1	1,43490- 1	3,49120- 3	1,40000- 1
4,79540+ 2	5,00000- 1	1,42630- 1	2,62780- 3	1,40000- 1
5,12270+ 2	5,00000- 1	1,55390- 1	1,53910- 2	1,40000- 1
5,24900+ 2	5,00000- 1	1,40460- 1	4,58210- 4	1,40000- 1
5,32200+ 2	5,00000- 1	1,41610- 1	1,61490- 3	1,40000- 1
5,54510+ 2	5,00000- 1	3,75480- 1	2,35480- 1	1,40000- 1
5,76670+ 2	5,00000- 1	2,13000- 1	7,30020- 2	1,40000- 1
5,87470+ 2	5,00000- 1	2,95120- 1	1,55120- 1	1,40000- 1
6,05060+ 2	5,00000- 1	1,42460- 1	2,45980- 3	1,40000- 1
6,25590+ 2	5,00000- 1	1,56010- 1	1,60080- 2	1,40000- 1
6,53500+ 2	5,00000- 1	1,65560- 1	2,55640- 2	1,40000- 1
6,74500+ 2	5,00000- 1	2,17910- 1	7,79130- 2	1,40000- 1
6,95890+ 2	5,00000- 1	1,68490- 1	2,84900- 2	1,40000- 1
7,03510+ 2	5,00000- 1	1,46900- 1	6,89620- 3	1,40000- 1
7,21260+ 2	5,00000- 1	1,41070- 1	1,07430- 3	1,40000- 1
7,34700+ 2	5,00000- 1	1,41080- 1	1,08420- 3	1,40000- 1
7,52570+ 2	5,00000- 1	1,94870- 1	5,48660- 2	1,40000- 1
7,84000+ 2	5,00000- 1	1,45880- 1	5,88000- 3	1,40000- 1
8,06000+ 2	5,00000- 1	1,46100- 1	6,10390- 3	1,40000- 1
8,13000+ 2	5,00000- 1	1,46840- 1	6,84320- 3	1,40000- 1
8,49000+ 2	5,00000- 1	1,48740- 1	8,74130- 3	1,40000- 1
8,82330+ 2	5,00000- 1	2,58820- 1	1,18820- 1	1,40000- 1
8,86670+ 2	5,00000- 1	1,51910- 1	1,19110- 2	1,40000- 1
9,14870+ 2	5,00000- 1	1,47260- 1	7,25920- 3	1,40000- 1

