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NONELASTIC NUCLEAR REACTIONS AND ACCOMPANYING GAMMA RADIATION

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FINAL REPORT
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NONELASTIC NUCLEAR REACTIONS AND ACCOMPANYING GAMMA RADIATION

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ABSTRACT

Several aspects of nonelastic nuclear reactions which proceed through the formation of a compound nucleus are dealt with. The full statistical model and the partial statistical model are described and computer programs based on these models are presented along with operating instructions and input and output for sample problems. A theoretical development of the expression for the reaction cross section for the "hybrid" case which involves a combination of the continuum aspects of the full statistical model with the discrete level aspects of the partial statistical model is presented. Cross sections for level excitation and gamma production by neutron inelastic scattering from the nuclei Al^{27}, Fe^{56}, Si^{28}, and Pb^{208} are calculated and compared with available experimental data. In addition, a computer program to convert inelastic neutron spectrum data from the ENDF/B tapes to a form compatible with input requirements of the H01 routine of the COHORT computer program is described.

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SUMMARY

This report consists of five separate sections, each dealing with a specific aspect of nonelastic nuclear reactions. The restriction is made that the reactions proceed through the formation of a compound nucleus, and attention is focused mainly on the inelastic neutron scattering process.

The first section describes the full statistical model of nuclear reactions for which the assumption is made that the level structure of both the compound nucleus and the residual nucleus can be represented by a continuous distribution of levels. A computer program based on the full statistical model is then presented. This program is designed to perform a spectral analysis of the energies of reaction products emerging from nonelastic reactions. Reactions of the types (y, n), (y, p), (y, α), (y, 2n), (y, 2p), (y, np), and, (y, pn) may be handled where y may be n, p, or α. Instructions for operating the program together with input and output for a sample problem involving reactions initiated by neutron bombardment of Fe^{56} are given.

The second section describes the partial statistical model of nuclear reactions. Here, the compound nucleus is assumed to have a continuous level structure as in the full statistical model, but the residual nucleus is assumed to have the more realistic discrete structure. Each level of the residual nucleus has, of course, a specific energy, spin, and parity. A computer program based on the partial statistical model is then presented. This program is designed to calculate the cross section for excitation of the various levels of the various residual nuclei created in the reaction. Reactions of the types (y, n), (y, p), and (y, α) may be handled where y may be n, p, or α.

Instructions for operating the program are given. Also given are the input and output for a sample problem involving cross section calculations for the ground level and the first four levels excited by inelastic scattering of 3 MeV neutrons from Fe^{56}. Results of similar calculations for the nucleus Y^{89} are presented in graphical form, and a comparison of these results with experimental data is made.

Contained in the third section is a theoretical development of the expression for the cross section for the "hybrid" case for which the level structure of the residual nucleus is represented by a set of discrete levels in the low excitation energy region and by a continuum of levels at higher energies. Thus, the continuous aspects of the full statistical model are combined with the discrete aspects of the partial statistical model.

Presented in the fourth section are results of calculations of cross sections for level excitation and gamma production by neutron inelastic scattering from the nuclei Al^{27}, Fe^{56}, Si^{28}, and Pb^{208}. Although the partial statistical model computer program presented in this report is more general than existing programs in that it is capable of treating reactions other than neutron inelastic scattering, it was decided to use the existing program Abacus-2 for the calculations of this section. The reason for this decision is that certain approximations are made in calculating the transmission coefficients in the program presented in this report, whereas the Abacus-2 program calculates these quantities to a considerably greater accuracy. An additional computer program was written to calculate cross sections for producing each of the various gamma rays which are emitted by the excited residual nucleus. This program uses as input the level excitation cross sections calculated by the Abacus-2 program and the gamma branching probabilities obtained from the literature. This

computer program is described in this section. Calculated cross sections for level excitation and gamma production are presented in both tabular and graphical form and compared with available experimental data.

A computer program to provide inelastic neutron spectrum probability tables for input to the HOl routine of the COHORT computer program is described in the fifth section. This program allows probability tables for exciting discrete energy levels to be obtained directly from ENDF/B data tapes for low incident energies. For incident energies above those defined by discrete excitation levels on the ENDF/B data tapes the inelastic neutron spectrum is assumed to be a continuum that is defined by a Maxwellian distribution, and the nuclear temperature is given as a function of incident energy. This distribution is used to calculate excitation probabilities for pseudo-excitation levels that are distributed over the continuum and used to approximate the continuum.

SECTION I. COMPUTER PROGRAM BASED ON THE FULL STATISTICAL MODEL

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INTRODUCTION

The FORTRAN program SPECTER performs a spectral analysis of the energies of reaction products emerging from nuclear reactions satisfying the following conditions:

- Compound-nucleus formation is the dominant reaction mechanism
- The statistical model may be applied to the compound nucleus and all participating residual nuclei.

Reactions of the types (y, n), (y, p), (y, α), (y, 2n), (y, 2p), (y, np), and (y, pn) may be handled where y may be n, p, or α. SPECTER is an outgrowth of the code EDISN (Refs. 1 and 2) which employs the same theoretical framework but is restricted to (n, n') and (n, 2n) reactions.

THEORETICAL ASSUMPTIONS

STATISTICAL – CONTINUUM FORMULATION

The computer code SPECTER is designed to calculate the energy distribution of various reaction products emerging from a certain class of nuclear reactions. Consider the process in which a nucleus Y (N, Z) is bombarded by a particle y. It is assumed that the ensuing nuclear reaction proceeds through the formation of a compound nucleus C (Ref. 3). This excited compound nucleus could in general decay by the emission of a gamma ray or a particle y'. For the class of reactions considered here, however, it is assumed that gamma de-excitation of the compound nucleus does not compete significantly with particle emission. Following the emission of y', a residual nucleus Y'' remains, generally, in an excited state. This state may likewise decay either by the emission of a gamma ray or a particle y''. The assumption here is that particle emission will be the predominant process so long as it is energetically possible. Such will be the case whenever the excitation energy exceeds the binding energy of y'' in the nucleus Y'. If particle emission does not occur, SPECTER gives no further consideration to the reaction. If particle emission occurs, the analysis is continued. Let Y'' be the residual nucleus that remains following the emission of y'' by Y'. In general, Y'' is also created in an excited state. At this point it is assumed that further particle emission does not occur and Y'' eventually reaches its ground state by the emission of one or more gamma rays.

Thus, the model on which SPECTER is based pictures the reaction as taking place in three distinct stages

- $y + Y \rightarrow C$
- $C \rightarrow y' + Y'$
- $Y' \rightarrow y'' + Y''$.

SPECTER restricts the incident particle to be either neutron, proton, or α-particle. The same restriction is imposed on the first emitted particle y', and the second emitted particle y'' must be either neutron or proton.

The energetics of a reaction of the type under consideration is depicted in Figure 1. The kinetic energy of the incident particle is denoted by ϵ, and ϵ' and ϵ'' are the kinetic energies of the first and second emitted particles, respectively. A more general formulation would introduce an exit channel energy which includes the recoil energy of the residual nucleus. The model employed here, however, is not expected to be applicable to reactions involving light nuclei. Consequently, the recoil energy, which need be considered only in such an instance, will be neglected throughout. The ground levels of the nuclei involved are represented by G_Y, G_c, $G_{Y'}$, and $G_{Y''}$. The quantities δ, δ', and δ'' are defined in terms of the total nuclear binding energies B as follows:

$$\delta = B(c) - B(Y) \quad , \tag{1}$$

$$\delta' = B(c) - B(Y') \quad , \tag{2}$$

and

$$\delta'' = B(Y') - B(Y'') \quad . \tag{3}$$

The excitation energy of the compound nucleus following absorption of particle y is E, and the excitation energies of the first and second residual nuclei are E' and E'', respectively.

One observes from Figure 1 that the energy available to the products y' and Y' of the decay of the level of C having energy E is $E - \delta'$. An apportioning of this energy between kinetic energy of y' and excitation energy of Y' takes place in a manner which is dependent on properties of the level E and the level structure of Y'. A similar apportioning of the available energy $E' - \delta''$ between the kinetic energy of y' and the excitation energy of Y'' takes place in the decay of Y'.

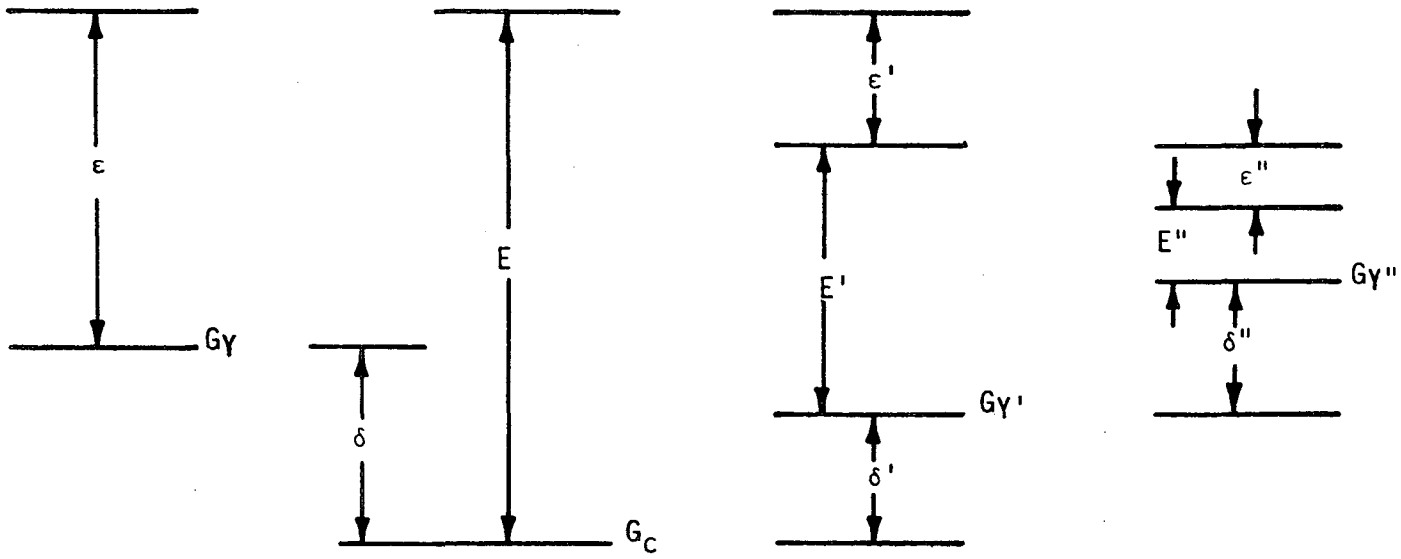

FIGURE 1. ENERGETICS OF A REACTION OF THE TYPE UNDER CONSIDERATION

It is the function of SPECTER to calculate the relative probability of each possible apportioning. For this purpose SPECTER employs certain simplifying assumptions embodied in the "statistical-continuum" model (Refs. 4 and 5). The essential features of this model are averaging over compound nucleus resonances, the neglect of phases between the various excited levels of the decaying nucleus, and the assumption of a continuously varying energy density of levels in the residual nucleus.

With application of the Bohr assumption (Ref. 3) to the reaction Y (y, y') Y' one obtains for the reaction cross section

$$\sigma(y, y') = \sigma_c(y)\, P_c(y') \quad . \tag{4}$$

Here $\sigma_c(y)$ is the cross section for the formation of the compound nucleus C and $P_c(y')$ is the probability that C decays by the emission of particle y'. The first factor in Equation 4 is commonly approximated by the reaction cross section σ_r which is given by

$$\sigma_r = \sigma_t - \sigma_{se} \tag{5}$$

where σ_t is the total cross section and σ_{se} is the shape elastic cross section. In equating σ_c to σ_r, it is implied that compound elastic scattering is negligible. Such is generally the case, provided the excitation energy of the compound nucleus is sufficiently high and the levels of the residual nucleus are sufficiently dense to provide several open decay channels. The assumption here is that these conditions are satisfied. A widely used means of calculating σ_r, and hence σ_c, is the optical model (Refs. 6 and 7). SPECTER, however, employs the considerably less detailed continuum model (Ref. 4). The expressions for evaluating σ_r which are derived from this model are given in the section entitled Cross Sections for Compound Nucleus Formation.

It is useful to specify the reaction $Y(y, y')Y'$ in greater detail by considering the cross section $\sigma(\xi, \xi')$ corresponding to a specific entrance channel ξ and specific exit channel ξ'. Here ξ and ξ' specify the quantum states of reaction partners before and after the reaction, respectively. The cross section is written as

$$\sigma(\xi, \xi') = \sigma_c(\xi)\, P_c(\xi') \qquad (6)$$

where $\sigma_c(\xi)$ is the cross section for the formation of C through channel ξ and $P_c(\xi')$ is the probability that C decays through channel ξ'. Application of the reciprocity theorem leads to the following expression for $P_c(\xi')$:

$$P_c(\xi') = \frac{k_{\xi'}^2\, \sigma_c(\xi')}{\sum_\gamma k_\gamma^2\, \sigma_c(\gamma)} \quad . \qquad (7)$$

Here $k_{\xi'}$ is the wave number of the particle emerging through channel ξ', and $\sigma_c(\xi')$ is the cross section for the formation of the compound nucleus by the inverse process in which ξ' is regarded as the entrance channel. The summation is extended over all channels through which C can decay. Thus, the cross section $\sigma(\xi, \xi')$ can be computed if the cross sections $\sigma_c(\xi')$ for the formation of C by all possible channels are known.

Suppose now that the excitation energy of Y' corresponding to channel ξ' is sufficiently high to allow the emission of y'' through channel ξ''. The cross section for the entire process can then be expressed as

$$\sigma(\xi, \xi', \xi'') = \sigma_c(\xi)\, P_c(\xi')\, P_{Y'\xi'}(\xi'') \quad . \qquad (8)$$

An expression similar to Equation 7,

$$P_{Y'\xi'}(\xi'') = \frac{k^2_{\xi''}\,\sigma_c(\xi'')}{\sum_{\gamma} k_\gamma^2\,\sigma_c(\gamma)} \quad , \tag{9}$$

obtains for the probability $P_{Y'\xi'}(\xi'')$ that Y' decays through channel ξ''. The compound nucleus C is here considered to be the nucleus Y', and $\sigma_c(\xi'')$ is the cross section for the formation of this nucleus by the inverse process in which ξ'' is regarded as the entrance channel. In order to arrive at the cross section for the process in which the second particle y'' emerges through channel ξ'' irrespective of the intervening states of the pair (y', Y'), one sums over all such states to obtain

$$\sigma(\xi,\ y',\ \xi'') = \sigma_c(\xi) \sum_{\xi'} P_c(\xi')\, P_{Y'\xi'}(\xi'') \quad . \tag{10}$$

The sum, of course, is extended over only those channels for which Y' is sufficiently excited to emit y''.

The exit channels ξ' and ξ'' appearing in Equations 6 through 10 have been assumed to correspond to discrete nuclear energy levels. At this point the concept of a continuous level density is introduced. Such a concept is expected to be applicable to certain reactions for which the participating residual nuclei have many closely spaced levels at the excitation energies encountered. It should be pointed out that such a classical statistical-continuum approach constitutes an averaging process that, for the most part, glosses over such purely quantum mechanical level properties as spin and parity.

Consider again the decay of C into particle y' having kinetic energy $\epsilon_{y'}$ and residual nucleus Y' having excitation energy $E'(\epsilon_{y'})$.

Let $D_{Y'}(E')$ be the average spacing between levels of Y' in the neighborhood of E'. The level density $\rho_{Y'}(E')$ in this region is defined by

$$\rho_{Y'}(E') = D^{-1}_{Y'}(E') \quad , \tag{11}$$

and $\rho_{Y'}(E')\,dE'$ is taken to be the number of levels having energy between E' and E' + dE'. The counterpart to Equation 7 for the situation in which the level density concept is employed is the familiar Weisskopf-Ewing formula (Ref. 8) as shown by

$$P_c(\epsilon_{y'}) = \frac{g_{y'}\,\mu_{y'}\,\epsilon_{y'}\,\sigma_c(\epsilon_{y'})\,\rho_{Y'}(E')}{\sum_{\nu} g_\nu\,\mu_\nu \int_0^{M_\nu} \epsilon_\nu\,\sigma_c(\epsilon_\nu)\,\rho_{R(\nu)}[E'(\epsilon_\nu)]\,dE'} \quad . \tag{12}$$

Here $g_{y'}$ and $\mu_{y'}$ are the spin-statistical weight $(2S_{y'} + 1)$ and the mass of y', respectively. The sum is extended over all particles ν which C can emit, and the $R(\nu)$ are the corresponding residual nuclei. The maximum kinetic energy available to particle ν is M_ν. This quantity is determined by energy conservation requirements as illustrated in Figure 1. The term $P_c(\epsilon_{y'})$ is to be interpreted as a probability density in the sense that $P_c(\epsilon_{y'})\,d\epsilon_{y'}$ is the probability that y' emerges with a kinetic energy between $\epsilon_{y'}$ and $\epsilon_{y'} + d\epsilon_{y'}$. In like manner, a counterpart to Equation 9 may be written which describes the decay of a level of the first residual nucleus into a continuum of levels of a second residual nucleus. Continuum counterparts to Equations 8 and 10 then may be constructed.

From the preceding discussion, it is apparent that SPECTER is applicable only to reactions for which several conditions are satisfied. These conditions are

- Compound nucleus formation is the dominant reaction mechanism

- Compound elastic scattering is negligible
- Reactions other than (y, n), (y, p), (y, α), (y, 2n), (y, np), (y, pn), or (y, 2p) do not occur to an appreciable extent. Here y is the incident particle which may be either neutron, proton, or α-particle.
- The statistical-continuum approximations may be applied to the compound nucleus and all residual nuclei.
- De-excitation of a level of the compound nucleus or a residual nucleus occurs by particle emission whenever such emission is energetically possible.

Whether or not these conditions are satisfied in a given reaction depends, of course, on such factors as the magnitude of the bombarding and excitation energies and the level characteristics of the particular target, compound, and product nuclei participating in the reaction.

CROSS SECTIONS FOR COMPOUND NUCLEUS FORMATION

A table of cross sections for compound nucleus formation by uncharged particles is generated at the beginning of the main program. The calculation employs the continuum theory of Weisskopf (Ref. 4). According to this theory, the cross section for compound nucleus formation through channel α is expressed as a sum of partial cross sections $\sigma_{c\ell}(\alpha)$ or

$$\sigma_c(\alpha) = \sum_{\ell=0}^{\infty} \sigma_{c\ell}(\alpha) \tag{13}$$

where ℓ is the orbital angular momentum quantum number associated with the ℓth partial wave of the incident particle wave function. Each partial cross section can be written

$$\sigma_{c\ell}(\alpha) = (2\ell + 1)\,\pi\lambda^2\, T_\ell(\alpha) \tag{14}$$

where $T_\ell(\alpha)$ is a transmission coefficient and $\lambda\!\!\!^{-}$ is the channel wavelength and is the reciprocal of the channel wave number k. This wave number is given by

$$k = \frac{(2\mu\,\epsilon)^{\frac{1}{2}}}{\hbar} \tag{15}$$

where μ is the mass and ϵ is the energy of the incident particle. The continuum theory yields the following expression for the transmission coefficient:

$$T_\ell(\alpha) = \frac{4x\,X\,\upsilon_\ell}{X^2 + (2x\,X + x^2\,\upsilon_\ell')\,\upsilon_\ell} \tag{16}$$

where

$x = kR$

$X = KR$

K - wave number inside the nucleus

and

$$\upsilon_\ell(X) = \frac{1}{G_\ell^2(X) + F_\ell^2(X)} \tag{17}$$

$$\upsilon_\ell'(X) = \left[\left(\frac{dG_\ell}{dx}\right)^2 + \left(\frac{dF_\ell}{dx}\right)^2\right]_{x=X} \tag{18}$$

$$F_\ell(x) = \left(\frac{\pi x}{2}\right)^{\frac{1}{2}} J_{\ell+\frac{1}{2}}(x) \tag{19}$$

$$G_\ell(x) = (-1)^\ell \left(\frac{\pi x}{2}\right)^{\frac{1}{2}} J_{-\left(\ell+\frac{1}{2}\right)}(x) \quad . \tag{20}$$

The incident channel radius is R which, in the case of neutron bombardment, is simply the radius of the target nucleus. This radius is assumed to be given by

$$R = r_0 A^{\frac{1}{3}} \tag{21}$$

where A is the mass number and r_0 is approximately 1.5 fermi. The wave number K within the nucleus can be approximated by

$$K = (K_0^2 + k^2)^{\frac{1}{2}} \tag{22}$$

where

$$K_0 = \left(\frac{9\pi}{8}\right)^{\frac{1}{3}} \frac{1}{r_0} \quad . \tag{23}$$

The Bessel function of half-integral order $J_{\pm\left(\ell+\frac{1}{2}\right)}$ is defined in Reference 9 and can be evaluated from a closed expression given in Reference 10 as

$$J_{\pm\left(\ell+\frac{1}{2}\right)}(x) = \left(\frac{2}{\pi x}\right)^{\frac{1}{2}} \left[P_{\mp} S_1(\ell, x) \pm Q_{\mp} S_2(\ell, x)\right] \tag{24}$$

where

$$S_1(\ell, x) = \sum_{i=0}^{\leq \ell/2} \frac{(-1)^i (\ell + 2i)!}{(2i)!\,(\ell - 2i)!\,(2x)^{2i}} \quad , \tag{25}$$

$$S_2(\ell, x) = \sum_{i=0}^{\leq(\ell-1)/2} \frac{(-1)^i (\ell + 2i + 1)!}{(2i + 1)!\ (\ell - 2i - 1)!\ (2x)^{2i+1}} \quad , \tag{26}$$

$$P_- = \sin(x - \ell\,\pi/2) \quad , \tag{27}$$

$$P_+ = \cos(x + \ell\,\pi/2) \quad , \tag{28}$$

$$Q_- = \cos(x - \ell\,\pi/2) \quad , \tag{29}$$

and

$$Q_+ = \sin(x + \ell\,\pi/2) \quad . \tag{30}$$

The quantities υ_ℓ and υ_ℓ' can be written explicitly in terms of the sums S_1 and S_2 as

$$\upsilon_\ell(X) = S_1^2(\ell, X) + S_2^2(\ell, X) \tag{31}$$

and

$$\upsilon_\ell'(X) = \left[\left(\frac{dS_1}{dx} - S_2\right)^2 + \left(\frac{dS_2}{dx} + S_1\right)^2\right]_{x=X} \quad . \tag{32}$$

Values of the dimensionless quantity $\sigma_c/\pi R^2$ can be tabulated once and for all as a function of the dimensionless quantities x and X_0 where

$$x = k R \tag{33}$$

and

$$X_0 = K_0 R \quad . \tag{34}$$

CODE DESCRIPTION

Given the mass and bombarding energy of an incident uncharged particle and the radius of the target nucleus, one can obtain σ_c for this reaction from the table. The computer code generates such a table and stores it on an auxiliary tape for repeated use. At the beginning of each energy distribution computation, the values of $\sigma_c/\pi R^2$ are transferred from the tape into the array SICO(J, I) for which the index J, which labels X_0, runs from 1 through 17 and the index I, which labels x, runs from 1 through 36. The value of X_0 corresponding to a specified J value is given by

$$X_0 = (J + 5)/2 \quad . \tag{35}$$

The value of $\log_{10} x$ corresponding to a specified I value is given by

$$\log_{10} x = -2 + (I - 1)/10 \quad . \tag{36}$$

Thus, 17×36 values of $\sigma_c/\pi R^2$ are tabulated at points (X_0, x) where

$$X_0 = 3, 3.5, 4, \ldots, 11 \tag{37}$$

and

$$x = 10^{-2}, 10^{-1.9}, 10^{-1.8}, \ldots, 10^{+1.5} \quad . \tag{38}$$

A portion of these cross section values is plotted in Figure 2.