Table II Resonance Parameters for Ag-109

E_R	J	Γ	Γ_n	Γ_γ
5,19000+ 0	1,00000+ 0	1,48600- 1	1.25980- 2	1,36000- 1
3,04000+ 1	1,00000+ 0	1,37280- 1	7.27800- 3	1,30000- 1
3,26300+ 1	5,00000- 1	1,42010- 1	1.08530- 5	1,40000- 1
4,01000+ 1	1,00000+ 0	1,35940- 1	4.93930- 3	1,31000- 1
5,56000+ 1	0,00000+ 0	1,71060- 1	3.20630- 2	1,39000- 1
7,06000+ 1	1,00000+ 0	1,47480- 1	2,74760- 2	1,20000- 1
8,74000+ 1	1,00000+ 0	1,36260- 1	6,26370- 3	1,30000- 1
9,15000+ 1	5,00000- 1	1,40050- 1	4.78280- 5	1,40000- 1
1,06290+ 2	5,00000- 1	1,40120- 1	1.23720- 4	1,40000- 1
1,13500+ 2	5,00000- 1	1,40060- 1	5,75300- 5	1,40000- 1
1,33900+ 2	1,00000+ 0	1,99840- 1	7,98430- 2	1,20000- 1
1,39700+ 2	5,00002- 1	1,42130- 1	2.12750- 3	1,40000- 1
1,60000+ 2	5,00000- 1	1,40100- 1	9,99280- 5	1,40000- 1
1,69800+ 2	5,00000- 1	1,40360- 1	3,64860- 4	1,40000- 1
1,72800+ 2	5,00000- 1	2,20187- 1	8,01866- 2	1,40000- 1
1,98400+ 2	5,00000- 1	1,40150- 1	1.54940- 4	1,40000- 1
2,09600+ 2	1,00000+ 0	1,56160- 1	2.31640- 2	1,33000- 1
2,51300+ 2	1,00000+ 0	1,32680- 1	1.26820- 2	1,20000- 1
2,58890+ 2	5,00000- 1	1,42010- 1	2.01130- 3	1,40000- 1
2,72500+ 2	5,00000- 1	1,41980- 1	1.98090- 3	1,40000- 1
2,74900+ 2	5,00000- 1	1,40330- 1	3,31600- 4	1,40000- 1
2,83900+ 2	5,00000- 1	1,40270- 1	2.69590- 4	1,40000- 1
2,90900+ 2	0,00000+ 0	1,75820- 1	3,58170- 2	1,40000- 1
2,93000+ 2	5,00000- 1	1,40340- 1	3,42340- 4	1,40000- 1
3,00640+ 2	5,00000- 1	1,41390- 1	1.38710- 3	1,40000- 1
3,16400+ 2	1,00000+ 0	3,08980- 1	1.68980- 1	1,40000- 1
3,22100+ 2	5,00000- 1	1,40360- 1	3,58940- 4	1,40000- 1
3,27800+ 2	5,00000- 1	1,47240- 1	7,24210- 3	1,40000- 1
3,40400+ 2	5,00000- 1	1,40180- 1	1.84500- 4	1,40000- 1
3,60000+ 2	5,00000- 1	1,41400- 1	1.40410- 3	1,40000- 1
3,87000+ 2	1,00000+ 0	1,81900- 1	4.19020- 2	1,40000- 1
3,91600+ 2	5,00000- 1	1,40320- 1	3,16620- 4	1,40000- 1
3,98000+ 2	1,00000+ 0	1,61940- 1	2.19450- 2	1,40000- 1
4,04400+ 2	0,00000+ 0	3,31010- 1	1.85010- 1	1,46000- 1
4,28400+ 2	5,00000- 1	1,58210- 1	1.82140- 2	1,40000- 1
4,41000+ 2	5,00000- 1	1,40190- 1	1.89000- 4	1,40000- 1
4,69610+ 2	5,00000- 1	1,83340- 1	4,33410- 2	1,40000- 1
4,87720+ 2	5,00000- 1	1,65620- 1	2.56180- 2	1,40000- 1
4,95200+ 2	5,00000- 1	1,40890- 1	8,90120- 4	1,40000- 1
5,00600+ 2	5,00000- 1	3,63740- 1	2.23740- 1	1,40000- 1
5,15470+ 2	5,00000- 1	2,39900- 1	9,98970- 2	1,40000- 1
5,26600+ 2	5,00000- 1	1,40920- 1	9,17910- 4	1,40000- 1
5,58000+ 2	5,00000- 1	1,46140- 1	6,14170- 3	1,40000- 1
5,60660+ 2	5,00000- 1	2,82070- 1	1,42070- 1	1,40000- 1
5,65430+ 2	5,00000- 1	3,32230- 1	1.90230- 1	1,40000- 1
6,07930+ 2	5,00000- 1	2,04110- 1	6.41060- 2	1,40000- 1
6,22170+ 2	5,00000- 1	2,79680- 1	1.39680- 1	1,40000- 1
6,34270+ 2	5,00000- 1	1,41010- 1	1.00740- 3	1,40000- 1
6,48210+ 2	5,00000- 1	1,41020- 1	1,01840- 3	1,40000- 1
6,69450+ 2	5,00000- 1	1,83470- 1	4,34680- 2	1,40000- 1
6,81500+ 2	5,00000- 1	1,44160- 1	4.17690- 3	1,40000- 1
6,87400+ 2	5,00000- 1	1,42100- 1	2,09750- 3	1,40000- 1
7,13870+ 2	5,00000- 1	1,41870- 1	1,87030- 3	1,40000- 1
7,26080+ 2	5,00000- 1	1,68020- 1	2,80240- 2	1,40000- 1
7,30390+ 2	5,00000- 1	1,41890- 1	1,89180- 3	1,40000- 1
7,47490+ 2	5,00000- 1	2,82170- 1	1,42170- 1	1,40000- 1
7,52600+ 2	5,00000- 1	1,94870- 1	5,48670- 2	1,40000- 1

Table II Resonance Parameters for Ag-109 (Cont'd)

E_R	J	Γ	Γ_n	Γ_γ
7,84700+ 2	5,00000- 1	4,64940- 1	3,24940- 1	1,40000- 1
8,03800+ 2	5,00000- 1	1,91030- 1	5,10320- 2	1,40000- 1
8,31390+ 2	5,00000- 1	1,45770- 1	5,76680- 3	1,40000- 1
8,49000+ 2	5,00000- 1	1,42620- 1	2,62240- 3	1,40000- 1
8,61830+ 2	5,00000- 1	1,55270- 1	1,52660- 2	1,40000- 1
9,02840+ 2	5,00000- 1	1,58030- 1	1,80280- 2	1,40000- 1

Table III Resonance Parameters for Cs-133

E_R	J	Γ	Γ_n	Γ_γ
5.90000+ 0	3.50000+ 0	1.20100- 1	5.10090- 3	1.15000- 1
2.26000+ 1	3.50000+ 0	1.26660- 1	6.65550- 3	1.20000- 1
4.78000+ 1	3.50000+ 0	1.59360- 1	1.93590- 2	1.40000- 1
6.31000+ 1	3.50000+ 0	1.19120- 1	9.11590- 3	1.10000- 1
9.48000+ 1	3.50000+ 0	1.29470- 1	1.94730- 2	1.10000- 1
1.26070+ 2	3.50000+ 0	2.20040- 1	1.10040- 1	1.10000- 1
1.42160+ 2	3.50000+ 0	1.15960- 1	5.96150- 3	1.10000- 1
1.45860+ 2	3.50000+ 0	1.37780- 1	2.77780- 2	1.10000- 1
1.81470+ 2	3.50000+ 0	1.12160- 1	2.15540- 3	1.10000- 1
1.92500+ 2	3.50000+ 0	1.10280- 1	2.77490- 4	1.10000- 1
2.00900+ 2	3.50000+ 0	1.38350- 1	2.83480- 2	1.10000- 1
2.07300+ 2	3.50000+ 0	1.12880- 1	2.87960- 3	1.10000- 1
2.20350+ 2	3.50000+ 0	1.32270- 1	2.22660- 2	1.10000- 1
2.34400+ 2	3.50000+ 0	5.08060- 1	3.98060- 1	1.10000- 1
2.38400+ 2	3.50000+ 0	1.23900- 1	1.38960- 2	1.10000- 1
2.59000+ 2	3.50000+ 0	1.10320- 1	3.21870- 4	1.10000- 1
2.95600+ 2	3.50000+ 0	2.01120- 1	9.11230- 2	1.10000- 1
3.04900+ 2	3.50000+ 0	1.10350- 1	3.49230- 4	1.10000- 1
3.59010+ 2	3.50000+ 0	1.47890- 1	3.78950- 2	1.10000- 1
3.77430+ 2	3.50000+ 0	1.28650- 1	1.86500- 2	1.10000- 1
4.01160+ 2	3.50000+ 0	3.50350- 1	2.40350- 1	1.10000- 1
4.13500+ 2	3.50000+ 0	1.68970- 1	5.89710- 2	1.10000- 1
4.15530+ 2	3.50000+ 0	1.14080- 1	4.07690- 3	1.10000- 1
4.30830+ 2	3.50000+ 0	1.74340- 1	6.43450- 2	1.10000- 1
4.37500+ 2	3.50000+ 0	1.10420- 1	4.18330- 4	1.10000- 1