The main program computes $\sigma_c/\pi R^2$ using Equations 14, 16, 31, and 32. The summation in Equation 14 is terminated at the point beyond which the contribution from additional partial cross sections is negligible. The transmission coefficients are calculated by the TRANS(TL, L, XS, XL) subroutine. The FORTRAN arguments L,

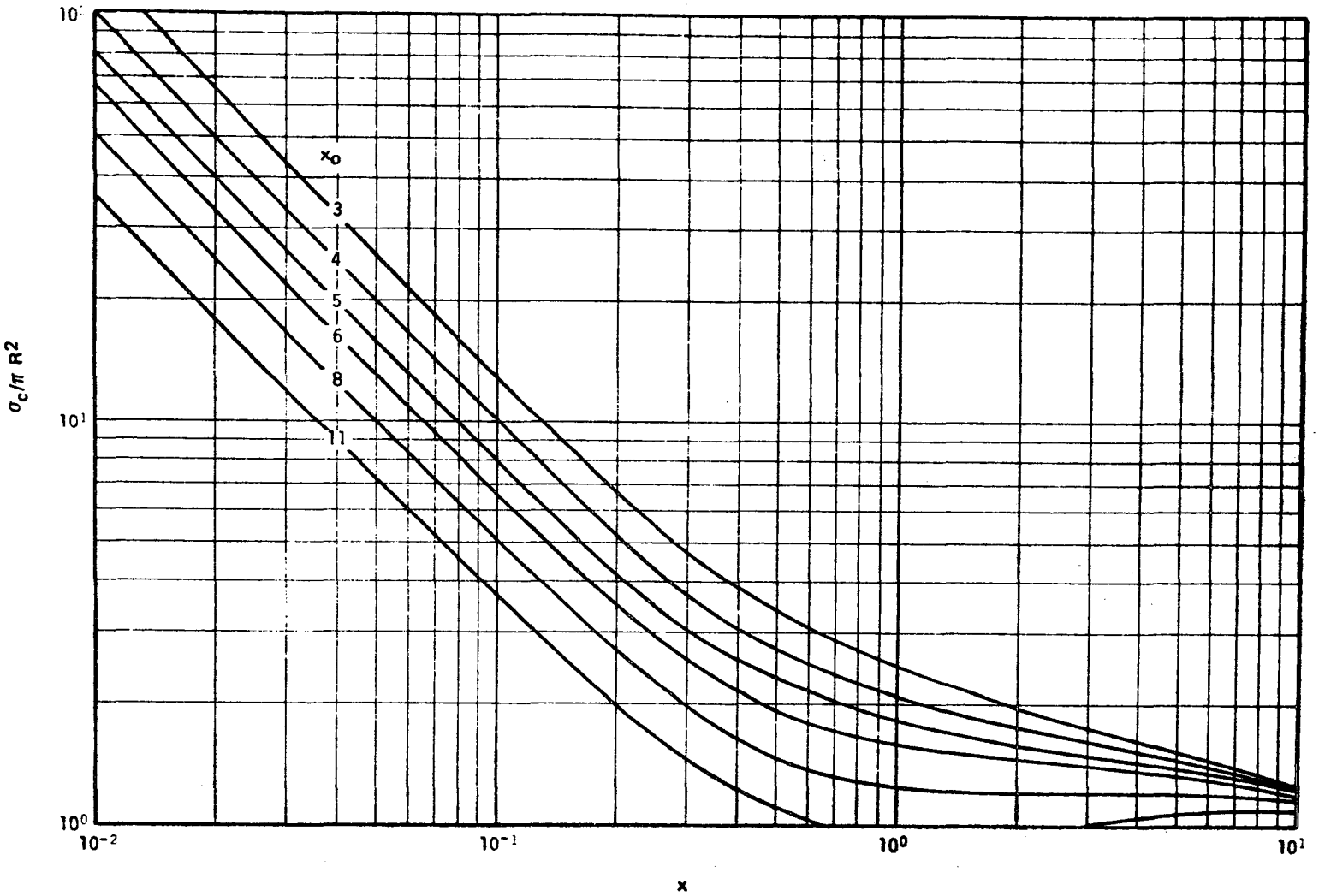

FIGURE 2. CROSS SECTIONS FOR COMPOUND NUCLEUS FORMATION BY UNCHARGED PARTICLES AS CALCULATED BY THE CONTINUUM THEORY

XS, and XL represent ℓ, x, and X of the above formulation; and TL represents the desired transmission coefficient T_ℓ which is returned to the main program.

In the course of an energy distribution computation the cross section for compound nucleus formation is required, not only for the original reaction, but for each possible inverse reaction as well. Thus, σ_c must be determined for reactions between various projectile-target pairs at various bombarding energies. The preceding formulation applies to reactions for which the bombarding particle is uncharged. Additional cross sections for compound nucleus formation are required in the treatment of cases in which the bombarding particle is a proton or α-particle. SPECTER employs tables of such cross sections obtained from Reference 4. The tables contain values of σ_c for protons and α-particles as a function of bombarding energy and target Z number. Values of σ_c are tabulated for r_0 values of 1.3 and 1.5 Fermi. The tables are input in card form, and optionally may be stored on the auxiliary tape for repeated use. The tabulated values are stored in the CSP array for protons and in the CSA array for α-particles. The tabulation is employed in cases for which the bombarding energy is less than 1.8 times the Coulomb barrier height V(R), where

$$V(R) = Z_y Z_Y e^2/R \quad . \tag{39}$$

Here Z_y and Z_Y are the proton numbers of the projectile and target, respectively, and e is the electronic charge. R is the channel radius, which in the case of proton bombardment is identical to the target radius. For α-particle bombardment, however, the channel radius is obtained by adding the α-particle radius ($\sim$1.2 Fermi) to the target radius. For bombardment by a charged particle of energy ϵ_y which is greater than 1.8 V(R) the following asymptotic formula is used:

$$\sigma_c \sim \sigma_c(u, \epsilon_y) \left[1 - \frac{V(R + \lambda\!\!\!^{-})}{\epsilon_y}\right], \qquad (40)$$

where $\sigma_c(u, \epsilon_y)$ is the cross section for compound nucleus formation by an uncharged particle u considered as having the same properties as y excepting the charge.

The subroutine COMPO (COM, JN, JZ, KIND, CHE) provides values of σ_c as requested by the main program. The main program specifies the neutron and proton number of the target nucleus, the type of incident particle, and the bombarding energy. These variables are represented by the FORTRAN arguments JN, JZ, KIND, and CHE, respectively. If the incident particle is a neutron, then subroutine NEUT is called. It is the function of NEUT to supply σ_c for the case in which the incident particle is uncharged. If the incident particle is a proton or α-particle, and the bombarding energy is greater than 1.8 times the Coulomb barrier height, then the appropriate value of σ_c for the corresponding uncharged particle is obtained from the NEUT routine. This cross section is then modified in accordance with Equation 40 to obtain σ_c for proton or α-particle bombardment. If, however, the incident particle is a proton or α-particle, and the bombarding energy is less than 1.8 times the Coulomb barrier height, then the cross section is extracted from the CSP or the CSA array with interpolation between tabulated values being employed as required.

The subroutine DENS (XE, PAIR, CP, AP, RHO) is included in the code listing appearing in the appendix. This subroutine calculates the density of levels of a specified nucleus in the neighborhood of a specified excitation energy. DENS employs a commonly adopted expression for the level density which is derived from the Fermi-gas model. The level density ρ is given as a function of the excitation energy E* by

$$\rho(E^*) = C \exp\left[(2aE^*)^{\frac{1}{2}}\right]. \qquad (41)$$

The level structure of a given nucleus is thus assumed to be characterized by the parameters C and a. DENS is called by the main program which furnishes values of these parameters and the excitation energy E*. The FORTRAN variables which represent these quantities are CP, AP, and XE, respectively, and RHO represents the calculated level density. For all but odd-odd nuclei the excitation energy to be used in Equation 41 should be shifted downward to take into account pairing effects (Ref. 11). For this purpose the fictitious excitation energy U given by

$$U = E^* + P(N) + P(Z) \qquad (42)$$

is introduced. Here, the negative quantities P(N) and P(Z) are the pairing energies for neutrons and protons, respectively. These quantities are tabulated in Reference 12. The absolute value of the total pairing energy $P(N) + P(Z)$ for the residual nucleus under consideration is represented by the FORTRAN variable PAIR. It is possible that the user may wish to use either a different analytical expression or a non-analytical representation of ρ. In this event the DENS subroutine may be suitably modified or replaced.

INPUT DATA PREPARATION

First Input Card

The first input card contains the control number ICON (FORMAT (I2)).

If ICON is assigned the value 1, then auxiliary tape 11 will be written, rewound, and read; and the program will proceed with the calculation for the problem defined by the data on the eight succeeding input cards.

If ICON is 2, it will be assumed that tape 11 has already been written. In this case tape 11 will be read, and the program will proceed

with the calculation. Once the cross sections for compound nucleus formation have been written on tape 11, this tape may be retained and used for successive problems in the same run or for subsequent runs. The cross sections on the tape do not depend on any of the input data defined below.

If ICON is 3, then tape 11 will be rewound and the run will be terminated.

For the initial run only, 68 cards are read in at this point. These cards contain a tabulation of cross sections for compound nucleus formation by protons and α-particles as a function of bombarding energy and target Z-number. This information, which is independent of all other input quantities, is then transferred from the cards to auxiliary tape 11. Therefore, for subsequent runs these cards are not required as input.

Second Input Card

The second input card contains values of RZ (FORMAT (F6.2)). RZ is the quantity r_0 of Equation 21, where R is the nuclear radius and A is the nuclear mass number. This quantity must satisfy $1.3 \leqq RZ \leqq 1.5$. It should be expressed in Fermi units.

Third Input Card

The third input card contains values of JTN, JTZ, KIND, BET, and BEC (FORMAT(3I4, 6X, 2F10.4)).

JTN and JTZ are the neutron and proton numbers, respectively, of the target nucleus. KIND specifies whether the incident particle is a neutron, proton, or α-particle:

- KIND = 1 implies neutron
- KIND = 2 implies proton
- KIND = 3 implies α-particle.

BET and BEC are the total binding energies of the target nucleus and compound nucleus, respectively. These quantities should be expressed in MeV units.

Fourth Input Card

The fourth input card contains values of JAN(M) for M = 1, 2, ···, 7 (FORMAT(7I4)). The index M labels the exit channels according to the scheme depicted in Figure 3. If a given channel I is known to be closed, then JAN(I) is assigned the value 0. Otherwise, JAN(I) is assigned the value 1.

Fifth Input Card

The fifth input card contains values of BE(M) for M = 1, 2, ···, 7 (FORMAT(7F10.4)). BE(I) is the total binding energy of the residual nucleus RN(I) (see Figure 3) which remains after a particle emission through the channel designated by I. The quantities should be expressed in MeV units.

Sixth Input Card

The sixth input card contains values of C(M) for M = 1, 2, ···, 7 (FORMAT(7F10.4)). C(I) is the level density parameter c appearing in Equations 42 and 43 for the level density of residual nucleus I. These quantities should be expressed in units of $(MeV)^{-1}$.

Seventh Input Card

The seventh input card contains values of A(M) for M = 1, 2, ···, 7 (FORMAT(7F10.4)). A(I) is the level density parameter a appearing in Equations 42 and 43 for the level density of residual nucleus I. These quantities should be expressed in units of $(MeV)^{-1}$.

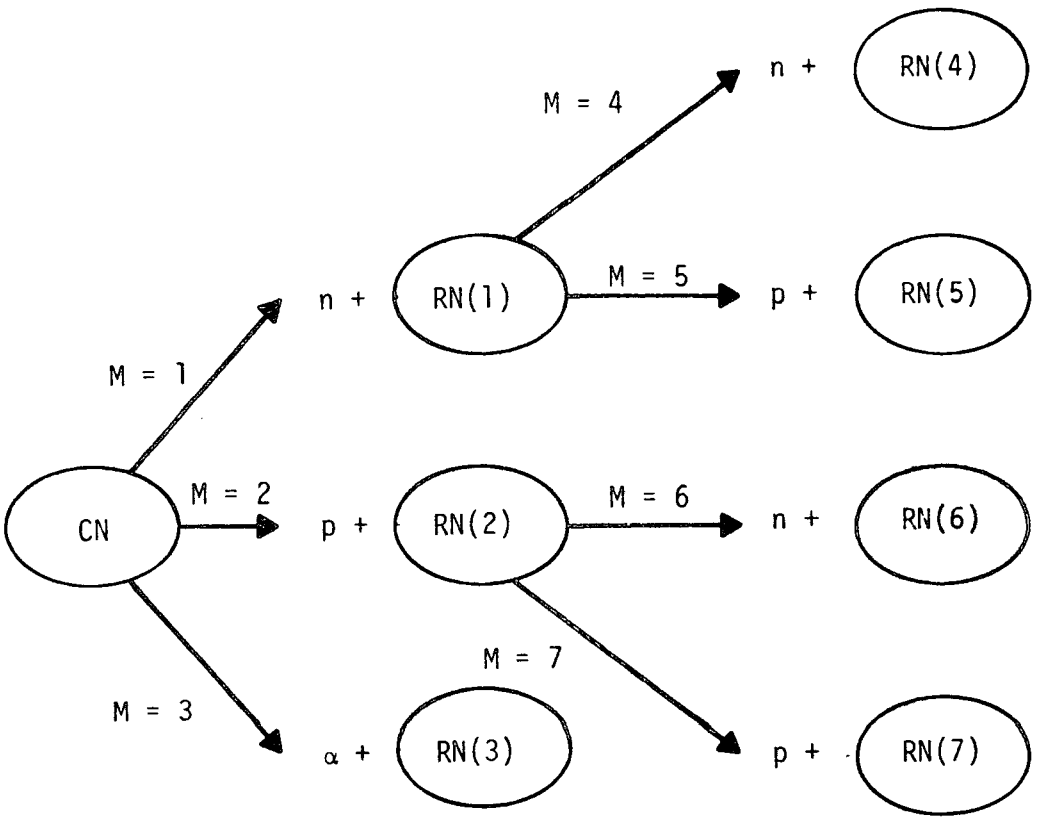

FIGURE 3. POSSIBLE DECAY MODES OF THE COMPOUND NUCLEUS (CN) AND THE VARIOUS RESIDUAL NUCLEI RN(M)

Eighth Input Card

The eighth input card contains values of PE(M) for M = 1, 2, . . . , 7 (FORMAT(7F10. 4)). PE(I) is the absolute value of the sum of the pairing energies P(N) and P(Z) for the residual nucleus I (see Equation 42). The se quantities should be expressed in MeV units.

Ninth Input Card

The ninth input card contains values of EIN and IN (FORMAT (F7. 3, I4)). EIN is the bombarding energy in MeV units. IN is the number of energy mesh points (equally spaced) at which the energy distribution calculations are made.

OUTPUT DATA INTERPRETATION

The first set of results to be printed out consists of total cross sections for each of the reactions under consideration. The incident particle is denoted by y, and the possible emergent particles are n, p, and α. The FORTRAN variable representing the cross section for each reaction is given below

Reaction	Cross Section
y, n	SYN
y, p	SYP
y, α	SYA
y, 2n	SYNN
y, np	SYNP
y, pn	SYPN
y, 2p	SYPP.

The remaining output gives the calculated probability densities which describe the energy distributions of the particles emerging from the reaction. In general, there will be seven sets of data, each corre-

sponding to a particular exit channel as shown in Figure 3. In a particular case, of course, sets corresponding to a closed exit channel may not appear. The seven sets of probability density are

- P1(1, I), which describes the energy distribution of a neutron emitted by CN
- P1(2, I), which describes the energy distribution of a proton emitted by CN
- P1(3, I), which describes the energy distribution of a α-particle emitted by CN
- P2(1, 1, I), which describes the energy distribution of a neutron emitted by RN(1)
- P2(1, 2, I), which describes the energy distribution of a proton emitted by RN(1)
- P2(2, 1, I), which describes the energy distribution of a neutron emitted by RN(2)
- P2(2, 2, I), which describes the energy distribution of a proton emitted by RN(2).

The index I which labels the energy mesh point appears in the first column of the output. The energy corresponding to I and the probability density evaluated at this energy are displayed in the second and third columns, respectively.