4.69890+ 2	3.50000+ 0	2.11880- 1	1.01880- 1	1.10000- 1
5.11630+ 2	3.50000+ 0	2.34410- 1	1.24410- 1	1.10000- 1
5.19670+ 2	3.50000+ 0	2.17140- 1	1.07140- 1	1.10000- 1
5.60300+ 2	3.50000+ 0	1.88110- 1	7.81130- 2	1.10000- 1
5.68390+ 2	3.50000+ 0	1.29070- 1	1.90730- 2	1.10000- 1
5.85520+ 2	3.50000+ 0	2.79380- 1	1.69380- 1	1.10000- 1
6.22590+ 2	3.50000+ 0	1.11000- 1	9.98070- 4	1.10000- 1
6.46280+ 2	3.50000+ 0	1.60840- 1	5.08440- 2	1.10000- 1
6.84440+ 2	3.50000+ 0	1.12620- 1	2.61620- 3	1.10000- 1
7.12310+ 2	3.50000+ 0	1.13200- 1	3.20270- 3	1.10000- 1
7.26610+ 2	3.50000+ 0	2.28610- 1	1.18610- 1	1.10000- 1
7.38000+ 2	3.50000+ 0	1.11090- 1	1.08660- 3	1.10000- 1
7.62870+ 2	3.50000+ 0	1.87340- 1	7.73360- 2	1.10000- 1
7.95720+ 2	3.50000+ 0	4.14650- 1	3.04650- 1	1.10000- 1
8.07560+ 2	3.50000+ 0	1.21370- 1	1.13670- 2	1.10000- 1
8.21000+ 2	3.50000+ 0	1.11720- 1	1.71920- 3	1.10000- 1
8.32710+ 2	3.50000+ 0	1.15770- 1	5.77130- 3	1.10000- 1
8.63920+ 2	3.50000+ 0	2.92230- 1	1.82230- 1	1.10000- 1
8.72340+ 2	3.50000+ 0	1.29490- 1	1.94930- 2	1.10000- 1
9.06570+ 2	3.50000+ 0	2.15380- 1	1.05380- 1	1.10000- 1
9.14110+ 2	3.50000+ 0	1.12420- 1	2.41870- 3	1.10000- 1
9.70480+ 2	3.50000+ 0	1.16230- 1	6.23050- 3	1.10000- 1
9.86440+ 2	3.50000+ 0	1.47690- 1	3.76890- 2	1.10000- 1
9.94150+ 2	3.50000+ 0	1.88820- 1	7.88250- 2	1.10000- 1
1.01870+ 3	3.50000+ 0	1.16380- 1	6.38340- 3	1.10000- 1
1.02140+ 3	3.50000+ 0	2.79380- 1	1.69380- 1	1.10000- 1
1.03860+ 3	3.50000+ 0	1.48670- 1	3.86730- 2	1.10000- 1
1.06960+ 3	3.50000+ 0	1.62330- 1	5.23280- 2	1.10000- 1
1.11830+ 3	3.50000+ 0	3.10650- 1	2.00650- 1	1.10000- 1
1.13490+ 3	3.50000+ 0	2.24540- 1	1.14540- 1	1.10000- 1
1.15620+ 3	3.50000+ 0	1.33800- 1	2.38020- 2	1.10000- 1
1.17700+ 3	3.50000+ 0	1.78610- 1	6.86150- 2	1.10000- 1
1.18700+ 3	3.50000+ 0	1.30670- 1	2.06720- 2	1.10000- 1
1.23970+ 3	3.50000+ 0	3.42380- 1	2.32380- 1	1.10000- 1

Table III Resonance Parameters for Cs-133 (Cont'd)

E_R	J	Γ	Γ_n	Γ_γ
1.24930+ 3	3.50000+ 0	1.52410- 1	4.24150- 2	1.10000- 1
1.26760+ 3	3.50000+ 0	4.66030- 1	3.56030- 1	1.10000- 1
1.27260+ 3	3.50000+ 0	1.12850- 1	2.85390- 3	1.10000- 1
1.28010+ 3	3.50000+ 0	2.88890- 1	1.78890- 1	1.10000- 1
1.30630+ 3	3.50000+ 0	1.12170- 1	2.16860- 3	1.10000- 1
1.31280+ 3	3.50000+ 0	1.12170- 1	2.17400- 3	1.10000- 1
1.32200+ 3	3.50000+ 0	2.69980- 1	1.59980- 1	1.10000- 1
1.32930+ 3	3.50000+ 0	2.55840- 1	1.45840- 1	1.10000- 1
1.34540+ 3	3.50000+ 0	1.11470- 1	1.46720- 3	1.10000- 1
1.38980+ 3	3.50000+ 0	1.47280- 1	3.72800- 2	1.10000- 1
1.42320+ 3	3.50000+ 0	2.53360- 1	1.43360- 1	1.10000- 1
1.42910+ 3	3.50000+ 0	1.22100- 1	1.20970- 2	1.10000- 1
1.44330+ 3	3.50000+ 0	1.13800- 1	3.79910- 3	1.10000- 1
1.45310+ 3	3.50000+ 0	3.15850- 1	2.05850- 1	1.10000- 1
1.46460+ 3	3.50000+ 0	1.22250- 1	1.22460- 2	1.10000- 1
1.48090+ 3	3.50000+ 0	1.15390- 1	5.38750- 3	1.10000- 1
1.52490+ 3	3.50000+ 0	1.95910- 1	8.59100- 2	1.10000- 1
1.53310+ 3	3.50000+ 0	1.27230- 1	1.72280- 2	1.10000- 1
1.54550+ 3	3.50000+ 0	1.49310- 1	3.93130- 2	1.10000- 1
1.58380+ 3	3.50000+ 0	1.13980- 1	3.97970- 3	1.10000- 1
1.59420+ 3	3.50000+ 0	5.09270- 1	3.99270- 1	1.10000- 1
1.61630+ 3	3.50000+ 0	2.30610- 1	1.20610- 1	1.10000- 1
1.62700+ 3	3.50000+ 0	1.13230- 1	3.22690- 3	1.10000- 1
1.66460+ 3	3.50000+ 0	1.99760- 1	8.97590- 2	1.10000- 1
1.68250+ 3	3.50000+ 0	5.20180- 1	4.10180- 1	1.10000- 1
1.70550+ 3	3.50000+ 0	2.33890- 1	1.23890- 1	1.10000- 1
1.72600+ 3	3.50000+ 0	1.11660- 1	1.66180- 3	1.10000- 1
1.73480+ 3	3.50000+ 0	1.59980- 1	4.99810- 2	1.10000- 1
1.76090+ 3	3.50000+ 0	2.35890- 1	1.25890- 1	1.10000- 1
1.80960+ 3	3.50000+ 0	1.44030- 1	3.40320- 2	1.10000- 1