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APPENDIX A

COMPUTER PROGRAM LISTING

```
      DIMENSION BE(7),C(7),A(7),PE(7),DEL(7),P1(3,50),
     1  AR1(3),P12A(2,2,50,50),AR2(2,2,50,50),P12(2,2,50),AR12(2,2),
     2  EMA(7),SPA(7),FLOG(71),SICO(18,37),JAN(7),
     3  JIN(7),JIZ(7),CHAM(7),SWAT(7),PA(9),CSP(2,18,10),CSA(2,18,10)
      COMMON FLOG,SICO,CSP,CSA,RZC,RALC,RMNC,RMPC,RMAC,ELEC,HBAR,PI
  505 READ(5,500)ICON
      GO TO (501,502,503),ICON
  501 REWIND 11
      FLOG(1)=0.
      DO 5 IT=2,71
      FIT=FLOAT(IT-1)
    5 FLOG(IT)=ALOG(FIT)+FLOG(IT-1)
      SPACE=0.1
      DO 822 J=1,17
      Y=(FLOAT(J+5))/2.
      DO 822 I=1,36
      XX=-2.+(SPACE*FLOAT(I-1))
      XS=10.**XX
      XL=SQRT((Y*Y)+(XS*XS))
      L=0
      SIC=0.
    7 FAC=((2.*FLOAT(L))+1.)/(XS*XS)
      TIC=SIC
      CALL TRANS(TL,L,XS,XL)
      SIC=SIC+(FAC*TL)
      IF((TIC/SIC)-0.99) 33,822,822
33    L=L+1
      GO TO 7
  822 WRITE (11,24) J,I,XX,XS,SIC
 8000 READ(5,8001) (PA(NZ),NZ=1,9),KI,KR,NY
      WRITE(11,8002) (PA(NZ),NZ=1,9),KI,KR,NY
      GO TO (8000,8000,502),KI
  502 REWIND 11
      DO 506 J=1,17
      DO 506 I=1,36
      READ(11,24)J,I,XX,XS,SIC
  506 SICO(J,I)=SIC
      DO 8200 J=1,18
 8200 SICO(J,37)=0.
      DO 8300 I=1,37
 8300 SICO(18,I)=0.
 8004 READ(11,8002) (PA(NZ),NZ=1,9),KI,KR,NY
      GO TO (8005,8005,504),KI
 8005 DO 8008 NZ=1,9
      GO TO (8006,8007),KI
 8006 CSP(KR,NY,NZ)=PA(NZ)
      GO TO 8008
 8007 CSA(KR,NY,NZ)=PA(NZ)
 8008 CONTINUE
      GO TO 8004
```

```
  503 REWIND 11
      CALL EXIT
  504 DO 8009 KR=1,2
      DO 8009 NY=1,18
      CSP(KR,NY,10)=0.
 8009 CSA(KR,NY,10)=0.
      DO 8010 KR=1,2
      DO 8010 NZ=1,10
      CSP(KR,18,NZ)=0.
 8010 CSA(KR,18,NZ)=0.
      READ (5,600) RZ
      READ(5,602)JTN,JTZ,KIND,BET,BEC
      READ(5,696)(JAN(M),M=1,7)
      READ(5,603)(BE(M),M=1,7)
      READ (5,603) (C(M),M=1,7)
      READ(5,603)(A(M),M=1,7)
      READ(5,603) (PE(M),M=1,7)
      READ (5,604) EIN,IN
      WRITE(6,620)RZ
      WRITE(6,621)JTN,JTZ,KIND,BET,BEC
      WRITE (6,697)
      WRITE (6,698) (JAN(M),M=1,7)
      WRITE(6,622)
      WRITE(6,623)(BE(M),M=1,7)
      WRITE (6,690)
      WRITE (6,623) (C(M),M=1,7)
      WRITE(6,624)
      WRITE(6,623)(A(M),M=1,7)
      WRITE(6,627)
      WRITE(6,623) (PE(M),M=1,7)
      WRITE (6,626) EIN,IN
      INC=IN-1
      RMN=939.505
      RMP=938.211
      RMA=3727.149
      RAL=1.2
      PI=3.1415926536
      HBAR=1.05443E-27
      ELEC=4.80286E-10
      RZC=RZ*1.0E-13
      RALC=RAL*1.0E-13
      RMNC=RMN/5.61000E+26
      RMPC=RMP/5.61000E+26
      RMAC=RMA/5.61000E+26
      GO TO (300,301,302),KIND
  300 JCNN=JTN+1
      JCNZ=JTZ
      GO TO 303
  301 JCNN=JTN
      JCNZ=JTZ+1
      GO TO 303
  302 JCNN=JTN+2
      JCNZ=JTZ+2
  303 CALL COMPO(COM,JTN,JTZ,KIND,EIN)
      SIG=COM
      JIN(1)=JCNN-1
      JIN(2)=JCNN
      JIN(3)=JCNN-2
      JIN(4)=JCNN-2
```

```
      JIN(5)=JCNN-1
      JIN(6)=JCNN-1
      JIN(7)=JCNN
      JIZ(1)=JCNZ
      JIZ(2)=JCNZ-1
      JIZ(3)=JCNZ-2
      JIZ(4)=JCNZ
      JIZ(5)=JCNZ-1
      JIZ(6)=JCNZ-1
      JIZ(7)=JCNZ-2
      CHAM(1)=RMN
      CHAM(2)=RMP
      CHAM(3)=RMA
      CHAM(4)=RMN
      CHAM(5)=RMP
      CHAM(6)=RMN
      CHAM(7)=RMP
      SWAT(1)=2.
      SWAT(2)=2.
      SWAT(3)=1.
      SWAT(4)=2.
      SWAT(5)=2.
      SWAT(6)=2.
      SWAT(7)=2.
      DELTA=BEC-BET
      DEL(1)=BEC-BE(1)
      DEL(2)=BEC-BE(2)
      DEL(3)=BEC-BE(3)
      DEL(4)=BE(1)-BE(4)
      DEL(5)=BE(1)-BE(5)
      DEL(6)=BE(2)-BE(6)
      DEL(7)=BE(2)-BE(7)
      DO 700 M=1,3
      AR1(M)=0.
      DO 700 J=1,IN
700   P1(M,J)=0.
      DO 750 M=1,2
      DO 750 K=1,2
      AR12(M,K)=0.
      DO 750 I=1,50
      P12(M,K,I)=0.
      DO 750 J=1,50
      P12A(M,K,J,I)=0.
750   AR2(M,K,J,I)=0.
      DO 11 M=1,3
      KAN=JAN(M)+1
      GO TO(11,702),KAN
702   EMA(M)=EIN+DELTA-DEL(M)
      IF(EMA(M)-0.1)11,11,60
60    SPA(M)=EMA(M)/FLOAT(INC)
      JN=JIN(M)
      JZ=JIZ(M)
      CHM=CHAM(M)
      SW=SWAT(M)
      CP=C(M)
      AP=A(M)
      PAIR=PE(M)
      DO 111 J=2,IN
      CHE=FLOAT(J-1)*SPA(M)
```

```
      CALL COMPO(COM,JN,JZ,M,CHE)
      XE=EMA(M)-CHE
      CALL DENS(XE,PAIR,CP,AP,RHO)
      P1(M,J)=SW*CHE*CHM*COM*RHO
  111 CONTINUE
   11 CONTINUE
      DO 12 M=1,3
      KAN=JAN(M)+1
      GO TO (12,703),KAN
  703 IF(EMA(M)-0.1)12,12,61
   61 DO 13 J=1,INC
      AJ=(P1(M,J)+P1(M,J+1))/2.
      AJ=AJ*SPA(M)
   13 AR1(M)=AR1(M)+AJ
   12 CONTINUE
      SUM1=AR1(1)+AR1(2)+AR1(3)
      DO 20 M=1,2
      KAN=JAN(M)+1
      GO TO (20,910),KAN
  910 IF(EMA(M)-0.1) 20,20,911
  911 JN1=JIN(M)
      JZ1=JIZ(M)
      CHM1=CHAM(M)
      SW1=SWAT(M)
      CP1=C(M)
      AP1=A(M)
      PR1=PE(M)
      DO 21 K=1,2
      MM=(2*M)+K+1
      KAN=JAN(MM)+1
      GO TO (21,705),KAN
  705 EMA(MM)=EIN+DELTA-DEL(M)-DEL(MM)
      IF(EMA(MM)-0.1) 21,21,970
  970 SPA(MM)=EMA(MM)/FLOAT(INC)
      JN2=JIN(MM)
      JZ2=JIZ(MM)
      CHM2=CHAM(MM)
      SW2=SWAT(MM)
      CP2=C(MM)
      AP2=A(MM)
      PR2=PE(MM)
      DO 2022 I=2,IN
      CHE2=FLOAT(I-1)*SPA(MM)
      EMA1=EMA(MM)-CHE2
      IF(EMA1-0.1)2022,2022,3022
 3022 SPA1=EMA1/FLOAT(INC)
      CALL COMPO(COM2,JN2,JZ2,K,CHE2)
      DO 2023 J=2,IN
      CHE1=FLOAT(J-1)*SPA1
      EMAX=EMA(MM)-CHE1
      SPACE=EMAX/FLOAT(INC)
      CALL COMPO(COM1,JN1,JZ1,M,CHE1)
      XE1=EMA(M)-CHE1
      XE2=EMA1-CHE1
      CALL DENS(XE1,PR1,CP1,AP1,RHO1)
      CALL DENS(XE2,PR2,CP2,AP2,RHO2)
      P1A=SW1*CHE1*CHM1*COM1*RHO1
      P2A=SW2*CHE2*CHM2*COM2*RHO2
      P12A(M,K,J,I)=P1A*P2A
```

```
      DO 2024 II=1,INC
      X=FLOAT(II)*SPACE
      CALL COMPO(COM,JN2,JZ2,K,X)
      XE=EMAX-X
      CALL DENS(XE,PR2,CP2,AP2,RHO)
      FUNC=SW2*X*CHM2*COM*RHO
 2024 AR2(M,K,J,I)=AR2(M,K,J,I)+FUNC
      AR2(M,K,J,I)=(AR2(M,K,J,I)-(FUNC/2.))*SPACE
 2023 CONTINUE
 2022 CONTINUE
   21 CONTINUE
   20 CONTINUE
      DO 400 M=1,2
      KAN=JAN(M)+1
      GO TO (400,920),KAN
  920 IF(EMA(M)-0.1) 400,400,921
  921 DO 401 K=1,2
      MM=(2*M)+K+1
      KAN=JAN(MM)+1
      GO TO (401,922),KAN
  922 IF(EMA(MM)-0.1) 401,401,992
  992 DO 402 I=2,IN
      CHE2=FLOAT(I-1)*SPA(MM)
      EMA1=EMA(MM)-CHE2
      IF(EMA1-0.1)402,402,404
  404 SPA1=EMA1/FLOAT(INC)
      DO 403 J=1,INC
      SUM2=AR2(M,1,J,I)+AR2(M,2,J,I)
      AJ1=P12A(M,K,J,I)/(SUM1*SUM2)
      SUM2=AR2(M,1,J+1,I)+AR2(M,2,J+1,I)
      AJ2=P12A(M,K,J+1,I)/(SUM1*SUM2)
      AJ=(AJ1+AJ2)/2.
  403 P12(M,K,I)=P12(M,K,I)+(AJ*SPA1)
  402 CONTINUE
  401 CONTINUE
  400 CONTINUE
      DO 450 M=1,2
      KAN=JAN(M)+1
      GO TO (450,380),KAN
  380 IF(EMA(M)-0.1) 450,450,381
  381 DO 451 K=1,2
      MM=(2*M)+K+1
      KAN=JAN(MM)+1
      GO TO (451,709),KAN
  709 IF(EMA(MM)-0.1) 451,451,382
  382 DO 460 I=1,INC
      AI=(P12(M,K,I)+P12(M,K,I+1))/2.
      AI=AI*SPA(MM)
  460 AR12(M,K)=AR12(M,K)+AI
  451 CONTINUE
  450 CONTINUE
      SYN=SIG*((AR1(1)/SUM1)-AR12(1,1)-AR12(1,2))
      SYP=SIG*((AR1(2)/SUM1)-AR12(2,1)-AR12(2,2))
      SYA=SIG*(AR1(3)/SUM1)
      SYNN=SIG*AR12(1,1)
      SYNP=SIG*AR12(1,2)
      SYPN=SIG*AR12(2,1)
      SYPP=SIG*AR12(2,2)
      WRITE(6,522)
```

```
      WRITE (6,523) SYN,SYP,SYA,SYNN,SYNP,SYPN,SYPP
      DO 470 M=1,3
      KAN=JAN(M)+1
      GO TO (470,710),KAN
  710 IF(EMA(M)-0.1) 470,470,471
  471 WRITE(6,481)M
      DO 482 J=1,IN
      EOUT=FLOAT(J-1)*SPA(M)
      SP1=P1(M,J)/SUM1
  482 WRITE (6,483) J,EOUT,SP1
  470 CONTINUE
      DO 492 M=1,2
      KAN=JAN(M)+1
      GO TO(492,395),KAN
  395 IF(EMA(M)-0.1) 492,492,396
  396 DO 493 K=1,2
      MM=(2*M)+K+1
      KAN=JAN(MM)+1
      GO TO(493,711),KAN
  711 IF(EMA(MM)-0.1) 493,493,397
  397 WRITE(6,491)M,K
      DO 494 I=1,IN
      EOUT=FLOAT(I-1)*SPA(MM)
      SP12=P12(M,K,I)
      WRITE(6,483)I,EOUT,SP12
  494 CONTINUE
  493 CONTINUE
  492 CONTINUE
      GO TO 505
  500 FORMAT(I2)
   24 FORMAT(2I3,4H XX=F6.3,5H  XS=E15.8,6H  SIC=E15.8)
  600 FORMAT(F6.2)
  602 FORMAT(3I4,6X,2F10.4)
  603 FORMAT(7F10.4)
  604 FORMAT(F7.3,I4)
  626 FORMAT(/5H EIN=F7.3,10X,5H  IN=I4)
  620 FORMAT(4H1RZ=F6.2)
  621 FORMAT(/5H JTN=I4,5H JTZ=I4,6H KIND=I4,5H BET=F10.4,5H BEC=F10.4)
  622 FORMAT(//50X,12H BE(M),M=1,7)
  623 FORMAT(/7(F10.4,8X))
  690 FORMAT(//50X,11H C(M),M=1,7)
  624 FORMAT(//50X,11H A(M),M=1,7)
  627 FORMAT(//50X,12H PE(M),M=1,7)
  696 FORMAT(7I4)
  697 FORMAT(//50X,13H JAN(M),M=1,7)
  698 FORMAT(/7(I9,8X))
  481 FORMAT(4H1  J,10X,7H ENERGY,10X,4H P1(I2,5H , J))
  483 FORMAT(/I4,7X,E15.8,6X,E15.8)
  491 FORMAT(4H1  I,10X,7H ENERGY,10X,5H P12(I2,2H ,I2,5H , I))
  522 FORMAT(2H1 ,35X,
     1   52H TOTAL CROSS SECTION IN BARN UNITS FOR EACH REACTION)
  523 FORMAT(5H SYN=E15.8//5H SYP=E15.8//5H SYA=E15.8
     1    //6H SYNN=E15.8//6H SYNP=E15.8//6H SYPN=E15.8//6H SYPP=E15.8)
 8001 FORMAT(E7.2,8E8.2,2X,2I2,I3)
 8002 FORMAT(9(1X,E9.2),4X,2I2,I3)
      END
```

```
      SUBROUTINE COMPO(COM,JN,JZ,KIND,CHE)
      DIMENSION C1(2),C2(2),C3(2),C4(2),C12(2),C34(2),C(2)
      DIMENSION FLOG(71),SICO(18,37),CSP(2,18,10),CSA(2,18,10)
      COMMON FLOG,SICO,CSP,CSA,RZC,RALC,RMNC,RMPC,RMAC,ELEC,HBAR,PI
      GO TO (1,2,2),KIND
    1 CALL NEUT(CM,JN,JZ,KIND,CHE)
      COM=CM
      RETURN
    2 IF(JZ-10) 50,3,51
   51 IF(JZ-90) 3,3,50
   50 WRITE(6,666)
  666 FORMAT(29H CROSS SECTION TABLE EXCEEDED)
   20 CALL EXIT
    3 GO TO (20,5,6),KIND
    5 CHAR=RZC*((FLOAT(JN+JZ))**(1./3.))
      B=(FLOAT(JZ)*ELEC*ELEC)/CHAR
      GO TO 7
    6 CHAR=(RZC*((FLOAT(JN+JZ))**(1./3.)))+RALC
      B=(2.*FLOAT(JZ)*ELEC*ELEC)/CHAR
    7 CHEC=CHE*1.60206E-6
      Y=CHEC/B
      IF(Y-0.2)60,61,62
   60 COM=0.
      RETURN
   62 IF(Y-1.8)61,61,63
   63 GO TO (20,71,72),KIND
   71 BLAM=HBAR/(SQRT(2.*RMPC*CHEC))
      BL=(FLOAT(JZ)*ELEC*ELEC)/(CHAR+BLAM)
      GO TO 81
   72 BLAM=HBAR/(SQRT(2.*RMAC*CHEC))
      BL=(2.*FLOAT(JZ)*ELEC*ELEC)/(CHAR+BLAM)
   81 BFAC=1.-(BL/CHEC)
      CALL NEUT(CM,JN,JZ,KIND,CHE)
      COM=BFAC*CM
      RETURN
   61 ANY=10.*ABS(Y-0.2)
      NY=ANY
      FNY=NY
      DNY=ANY-FNY
      ANZ=FLOAT(JZ-10)/10.
      NZ=ANZ
      FNZ=NZ
      DNZ=ANZ-FNZ
      DO 100 I=1,2
      GO TO (20,82,83),KIND
   82 C1(I)=CSP(I,NY+1,NZ+1)
      C2(I)=CSP(I,NY+1,NZ+2)
      C3(I)=CSP(I,NY+2,NZ+1)
      C4(I)=CSP(I,NY+2,NZ+2)
      GO TO 84
```

```
 83 C1(I)=CSA(I,NY+1,NZ+1)
    C2(I)=CSA(I,NY+1,NZ+2)
    C3(I)=CSA(I,NY+2,NZ+1)
    C4(I)=CSA(I,NY+2,NZ+2)
 84 C1(I)=ALOG10(C1(I))
    C2(I)=ALOG10(C2(I))
    C3(I)=ALOG10(C3(I))
    C4(I)=ALOG10(C4(I))
    C12(I)=C1(I)+(DNZ*(C2(I)-C1(I)))
    C34(I)=C3(I)+(DNZ*(C4(I)-C3(I)))
    C(I)=C12(I)+(DNY*(C34(I)-C12(I)))
100 C(I)=10.**C(I)
    RZ=RZC*1.0E+13
    FRAC=(RZ-1.3)/(1.5-1.3)
    COM=C(1)+(FRAC*(C(2)-C(1)))
    RETURN
    END
```

```
      SUBROUTINE NEUT(CM,JN,JZ,KIND,CHE)
      DIMENSION FLOG(71),SICO(18,37),CSP(2,18,10),CSA(2,18,10)
      COMMON FLOG,SICO,CSP,CSA,RZC,RALC,RMNC,RMPC,RMAC,ELEC,HBAR,PI
      CHEC=CHE*1.60206E-6
      ZK=(((9.*PI)/8.)**(1./3.))/RZC
      TA=JN+JZ
      TR=RZC*(TA**(1./3.))
      GO TO (1,2,3),KIND
    1 CHAR=TR
      CHM=RMNC
      GO TO 4
    2 CHAR=TR
      CHM=RMPC
      GO TO 4
    3 CHAR=TR+RALC
      CHM=RMAC
    4 XZ=ZK*CHAR
      IF(XZ-3.)18,23,19
   19 IF(XZ-11.)23,23,18
   23 ANJ=ABS((2.*XZ)-6.)
      NJ=ANJ
      FNJ=NJ
      DNJ=ANJ-FNJ
      SK=(SQRT(2.*CHM*CHEC))/HBAR
      X=SK*CHAR
      XG=ALOG10(X)
      XGN=XG+2.
      IF(XGN)18,33,22
   22 IF(XGN-3.5)33,33,18
   33 SPACE=0.1
      ANI=ABS(XGN/SPACE)
      NI=ANI
      FNI=NI
      DNI=ANI-FNI
      C1=SICO(NJ+1,NI+1)
      C2=SICO(NJ+1,NI+2)
      C3=SICO(NJ+2,NI+1)
      C4=SICO(NJ+2,NI+2)
      C12=C1+(DNI*(C2-C1))
      C34=C3+(DNI*(C4-C3))
      CM=C12+(DNJ*(C34-C12))
      CM=(CM*PI*CHAR*CHAR)/1.0E-24
      GO TO 50
   18 WRITE(6,20)
   20 FORMAT(29H CROSS SECTION TABLE EXCEEDED)
      CALL EXIT
   50 RETURN
      END
```

```
      SUBROUTINE TRANS(TL,L,XS,XL)
      DIMENSION FLOG(71)
      COMMON FLOG
      IMAX=L/2
      IMAX=IMAX+1
      SUM1=0.
      DSUM1=0.
      DO 1 J=1,IMAX
      I=J-1
      FI=I
      I1=L+(2*I)
      I2=2*I
      I3=L-(2*I)
      IF(I1-70) 80,80,90
   80 IF(I2-70) 81,81,90
   81 IF(I3-70) 82,82,90
   82 AX=FLOG(I1+1)-FLOG(I2+1)-FLOG(I3+1)
      AX=AX-(2.*FI*ALOG(ABS(2.*XS)))
      AX=EXP(AX)
      FONE=(2.*FI)/XS
      AXX=AX*FONE
      KI=I/2
      IF((2*KI)-I)8,9,8
    8 SUM1=SUM1-AX
      DSUM1=DSUM1+AXX
      GO TO 1
    9 SUM1=SUM1+AX
      DSUM1=DSUM1-AXX
    1 CONTINUE
      SUM2=0.
      DSUM2=0.
      IF(L)6,6,7
    7 IMAX=(L-1)/2
      IMAX=IMAX+1
      DO 2 J=1,IMAX
      I=J-1
      FI=I
      I1=L+(2*I)+1
      I2=(2*I)+1
      I3=L-(2*I)-1
      IF(I1-70) 83,83,90
   83 IF(I2-70) 84,84,90
   84 IF(I3-70) 85,85,90
   85 AX=FLOG(I1+1)-FLOG(I2+1)-FLOG(I3+1)
      AX=AX-(((2.*FI)+1.)*ALOG(ABS(2.*XS)))
      AX=EXP(AX)
      FTWO=((2.*FI)+1.)/XS
      AXX=AX*FTWO
      KI=I/2
      IF((2*KI)-I)10,11,10
```

```
10 SUM2=SUM2-AX
   DSUM2=DSUM2+AXX
   GO TO 2
11 SUM2=SUM2+AX
   DSUM2=DSUM2-AXX
 2 CONTINUE
 6 VL=(SUM1*SUM1)+(SUM2*SUM2)
   VL=1./VL
   VLP=(DSUM1-SUM2)*(DSUM1-SUM2)
   VLP=VLP+((DSUM2+SUM1)*(DSUM2+SUM1))
   TL=4.*XS*XL*VL
   DEN=(XL*XL)+(((2.*XS*XL)+(XS*XS*VLP))*VL)
   TL=TL/DEN
   GO TO 50
90 WRITE(6,91)
91 FORMAT(25H FACTORIAL TABLE EXCEEDED)
   CALL EXIT
50 RETURN
   END
```

SUBROUTINE DENS

```
      SUBROUTINE DENS(XE,PAIR,CP,AP,RHO)
      U=XE-PAIR
      IF(U)1,2,2
    1 RHO=0.
      RETURN
    2 RHO=CP*EXP(2.*SQRT(ABS(AP*U)))
      RETURN
      END
```

APPENDIX B

SAMPLE PROBLEM

INPUT DATA

```
 1
.10E-01 .56E-03 .40E-04 .39E-05 .49E-06 .75E-07 .10E-07 .17E-08 .31E-09   1 1  1
.45E-01 .78E-02 .16E-02 .39E-03 .10E-04 .30E-04 .92E-05 .30E-05 .11E-05   1 1  2
.10E+00 .28E-01 .11E-01 .48E-02 .23E-02 .11E-02 .48E-03 .23E-03 .12E-03   1 1  3
.17E+00 .77E-01 .41E-01 .23E-01 .15E-01 .91E-02 .56E-02 .36E-02 .24E-02   1 1  4
.21E+00 .13E+00 .89E-01 .65E-01 .48E-01 .38E-01 .29E-01 .22E-01 .17E-01   1 1  5
.26E+00 .19E+00 .15E+00 .13E+00 .11E+00 .98E-01 .84E-01 .74E-01 .64E-01   1 1  6
.28E+00 .24E+00 .22E+00 .21E+00 .20E+00 .18E+00 .18E+00 .17E+00 .16E+00   1 1  7
.31E+00 .29E+00 .29E+00 .29E+00 .29E+00 .28E+00 .28E+00 .27E+00 .27E+00   1 1  8
.33E+00 .33E+00 .35E+00 .36E+00 .37E+00 .37E+00 .39E+00 .40E+00 .40E+00   1 1  9
.35E+00 .37E+00 .41E+00 .43E+00 .45E+00 .46E+00 .48E+00 .50E+00 .53E+00   1 1 10
.38E+00 .40E+00 .45E+00 .49E+00 .52E+00 .55E+00 .59E+00 .61E+00 .64E+00   1 1 11
.40E+00 .43E+00 .49E+00 .53E+00 .59E+00 .62E+00 .67E+00 .70E+00 .74E+00   1 1 12
.42E+00 .46E+00 .53E+00 .58E+00 .65E+00 .69E+00 .75E+00 .80E+00 .83E+00   1 1 13
.45E+00 .49E+00 .56E+00 .63E+00 .70E+00 .75E+00 .81E+00 .87E+00 .91E+00   1 1 14
.47E+00 .51E+00 .59E+00 .66E+00 .74E+00 .79E+00 .86E+00 .93E+00 .98E+00   1 1 15
.50E+00 .53E+00 .61E+00 .69E+00 .77E+00 .83E+00 .91E+00 .99E+00 .10E+01   1 1 16
.53E+00 .54E+00 .62E+00 .71E+00 .80E+00 .87E+00 .96E+00 .10E+01 .11E+01   1 1 17
.74E-02 .32E-03 .18E-04 .15E-05 .15E-06 .20E-07 .29E-08 .38E-09 .59E-10   1 2  1
.37E-01 .59E-02 .11E-02 .23E-03 .57E-04 .15E-04 .47E-05 .14E-05 .45E-06   1 2  2
.10E+00 .28E-01 .96E-02 .39E-02 .15E-02 .70E-03 .32E-03 .15E-03 .75E-04   1 2  3
.16E+00 .76E-01 .39E-01 .21E-01 .12E-01 .76E-02 .47E-02 .29E-02 .18E-02   1 2  4
.22E+00 .13E+00 .91E-01 .66E-01 .48E-01 .35E-01 .26E-01 .22E-01 .17E-01   1 2  5
.27E+00 .21E+00 .17E+00 .14E+00 .12E+00 .10E+00 .87E-01 .75E-01 .65E-01   1 2  6
.31E+00 .27E+00 .25E+00 .24E+00 .22E+00 .21E+00 .19E+00 .18E+00 .17E+00   1 2  7
.35E+00 .34E+00 .34E+00 .33E+00 .33E+00 .33E+00 .32E+00 .32E+00 .33E+00   1 2  8
.39E+00 .39E+00 .42E+00 .43E+00 .44E+00 .45E+00 .46E+00 .48E+00 .46E+00   1 2  9
.42E+00 .45E+00 .50E+00 .52E+00 .55E+00 .58E+00 .61E+00 .63E+00 .64E+00   1 2 10
.46E+00 .50E+00 .56E+00 .60E+00 .65E+00 .68E+00 .72E+00 .76E+00 .79E+00   1 2 11
.49E+00 .55E+00 .62E+00 .67E+00 .74E+00 .78E+00 .83E+00 .88E+00 .93E+00   1 2 12
.52E+00 .58E+00 .67E+00 .74E+00 .81E+00 .88E+00 .94E+00 .10E+01 .11E+01   1 2 13
.56E+00 .62E+00 .72E+00 .79E+00 .87E+00 .97E+00 .10E+01 .11E+01 .12E+01   1 2 14
.59E+00 .64E+00 .75E+00 .84E+00 .93E+00 .10E+01 .11E+01 .12E+01 .13E+01   1 2 15
.61 +00 .67E+00 .77E+00 .88E+00 .97E+00 .11E+01 .12E+01 .12E+01 .14E+01   1 2 16
.64E+00 .68E+00 .78E+00 .90E+00 .10E+01 .11E+01 .12E+01 .13E+01 .15E+01   1 2 17
.75E-06 .19E-10 .52E-14 .70E-17 .93E-20 .22E-22 .54E-25 .40E-27 .29E-29   2 1  1
.29E-04 .12E-06 .11E-08 .30E-10 .81E-12 .12E-13 .18E-15 .88E-17 .43E-18   2 1  2
.84E-03 .24E-04 .11E-05 .79E-07 .57E-08 .53E-09 .50E-10 .70E-11 .97E-12   2 1  3
.71E-02 .64E-03 .13E-03 .19E-04 .28E-05 .69E-06 .17E-06 .45E-07 .12E-07   2 1  4
.25E-01 .61E-02 .18E-02 .64E-03 .23E-03 .92E-04 .37E-04 .16E-04 .68E-05   2 1  5
.65E-01 .28E-01 .14E-01 .74E-02 .39E-02 .24E-02 .15E-02 .11E-02 .79E-03   2 1  6
.11E+00 .75E-01 .54E-01 .40E-01 .30E-01 .24E-01 .19E-01 .15E-01 .12E-01   2 1  7
.17E+00 .14E+00 .12E+00 .11E+00 .11E+00 .10E+00 .97E-01 .91E-01 .85E-01   2 1  8
.22E+00 .21E+00 .21E+00 .21E+00 .21E+00 .21E+00 .21E+00 .21E+00 .22E+00   2 1  9
.27E+00 .28E+00 .29E+00 .31E+00 .33E+00 .34E+00 .36E+00 .37E+00 .38E+00   2 1 10
.31E+00 .34E+00 .38E+00 .41E+00 .44E+00 .46E+00 .49E+00 .51E+00 .53E+00   2 1 11
.36E+00 .39E+00 .45E+00 .49E+00 .54E+00 .57E+00 .60E+00 .63E+00 .67E+00   2 1 12
.39E+00 .44E+00 .51E+00 .56E+00 .62E+00 .66E+00 .71E+00 .76E+00 .81E+00   2 1 13
.42E+00 .49E+00 .56E+00 .63E+00 .70E+00 .75E+00 .81E+00 .87E+00 .93E+00   2 1 14
```

INPUT DATA (CONT'D)

```
.44E+00 .53E+00 .61E+00 .69E+00 .77E+00 .83E+00 .90E+00 .99E+00 .11E+01   2 1 15
.46E+00 .56E+00 .66E+00 .74E+00 .84E+00 .91E+00 .98E+00 .10E+01 .11E+01   2 1 16
.47E+00 .59E+00 .70E+00 .79E+00 .89E+00 .99E+00 .11E+01 .11E+01 .12E+01   2 1 17
.79E-07 .29E-11 .76E-15 .70E-18 .64E-21 .15E-23 .34E-26 .12E-28 .44E-31   2 2  1
.18E-04 .54E-06 .37E-08 .15E-10 .62E-13 .15E-14 .36E-16 .11E-17 .35E-19   2 2  2
.61E-03 .16E-04 .59E-06 .27E-07 .12E-08 .27E-09 .63E-10 .51E-11 .42E-12   2 2  3
.59E-02 .51E-03 .63E-04 .97E-05 .15E-05 .35E-06 .81E-07 .19E-07 .46E-08   2 2  4
.25E-01 .56E-02 .16E-02 .52E-03 .17E-03 .65E-04 .25E-04 .10E-04 .42E-05   2 2  5
.67E-01 .28E-01 .14E-01 .74E-02 .39E-02 .23E-02 .13E-02 .77E-03 .46E-03   2 2  6
.13E+00 .81E-01 .58E-01 .43E-01 .32E-01 .25E-01 .19E-01 .15E-01 .12E-01   2 2  7
.19E+00 .16E+00 .14E+00 .11E+00 .94E-01 .97E-01 .10E+00 .11E+00 .12E+00   2 2  8
.26E+00 .25E+00 .25E+00 .25E+00 .25E+00 .25E+00 .25E+00 .25E+00 .26E+00   2 2  9
.32E+00 .33E+00 .36E+00 .38E+00 .40E+00 .41E+00 .42E+00 .43E+00 .45E+00   2 2 10
.37E+00 .40E+00 .46E+00 .49E+00 .53E+00 .56E+00 .60E+00 .63E+00 .66E+00   2 2 11
.42E+00 .47E+00 .55E+00 .60E+00 .65E+00 .70E+00 .76E+00 .80E+00 .85E+00   2 2 12
.46E+00 .53E+00 .63E+00 .69E+00 .76E+00 .82E+00 .89E+00 .94E+00 .10E+01   2 2 13
.50E+00 .58E+00 .70E+00 .78E+00 .86E+00 .93E+00 .10E+01 .11E+01 .12E+01   2 2 14
.53E+00 .63E+00 .76E+00 .85E+00 .95E+00 .10E+01 .11E+01 .12E+01 .13E+01   2 2 15
.55E+00 .68E+00 .81E+00 .90E+00 .10E+01 .11E+01 .12E+01 .13E+01 .14E+01   2 2 16
.57E+00 .72E+00 .86E+00 .97E+00 .11E+01 .12E+01 .13E+01 .14E+01 .15E+01   2 2 17
                                                                          3
  1.50
  30  26   1          492.31     499.85
   1   1   0   1   0   0   0
  492.31     489.32     464.15     481.30     482.04     482.04     480.14
     .35        .35        .35        .35        .35        .35        .35
    6.0        6.0        7.0        8.0        7.0        7.0        7.0
    2.77       0.0        1.44       1.45       1.32       1.32       1.44
14.0      50
 3
```

RESULTS

TOTAL CROSS SECTION IN BARN UNITS FOR EACH REACTION

SYN= 0.86170717E 00

SYP= 0.34060419E-01

SYA= 0.00000000E-38

SYNN= 0.48655273E 00

SYNP= 0.00000000E-38

SYPN= 0.00000000E-38

SYPP= 0.00000000E-38

RESULTS (CONT'D)