1.82860+ 3	3.50000+ 0	1.14280- 1	4.27620- 3	1.10000- 1
1.84300+ 3	3.50000+ 0	1.15150- 1	5.15160- 3	1.10000- 1
1.84930+ 3	3.50000+ 0	1.40100- 1	3.01020- 2	1.10000- 1
1.85370+ 3	3.50000+ 0	1.22920- 1	1.29160- 2	1.10000- 1
1.89950+ 3	3.50000+ 0	1.14360- 1	4.35830- 3	1.10000- 1
1.91550+ 3	3.50000+ 0	1.23130- 1	1.31300- 2	1.10000- 1
1.93440+ 3	3.50000+ 0	1.13520- 1	3.51850- 3	1.10000- 1
1.95400+ 3	3.50000+ 0	1.98410- 1	8.84080- 2	1.10000- 1
2.00000+ 3	3.50000+ 0	1.12680- 1	2.68330- 3	1.10000- 1
2.05100+ 3	3.50000+ 0	1.41700- 1	3.17020- 2	1.10000- 1
2.06000+ 3	3.50000+ 0	6.09260- 1	4.99260- 1	1.10000- 1
2.09000+ 3	3.50000+ 0	1.14570- 1	4.57170- 3	1.10000- 1
2.09900+ 3	3.50000+ 0	2.29120- 1	1.19120- 1	1.10000- 1
2.11400+ 3	3.50000+ 0	1.11840- 1	1.83910- 3	1.10000- 1
2.12200+ 3	3.50000+ 0	4.14030- 1	3.04030- 1	1.10000- 1
2.13300+ 3	3.50000+ 0	1.14620- 1	4.61840- 3	1.10000- 1
2.16100+ 3	3.50000+ 0	1.19300- 1	9.29730- 3	1.10000- 1
2.17200+ 3	3.50000+ 0	1.33300- 1	2.33020- 2	1.10000- 1
2.18200+ 3	3.50000+ 0	2.40790- 1	1.30790- 1	1.10000- 1
2.19700+ 3	3.50000+ 0	1.56870- 1	4.68720- 2	1.10000- 1
2.26100+ 3	3.50000+ 0	4.42850- 1	3.32850- 1	1.10000- 1
2.28000+ 3	3.50000+ 0	3.39200- 1	2.29200- 1	1.10000- 1
2.29500+ 3	3.50000+ 0	1.77070- 1	6.70690- 2	1.10000- 1
2.31200+ 3	3.50000+ 0	3.31180- 1	2.21180- 1	1.10000- 1
2.34300+ 3	3.50000+ 0	1.11940- 1	1.93620- 3	1.10000- 1
2.35200+ 3	3.50000+ 0	1.11940- 1	1.93990- 3	1.10000- 1
2.37600+ 3	3.50000+ 0	1.18240+ 0	1.07240+ 0	1.10000- 1
2.38700+ 3	3.50000+ 0	1.19770- 1	9.77140- 3	1.10000- 1
2.39200+ 3	3.50000+ 0	1.24670- 1	1.46720- 2	1.10000- 1
2.42900+ 3	3.50000+ 0	3.07140- 1	1.97140- 1	1.10000- 1
2.44700+ 3	3.50000+ 0	1.14950- 1	4.94670- 3	1.10000- 1