J	ENERGY	PI(1 , J)
1	0.00000000E-38	0.00000000E-38
2	0.28571428E 00	0.17434641E 00
3	0.57142857E 00	0.25656329E 00
4	0.85714285E 00	0.29794488E 00
5	0.11428571E 01	0.31196531E 00
6	0.14285714E 01	0.30779735E 00
7	0.17142857E 01	0.29169006E 00
8	0.20000000E 01	0.26861674E 00
9	0.22857143E 01	0.24170206E 00
10	0.25714285E 01	0.21349694E 00
11	0.28571428E 01	0.18575542E 00
12	0.31428571E 01	0.15941192E 00
13	0.34285714E 01	0.13513329E 00
14	0.37142857E 01	0.11326992E 00
15	0.40000000E 01	0.93949739E-01
16	0.42857142E 01	0.77150489E-01
17	0.45714285E 01	0.62741701E-01
18	0.48571428E 01	0.50538064E-01
19	0.51428571E 01	0.40321791E-01
20	0.54285713E 01	0.31862759E-01
21	0.57142857E 01	0.24932437E-01
22	0.59999999E 01	0.19313077E-01
23	0.62857142E 01	0.14803403E-01
24	0.65714285E 01	0.11218772E-01
25	0.68571428E 01	0.84027598E-02

26	0.71428571E 01	0.62147885E-02
27	0.74285713E 01	0.45342629E-02
28	0.77142856E 01	0.32591711E-02
29	0.79999999E 01	0.23043080E-02
30	0.82857141E 01	0.15993702E-02
31	0.85714284E 01	0.10870422E-02
32	0.88571427E 01	0.72116061E-03
33	0.91428571E 01	0.46500165E-03
34	0.94285713E 01	0.28972680E-03
35	0.97142856E 01	0.17299848E-03
36	0.99999999E 01	0.97767902E-04
37	0.10285714E 02	0.51231339E-04
38	0.10571428E 02	0.23978225E-04
39	0.10857143E 02	0.91883916E-05
40	0.11142857E 02	0.20078580E-05
41	0.11428571E 02	0.00000000E-38
42	0.11714286E 02	0.00000000E-38
43	0.12000000E 02	0.00000000E-38
44	0.12285714E 02	0.00000000E-38
45	0.12571428E 02	0.00000000E-38
46	0.12857143E 02	0.00000000E-38
47	0.13142857E 02	0.00000000E-38
48	0.13428571E 02	0.00000000E-38
49	0.13714286E 02	0.00000000E-38
50	0.14000000E 02	0.00000000E-38

RESULTS (CONT'D)

J	ENERGY	P(I 2 , J)
1	0.00000000E-38	0.00000000E-38
2	0.22469384E 00	0.00000000E-38
3	0.44938768E 00	0.00000000E-38
4	0.67408153E 00	0.00000000E-38
5	0.89877537E 00	0.00000000E-38
6	0.11234692E 01	0.00000000E-38
7	0.13481631E 01	0.21446762E-04
8	0.15728569E 01	0.73724262E-04
9	0.17975507E 01	0.24770646E-03
10	0.20222446E 01	0.56467008E-03
11	0.22469384E 01	0.10161817E-02
12	0.24716322E 01	0.18061251E-02
13	0.26963261E 01	0.26062832E-02
14	0.29210199E 01	0.35812052E-02
15	0.31457138E 01	0.48413001E-02
16	0.33704076E 01	0.54542652E-02
17	0.35951015E 01	0.60996356E-02
18	0.38197953E 01	0.66894802E-02
19	0.40444891E 01	0.70191272E-02
20	0.42691830E 01	0.73176241E-02
21	0.44938768E 01	0.72950027E-02
22	0.47185706E 01	0.69072100E-02
23	0.49432645E 01	0.64996734E-02
24	0.51679583E 01	0.60068436E-02
25	0.53926522E 01	0.54842368E-02

26	0.56173460E 01	0.49752327E-02
27	0.58420399E 01	0.43527065E-02
28	0.60667337E 01	0.37665635E-02
29	0.62914276E 01	0.32350898E-02
30	0.65161214E 01	0.27443473E-02
31	0.67408152E 01	0.23102233E-02
32	0.69655091E 01	0.19190691E-02
33	0.71902030E 01	0.15607601E-02
34	0.74148968E 01	0.12576403E-02
35	0.76395906E 01	0.10013632E-02
36	0.78642845E 01	0.78716676E-03
37	0.80889783E 01	0.61145762E-03
38	0.83136721E 01	0.46481014E-03
39	0.85383660E 01	0.34696687E-03
40	0.87630597E 01	0.25472452E-03
41	0.89877536E 01	0.18371335E-03
42	0.92124475E 01	0.12960320E-03
43	0.94371413E 01	0.88917071E-04
44	0.96618352E 01	0.58467582E-04
45	0.98865290E 01	0.36923584E-04
46	0.10111223E 02	0.22111453E-04
47	0.10335917E 02	0.12289677E-04
48	0.10560611E 02	0.60805801E-05
49	0.10785304E 02	0.23937497E-05
50	0.11009998E 02	0.24121363E-06

I	ENERGY	P12(1 , 1 , I)
1	0.00000000E-38	0.00000000E-38
2	0.61020365E-01	0.10029256E 01
3	0.12204073E 00	0.96285214E 00
4	0.18306109E 00	0.77832109E 00
5	0.24408146E 00	0.66043413E 00
6	0.30510182E 00	0.53182644E 00
7	0.36612219E 00	0.42351342E 00
8	0.42714255E 00	0.34352968E 00
9	0.48816292E 00	0.26893460E 00
10	0.54918328E 00	0.20738040E 00
11	0.61020364E 00	0.16187022E 00
12	0.67122401E 00	0.12254189E 00
13	0.73224437E 00	0.91437061E-01
14	0.79326473E 00	0.67099845E-01
15	0.85428510E 00	0.48359680E-01
16	0.91530547E 00	0.34166319E-01
17	0.97632583E 00	0.23577525E-01
18	0.10373462E 01	0.15844238E-01
19	0.10983666E 01	0.10305487E-01
20	0.11593869E 01	0.64168422E-02
21	0.12204073E 01	0.36080152E-02
22	0.12814277E 01	0.19868295E-02
23	0.13424480E 01	0.88906447E-03
24	0.14034684E 01	0.37201940E-03
25	0.14644887E 01	0.89130644E-04

RESULTS (CONT'D)

26	0.15255091E 01	0.00000000E-38
27	0.15865295E 01	0.00000000E-38
28	0.16475498E 01	0.00000000E-38
29	0.17085702E 01	0.00000000E-38
30	0.17695906E 01	0.00000000E-38
31	0.18306109E 01	0.00000000E-38
32	0.18916313E 01	0.00000000E-38
33	0.19526517E 01	0.00000000E-38
34	0.20136720E 01	0.00000000E-38
35	0.20746924E 01	0.00000000E-38
36	0.21357127E 01	0.00000000E-38
37	0.21967331E 01	0.00000000E-38
38	0.22577535E 01	0.00000000E-38
39	0.23187738E 01	0.00000000E-38
40	0.23797942E 01	0.00000000E-38
41	0.24408146E 01	0.00000000E-38
42	0.25018349E 01	0.00000000E-38
43	0.25628553E 01	0.00000000E-38
44	0.26238756E 01	0.00000000E-38
45	0.26848960E 01	0.00000000E-38
46	0.27459164E 01	0.00000000E-38
47	0.28069367E 01	0.00000000E-38
48	0.28679571E 01	0.00000000E-38
49	0.29289775E 01	0.00000000E-38
50	0.29899978E 01	0.00000000E-38

SECTION II. COMPUTER PROGRAM BASED ON THE PARTIAL STATISTICAL MODEL

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INTRODUCTION

Consider a nuclear reaction Y(y, y') Y' which proceeds through the formation of a compound nucleus C (Ref. 1). The compound nucleus, which is created in an excited state, can, in general, decay by gamma-ray or particle emission. For the present study, however, it will be assumed that particle emission is by far the predominant process. This is generally the case whenever the excitation energy exceeds the threshold for particle emission by as much as several hundred kilovolts. After the compound nucleus emits particle y', the residual nucleus remains in an excited state. At this point, it is assumed that the excitation energy of Y' is insufficient to permit further particle emission so that Y' eventually reaches its ground state by emitting one or more gamma rays. Attention will be given in a future study to the number and energy distribution of these gamma rays. The present study is restricted to the prediction of cross sections for exciting the various levels of the residual nucleus Y'.

The energetics of the reaction Y (y, y') Y' are depicted in Figure 1. The kinetic energies of the incident and emerging particle are ϵ and ϵ', respectively. For the purposes of this investigation, these particles are restricted to be neutron, proton, or α-particle. The ground states of the nuclei involved in the reaction are G_Y, G_C, and $G_{Y'}$, and the quantities δ and δ' are given in terms of the total nuclear binding energies B:

$$\delta = B(C) - B(Y) \tag{1}$$

$$\delta' = B(C) - B(Y') . \tag{2}$$

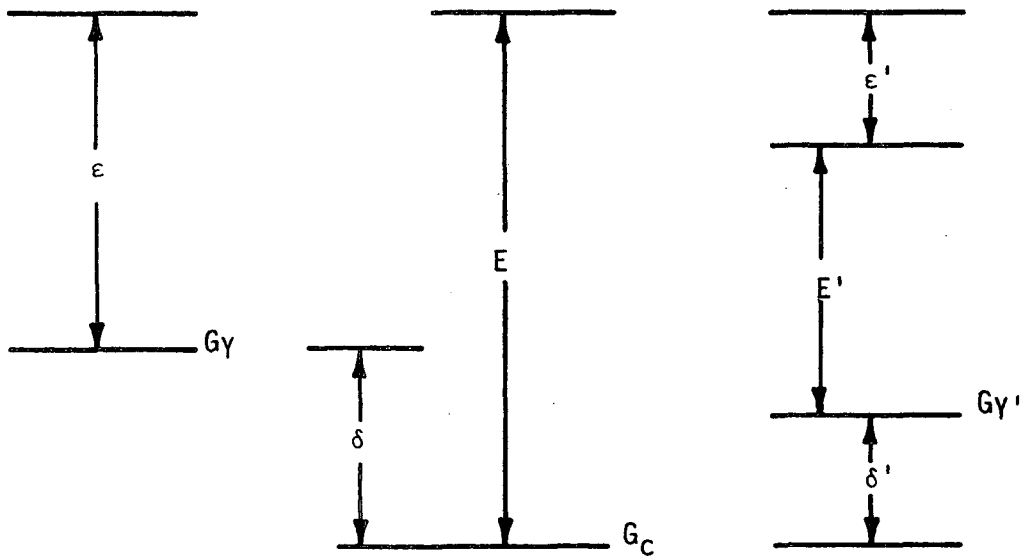

FIGURE 1. ENERGETICS OF A REACTION OF THE TYPE UNDER CONSIDERATION

The excitation energies of the compound nucleus and the residual nucleus are E and E', respectively. It is seen that the decay of the level of C having energy E makes available to the products y' and Y' an energy E - δ'. An apportioning of this energy between kinetic energy of y' and excitation energy of Y' takes place in a manner which is dependent on the properties of the level E and the level structure of Y'.

In a previous Teledyne Brown Engineering study (Ref. 2, also found in Section I of this report), the computer program SPECTER was developed for predicting the cross sections for exciting the various levels of Y' for the case in which these levels are continuously distributed. This program was based on the "complete" statistical model of nuclear reactions (Ref. 3). The "partial" statistical model (Ref. 4) may be used for predicting the level excitation cross sections for the case of discrete levels. It is the ultimate objective of the present study to develop a computer program which can be applied to hybrid cases in which the lower lying levels of the residual nuclei are discrete, whereas the higher levels may be represented by a continuum. This report presents a computer program which was developed to handle the discrete levels. In the future, it will be incorporated with SPECTER to achieve the ultimate objective.

According to the Bohr assumption, the cross section $\sigma(y, y')$ for the reaction $Y(y, y')\ Y'$ is given by

$$\sigma(y, y') = \sigma_C(y)\ P_C(y'), \tag{3}$$

where $\sigma_C(y)$ is the cross section for the formation of the compound nucleus C, and $P_C(y')$ is the probability that C decays by the emission of particle y'. It is useful to specify the reaction $Y(y, y')\ Y'$ in greater detail by considering the cross section $\sigma(\xi, \xi')$ corresponding to a specific entrance channel ξ, and specific exit channel ξ'. Here, ξ and ξ' represent sets of quantum numbers which completely specify the

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quantum states of reaction partners before and after the reaction, respectively. The cross section is written as

$$\sigma(\xi, \xi') = \sigma_C(\xi)\, P_C(\xi') \quad , \tag{4}$$

where $\sigma_C(\xi)$ is the cross section for the formation of C through channel ξ, and $P_C(\xi')$ is the probability that C decays through channel ξ'. Application of the reciprocity theorem leads to the following expression for $P_C(\xi')$:

$$P_C(\xi') = \frac{k_{\xi'}^2\, \sigma_C(\xi')}{\sum_\gamma k_\gamma^2\, \sigma_C(\gamma)} \quad . \tag{5}$$

Here, $k_{\xi'}$, is the wave number of the particle emerging through channel ξ', and $\sigma_C(\xi')$ is the cross section for the formation of the compound nucleus by the inverse process in which ξ' is regarded as the entrance channel. The summation is extended over all channels through which C can decay. Thus, the cross section $\sigma(\xi, \xi')$ can be computed if the cross sections $\sigma_C(\xi')$ for the formation of C by all possible channels are known.

The cross section for compound nucleus formation can be expressed as a sum over transmission coefficients T_ℓ as follows:

$$\sigma_C(\xi) = \sum_{\ell=0}^{\infty} (2\ell + 1)\, \pi\, \lambda\!\!\!^{-2}\, T_\ell(\xi) \, , \tag{6}$$

where

$$\lambda\!\!\!^{-} = 1/k_\xi \quad . \tag{7}$$

In practice, the sum is terminated at a point beyond which additional terms become negligible. The derivation in the section of this report entitled, "Reaction Cross Section", supplies Equations 4 and 5 with the explicit dependence on the relevant quantum numbers which are here combined in ξ and ξ'.

THEORETICAL DEVELOPMENT

REACTION CROSS SECTION

The derivation of the complete expression for the reaction cross section presented in this section essentially follows the development of Blatt and Biedenharn (Ref. 5). It is noted, however, that this cited paper involves a phase error, as has been pointed out by Huby (Ref. 6), and that this phase error has been corrected in the present development. This is pointed out again below, at the appropriate place in the derivation.

Additional relevant discussions of the reaction cross section on the partial statistical model may also be found in Feshbach (Ref. 7) and in Goldstein (Ref. 4). An important paper in the early development of reaction cross sections in the (n, n') case is that of Hauser and Feshbach (Ref. 8), where the method developed in this report is applied for the first time. The most recent review paper on the subject is that of Cindro (Ref. 9), giving a brief outline, but without calculational details.

The present development was carried out for three reasons:

- To serve as a check on the theory, especially as concerns the details of the angular momentum algebra involved
- To facilitate the setting up of the corresponding computer program, and also the future extension to hybrid cases
- To establish the detailed form of the angular momentum and parity selection rules in a reliable manner.

In addition, the present derivation disposes of the phase error of Blatt and Biedenharn in a straightforward manner, involving only a change of representation, rather than a dynamical argument as offered by Huby (Ref. 6). This has the advantage of showing the source of the phase error as residing in the definition of the channel wavefunctions, so that, if the natural forms of these wavefunctions are used, the phases resolve correctly in a natural manner.

As already pointed out, the physical process may be designated by the relation

$$a + Y \rightarrow Y' + b \quad , \tag{8}$$

stating that particle a collides with nucleus Y, and that particle b emerges, leaving behind the nucleus Y'. The reaction is considered to be "sharp", in that the following are completely specified:

- Entrance channel: $(\alpha,\ s,\ \ell)$
- Exit channel: $(\alpha',\ s',\ \ell')$,

where α, α' designate the channels (a, Y) and (Y', b), respectively; s, s' are the channel spins, and ℓ, ℓ' are the orbital angular momenta in the center-of-mass system.

The conservation of angular momentum requires the following to hold:

$$\begin{aligned} \vec{s} &= \vec{i} + \vec{I}, \\ \vec{s}' &= \vec{i}' + \vec{I}' \quad , \end{aligned} \tag{9}$$

where

$\vec{s},\ \vec{s}'$ - channel spin vectors

$\vec{i},\ \vec{i}'$ - intrinsic particle spin vectors

$\vec{I},\ \vec{I}'$ - spin vectors of the target and residual nucleus, respectively.

Also,

$$\vec{s} + \vec{\ell}' = \vec{J} = \vec{s}' + \vec{\ell}' \quad , \tag{10}$$

where $\vec{\ell}$, $\vec{\ell}'$ are the orbital angular momentum vectors, and $\vec{J}$ is the total angular momentum of the compound (intermediate) nucleus formed by (a + Y).

The problem thus resolves into the calculation of the geometrical and dynamical dependence of the cross section of the collision:

$$(\alpha,\ s,\ \ell) \rightarrow J \rightarrow (\alpha',\ s',\ \ell') \quad .$$

As will be seen, the geometrical development, involving Racah algebra, automatically leads to the selection rules of the conservation of angular momentum and parity. The dynamical dependence is then contained in the matrix elements of the scattering matrix, and the essential point in invoking the partial statistical model lies in replacing these matrix elements by combinations of transmission coefficients, in the absence of detailed knowledge of the strong interaction.

As is well known, in the elastic case, where $\alpha' = \alpha$ and there is only one open channel, the S-matrix is diagonal, or specifically,

$$\langle \ell | S | \ell \rangle = \exp(2i\,\delta_\ell) \quad , \tag{11}$$

where δ_ℓ is the phase shift of the ℓth partial wave. In the present general case, the matrix element

$$\langle \alpha'\ s'\ \ell' | S^J | \alpha\ s\ \ell \rangle \tag{12}$$

gives the probability amplitude for the corresponding inelastic collision, as discussed above.

The procedure employed now consists of two steps:

- The definition of the S-matrix elements (Equation 12), by writing the wavefunctions
- The partial wave decomposition of the incident plane wave.

With the restriction to one value of J(M), and the open channels $\alpha(k_\alpha, v_\alpha)$, where $k_\alpha = 1/\lambda\!\!\!^{-}_\alpha$ is the wave number of channel α and v_α is the incident particle velocity of channel α -- both depending on the channel energy E_α -- one may write

$|\alpha\, s>$ = product of wavefunctions $\psi(Y)\,\psi(a)$, for channel α and total channel spin s(i, I)

$Y^M_{J\ell s}$ = spin-angle function of compound nucleus, J(ℓ, s, M), i. e.,

$$Y^M_{J\ell s} = \sum_{m_\ell} \sum_{m_s} C(\ell\ s\ J;\ m_\ell\ m_s\ M)\ Y^{m_\ell}_\ell\ (\theta,\ \phi)\ X^{m_s}_s \qquad (13)$$

where

$C(\ell\ s\ J;\ m_\ell\ m_s\ M)$ - Clebsch-Gordan coefficients

$Y^{m_\ell}_\ell(\theta,\ \phi)$ - spherical harmonics

$X^{m_s}_s$ - spin-s eigenvectors.

In the asymptotic region ($r \to \infty$), one may thus put for the total wavefunction, consisting of an incoming and an outgoing part, as the asymptotic solution of the wave equation, for the entrance channel α,

$$|\alpha(\ell)\ s,\ J\ M> = \frac{1}{(v_\alpha)^{\frac{1}{2}}\ r_\alpha}\ Y^M_{J\ell s}\ |\alpha\ s>$$

$$\times\ i^\ell \left\{ A^{JM}_{\alpha s\ell}\ \exp\left[-i\left(k_\alpha\ r_\alpha - \tfrac{1}{2}\pi\ell\right)\right] \right.$$

$$\left. - B^{JM}_{\alpha s\ell}\ \exp\left[i\left(k_\alpha\ r_\alpha - \tfrac{1}{2}\pi\ \ell\right)\right]\right\}. \qquad (14)$$

It is noted that in contrast to Blatt and Biedenharn (Ref. 5), the phase factor i^{ℓ} is inserted explicitly by analogy with the plane wave expansion (see below). This automatically ensures that in the final expressions the correct phases will appear.

The S-matrix elements are now defined through the coupling of the wave amplitudes by the dynamics of the collision, or the dependence of the outgoing wave on the incoming wave, in the form

$$B^{JM}_{\alpha' s' \ell'} \equiv \sum_{\alpha} \sum_{s} \sum_{\ell} < \alpha' \; s' \; \ell' \; | S^{J} | \; \alpha \; s \; \ell > A^{JM}_{\alpha s \ell} \quad . \qquad (15)$$

It is noted that because of the factor $1/\sqrt{v}$ in the wavefunction, the A's and B's are probability flux amplitudes; the S-matrix is unitary (normalization of the wavefunction conserved in time) and symmetric (reciprocity); the S-matrix is independent of M, as it must be, since the dynamics of the collision is independent of the orientation of the coordinate system.

The next step is the decomposition of the plane wave

$$\exp (i \, k_{\alpha} \, z_{\alpha}) \, X^{ms}_{s} \quad | \alpha \; s >$$

in the asymptotic region, where its incoming part will be set equal to the incoming part of Equation 14. The familiar Rayleigh expansion is

$$\exp \; (i \, k \, z) \; = \; (4\pi)^{\frac{1}{2}} \sum i^{\ell} \; (2\ell + 1)^{\frac{1}{2}} \; j_{\ell} \; (k \, r) \; Y_{\ell}^{0} \; (\theta) \quad , \qquad (16)$$

and, using the asymptotic form of the spherical Bessel functions, it is found in the present case that

$$\exp(i k_\alpha z_\alpha) X_s^{m_s} |\alpha\ s> \xrightarrow[r \to \infty]{} \frac{i\sqrt{\pi}}{k_\alpha r_\alpha} \sum_\ell i^\ell (2\ell+1)^{\frac{1}{2}} \left\{ \exp\left[-i\left(k_\alpha r_\alpha - \frac{1}{2}\pi\ \ell\right)\right] \right.$$

$$\left. - \exp\left[i\left(k_\alpha r_\alpha - \frac{1}{2}\pi\ \ell\right)\right] \right\} Y_\ell{}^0(\theta)\ X_s^{m_s} |\alpha\ s> . \tag{17}$$

Performing the inverse decomposition, or decoupling,

$$Y_\ell{}^0(\theta)\ X_s^{m_s} = \sum_{J=|\ell-s|}^{\ell+s} \sum_{M=-J}^{J} C(\ell\ s\ J;\ 0 m_s\ M)\ Y_{J\ell s}^M . \tag{18}$$

Substituting in Equation 17 and equating the incoming part of Equation 17 to that of

$$\sum_J \sum_M \sum_\ell |\alpha(\ell)\ s,\ J\ M>$$

of Equation 14 yields the explicit forms of the amplitude coefficients: also, using Equation 15,

$$A_{\alpha s \ell}^{JM} = i \lambda\!\!\!^{-}_\alpha (\pi v_\alpha)^{\frac{1}{2}} C(\ell\ s\ J;\ 0 m_s\ M) (2\ell+1)^{\frac{1}{2}} \text{ (channel } \alpha,\ s),$$

$$= 0 \text{ (all other channels) ;} \tag{19}$$

$$B_{\alpha' s' \ell'}^{JM} = i \lambda\!\!\!^{-}_\alpha (\pi v_\alpha)^{\frac{1}{2}} \sum_{\ell=|J-s|}^{J+S} C(\ell\ s\ J;\ 0 m_s\ M)$$

$$\times (2\ell+1)^{\frac{1}{2}} < \alpha'\ s'\ \ell' |\ S^J\ |\ \alpha\ s\ \ell > \quad . \tag{20}$$

It is now clear that the exit channel reaction wavefunction, consisting of the difference of the outcoming spherical waves in the asymptotic region, will be given by

$$\Psi_{\alpha' s'}(\text{reaction}) = i \lambda_{\alpha} \left(\frac{\pi v_{\alpha}}{v_{\alpha'}} \right)^{\frac{1}{2}} |\alpha' s'> \frac{\exp(i k_{\alpha'} r_{\alpha'})}{r_{\alpha'}}$$

$$\times \sum_{J} \sum_{M} \sum_{\ell} \sum_{\ell'} C(\ell s J; 0 m_s M)$$

$$\times (2\ell + 1)^{\frac{1}{2}} \left(\delta_{\alpha' \alpha} \delta_{s' s} \delta_{\ell' \ell} - <\alpha' s' \ell' | S^J | \alpha s \ell > \right)$$

$$\times Y^M_{J \ell' s'} \quad . \tag{21}$$

It is at this point that the natural choice of phases in Equation 14 is seen to bear fruit, since the incorrect phase factor $i^{\ell - \ell'}$ of Blatt and Biedenharn has disappeared from the dynamical matrix element in Equation 21.