Table III Resonance Parameter for Cs-133 (Cont'd)

E_R		J		Γ		Γ_n		Γ_γ	
2.45800+	3	3.50000+	0	1.11980-	1	1.98310-	3	1.10000-	1
2.47400+	3	3.50000+	0	1.63720-	1	5.37180-	2	1.10000-	1
2.49200+	3	3.50000+	0	1.14990-	1	4.99200-	3	1.10000-	1
2.50300+	3	3.50000+	0	1.40020-	1	3.00180-	2	1.10000-	1
2.52400+	3	3.50000+	0	1.12010-	1	2.00960-	3	1.10000-	1
2.53700+	3	3.50000+	0	1.45260-	1	3.52580-	2	1.10000-	1
2.56100+	3	3.50000+	0	2.31460-	1	1.21460-	1	1.10000-	1
2.57000+	3	3.50000+	0	1.45490-	1	3.54870-	2	1.10000-	1
2.59100+	3	3.50000+	0	1.25270-	1	1.52710-	2	1.10000-	1
2.60400+	3	3.50000+	0	1.81440-	1	7.14410-	2	1.10000-	1
2.62300+	3	3.50000+	0	1.15120-	1	5.12150-	3	1.10000-	1
2.68300+	3	3.50000+	0	2.34310-	1	1.24310-	1	1.10000-	1
2.70500+	3	3.50000+	0	1.12080-	1	2.08040-	3	1.10000-	1
2.72300+	3	3.50000+	0	6.84010-	1	5.74010-	1	1.10000-	1
2.73300+	3	3.50000+	0	1.12090-	1	2.09110-	3	1.10000-	1
2.75500+	3	3.50000+	0	7.39860-	1	6.29860-	1	1.10000-	1
2.77700+	3	3.50000+	0	1.15270-	1	5.26970-	3	1.10000-	1
2.79400+	3	3.50000+	0	3.84860-	1	2.74860-	1	1.10000-	1
2.83800+	3	3.50000+	0	1.15330-	1	5.32730-	3	1.10000-	1
2.87600+	3	3.50000+	0	1.12150-	1	2.14510-	3	1.10000-	1
2.89200+	3	3.50000+	0	1.12150-	1	2.15110-	3	1.10000-	1
2.89800+	3	3.50000+	0	3.03800-	1	1.93800-	1	1.10000-	1
2.91000+	3	3.50000+	0	2.55650-	1	1.45650-	1	1.10000-	1
2.92500+	3	3.50000+	0	1.12160-	1	2.16330-	3	1.10000-	1
2.94300+	3	3.50000+	0	4.13800-	1	3.03800-	1	1.10000-	1
2.98200+	3	3.50000+	0	2.08290-	1	9.82940-	2	1.10000-	1
3.00700+	3	3.50000+	0	1.97740-	1	8.77380-	2	1.10000-	1
3.01600+	3	3.50000+	0	3.73610-	1	2.63610-	1	1.10000-	1
3.07100+	3	3.50000+	0	1.48790-	1	3.87920-	2	1.10000-	1
3.09500+	3	3.50000+	0	1.26690-	1	1.66900-	2	1.10000-	1
3.11400+	3	3.50000+	0	1.32320-	1	2.23210-	2	1.10000-	1
3.12000+	3	3.50000+	0	4.45140-	1	3.35140-	1	1.10000-	1
3.15000+	3	3.50000+	0	1.43670-	1	3.36750-	2	1.10000-	1
3.19000+	3	3.50000+	0	1.23960+	0	1.12960+	0	1.10000-	1
3.30600+	3	3.50000+	0	8.57470-	1	7.47470-	1	1.10000-	1
3.33500+	3	3.50000+	0	3.23670-	1	2.13670-	1	1.10000-	1
3.35400+	3	3.50000+	0	3.76400-	1	2.66400-	1	1.10000-	1
3.37300+	3	3.50000+	0	2.14540-	1	1.04540-	1	1.10000-	1
3.40200+	3	3.50000+	0	1.33330-	1	2.33310-	2	1.10000-	1
3.42200+	3	3.50000+	0	4.60990-	1	3.50990-	1	1.10000-	1
3.44400+	3	3.50000+	0	1.68690-	1	5.86860-	2	1.10000-	1
3.48000+	3	3.50000+	0	1.64380+	0	1.53380+	0	1.10000-	1
3.50000+	3	3.50000+	0	2.28320-	1	1.18320-	1	1.10000-	1

Table IV: Optical Model Parameters

$$V(r) = Uf(r) + iWg(r)$$

$$f(r) = \left[1 + \exp(r-R)/a_U\right]^{-1}$$

$$g(r) = 4\exp\left\{(r-R)/a_W\right\}\left[1 + \exp(r-R)/a_W\right]^{-2}$$

$r_o = 1.26\text{fm}$ $a_U = 0.66\text{fm}$ $a_W = 0.48\text{fm}$

$R = r_o A^{1/3}\text{fm}$

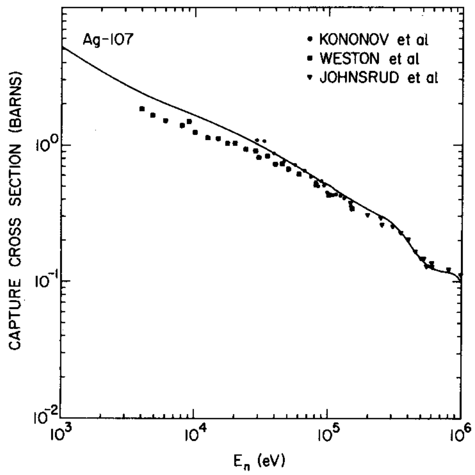
$U = 47.01 - 0.267 - 0.00118E^2$ MeV

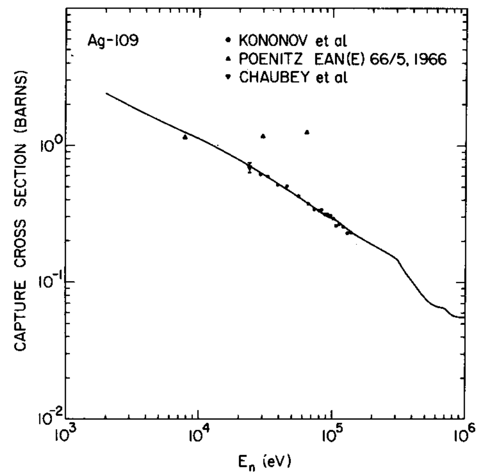
$W = 9.52 - 0.053$ MeV

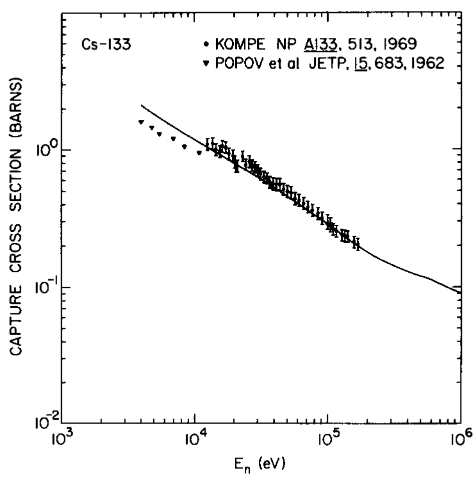
Spin orbit term = 0.

Table V Energy Levels

Ag-107 E_{ex}(keV)	Ag-107 J^{π}	Ag-109 E_{ex}(keV)	Ag-109 J^{π}	Cs-133 E_{ex}(keV)	Cs-133 J^{π}
0.0	1/2-	0.0	1/2-	0.0	7/2+
93.0	7/2+	88.0	7/2+	81.0	5/2+
126.0	9/2+	133.0	9/2+	161.0	5/2+
325.0	3/2-	311.0	3/2-	384.0	3/2+
423.0	5/2-	415.0	5/2-	437.0	1/2+
787.0	3/2-	702.0	3/2-	633.0	9/2+
922.0	5/2+				
Continuum $\geq$ 950 keV		Continuum $\geq$ 710 keV		Continuum $\geq$ 650 keV	


Ag-107
• KONONOV et al
▪ WESTON et al
▾ JOHNSRUD et al
CAPTURE CROSS SECTION (BARNS)
10^0
10^{-1}
10^{-2}
10^3
10^4
10^5
10^6
E_n (eV)


Ag-109
• KONONOV et al
▴ POENITZ EAN(E) 66/5, 1966
▾ CHAUBEY et al
CAPTURE CROSS SECTION (BARNS)
10^0
10^{-1}
10^{-2}
10^3
10^4
10^5
10^6
E_n (eV)


Cs-133
• KOMPE NP A133, 513, 1969
▾ POPOV et al JETP, 15, 683, 1962
CAPTURE CROSS SECTION (BARNS)
10^0
10^{-1}
10^{-2}
10^3
10^4
10^5
10^6
E_n (eV)