The next step is to decompose the exit channel spin-angle function according to

$$Y^M_{J \ell' s'} = \sum_{m_{s'}} \sum_{\mu'} C(\ell' s' J; \mu' m_{s'} M) Y^{\mu'}_{\ell'}(\theta, \phi) X^{m_{s'}}_{s'}, \tag{22}$$

leading to

$$\Psi_{\alpha' s'}(\text{reaction}) = i \lambda_{\alpha} \left(\frac{v_{\alpha}}{v_{\alpha'}} \right)^{\frac{1}{2}} \frac{\exp(i k_{\alpha'} r_{\alpha'})}{r_{\alpha'}} |\alpha' s'>$$

$$\times \sum_{m_{s'} = -s'}^{s'} <\alpha' s' m_{s'} | g(\theta, \phi) | \alpha s m_s > X^{m_{s'}}_{s'} ,$$

(23)

where the total reaction amplitudes are given by

$$<\alpha' \; s' \; m_{s'} \; | g(\theta, \phi) | \alpha \; s \; m_s > \; = \; \sum_{J=0}^{\infty} \sum_{M=-J}^{J} \sum_{\ell=|J-s|}^{J+s} \sum_{\ell'=|J-s'|}^{J+s'} \sum_{\mu'=-\ell'}^{\ell'} [\pi(2\ell+1)]^{\frac{1}{2}}$$

$$\times C(\ell' \; s' \; J; \; \mu' \; m_{s'} \; M) \left(\delta_{\alpha'\alpha} \; \delta_{s's} \; \delta_{\ell'\ell} \right.$$

$$\left. - <\alpha' \; s' \; \ell' \; | S^J | \; \alpha \; s \; \ell > \right) Y_{\ell'}^{\mu'} (\theta, \; \phi) \; . \qquad (24)$$

The reaction cross sections may now be obtained from Equation 24 in the following manner. The differential cross sections are given by

$$d\sigma (\alpha' \; s' \; m_{s'} \; | \; \alpha \; s \; m_s) \; = \; \lambda_\alpha^2 \; | <\alpha' \; s' m_{s'} \; | g(\theta, \phi) | \alpha \; s m_s > |^2 \; d\Omega \; , \qquad (25)$$

and summing over final states and averaging over initial states,

$$d\sigma(\alpha' \; s' | \alpha \; s) \; = \; \frac{1}{2s+1} \sum_{m_s} \sum_{m_{s'}} d\sigma(\alpha' \; s' \; m_{s'} \; | \; \alpha \; s \; m_s > \; . \qquad (26)$$

It will be seen below that, as expected, $d\sigma(\alpha' \; s' \; | \; \alpha \; s)$ and $\sigma(\alpha' \; s' \; | \; \alpha s)$ are independent of the azimuth ϕ.

The total reaction cross section is then obtained as follows. Writing

$$d\sigma(\alpha' \; s' \; | \alpha \; s) \; = \; \sigma \; (\alpha' \; s' | \; \alpha s) \; d\Omega \qquad (27)$$

and inserting the proper statistical factor for averaging over s and summing over s' yields

$$\sigma(\alpha' | \alpha) = \sum_{s=|I-i|}^{I+i} \sum_{s'=|I'-i'|}^{I'+i'} \frac{2s+1}{(2I+1)(2i+1)} \int \sigma(\alpha' \; s' \; | \alpha \; s) \; d\Omega \; , \tag{28}$$

where the integration is over all angles. As can already be anticipated, at this point, the factor (2s + 1) will cancel out between Equations 26 and 28.

Substituting from Equations 24 and 25 in Equation 26 yields

$$d\sigma(\alpha' \; s' \; | \alpha \; s) = \frac{\lambda_\alpha^2}{2s+1} \sum_{J_1} \sum_{\ell_1} \sum_{\ell_1'} \sum_{J_2} \sum_{\ell_2} \sum_{\ell_2'}$$

$$\times \left[\delta_{\alpha'\alpha} \, \delta_{s's} \, \delta_{\ell_1'\ell_1} - \langle \alpha' \; s' \; \ell_1' \; | S^{J_1} | \alpha \; s \; \ell_1 \rangle \right]^*$$

$$\times \left[\delta_{\alpha'\alpha} \, \delta_{s's} \, \delta_{\ell_2'\ell_2} - \langle \alpha' \; s' \; \ell_2' \; | S^{J_2} | \alpha \; s \; \ell_2 \rangle \right]$$

$$\times \quad K(J_1 \; \ell_1 \; \ell_1' ; \; J_2 \; \ell_2 \; \ell_2' ; \; s' \; s ; \; \theta) \; d\Omega \; , \tag{29}$$

where

$$K(J_1\ \ell_1\ \ell_1';\ J_2\ \ell_2\ \ell_2';\ s'\ s;\ \theta) = [(2\ell_1+1)(2\ell_2+1)(2\ell_1'+1)(2\ell_2'+1)]^{\frac{1}{2}}$$

$$\times \sum_L \sum_M \Bigg\{ \sum_{m_s} \sum_{M_1} \sum_{M_2} \Bigg[\sum_{m_s'} \sum_{\mu_1'} \sum_{\mu_2'} (-1)^{\mu_1'}$$

$$\times C(\ell_1\ s\ J_1;\ \mu_1'\ m_s'\ M_1)\, C(\ell_2'\ s'\ J_2;\ \mu_2'\ m_s'\ M_2)$$

$$\times C(\ell_1'\ \ell_2'\ L;\ -\mu_1',\ \mu_2',\ M) \Bigg]\ C(\ell_1\ s\ J_1;\ 0\ m_s\ M_1)$$

$$\times C(\ell_2\ s\ J_2;\ 0\ m_s\ M_2)\, C(\ell_1'\ \ell_2'\ L;\ 0\ 0) \Bigg\}$$

$$\times \frac{Y_L^M(\theta, \phi)}{[(4\pi\ (2L+1)]^{\frac{1}{2}}} \quad . \qquad (30)$$

Here, the coupling rule of spherical harmonics has been used, i.e.,

$$Y_\ell^{m*}(\theta,\ \phi)\ Y_{\ell'}^{m'}(\theta,\ \phi) = \sum_L \left[\frac{(2\ell+1)(2\ell'+1)}{4\pi(2L+1)}\right]^{\frac{1}{2}} (-1)^m$$

$$\times C(\ell\ \ell'\ L;\ -\ m,\ m',\ M)$$

$$\times C(\ell\ \ell'\ L;\ 0\ 0)\ Y_L^M(\theta,\ \phi)\ , \qquad (31)$$

and in the arguments of K, the independence of ϕ has been anticipated, which will be seen explicitly below. In Equation 30, the summations have been arranged in such a way that the Racah identity (Ref. 10)

$$\sum_\beta C(a\ b\ e;\ \alpha\ \beta)\, C(e\ d\ c;\ \alpha+\beta,\ \delta)\, C(b\ d\ f;\ \beta\ \delta) = [(2e+1)(2f+1)]^{\frac{1}{2}}$$

$$\times C(a\ f\ c;\ \alpha,\ \beta+\delta)$$

$$\times W(a\ b\ c\ d;\ e\ f)$$

$$(32)$$

can be used twice in succession. The W's are Racah coefficients. The reduction consists of the following. First, the sum in square brackets in Equation 30 is evaluated by transforming the Clebsch-Gordan coefficients and by application of Equation 32. Next, the resulting Clebsch-Gordan coefficient on the right side of Equation 32 combines with two others in the braces of Equation 30 to form another triple product. This is again transformed and reduced by means of Equation 32. Finally, a reduction of the various powers of (-1) is made, and also, the sum over M collapses to the term M = 0, in virtue of the parity coefficients $C(\ell\ \ell'\ L;\ 00)$, leaving

$$K(J_1\ \ell_1\ \ell_1';\ J_2\ \ell_2\ \ell_2',\ s'\ s;\ \theta) = \frac{1}{4}\left[(2\ell_1+1)(2\ell_2'+1)(2\ell_1'+1)(2\ell_2'+1)\right]^{\frac{1}{2}}$$
$$\times (2J_2+1)(2J_2+1)(-1)^{s'-s} \sum_L C(\ell_1\ \ell_2\ L;00)$$
$$\times C(\ell_1'\ell_2'\ L;\ 00)\ W(\ell_1\ J_1\ \ell_2\ J_2;\ sL)$$
$$\times W(\ell_1'\ J_1\ \ell_2'\ J_2;\ s'L)\ P_L(\cos\theta)\ , \qquad (33)$$

and K is indeed a function of θ only.

Substitution of Equation 33 in Equation 29 then gives

$$\frac{d\sigma(\alpha'\ s'|\ \alpha\ s)}{d\Omega} = \frac{\lambda_\alpha^2}{2s+1} \sum_{L=0}^{\infty} B_L(\alpha'\ s'\ |\alpha\ s)\ P_L(\cos\theta)\ , \qquad (34)$$

where

$$B_L(\alpha' s' | \alpha s) = \frac{(-1)^{s'-s}}{4} \sum_{J_1} \sum_{J_2} \sum_{\ell_1} \sum_{\ell_2} \sum_{\ell_1'} \sum_{\ell_2'} Z(\ell_1 J_1 \ell_2 J_2; s L)$$

$$\times Z(\ell_1' J_1 \ell_2' J_2; s' L) \times \mathrm{Re}\Big[\Big(\delta_{\alpha'\alpha}\, \delta_{s's}\, \delta_{\ell_1'\ell_1}$$

$$- \langle \alpha' s' \ell_1' | S^{J_1} | \alpha s \ell \rangle\Big)^{*} \Big(\delta_{\alpha'\alpha}\, \delta_{s's}\, \delta_{\ell_2'\ell_2}$$

$$- \langle \alpha' s' \ell_2' | S^{J_2} | \alpha s \ell_2 \rangle\Big)\Big] , \qquad (35)$$

and the natural Z-coefficients are

$$Z(\ell_1 J_1 \ell_2 J_2; sL) = [(2\ell_1 + 1)(2\ell_2 + 1)(2J_1 + 1)(2J_2 + 1)]^{\frac{1}{2}}$$

$$\times C(\ell_1 \ell_2 L; 00)\, W(\ell_1 J_1 \ell_2 J_2; s L). \qquad (36)$$

It is noted that in Equation 35 all dependence on unobservable substates has properly disappeared; the angular momentum conservations of Equations 9 and 10 are contained in the triangle conditions governing the Racah coefficients $W(\ell_1 J_1 \ell_2 J_2; s L)$; the parity conservation selection rules are given by the parity coefficients $C(\ell_1 \ell_2 L; 00)$. These are given explicitly below.

It is now an easy matter to calculate

$$\int d\sigma(\alpha' s' | \alpha s) = \frac{2\pi \lambda_\alpha^2}{2s + 1} \sum_L B_L(\alpha' s' | \alpha s) \int_0^\pi P_L(\cos\theta) \sin\theta\, d\theta$$

$$= \frac{4\pi \lambda_\alpha^2}{2s + 1} B_0(\alpha' s' | \alpha s) , \qquad (37)$$

since $P_0(\cos\theta) = 1$, and, from the orthogonality of the Legendre polynomials,

$$\int_0^{\pi} P_L(\cos\theta)\, P_0(\cos\theta)\, \sin\theta\, d\theta = \frac{2\delta_{L_0}}{2L+1} = 2\delta_{L_0} .$$

The single remaining coefficient $B_0(\alpha' s' | \alpha s)$ is calculated by setting $L = 0$ in Equation 35 and reducing the Clebsch-Gordan and Racah coefficients in Equation 36 for $L = 0$. The result is

$$Z(\ell_1 J_1 \ \ell_2 \ J_2 ; s \ 0) = (-1)^{s-J_1} \delta_{\ell_1 \ell_2} \delta_{J_1 J_2} (2J_1 + 1)^{\frac{1}{2}}, \quad (38)$$

so that

$$B_0(\alpha' s' | \alpha s) = \frac{1}{4} \sum_J \sum_{\ell} \sum_{\ell'} (2J+1) \left| \delta_{\alpha'\alpha} \delta_{s's} \delta_{\ell'\ell} - \langle \alpha' s' \ell' | S^J | \alpha s \ell \rangle \right|^2 \quad (39)$$

and

$$\int d\sigma(\alpha' s' | \alpha s) = \frac{\pi \lambda_\alpha^2}{2s+1} \sum_{J=0}^{\infty} \sum_{\ell=|J-s|}^{J+s} \sum_{\ell'=|J-s'|}^{J+s'} (2J+1)$$

$$\times \left| \delta_{\alpha'\alpha} \delta_{s's} \delta_{\ell'\ell} - \langle \alpha' s' \ell' | S^J | \alpha s \ell \rangle \right|^2 . \quad (40)$$

Then, substitution into Equation 28 finally gives

$$\sigma(\alpha' | \alpha) = \pi \lambda_\alpha^2 \sum_J \sum_s \sum_{\ell} \sum_{s'} \sum_{\ell'} \frac{2J+1}{(2I+1)(2i+1)}$$

$$\left| \delta_{\alpha'\alpha} \delta_{s's} \delta_{\ell'\ell} - \langle \alpha' s' \ell' | S^J | \alpha s \ell \rangle \right|^2 . \quad (41)$$

This expression is exact in the sense that if the detailed dynamics of the nuclear interaction were known, the dynamical matrix elements could be calculated to give the precise reaction cross section for $\alpha(a, Y) \rightarrow \alpha'(b, Y')$.

In the absence of this knowledge, the implementation of the partial statistical model consists of considering the excited levels of the compound nucleus to be sufficiently closely spaced so that the replacement may be made:

$$< |\delta_{\alpha'\alpha}\, \delta_{s's}\, \delta_{\ell'\ell} - < \alpha'\, s'\, \ell' \,|S^J|\, \alpha\, s\, \ell > |^2 > \;=\; \frac{T^J_{\alpha'\ell's'}\, T^J_{\alpha\ell s}}{\sum\limits_{\alpha''}\sum\limits_{\ell''}\sum\limits_{s''} T^J_{\alpha''\ell''s''}} \;, \tag{42}$$

where the T's are the transmission coefficients of compound nucleus formation, i.e., they are defined through

$$\sigma_{C\alpha} \;=\; \pi \lambda\!\!\!^{-2}_{\alpha} \sum_{\ell} (2\ell + 1)\, T_{\alpha\ell}(E) \quad , \tag{43}$$

where $\sigma_{C\alpha}$ is the cross section for compound nucleus (C) formation through channel α. On the partial statistical model, the final expression of the reaction cross section is then

$$\sigma(\alpha' |\alpha) \;=\; \pi \lambda\!\!\!^{-2}_{\alpha} \sum_{J}\sum_{s}\sum_{\ell}\sum_{s'}\sum_{\ell'} \frac{2J+1}{(2I+1)(2i+1)} \frac{T^J_{\alpha'\ell's'}\; T^J_{\alpha\ell s}}{\sum\limits_{\alpha'',\, \ell'',\, s''} T^J_{\alpha''\ell''s''}} \;. \tag{44}$$

(For additional discussions, see References 4 and 7.)

The angular momentum selection rules are contained in Equations 9 and 10. The parity selection rules are as follows. Note that in an obvious manner,

$$\Pi_\alpha = \Pi_a \Pi_Y \ ,$$

$$\Pi_{\alpha'} = \Pi_{b'} \Pi_{Y'} \ , \tag{45}$$

$$\Pi_{\alpha''} = \Pi_{b''} \Pi_{Y''} \ .$$

Further, for $a(Y \rightarrow C)$,

$$(-1)^{\ell} = \Pi_\alpha \Pi_C \ , \tag{46}$$

for $(C \rightarrow Y')b'$,

$$(-1)^{\ell'} = \Pi_{\alpha'} \Pi_C \ , \tag{47}$$

and for $(C \rightarrow Y'')b''$,

$$(-1)^{\ell''} = \Pi_{\alpha''} \Pi_C \ . \tag{48}$$

Combining Equations 46 and 47, it is clear that it is necessary to have

$$(-1)^{\ell+\ell'} = \Pi_\alpha \Pi_{\alpha'} \ ,$$

or

$$\ell + \ell' = \begin{Bmatrix} \text{even} \\ \text{odd} \end{Bmatrix} \text{ according to } \Pi_\alpha \Pi_{\alpha'} = \begin{Bmatrix} +1 \\ -1 \end{Bmatrix} \ . \tag{49}$$

The restriction on ℓ'' is obtained by noting that in Equation 44 , the "competition ratios",

$$\frac{T^J_{\alpha' s' \ell'}}{\sum_{\alpha'', \ell'', s''} T^J_{\alpha'' \ell'' s''}} \quad ,$$

are calculated for all possible exit channels in reactions induced by the given entrance channel α. Therefore, analogous to the above,

$$(-1)^{\ell+\ell''} = \Pi_\alpha \, \Pi_{\alpha''} \quad ,$$

or using Equation 48,

$$\ell + \ell'' = \begin{Bmatrix} \text{even} \\ \text{odd} \end{Bmatrix} \text{ according to } \Pi_\alpha \, \Pi_{\alpha''} = \begin{Bmatrix} +1 \\ -1 \end{Bmatrix} . \qquad (50)$$

TRANSMISSION COEFFICIENTS

The calculation of the transmission coefficients T_ℓ required in the evaluation of Equation 44 employs the continuum theory of Weisskopf (Ref. 3). As noted in the Introduction, the cross section for compound nucleus formation through channel ξ is expressed as a sum of partial cross sections $\sigma_{C\ell}(\xi)$ or

$$\sigma_C(\xi) = \sum_{\ell=0}^{\infty} \sigma_{C\ell}(\xi) \quad , \qquad (51)$$

where ℓ is the orbital angular momentum quantum number associated with the ℓth partial wave of the incident particle wave function. Each partial cross section can be written

$$\sigma_{C\ell}(\xi) = (2\ell + 1)\, \pi \lambda\!\!\!^{-2} \, T_\ell(\xi) \quad , \qquad (52)$$

where $T_\ell(\xi)$ is a transmission coefficient and λ is the channel wavelength and is also the reciprocal of the channel wave number k. This wave number is given by

$$k = \frac{(2\mu\epsilon)^{\frac{1}{2}}}{\hbar} \quad , \tag{53}$$

where μ is the mass and ϵ is the energy of the incident particle. The continuum theory yields the following expression for the transmission coefficient:

$$T_\ell(\xi) = \frac{4x\,X\,v_\ell}{X^2 + (2x\,X + x^2\,v_\ell')\,v_\ell} \quad , \tag{54}$$

where

$$x = k\,R \tag{55}$$

$$X = K\,R \tag{56}$$

and K is the wave number inside the nucleus and

$$v_\ell(X) = \frac{1}{G_\ell^{\,2}(X) + F_\ell^{\,2}(X)} \tag{57}$$

$$v_\ell'(X) = \left[\left(\frac{dG_\ell}{dx}\right)^2 + \left(\frac{dF_\ell}{dx}\right)^2\right]_{x=X} \tag{58}$$

$$F_\ell(x) = \left(\frac{\pi x}{2}\right)^{\frac{1}{2}} J_{\ell+\frac{1}{2}}(x)$$

$$G_\ell(x) = (-1)^\ell \left(\frac{\pi x}{2}\right)^{\frac{1}{2}} J_{-(\ell+\frac{1}{2})}(x) \quad . \tag{59}$$

The incident channel radius is R which, in the case of neutron bombardment, is simply the radius of the target nucleus. This radius is assumed to be given by

$$R = r_0 A^{\frac{1}{3}} \tag{60}$$

where A is the mass number and r_0 lies approximately between 1 and 2 fermi. The wave number K within the nucleus can be approximated by

$$K = (K_0^2 + k^2)^{\frac{1}{2}} \tag{61}$$

where

$$K_0 = \left(\frac{9\pi}{8}\right)^{\frac{1}{3}} \frac{1}{r_0} \quad . \tag{62}$$

The Bessel function of the half-integral order $J_{\pm(\ell+\frac{1}{2})}$ is defined in Reference 11 and can be evaluated from a closed expression given in Reference 12 as

$$J_{\pm(\ell+\frac{1}{2})}(x) = \left(\frac{2}{\pi x}\right)^{\frac{1}{2}} \left[P_{\mp} S_1(\ell, x) \pm Q_{\mp} S_2(\ell, x)\right] \quad , \tag{63}$$

where

$$S_1(\ell, x) = \sum_{i=0}^{\leqq \ell/2} \frac{(-1)^i (\ell + 2i)!}{(2i)!\ (\ell - 2i)!\ (2x)^{2i}} \quad , \tag{64}$$

$$S(\ell, x) = \sum_{i=0}^{\leqq (\ell-1)/2} \frac{(-1)^i (\ell + 2i + 1)!}{(2i + 1)!\ (\ell - 2i - 1)!\ (2x)^{2i+1}} \tag{65}$$

$$P_{-} = \sin(x - \ell\,\pi/2) \tag{66}$$

$$P_+ = \cos (x + \ell \pi/2) \tag{67}$$

$$Q_- = \cos (x - \ell \pi/2) \tag{68}$$

and

$$Q_+ = \sin (x + \ell \pi/2) \quad . \tag{69}$$

The quantities v_ℓ and v_ℓ' can be written explicitly in terms of the sums S_1 and S_2 as

$$v_\ell(X) = S_1^2(\ell, X) + S_2^2(\ell, X) \tag{70}$$

and

$$v_\ell'(X) = \left[\left(\frac{dS_1}{dx} - S_2\right)^2 + \left(\frac{dS_2}{dx} + S_1\right)^2\right]_{x=X} . \tag{71}$$

The calculation of a reaction cross section by Equation 44 requires a transmission coefficient not only for the original reaction but for each possible inverse reaction as well. Thus, T_ℓ must be determined, in the general case, for reactions between various projectile-target pairs at various bombarding energies. The preceding formulation applies to reactions for which the bombarding particle is uncharged. The assumption is now made that the transmission coefficient for the process in which a charged particle y is incident upon a nucleus can be approximated by

$$T_\ell(y, \epsilon) = \begin{cases} T_\ell(n, \epsilon)\left[1 - \frac{V(R_c)}{\epsilon}\right], & \epsilon \geqq V(R_c) \\ 0 & \epsilon < V(R_c) \end{cases} \tag{72}$$

where

ϵ - bombarding energy

$T_\ell(n, \epsilon)$ - corresponding transmission coefficient reaction in which the projectile is uncharged

$V(R_c)$ - Coulomb potential evaluated at the channel radius.

This latter quantity is given by

$$V(R_c) = \frac{Z_y Z_Y e^2}{R_c} \quad , \tag{73}$$

where Z_y and Z_Y are the charge numbers of the projectile and target, respectively, and e is the electronic charge. In the case of proton bombardment, the channel radius R_c is simply the target radius R. For α-particle bombardment, it is assumed that

$$R_c = R + R_\alpha \quad , \tag{74}$$

where R_α is roughly 1.2 fermi.

COMPUTER PROGRAM DESCRIPTION

INPUT DATA PREPARATION

The main program evaluates Equation 44, using the following input information:

LSM	-	the orbital quantum number of the last partial wave used in the expansion of incoming and outgoing wavefunctions
RZ	-	the value of the parameter r_0 of Equation 60 in fermi units
JTN	-	the neutron number of the target nucleus
JTZ	-	the proton number of the target nucleus
BET	-	the binding energy of the target nucleus in MeV units
BE(1)	-	the binding energy, in MeV units, of the residual nucleus (1) which remains after the emission of a neutron from the compound nucleus
BE(2)	-	the binding energy, in MeV units, of the residual nucleus (2) which remains after the emission of a proton from the compound nucleus
BE(3)	-	the binding energy, in MeV units, of the residual nucleus (3) which remains after the emission of an α-particle from the compound nucleus
NLEV(M) (for M = 1, 2, 3)	-	the number of levels which can be excited in residual nucleus (M) by the reaction
KI	-	the type of incident particle; KI = 1, 2, 3, implies neutron, proton, α-particle, respectively

LV - the energy level of the target nucleus prior to the reaction; LV = 1 corresponds to the ground state, LV = 2 to the first excited state, etc.

EIN - the bombarding energy, in MeV units

BI - the spin of level LV of the target

ITPAR - the parity of level LV of the target

E - the energy of a residual nucleus level, in MeV units

SPI - the spin of a residual nucleus level

IPA - the parity of a residual nucleus level

The first input card contains values of LSM, RZ, JTN, JTZ, and BET. The format is I5, F5.2, 2I5, F10.4.

The second input card contains values of BE(M) for M = 1, 2, and 3 and NLEV(M) for M = 1, 2, and 3. The format is 3F10.4, 3I5. The value of NLEV(M) is determined by the quantity EMA(M) = EIN - BET + BE(M). The level structure of residual nucleus M must now be examined in order to determine the number of levels (including the ground level) whose energies are less than or equal to EMA(M). This number is NLEV(M).

The third input card contains values of KI, LV, EIN, BI, ITPAR. The format is 2I5, 2F5.2, I5. An even parity ITPAR is designated by a +1, whereas an odd parity is designated by a -1.

Next, there are, in general, three sets of cards, each containing values for E, SPI, and IPA. However, in a specific case, there may be only one or two sets if it is not energetically possible to excite by the reaction any of the levels of any of the residual nuclei (1), (2), or (3). In such an instance, one or more of the EMA(M) would not be positive, and the corresponding NLEV(M) would be zero. In general, the number of cards in the Mth set is, of course, NLEV(M).

This completes a description of the input required to solve a given problem. Having solved this problem, the computer will attempt, at this point, to read another LSM, RZ, etc., card. If LSM is positive, the remaining cards which define another problem will be expected. If LSM is negative or zero, the run will be terminated.

OUTPUT DATA INTERPRETATION

First, the values of the input quantities LSM, RZ, JTN, JTZ, BET, BE(M), NLEV(M), KI, LV, EIN, BI, and ITPAR are printed out in a format which is self-explanatory. Next appear one to three sets of input data, depending on the number of energetically "open" reaction channels. The first set consists of the energy, spin, and parity of the ground state and each state of residual nucleus 1 which may be excited by the reaction. The second and third sets contain the same information for residual nuclei 2 and 3, respectively. Residual nuclei 1, 2, and 3 are the nuclei which remain after the emission by the compound nucelus of a neutron, proton, or α-particle, respectively.

There now follow one to three sets of output information, each set being headed by a value of KIP which designates the residual nucleus according to the scheme described above. Every other line of each set gives values for LVP, ELVP, EOUT, BIT, and IRPAR, LVP numbers the levels of the residual nucleus, with LVP = 1, corresponding to the ground state and LVP = 2 corresponding to the first excited state, etc. The variables ELVP, BIP, and IRPAR are the energy (in MeV), spin, and parity of the state, respectively, and EOUT is the corresponding energy (in MeV) of the particle emitted by the compound nucleus. Each of these lines, which define a residual nucleus level, is followed by a value of the calculated cross section (labeled SIGMA) for exciting this level.

In the evaluation of Equation 44, the three subroutines ADDEM, PEN, TRANS are employed. ADDEM evaluates the sum S(J) in the denominator, where

$$S(J) = \sum_{\alpha'', s'', \ell''} T^{J}_{\alpha'' s'' \ell''} \quad .$$

TRANS calculates the transmission coefficients for uncharged particles. The model adopted here does not take spin-orbit interactions into consideration. Therefore, the dependence of the transmission coefficient on s'' and J is neglected. Transmission coefficients for charged particles are calculated by the subroutine PEN by modifying the results of the TRANS subroutine to take into account the Coulomb barrier of Equation 72.

APPENDIX A. PROGRAM LISTING

MAIN PROGRAM

```
      DIMENSION FLOG(71)
      DIMENSION NLEV(3),EMA(3),EN(3,20),SPIN(3,20),PSPIN(3),
     1  T(3,20,20),IPAR(3,20)
      DIMENSION BE(3),JIN(3),JIZ(3),CHAM(3)
      COMMON FLOG,PI,HBAR,RZC,ELEC,RMNC,RMPC,RMAC,RALC
     1  ,NLEV,EMA,EN,SPIN,PSPIN,T,IPAR
      FLOG(1)=0.
      DO 5 IT=2,71
      FIT=FLOAT(IT-1)
    5 FLOG(IT)=ALOG(FIT)+FLOG(IT-1)
      RMN=939.505
      RMP=938.211
      RMA=3727.149
      RAL=1.2
      PI=3.1415926536
      HBAR=1.05443E-27
      ELEC=4.80286E-10
      RALC=RAL*1.0E-13
      RMNC=RMN/5.61000E+26
      RMPC=RMP/5.61000E+26
      RMAC=RMA/5.61000E+26
      CHAM(1)=RMN
      CHAM(2)=RMP
      CHAM(3)=RMA
      PSPIN(1)=0.5
      PSPIN(2)=0.5
      PSPIN(3)=0.0
  908 READ(2,600) LSM,RZ,JTN,JTZ,BET
  600 FORMAT(I5,F5.2,2I5,F10.4)
      IF(LSM)712,712,713
  712 CALL EXIT
  713 WRITE(3,911) LSM,RZ,JTN,JTZ,BET
  911 FORMAT(5H1LSM=I3,5H  RZ=F5.2,6H  JTN=I3,6H  JTZ=I3,
     1      6H  BET=F10.4)
      RZC=RZ*1.0E-13
      READ(2,603) (BE(M),M=1,3), (NLEV(M),M=1,3)
  603 FORMAT(3F10.4,3I5)
      WRITE(3,912) (BE(M),M=1,3),(NLEV(M),M=1,3)
  912 FORMAT(15H (BE(M),M=1,3)=3(F10.4,3X),
     1       /17H (NLEV(M),M=1,3)=3(I5,3X))
      READ(2,703)KI,LV,EIN,BI,ITPAR
  703 FORMAT(2I5,2F5.2,I5)
      WRITE(3,915)KI,LV,EIN,BI,ITPAR
  915 FORMAT(4H KI=I2,5H  LV=I3,6H  EIN=F5.2,
     1      5H  BI=F5.2,8H  ITPAR=I2)
      DO 701 M=1,3
      EMA(M)=EIN-BET+BE(M)
      IF(EMA(M)-0.1)701,952,952
  952 WRITE(3,913)M
  913 FORMAT(/7X,7H ENERGY,12X,5H SPIN,11X,7H PARITY,
     1    5X,20H OF RESIDUAL NUCLEUS,I3)
```

```
      NL=NLEV(M)
      DO 704 N=1,NL
      READ(2,702)E,SPI,IPA
  702 FORMAT(2F10.4,I5)
      WRITE(3,914) E,SPI,IPA
  914 FORMAT(4X,F10.4,8X,F10.4,13X,I2)
      EN(M,N)=E
      SPIN(M,N)=SPI
  704 IPAR(M,N)=IPA
  701 CONTINUE
      GO TO (800,801,802),KI
  800 JCNN=JTN+1
      JCNZ=JTZ
      GO TO 803
  801 JCNN=JTN
      JCNZ=JTZ+1
      GO TO 803
  802 JCNN=JTN+2
      JCNZ=JTZ+2
  803 JIN(1)=JCNN-1
      JIN(2)=JCNN
      JIN(3)=JCNN-2
      JIZ(1)=JCNZ
      JIZ(2)=JCNZ-1
      JIZ(3)=JCNZ-2
      DO 150 M=1,3
      IF(EMA(M)-0.1)150,951,951
  951 JN=JIN(M)
      JZ=JIZ(M)
      NL=NLEV(M)
      DO 151 LEV=1,NL
      CHE=EMA(M)-EN(M,LEV)
      IF(ABS(CHE)-1.0E-5)150,907,907
  907 IF(CHE)150,150,152
  152 LSMA=LSM+1
      DO 151 LS=1,LSMA
      LLS=LS-1
      CALL PEN(JN,JZ,M,CHE,LLS,TAL)
  151 T(M,LEV,LS)=TAL
  150 CONTINUE
      SI=PSPIN(KI)
      FACI=(2.*SI+1.)*(2.*BI+1.)
      CHMC=CHAM(KI)/5.61000E+26
      EINC=EIN*1.60206E-6
      SSK=(SQRT(2.*CHMC*EINC))/HBAR
      BLAM=1./SSK
      FAC=(PI*BLAM*BLAM)/FACI
      FAC=FAC/1.0E-24
      DO 953 M=1,3
      IF(EMA(M)-0.1)953,954,954
  954 WRITE(3,958)M
  958 FORMAT(/30X,5H KIP=I2)
```

```
      KIP=M
      SIP=PSPIN(M)
      NLP=NLEV(M)
      DO 955 LVP=1,NLP
      EOUT=EMA(M)-EN(M,LVP)
      IF(ABS(EOUT)-1.0E-5)953,956,956
  956 IF(EOUT)953,953,957
  957 ELVP=EN(M,LVP)
      BIP=SPIN(M,LVP)
      IRPAR=IPAR(M,LVP)
      WRITE(3,959)LVP,ELVP,EOUT,BIP,IRPAR
  959 FORMAT(5H LVP=I3,7H  ELVP=F5.2,7H  EOUT=F5.2,
     1      6H  BIP=F5.2,8H  IRPAR=I2)
      SUM=0.
      SJMI=ABS(BI-SI)
      SJPMI=ABS(BIP-SIP)
      SJMA=BI+SI
      SJPMA=BIP+SIP
      JPAR=ITPAR*IRPAR+2
      LS=0
  408 LSP=0
  406 LSUM=LS+LSP
      LSUM2=(FLOAT(LSUM)/2.)+0.00001
      GO TO (1000,712,1001),JPAR
 1000 IF(2*LSUM2-LSUM)1002,405,1002
 1001 IF(2*LSUM2-LSUM)405,1002,405
 1002 SJ=SJMI
  404 BJ1MI=ABS(SJ-FLOAT(LS))
      BJ1MA=SJ+FLOAT(LS)
      SJP=SJPMI
  402 BJ2MI=ABS(SJP-FLOAT(LSP))
      BJ2MA=SJP+FLOAT(LSP)
      BJ=BJ1MI
  400 IF(ABS(BJ-BJ2MI)-1.0E-5)5001,6001,6001
 6001 IF(BJ-BJ2MI)5002,5001,5001
 5001 IF(ABS(BJ-BJ2MA)-1.0E-5)5003,6002,6002
 6002 IF(BJ-BJ2MA)5003,5003,5002
 5003 FACJ=2.*BJ+1.
      CALL ADDEM(TJ,ITPAR,LS,LSM,SUMPP)
      JLS=LS+1
      JLSP=LSP+1
      TERM=FACJ*T(KI,LV,JLS)*T(KIP,LVP,JLSP)
      SUM=SUM+(TERM/SUMPP)
 5002 BJ=BJ+1.
      IF(ABS(BJ-BJ1MA)-1.0E-5)400,904,904
  904 IF(BJ-BJ1MA)400,400,401
```

```
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  401 SJP=SJP+1.
      IF(ABS(SJP-SJPMA)-1.0E-5)402,905,905
  905 IF(SJP-SJPMA)402,402,403
  403 SJ=SJ+1.
      IF(ABS(SJ-SJMA)-1.0E-5)404,906,906
  906 IF(SJ-SJMA)404,404,405
  405 LSP=LSP+1
      IF(LSP-LSM)406,406,407
  407 LS=LS+1
      IF(LS-LSM)408,408,409
  409 SIGMA=FAC*SUM
  955 WRITE(3,900)SIGMA
  900 FORMAT(7H SIGMA=E15.8)
  953 CONTINUE
      GO TO 908
      END
```

SUBROUTINE ADDEM

```
      SUBROUTINE ADDEM(TJ,ITPAR,LS,LSM,SUMPP)
      DIMENSION FLOG(71)
      DIMENSION NLEV(3),EMA(3),EN(3,20),SPIN(3,20),PSPIN(3),
     1  T(3,20,20),IPAR(3,20)
      COMMON FLOG,PI,HBAR,RZC,ELEC,RMNC,RMPC,RMAC,RALC
     1  ,NLEV,EMA,EN,SPIN,PSPIN,T,IPAR
      SUMPP=0.
      DO 200 MPP=1,3
      IF(EMA(MPP)-0.1)200,950,950
  950 NLPP=NLEV(MPP)
      DO 201 LVPP=1,NLPP
      CHEPP=EMA(MPP)-EN(MPP,LVPP)
      IF(ABS(CHEPP)-1.0E-5)200,908,908
  908 IF(CHEPP)200,200,202
  202 SMI=ABS(SPIN(MPP,LVPP)-PSPIN(MPP))
      TSMI=2.*SMI+0.00001
      ISMI=TSMI
      JSMI=TSMI/2.
      IDS=ISMI-(2*JSMI)
      TTJ=2.*TJ+0.00001
      ITJ=TTJ
      JTJ=TTJ/2.
      IDJ=ITJ-(2*JTJ)
      IF(IDS)300,301,300
  300 IF(IDJ)302,201,302
  301 IF(IDJ)201,302,201
  302 SMA=SPIN(MPP,LVPP)+PSPIN(MPP)
      SJPP=SMI
      JPAR=ITPAR*IPAR(MPP,LVPP)+2
  308 LSPP=0
  306 LSUM=LS+LSPP
      LSUM2=(FLOAT(LSUM)/2.)+0.00001
      GO TO (1000,712,1001),JPAR
 1000 IF(2*LSUM2-LSUM)1002,303,1002
 1001 IF(2*LSUM2-LSUM)303,1002,303
 1002 SMIN=ABS(SJPP-FLOAT(LSPP))
      SMAX=SJPP+FLOAT(LSPP)
      IF(ABS(TJ-SMIN)-1.0E-5)304,905,905
  905 IF(TJ-SMIN)303,304,304
  304 IF(ABS(TJ-SMAX)-1.0E-5)305,906,906
  906 IF(TJ-SMAX)305,305,303
  305 SUMPP=SUMPP+T(MPP,LVPP,LSPP+1)
  303 LSPP=LSPP+1
      IF(LSPP-LSM)306,306,307
  307 SJPP=SJPP+1.
      IF(ABS(SJPP-SMA)-1.0E-5)308,907,907
  907 IF(SJPP-SMA)308,308,201
  201 CONTINUE
  200 CONTINUE
      RETURN
  712 CALL EXIT
      END
```

```
      SUBROUTINE TRANS(TL,L,XS,XL)
      DIMENSION FLOG(71)
      COMMON FLOG
      IMAX=L/2
      IMAX=IMAX+1
      SUM1=0.
      DSUM1=0.
      DO 1 J=1,IMAX
      I=J-1
      FI=I
      I1=L+(2*I)
      I2=2*I
      I3=L-(2*I)
      IF(I1-70) 80,80,90
   80 IF(I2-70) 81,81,90
   81 IF(I3-70) 82,82,90
   82 AX=FLOG(I1+1)-FLOG(I2+1)-FLOG(I3+1)
      AX=AX-(2.*FI*ALOG(ABS(2.*XS)))
      AX=EXP(AX)
      FONE=(2.*FI)/XS
      AXX=AX*FONE
      KI=I/2
      IF((2*KI)-I)8,9,8
    8 SUM1=SUM1-AX
      DSUM1=DSUM1+AXX
      GO TO 1
    9 SUM1=SUM1+AX
      DSUM1=DSUM1-AXX
    1 CONTINUE
      SUM2=0.
      DSUM2=0.
      IF(L)6,6,7
    7 IMAX=(L-1)/2
      IMAX=IMAX+1
      DO 2 J=1,IMAX
      I=J-1
      FI=I
      I1=L+(2*I)+1
      I2=(2*I)+1
      I3=L-(2*I)-1
      IF(I1-70) 83,83,90
   83 IF(I2-70) 84,84,90
   84 IF(I3-70) 85,85,90
   85 AX=FLOG(I1+1)-FLOG(I2+1)-FLOG(I3+1)
      AX=AX-(((2.*FI)+1.)*ALOG(ABS(2.*XS)))
      AX=EXP(AX)
      FTWO=((2.*FI)+1.)/XS
      AXX=AX*FTWO
      KI=I/2
      IF((2*KI)-I)10,11,10
   10 SUM2=SUM2-AX
      DSUM2=DSUM2+AXX
      GO TO 2
   11 SUM2=SUM2+AX
      DSUM2=DSUM2-AXX
```

SUBROUTINE TRANS - Concluded

```
 7 CONTINUE
 6 VL=(SUM1*SUM1)+(SUM2*SUM2)
   VL=1./VL
   VLP=(DSUM1-SUM2)*(DSUM1-SUM2)
   VLP=VLP+((DSUM2+SUM1)*(DSUM2+SUM1))
   TL=4.*XS*XL*VL
   DEN=(XL*XL)+(((2.*XS*XL)+(XS*XS*VLP))*VL)
   TL=TL/DEN
   GO TO 50
90 WRITE(3,91)
91 FORMAT(25H FACTORIAL TABLE EXCEEDED)
   CALL EXIT
50 RETURN
   END
```

```
      SUBROUTINE PEN(JN,JZ,M,CHE,LS,TAL)
      DIMENSION FLOG(71)
      COMMON FLOG,PI,HBAR,RZC,ELEC,RMNC,RMPC,RMAC,RALC
      TN=JN
      TZ=JZ
      TA=TN+TZ
      TR=RZC*(TA**(1./3.))
      CHEC=CHE*1.60206E-6
      GO TO (1,2,3),M
    1 CHAR=TR
      CHMC=RMNC
      CB=1.
      GO TO 4
    2 CHAR=TR
      CHMC=RMPC
      CA=(TZ*ELEC*ELEC)/CHAR
    5 CB=1.-(CA/CHEC)
      IF(ABS(CB)-1.0E-5)31,100,100
  100 IF(CB)31,31,4
   31 TAL=0.
      RETURN
    3 CHAR=TR+RALC
      CHMC=RMAC
      CA=(2.*TZ*ELEC*ELEC)/CHAR
      GO TO 5
    4 BKZ=(((9.*PI)/8.)**(1./3.))/RZC
      SK=(SQRT(2.*CHMC*CHEC))/HBAR
      XS=SK*CHAR
      BK=SQRT((BKZ*BKZ)+(SK*SK))
      XL=BK*CHAR
      CALL TRANS (TL,LS,XS,XL)
      TAL=CB*TL
      RETURN
      END
```

APPENDIX B. SAMPLE PROBLEMS

Given below are input and output data for cross section calculations for the ground state and the first four levels excited by the inelastic scattering of 3 MeV neutrons from Fe^{56}.

INPUT DATA

```
  7 1.30   30   26  492.31
492.31    489.32    464.15      5    0    0
  1    1 3.0  0.0    +1
  0.0       0.0      +1
  0.8469    2.0      +1
  2.085     4.0      +1
  2.658     2.0      +1
  2.957     2.0      +1
```

OUTPUT DATA

```
LSM=  7  RZ= 1.30  JTN= 30  JTZ= 26  BET=  492.3100
(BE(M),M=1,3)=  492.3100     489.3200     464.1500
(NLEV(M),M=1,3)=    5          0          0
KI= 1  LV=  1  EIN= 3.00  BI= 0.00  ITPAR= 1

       ENERGY              SPIN              PARITY      OF RESIDUAL NUCLEUS  1
       0.0000             0.0000               1
       0.8469             2.0000               1
       2.0850             4.0000               1
       2.6580             2.0000               1
       2.9570             2.0000               1

                                KIP= 1
LVP=  1  ELVP= 0.00  EOUT= 3.00  BIP= 0.00  IRPAR= 1
SIGMA= 0.53890240E 00
LVP=  2  ELVP= 0.84  EOUT= 2.15  BIP= 2.00  IRPAR= 1
SIGMA= 0.10819439E 01
LVP=  3  ELVP= 2.08  EOUT= 0.91  BIP= 4.00  IRPAR= 1
SIGMA= 0.11998973E 00
LVP=  4  ELVP= 2.65  EOUT= 0.34  BIP= 2.00  IRPAR= 1
SIGMA= 0.25748694E 00
LVP=  5  ELVP= 2.95  EOUT= 0.04  BIP= 2.00  IRPAR= 1
SIGMA= 0.66001668E-01
```

Figure B-1 compares the theoretically calculated cross sections with experimental values (Ref. 13) for the case of inelastic neutron scattering from Y^{89}. For this calculation, r_0 was given the value 1.10 fermi and the following spin and parity assignments (Ref. 14) were made:

Level	Energy	Spin	Parity
1	0	1/2	-
2	0.92	9/2	+
3	1.53	3/2	-
4	1.75	5/2	-
5	2.22	5/2	+
6	2.53	7/2	+
7	2.61	9/2	+
8	2.86	3/2	-

The agreement between experiment and theory is seen to be only fair in most cases, and a considerable disagreement is apparent for the 2.22 MeV level. Assuming that the experimental measurements and the spin-parity assignments are correct, the disagreement is likely to be due to inadequacies in the totally-absorbing-nucleus model used here and in the neglect of spin orbit interactions. The introduction of a more realistic nuclear potential containing both real and imaginary components and the spin-orbit term would probably bring the theoretical results into closer agreement with experiment.

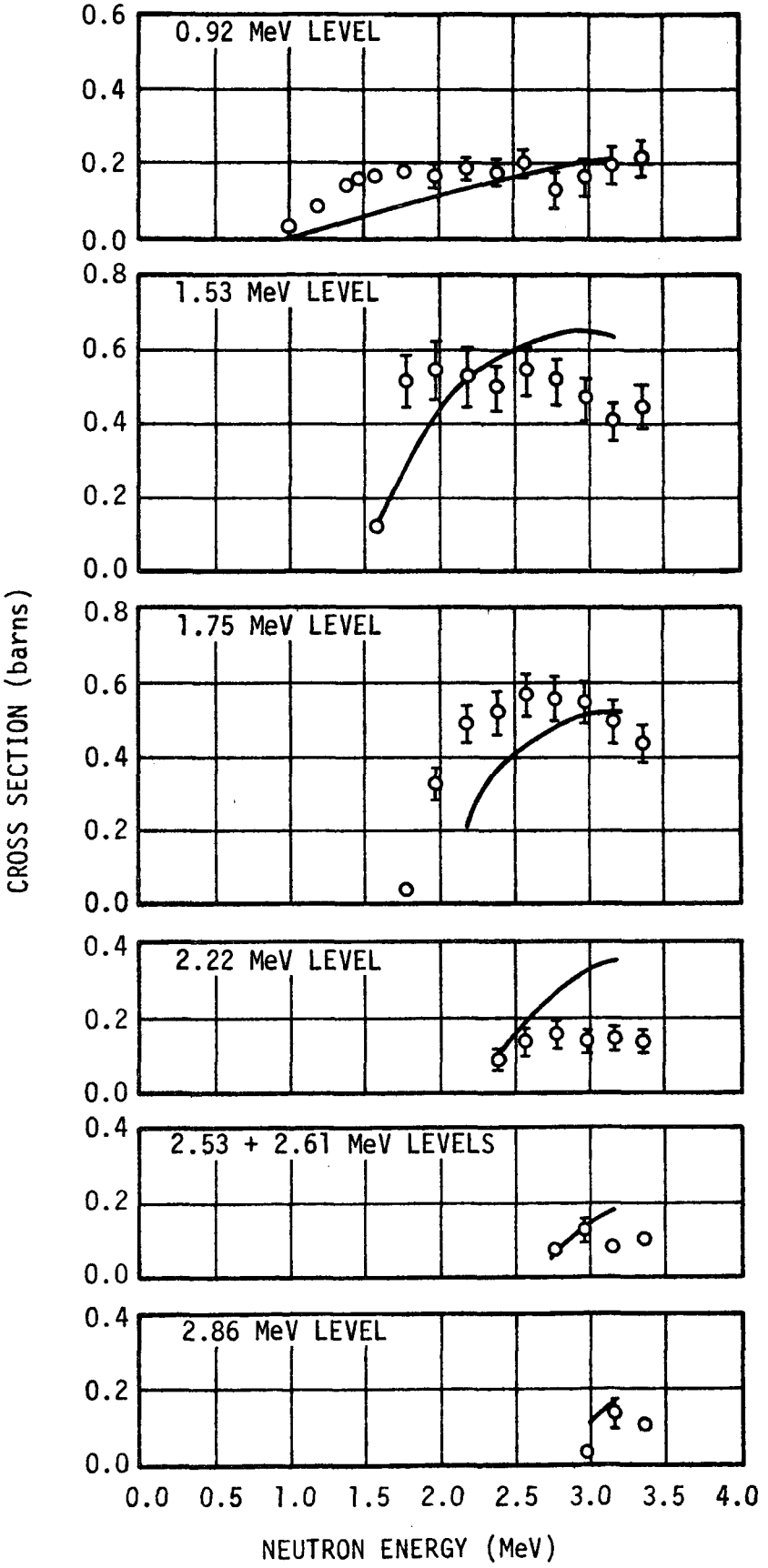

FIGURE B-1. COMPARISON OF THEORY WITH EXPERIMENT FOR INELASTIC SCATTERING FROM Y^{89}

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SECTION III. THEORETICAL CONSIDERATION OF THE HYBRID CASE

TABLE OF CONTENTS

PRELIMINARY CONSIDERATIONS

Nuclear reactions which proceed through the compound nucleus mechanism have already been considered in this report. The section entitled "Computer Program Based on the Full Statistical Model of Nuclear Reactions" dealt with the situation in which the level structure of the residual nucleus consists of a continuum of levels. The section entitled "Computer Program Based on the Partial Statistical Model of Nuclear Reactions", on the other hand, considered the case in which the level structure of the residual nucleus consists of discrete levels of definite energy, spin, and parity. It is now appropriate to examine the case in which the residual nucleus level structure consists of a discrete portion $\epsilon_0, \epsilon_1, \ldots, \epsilon_N$ and a continuum portion beyond some value $\epsilon_m > \epsilon_N$ (see Figure 1). This is referred to hereafter as the "hybrid" case.

The reaction is assumed to proceed as follows:

$$a + X \rightarrow C \rightarrow b + Y \qquad (1)$$

where C is the compound nucleus. The following definitions are now made.

α - entrance channel index

s - entrance channel spin index.

The spin $\vec{s}$ is given by

$$\vec{s} = \vec{i} + \vec{I}, \qquad (2)$$

where

$\vec{i}$ - spin of incoming projectile a

$\vec{I}$ - spin of target nucleus X ,

and s takes on values in integral steps from $|i-I|$ through $(i+I)$. The ℓ is the entrance channel orbital angular momentum. For the exit channel one has

α' - exit channel index

s' - exit channel spin index .

The spin $\vec{s}'$ is given by

$$\vec{s}' = \vec{i}' + \vec{I}' \tag{3}$$

where

$\vec{i}'$ - spin of outgoing particle

$\vec{I}'$ - spin of residual nucleus Y,

and s' takes on values in integral steps from $|i'-I'|$ through $(i'+I')$. ℓ' is the exit channel orbital angular momentum. Thus, one designates an entrance channel by (α, s, ℓ) and an exit channel by (α', s', ℓ').

If the total angular momentum of the compound nucleus is $\vec{J}$, then one has from conservation of angular momentum that

$$\vec{s} + \vec{\ell} = \vec{J} \tag{4}$$

The quantum number J takes on values in integral steps from $|s-\ell|$ through $(s+\ell)$ or from $|s'-\ell'|$ through $(s'+\ell')$. The orbital angular momentum ℓ, of course, takes on values from $|J-s|$ through $(J+s)$, and similarly ℓ' takes on values from $|J-s'|$ through $(J+s')$.

Now it has been shown in the section entitled "Computer Program Based on the Partial Statistical Model", based

only on compound nucleus formation (Bohr assumption) and reciprocity (and conservation of normalization under time reversal), that

$$\sigma(\alpha' s', \alpha s) = \frac{\pi \lambda_\alpha^2}{(2s+1)} \sum_{J=0}^{\infty} \sum_{\ell} \sum_{\ell'} \times \left| (2J+1)\ \delta_{\alpha'\alpha}\, \delta_{s's}\, \delta_{\ell'\ell} - S^{J}_{\alpha' s' \ell', \alpha s \ell} \right|^2 \tag{5}$$

and

$$\sigma(\alpha', \alpha) = \sum_{s} \sum_{s'} \frac{(2s+1)}{(2I+1)(2i+1)}\ \sigma(\alpha' s', \alpha s)\ . \tag{6}$$

Substituting from Equation 5 in Equation 6 one obtains

$$\sigma(\alpha', \alpha) = \pi \lambda_\alpha^2 \sum_{J} \sum_{s} \sum_{\ell} \sum_{s'} \sum_{\ell'} \frac{(2J+1)}{(2I+1)(2i+1)} \times \left| \delta_{\alpha'\alpha}\, \delta_{s's}\, \delta_{\ell'\ell} - S^{J}_{\alpha' s' \ell', \alpha s \ell} \right|^2 . \tag{7}$$

It is important to note that all statistical factors have been calculated and now reside in the sums over the statistical weight factor. The conservation of angular momentum is secured by the respective ranges of summation and will be independent of any specific assumptions made below concerning the squared dynamical matrix elements. Furthermore, conservation of parity requires that

$$(-1)^{\ell+\ell'} = \Pi_\alpha \Pi_{\alpha'} = \Pi_a \Pi_X \Pi_Y \Pi_b , \tag{8}$$

or

$$\ell + \ell' = \begin{bmatrix} \text{even} \\ \text{odd} \end{bmatrix} \text{ according as } \Pi_\alpha \Pi_{\alpha'} = \begin{bmatrix} + \\ - \end{bmatrix} . \tag{9}$$

Now in the light of the above, the partial statistical model consists of relacing the squared matrix element by its expectation value (because a very large number of states of the compound nucleus are assumed and only resonance contributions are considered), and then making the replacement

$$\left\langle \left| \delta_{\alpha'\alpha} \delta_{s's} \delta_{\ell'\ell} - S^J_{\alpha's'\ell', \alpha s \ell} \right|^2 \right\rangle = \frac{T^J_{\alpha\ell s} T^J_{\alpha's'\ell'}}{\sum_{\alpha''} \sum_{s''} \sum_{\ell''} T^J_{\alpha''s''\ell''}} \tag{10}$$

This gives

$$\sigma(\alpha', \alpha) = \Pi \lambda^2_\alpha \sum_J \sum_s \sum_\ell \sum_{s'} \sum_{\ell'} \frac{(2J+1)}{(2I+1)(2i+1)} \times \frac{T^J_{\alpha\ell s} T^J_{\alpha'\ell's'}}{\sum_{\alpha''} \sum_{s''} \sum_{\ell''} T^J_{\alpha''\ell''s''}} . \tag{11}$$

It should be noted that, because of the above, no further statistical factors enter in Equation 10, and therefore in Equation 11. Also, the factors

$$\frac{T^J_{\alpha'\ell's'}}{\sum_{\alpha''} \sum_{s''} \sum_{\ell''} T^J_{\alpha''s''\ell''}} \tag{12}$$

can be regarded as branching ratios, or relative probabilities of decay of the compound nucleus via channel α'. Thus, the channels α'' are all those that compete with channel α'. Consequently, one has the additional parity selection rule

$$(-1)^{\ell+\ell''} = \Pi_\alpha \, \Pi_{\alpha''} \ , \tag{13}$$

or

$$\ell + \ell'' = \begin{bmatrix} \text{even} \\ \text{odd} \end{bmatrix} \text{ according as } \Pi_\alpha \, \Pi_{\alpha''} = \begin{bmatrix} + \\ - \end{bmatrix} \tag{14}$$

PASSAGE FROM THE DISCRETE LEVEL CASE TO THE CONTINUUM CASE

It is now desired to pass to the complete statistical model, as concerns the continuum shown in Figure 1, and then to include the discrete level portion in an approximate fashion. Two cases will be considered

- Exit channel residual nucleus energy $\epsilon'(\alpha')$ in the continuum
- Exit channel residual nucleus energy $\epsilon'(\alpha')$ in the discrete portion, i.e., $\epsilon' = \epsilon_i$.

The following designations are made.

$E = E_\alpha$ - energy of partical a, i.e., energy of entrance channel α

$E' = E_{\alpha'}$ - energies of particles b in exit channel α'

Q - reaction energy.

Thus, the excitation energy of the residual nucleus is given by

$$\epsilon' = E - E' - Q , \tag{15}$$

and ϵ' ranges from 0 (when $E' = E - Q$) to $E - Q$ (when $E' = 0$). The case $E' = E - Q$ clearly corresponds to the ground state of the residual nucleus, i.e., $\epsilon' = \epsilon_0 = 0$.

The expression to be used in passing from the discrete level case (Equation 11) to the continuum case is given by Goldstein (Ref. 1).

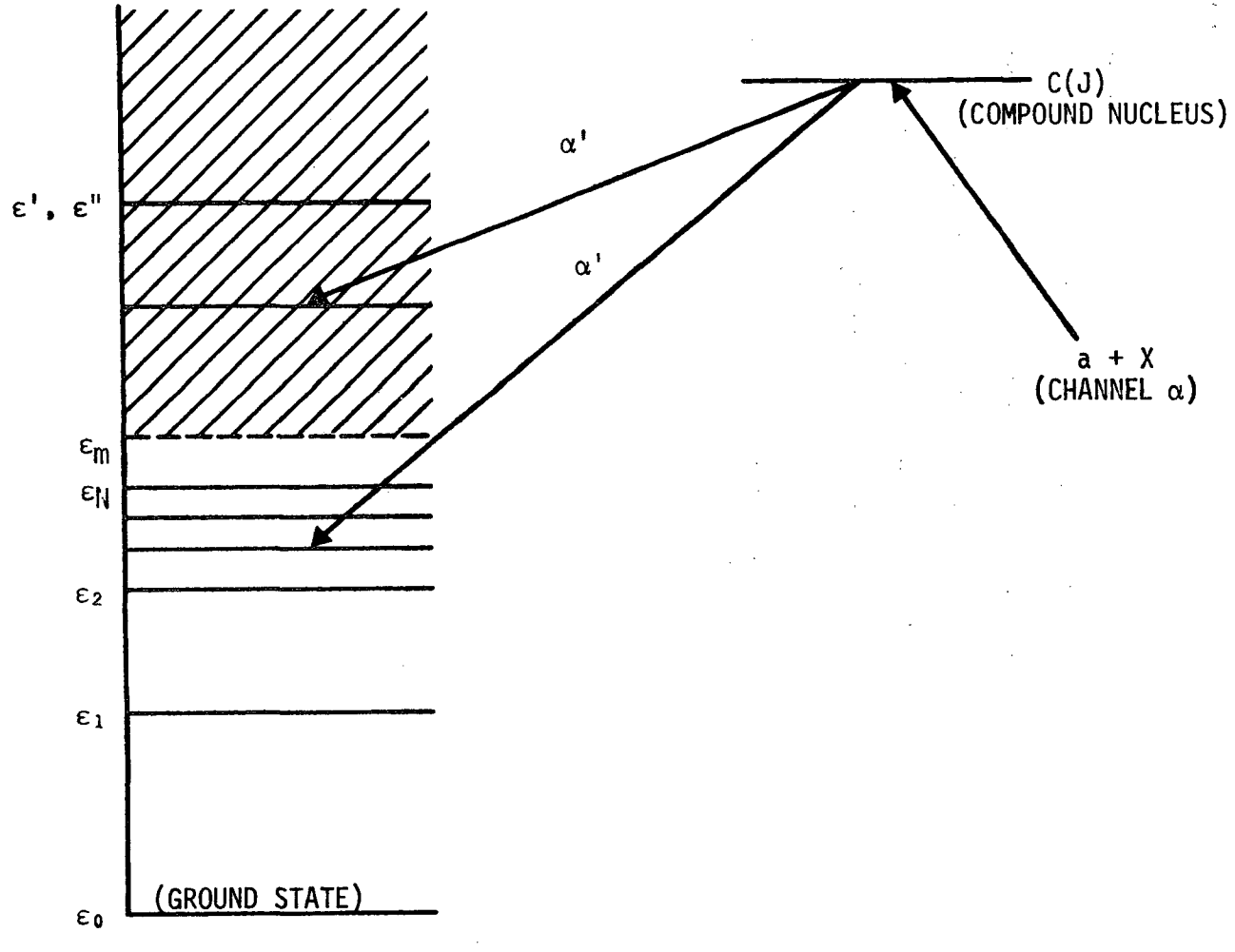

FIGURE 1. NUCLEAR REACTION LEAVING THE RESIDUAL NUCLEUS WITH AN EXCITATION ENERGY IN EITHER THE CONTINUUM REGION OR THE DISCRETE REGION

$$\sigma_{\alpha'\alpha}(E, E')\,dE' = \pi \lambda_{\alpha}^{2} \sum_{J} \sum_{s} \sum_{\ell} \frac{(2J+1)}{(2I+1)(2i+1)}$$

$$\times \frac{T^{J}_{\alpha s \ell}(E) \sum_{s'} \sum_{\ell'} \sum_{I'} T^{J}_{\alpha' s' \ell'}(E')\, \omega_{\alpha'}(I', \epsilon')\, dE'}{\sum_{\alpha''} \sum_{s''} \sum_{\ell''} \sum_{I''} \int_{0}^{E-Q} T^{J}_{\alpha'' s'' \ell''}(E'')\, \omega_{\alpha''}(I'', \epsilon'')\, d\epsilon''} \tag{16}$$

Here $\omega_{\alpha'}(I', \epsilon')$ is the level density of the residual nucleus as a function of both level energy ϵ' and residual nucleus spin I'. The summation over α'' in the denominator is to be extended over all possible exit channels, including the cases where particles of different species are emitted in the reaction. The next assumption is the well known factorization of ω into a statistical factor and an energy factor.

$$\omega_{\alpha'}(I', \epsilon') = (2I'+1)\, \omega_{0\alpha'}(\epsilon') \tag{17}$$

DERIVATION OF THE REACTION CROSS SECTION FOR FOR THE HYBRID CASE

It is now assumed that Equation 17 applies also when the discrete states are included. One can then introduce delta functions in $\omega_{0\alpha'}(\epsilon')$, so that

$$\omega_{0\alpha'}(\epsilon') = \sum_{j=1}^{N} \delta(\epsilon' - \epsilon_j) + \omega_{0\alpha'}(\epsilon' \geqq \epsilon_m) . \tag{18}$$

Thus, one obtains

$$\omega_{\alpha'}(I', \epsilon') = (2I' + 1) \sum_{j=1}^{N} \delta(\epsilon' - \epsilon_j) + (2I' + 1)\, \omega_{0\alpha'}(\epsilon' \geqq \epsilon_m), \tag{19}$$

with a corresponding expression for $\omega_{\alpha''}(I'', \epsilon'')$. Introducing Equation 17 into Equation 16 one obtains after rearrangement

$$\sigma_{\alpha'\alpha}(E, E') = \frac{\pi \lambda_\alpha^2}{(2i + 1)(2I + 1)} \sum_J \sum_s \sum_\ell (2J + 1)\, T^J_{\alpha s \ell}(E) \times \sum_{s'} \sum_{\ell'} \frac{T^J_{\alpha' s' \ell'}(E') \left[\sum_{I'} (2I' + 1)\right] \omega_{0\alpha'}(\epsilon')\, dE'}{\int_0^{E-Q} \sum_{\alpha''} \sum_{s''} \sum_{\ell''} T_{\alpha'' s'' \ell''}(E'') \left[\sum_{I''} (2I'' + 1)\right] \omega_{0\alpha''}(\epsilon'')\, d\epsilon''} \tag{20}$$

In carrying out the sums over I' and I'' it is to be noted that I' takes on values from $|s' - i'|$ through $(s' + i')$ and I'' takes on values from $|s'' - i''|$ through $(s'' + i'')$. It follows then that

$$\sum_{I'} (2I' + 1) = (2s' + 1)(2i' + 1)$$

$$\sum_{I''} (2I'' + 1) = (2s'' + 1)(2i'' + 1) \quad , \tag{21}$$

whence Equation 20 becomes

$$\sigma_{\alpha'\alpha}(E, E')\,dE' = \frac{\pi \lambda_\alpha^2}{(2i + 1)(2I + 1)} \sum_J \sum_s \sum_\ell (2J + 1)\, T^J_{\alpha s \ell}(E)$$

$$\times \sum_{s'} \sum_{\ell'} \frac{(2s' + 1)(2i' + 1)\, T_{\alpha' s' \ell'}(E')\, \omega_{0\alpha'}(\epsilon')\, d\epsilon'}{\sum_{\alpha''} (2i'' + 1) \int_0^{E-Q} \sum_{s''} \sum_{\ell''} (2s'' + 1)\, T^J_{\alpha'' s'' \ell''}(E'')\, \omega_{0\alpha''}(\epsilon'')\, d\epsilon''} \tag{22}$$

Finally, the cross section for the hybrid case can be written. For the case in which the residual nucleus is in the continuum the result is

$$\sigma^{(1)}_{\alpha'\alpha}(E, E')\,dE' = \pi \lambda_\alpha^2 \sum_J \sum_s \sum_\ell \frac{(2J + 1)}{(2i + 1)(2I + 1)}\, T^J_{\alpha s \ell}(E)$$

$$\times \frac{(2i' + 1) \sum_{s'} \sum_{\ell'} (2s' + 1)\, T^{(J)}_{\alpha' s' \ell'}(E')\, \omega_{0\alpha'}(\epsilon \geq \epsilon_m)\, dE'}{\sum_{\alpha''} (2i'' + 1) \sum_{s''} \sum_{\ell''} (2s'' + 1) \left\{ \sum_{j=0}^{N} T_{\alpha'' s'' \ell''}(E_j'') + \int_0^{E-Q} T^J_{\alpha'' s'' \ell''}(E'')\, \omega_{0\alpha''}(\epsilon'' \geq \epsilon_m)\, d\epsilon'' \right\} \tag{23}$$

where

$$E_j'' = (E - Q) - \epsilon_j \, ,$$

$$\epsilon' = (E - Q) - E' \geqq \epsilon_m \, . \tag{24}$$

It is also noted that in the sum over j is the denominator only those discrete levels will contribute for which $(E - Q) \geqq \epsilon_j$. In the present case of going into the continuum all discrete levels will of course contribute, so that the sum is complete, from j = 0 to j = N as shown. For the case in which the residual nucleus is in the discrete portion the result is

$$\sigma^{(2)}_{\alpha'\alpha}(E, E_j') = \pi \lambda_\alpha^2 \sum_J \sum_s \sum_\ell \frac{(2J+1)}{(2i+1)(2I+1)} T^J_{\alpha s \ell}(E) \times \frac{(2i'+1) \sum_{s'} \sum_{\ell'} (2s'+1) T^{(J)}_{\alpha' s' \ell'}(E_j')}{\sum_{\alpha''} (2i''+1) \sum_{s''} \sum_{\ell''} (2s''+1) \left\{ \sum_{k=0}^{N} T_{\alpha'' s'' \ell''}(E_k'') + \int_{\epsilon_m}^{E-Q} T^J_{\alpha'' s'' \ell''}(E'') \, \omega_{0\alpha''}(\epsilon'' \geqq \epsilon_m) \, d\epsilon'' \right\}} \tag{25}$$

where

$$E_j' = E - Q - \epsilon_j \, ,$$

$$E_k'' = E - Q - \epsilon_k \, . \tag{26}$$

An expression for the reaction cross section for the hybrid case can be found in Reference 2. There the approximation is made that the transmission coefficients $T^J_{\alpha s \ell}$ do not depend on s. This, of

course, is a perfectly valid approximation, although cross sections calculated under this restriction would not be expected to be as accurate as those calculated under more general conditions in which spin-orbit interactions may be present. The present authors wish to point out here, however, that the expression presented in Reference 2 appears to them to be erroneous on the following grounds. In the first place, the expression is derived directly from the expression for the cross section in the full statistical model by the artifice of replacing the continuous level density by delta functions to represent discrete levels and by replacing the integral over the continuum by a sum over discrete levels. The present authors believe that this approach is not valid and that the cross section for the hybrid case can only be correctly derived by going back to the expression for the cross section in the partial statistical model for which discrete levels are assumed. Many assumptions are made in going from the cross section expression in the partial statistical model to the corresponding expression in the full statistical model. After these assumptions have been made it is not valid to reintroduce the discrete levels in the simplistic manner of Reference 2. Secondly, the writing of the cross section for the hybrid case explicitly in terms of the cross section for compound nucleus formation σ_c is not valid. The cross section σ_c is a sum over partial cross sections $\sigma_{c\ell}$,

$$\sigma_c = \sum_{\ell=0}^{\infty} \sigma_{c\ell} \quad , \tag{27}$$

where ℓ is the orbital angular momentum. Because of the parity restrictions given by Equations 9 and 14 all values of ℓ are not allowed, so that the reduction in terms of σ_c can not be performed in the expression for the reaction cross section in either the partial statistical model or the hybrid case.

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SECTION IV. CROSS SECTIONS FOR LEVEL EXCITATION AND GAMMA PRODUCTION BY NEUTRON INELASTIC SCATTERING

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INTRODUCTION

A neutron inelastic scattering reaction leaves the target nucleus in one of its excited states, and the remaining available energy appears as kinetic energy of the scattered neutron and target nucleus. If the excitation energy is not sufficiently high to allow the emission of another nuclear particle, the nucleus will generally proceed to decay by a series of gamma transitions until the ground state is reached. For neutron shielding applications, it is desirable to know for a given bombarding energy the quantity of neutrons and gamma rays which emerge with a given energy. If the cross section for exciting each of the various nuclear levels is known, the cross section for the production of neutrons of a given energy can be readily obtained from energy conservation requirements. If, in addition to the level excitation cross sections, the gamma transition probabilities between the various pairs of nuclear levels are known, the cross section for producing each of the possible gamma rays may be determined.

The level excitation cross sections depend, of course, on the nature of the interaction between the incoming neutron and the target nucleus. An approach which has been highly successful in predicting these cross sections is that of Hauser and Feshbach (Ref. 1), with the neutron penetrabilities being obtained from calculations employing a realistic optical-model nuclear potential. The basic assumption of this approach is that the scattering process takes place through compound nucleus formation and that direct interaction effects are not appreciable. This is expected to be the case for the target nuclei and bombarding energy range considered in this report.

The computer program Abacus-2 (Ref. 2), which is based on the Hauser-Feshbach procedure and calculates the necessary optical model

penetrabilities, was used to perform the level excitation cross section calculations presented in this report. Input required for these calculations consists of optical model potential parameters and the energy level scheme for each of the nuclei under consideration.

Consideration is now given to the gamma decay of the levels excited by the inelastic scattering process. Consider the first n levels of the target nucleus with the ground state being designated as level 1. The levels are assumed to be excited by inelastic scattering of neutrons of energy ϵ. In the general case, lower levels will be subsequently excited when an initially excited level i decays by gamma emission to the lower levels. The particular levels which are fed in this manner and the extent to which each is fed depends, of course, on the gamma transition probability P_j^i for the transition from the initial level i to the lower level j. The levels which are fed by gamma decay from the initially excited levels can, in turn, feed still lower levels. In general, there results a cascade of gamma rays of various energies and intensities.

Let the cross section for the initial excitation of levels i, i+1, ..., n be denoted by $\sigma^i(\epsilon)$, $\sigma^{i+1}(\epsilon)$, ..., $\sigma^n(\epsilon)$, respectively. The cross section $\Sigma_j^i(\epsilon)$ for producing a gamma transition between level i and level j is given by

$$\begin{aligned}
\Sigma_j^i(\epsilon) = P_j^i \Big\{ & \sigma^i(\epsilon) + \sigma^{i+1}(\epsilon)\, P_i^{i+1} \\
& + \sigma^{i+2}(\epsilon) \left[P_i^{i+2} + P_{i+1}^{i+2}\, P_i^{i+1} \right] \\
& + \sigma^{i+3}(\epsilon) \left[P_i^{i+3} + P_{i+1}^{i+3}\, P_i^{i+1} + P_{i+2}^{i+3}\, P_{i+1}^{i+2}\, P_i^{i+1} \right] \\
& + \cdots\cdots \\
& + \sigma^n(\epsilon) \left[P_i^n + P_{i+1}^n\, P_i^{i+1} + P_{i+2}^n\, P_{i+1}^{i+2}\, P_i^{i+1} \right. \\
& \qquad \left. + \cdots + P_{n-1}^n\, P_{n-2}^{n-1} \cdots P_i^{i+1} \right] \Big\}, \qquad (1)
\end{aligned}$$

where the indices i, j, and n satisfy $2 \leqq i \leqq n$ and $j < i$. A computer program for evaluating this expression is described in the section of this report entitled "Gamma-Ray Cascade Computer Program". Input required for this program consists of the cross sections $\sigma^m(\epsilon)$ for $2 \leqq m \leqq n$ and the transition probabilities P_ℓ^m for $1 \leqq \ell < m$.

THEORETICAL ASSUMPTIONS

LEVEL SCHEMES AND GAMMA DECAY SCHEMES

The level schemes and gamma decay schemes of the nuclei under consideration are shown in Figures 1 through 4. For Al^{27} levels up to 5.25 MeV were considered. The Al^{27} and Si^{28} data were taken to be those deduced from a variety of experiments and theoretical considerations and given in the review article of Endt and Van der Leun (Ref. 3). The levels of Al^{27} for which parity assignments were not given in this article were assumed to have (+) parity, and the 4.51 MeV level was assumed to have a spin of 5/2. Further investigation will be required to establish whether these assumptions are valid. At any rate, the Al^{27} results presented in this report can be trusted for bombarding energies up to about 4 MeV, since all data pertaining to levels excited at these energies are well established. Energy levels for Fe^{56} up to 4.100 MeV were taken into consideration. The energies, spins, and parities, and the gamma decay scheme of these levels were taken to be those deduced from a variety of experiments including $Fe^{56}(n, n'\gamma)$, $Fe^{56}(p, p'\gamma)$, and the decay of Mn^{56} and Co^{56}. These data are reported in References 4 through 8. The Fe^{56} gamma transition probabilities of Reference 4 have been adopted for levels up to 3.856 MeV. For the higher levels, an average of the values reported in References 5 and 6 have been adopted. The energy level scheme and gamma decay scheme of Pb^{208} for levels up to 3.999 MeV were taken from Reference 9. As suggested by the calculations of Kuo and Markiewicz (Ref. 10), the 3.920 and 3.999 MeV levels were assigned spins and parities of 5^- and 7^-, respectively. There is also known to be a level at 3.750 MeV (Ref. 11) whose spin and parity have been assumed to be 3^-.

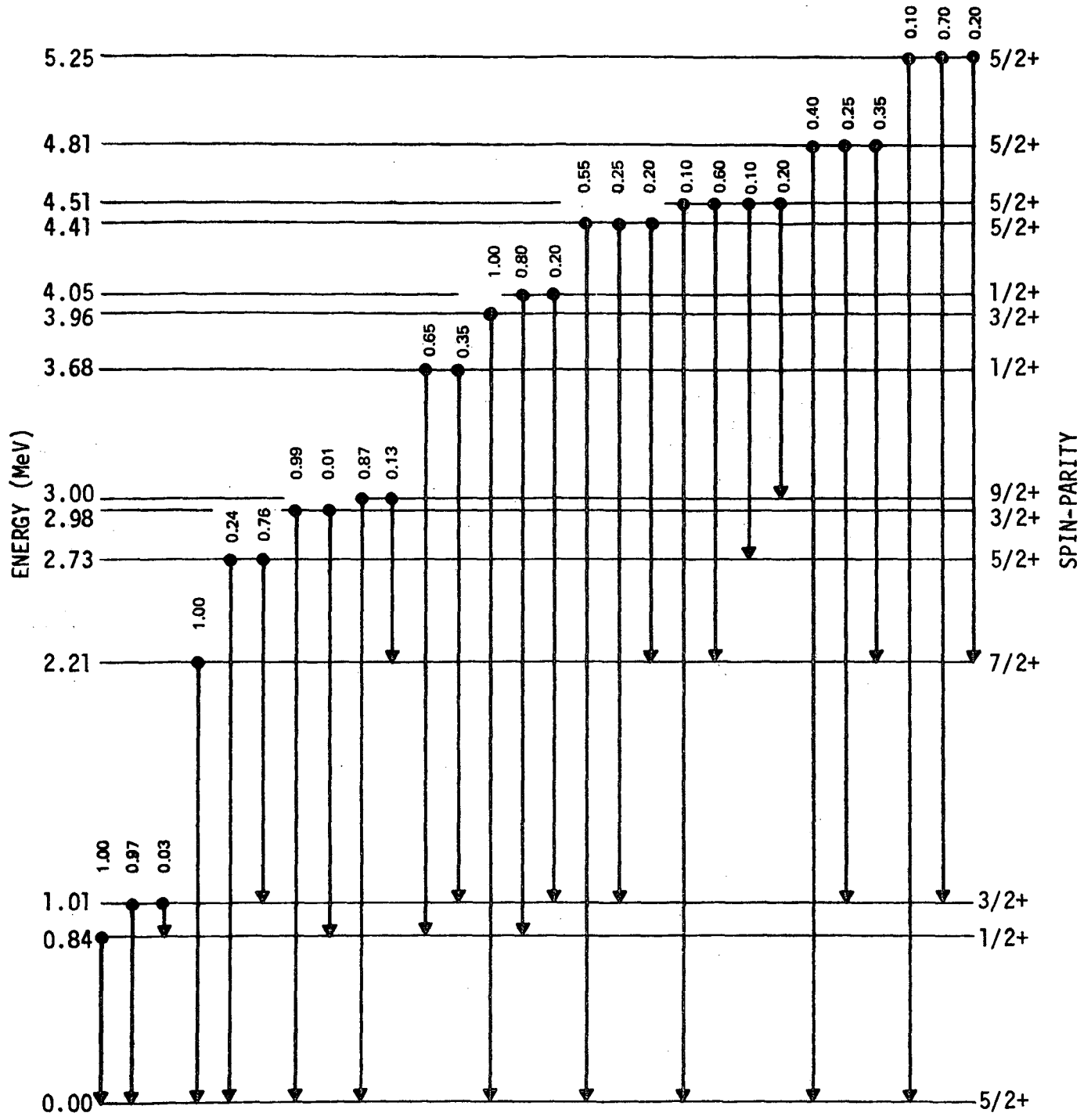

FIGURE 1. NUCLEAR LEVEL SCHEME AND GAMMA TRANSITION PROBABILITIES FOR Al^{27}

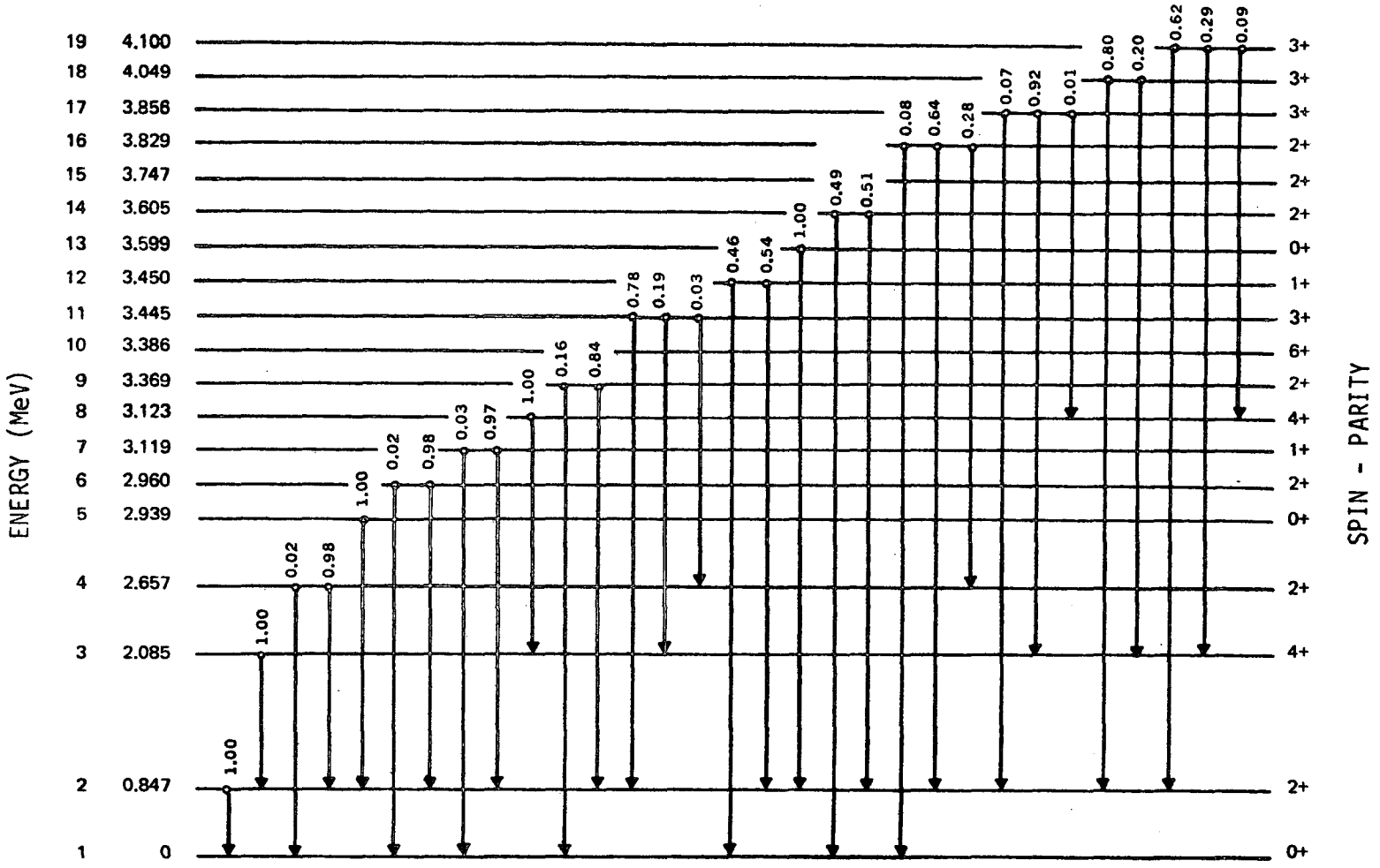

FIGURE 2. NUCLEAR LEVEL SCHEME (NOT TO SCALE) AND GAMMA TRANSITION PROBABILITIES FOR Fe^{56}

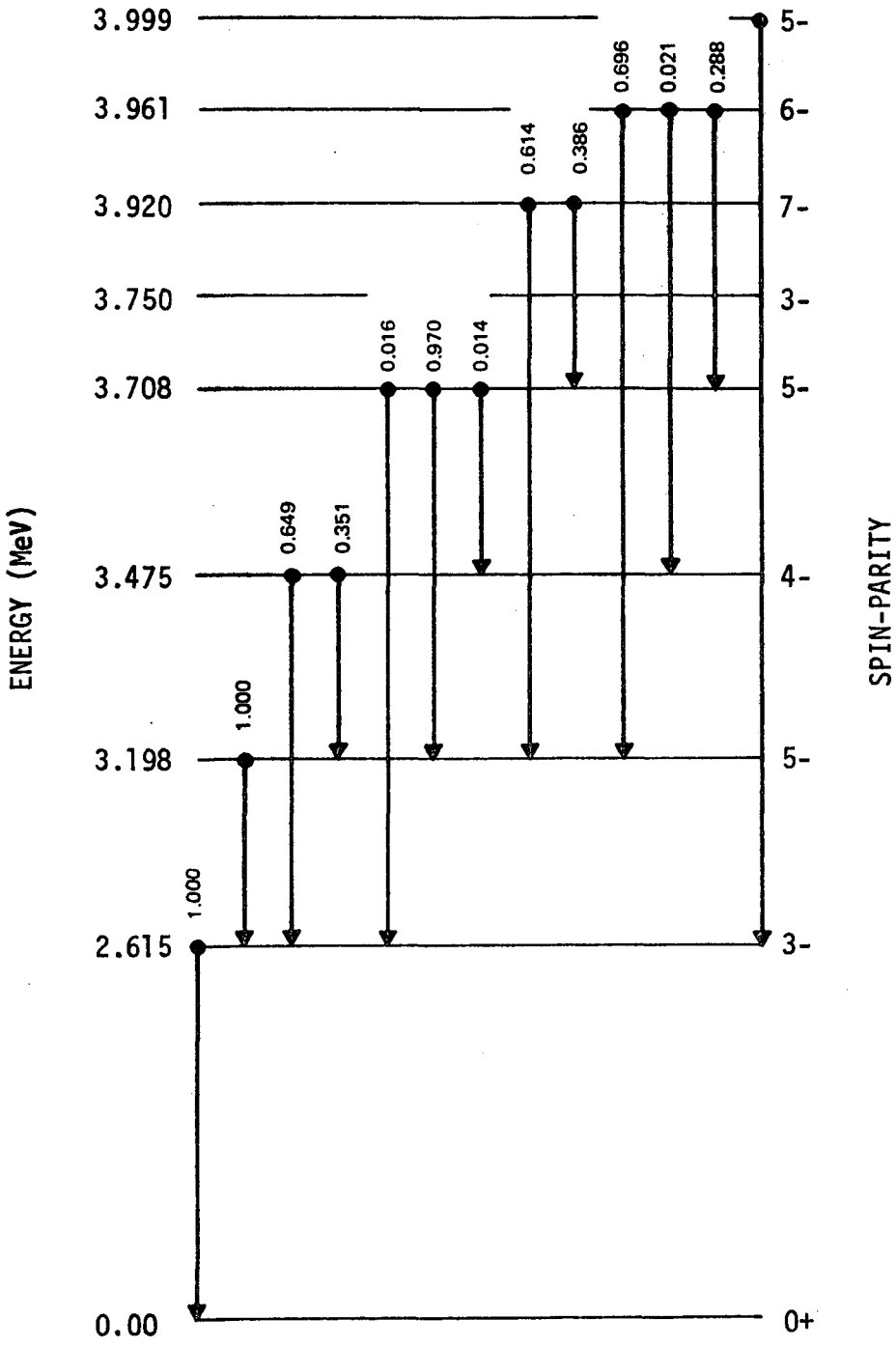

FIGURE 3. NUCLEAR LEVEL SCHEME (NOT TO SCALE) AND GAMMA TRANSITION PROBABILITIES FOR Pb^{208}

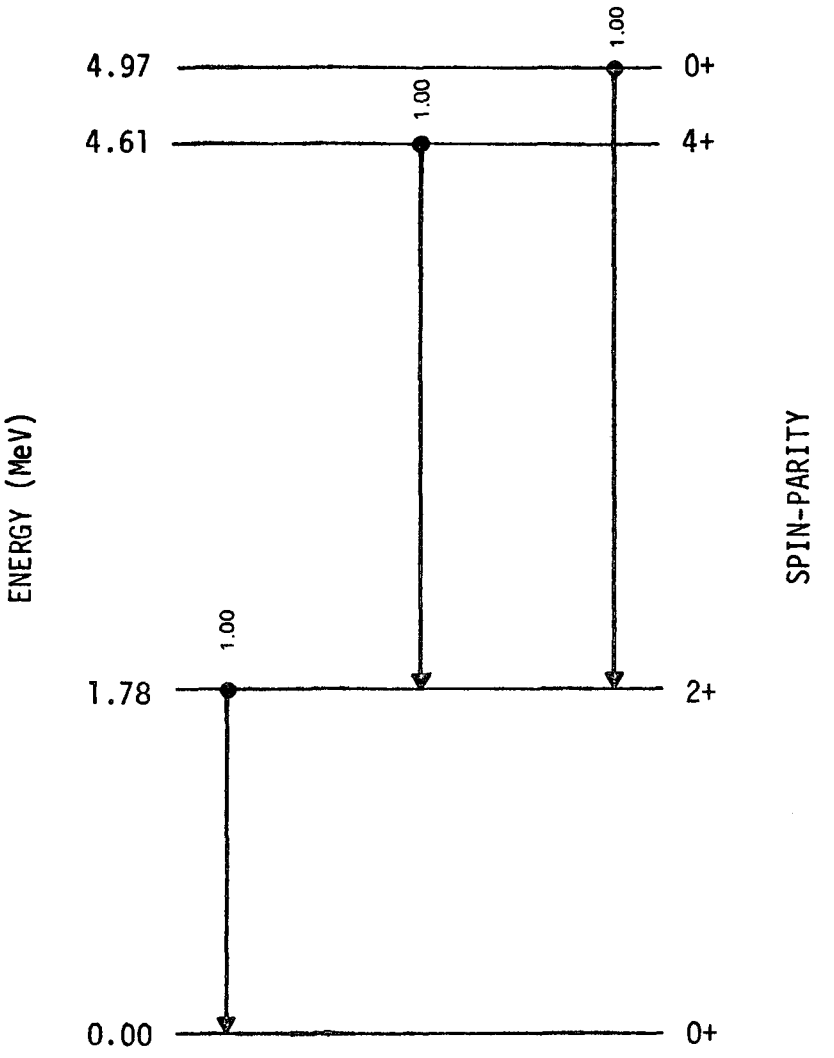

FIGURE 4. NUCLEAR LEVEL SCHEME AND GAMMA TRANSITION PROBABILITIES FOR Si^{28}

SPECIFIC FORM OF THE OPTICAL-MODEL POTENTIAL

For the Hauser-Feshbach calculations, an optical model potential was adopted whose real part consists of a Saxon term,

$$V_{re}(r) = \frac{-V_1}{1 + \exp[(r - R_1)/a_1]} \qquad (2)$$

and a spin-orbit term of the Thomas form,

$$V_{so} = \frac{-V_3}{V_1} \left(\frac{h}{M_n \pi C} \right)^2 \frac{1}{r} \left| \frac{d}{dr} V_{re}(r) \right| \vec{\ell} \cdot \vec{\sigma} \ . \qquad (3)$$

The imaginary part of the potential was assumed to be of the Gaussian form,

$$V_{im}(r) = -V_2 \exp\{-[(r - R_2)/a_2]^2\} \ . \qquad (4)$$

The potential parameters for Al^{27} and Si^{28} were assigned the values given in Reference 12 which have been found to yield agreement between calculated and measured elastic and inelastic scattering cross sections for neutrons on Al^{27}. The potential parameters for Fe^{56} and Pb^{208} were taken from References 13 and 14, respectively. The parameter values are given in Table 1.

TABLE 1. VALUES OF OPTICAL MODEL POTENTIAL PARAMETERS ADOPTED FOR THE HAUSER-FESHBACH CALCULATIONS

	Al^{27}	Si^{28}	Fe^{56}	Pb^{208}
V_1(MeV)	45.68	45.68	46.90	46.00
V_2(MeV)	5.44	5.44	5.10	5.50
V_3(MeV)	5.00	5.00	14.80	7.00
R_1(fermi)	3.72	3.72	4.90	7.76
R_2(fermi)	3.72	3.72	4.90	7.76
a_1(fermi)	0.655	0.655	0.55	0.43
a_2(fermi)	0.98	0.98	1.00	1.00

GAMMA-RAY CASCADE COMPUTER PROGRAM

GENERAL DESCRIPTION

The computer program listed in Appendix A evaluates as a function of neutron bombarding energy the cross section for the production of each of the various gamma rays emitted by a nucleus excited through an inelastic scattering process. This gamma production cross section for the gamma ray emitted in the transition from level i to level j is given by Equation 1. The program is given a series of bombarding energies (laboratory system) and the nuclear level energies of the target nucleus. For each of the bombarding energies, the program is also given the cross section for exciting each of the nuclear levels which can be excited by the particular bombarding energy. The level excitation cross sections used in this report were calculated by the Abacus-2 program referred to in the Introduction of this report. In addition, the program is given the gamma transition probability P_j^i for each pair of levels i and j ($j < i$). The program then calculates the cross section for the production of each gamma ray for each of the bombarding energies which is above the threshold for producing the particular gamma ray.

INPUT PREPARATION

The first card contains the number of bombarding energies for which gamma-production cross sections are to be evaluated. This quantity is denoted by KMAX and is input according to format I5.

A set of cards follows which is KMAX in number. Each card contains a bombarding energy index K, a corresponding bombarding energy, and an additional energy ϵ_a which is given by

$$\epsilon_a = \frac{M_T}{M_n + M_T} \epsilon \quad . \qquad (5)$$

Here, M_n and M_T are the neutron mass and target mass, respectively, and ϵ is the neutron bombarding energy in the laboratory system. This energy may be viewed as the energy which is available for exciting the nucleus. A nuclear level can be excited in the scattering process only if its energy is less than ϵ_a. The energies ϵ and ϵ_a are denoted by EN(K) and EA(K), respectively, and are in MeV units. The cards are arranged in the order of increasing K and correspondingly increasing bombarding energy. The format is I5, 10X, F8.4, 10X, F8.4.

The next card contains the number of levels N (including the ground level) in which the nucleus may remain, following the scattering process when the bombarding energy has the maximum, EN(KMAX), of its input values. The format is I5.

A set of cards follows which is N-1 in number. Each card contains an energy level index I and a corresponding level energy ELEV(I) in MeV units. The ground state (I = 1) is not included in this set, and the cards are arranged in the order of increasing I and correspondingly increasing ELEV(I). The format is I5, 10X, F8.4.

Next follows a set of cards, each of which contains an initial level index I, a final level index J, and the branching probability P(I, J) for the gamma transition from level I to J. The first card has I = 2, J = 1. The next two cards have I = 3, J = 1 and I = 3, J = 2. The sequence is continued in this fashion until the last card, which has I = N, J = N - 1, is reached. The format is 2I5, 10X, F7.4.

Next follows a set of cards, each of which contains a bombarding energy index K, an energy level index I, and a corresponding cross

section, SL(K, I), for the excitation of level I by a neutron of bombarding energy EN(K). The cards are arranged in order of increasing K which takes on values from 1 to KMAX. For each value of K, there must be a card for each level I which can be excited from the available energy EA(K). The condition for the excitation of level I is that ELEV(I) must be less than EA(K). Cards having the same K value are arranged in the order of increasing I. The cross sections SL(K, I), which correspond to the $\sigma^i(\epsilon)$ of Equation 1, are to be given in barn units. The format is 2I5, 10X, E10.3. If more than one problem is to be solved in the same run, additional sets of data, each beginning with a KMAX card, may be stacked. To terminate a run, a KMAX card containing a zero or a negative integer should be included after the last data set.

OUTPUT INTERPRETATION

The first several pages of output consist of merely a printout in self-explanatory format of all the input data described above. Next, the results obtained for the gamma-production cross sections $\Sigma_j^i(\epsilon)$ are printed out. There is a set of results for each allowed gamma transition. Each set is headed by a line consisting of an I value and a J value, where I specifies the initial level and J specifies the final level of the transition. On the same line appears the energy, EGAM, of the gamma ray produced in this transition. Each line of the following set contains a K value, a corresponding value of the bombarding energy EN(K), and a corresponding calculated value of the cross section $\Sigma_j^i(\epsilon)$. The FORTRAN variable which designates this cross section is SB, and the cross section is given in barn units. The first K value given is that which corresponds to the first energy in the input set of bombarding energies which is above the threshold for the production of the particular gamma ray. The index K then takes on increasing

values until the value KMAX is reached. At this point, a line specifying another gamma ray is printed out and is followed by the corresponding set of SB values for this gamma.

RESULTS OF CROSS SECTION CALCULATIONS IN GRAPHICAL FORM

LEVEL EXCITATION CROSS SECTIONS

Calculated cross sections for excitation of the levels of Al^{27} are shown in Figures 5 through 16. Results for levels up to and including that at 4.05 MeV are given. The neutron energy was varied from 0.90 MeV to 5.50 MeV. Results for several additional levels are given in tabular form in Appendix B. These additional results should be regarded as uncertain, however, because of possible incompleteness of the level scheme beyond the 4.05 MeV level. Figures 29 through 35 show calculated cross sections for excitation of the levels of Fe^{56}. Results for levels up to and including that at 3.123 MeV are shown. The neutron energy was varied from 1.00 to 4.20 MeV. Results for several additional levels are given in tabular form in Appendix C. Figures 41 through 43 show calculated cross sections for excitation of the levels of Pb^{208} up to and including the level at 3.475 MeV. The neutron energy was varied from 2.70 to 4.10 MeV. Results for a few additional levels are given in tabular form in Appendix D. The calculated cross sections for the excitation of the levels of Si^{28} up to and including the level at 4.97 MeV are shown in Figures 48 through 50. The neutron energy was varied from 1.90 to 6.40 MeV. Results for Si^{28} are given in tabular form in Appendix E. In the cases of Al^{27}, Fe^{56}, and Pb^{208}, available experimental cross sections for level excitation are shown on the graphs.

GAMMA PRODUCTION CROSS SECTIONS

Calculated cross sections for production of gamma transitions between excited levels of Al^{27} are shown in Figures 17 through 28. These results are based on the level excitation cross sections tabulated

in Appendix B and the gamma transition probabilities shown in Figure 1. Results for allowed transitions between levels up to and including that at 4.05 MeV are shown. Results for several additional gamma transitions from higher levels are included in the Tables of Appendix B. As in the case of the level excitation cross sections, these additional results should be regarded as uncertain, however, because of possible incompleteness of the level scheme beyond the 4.05 MeV level. Figures 36 through 40 show calculated cross sections for production of gamma transitions between some of the levels of Fe^{56}. These results are based on the level excitation cross sections tabulated in Appendix C and the gamma transition probabilities shown in Figure 2. Results for several additional gamma transitions are given in tabular form in Appendix C. Figures 44 through 47 show calculated cross sections for production of gamma transitions between some of the levels of Pb^{208}. These cross sections are based on the level excitation cross sections tabulated in Appendix D and the gamma transition probabilties shown in Figure 3. These results appear in tabular form in Appendix D. Calculated cross sections for gamma production for Si^{28} are shown in Figures 51 through 53 and are presented in tabular form in Appendix E. These results are based on the level excitation cross sections tabulated in Appendix E and the gamma transition probabilities shown in Figure 4. In the cases of Al^{27} and Fe^{56}, available experimental gamma production cross sections are shown on the graphs.

DISCUSSION OF RESULTS

Most of the level excitation cross sections for Al^{27} are in fairly good agreement with the experimental values. It should be pointed out that the Hauser-Feshbach approach with optical model penetrabilities yields "average" cross sections in the sense that resonances are smoothed over. It is known that the cross sections

fluctuate quite rapidly with neutron energy, especially at the lower energies (<2 MeV). This behavior has been observed experimentally for the 0.84 and 1.01 MeV levels of Al^{27} by Chien and Smith (Ref. 30) at neutron energies below 1.5 MeV. Most of the discrepancies between the calculated and experimental level excitation cross sections are probably due to the fact that the measurements in question were made at energies for which the cross section is near a peak or trough which departs somewhat from the average calculated value.

There is one case, however, for which the calculated and experimental values are in wide disagreement. This is the case of the composite cross section for excitation of the 2.73, 2.98, and 3.00 MeV levels of Al^{27} shown in Figure 13. The disagreement occurs for energies greater than 4.00 MeV where resonance effects are not expected to be pronounced. It is observed in Figure 9 that at 4.00 MeV, the measurement of Towle and Gilboy (Ref. 17) agrees with the calculated cross section for the excitation of the 2.73 MeV level alone. Furthermore, the composite calculation for the 2.98 and 3.00 MeV levels (Fig. 12) is also in agreement with the measurement of these workers at 4.00 MeV. Unless sharp fluctuations in the cross section are present around this energy value, it would appear that the experimental values shown in Figure 13 are in disagreement with the experimental values shown in Figures 9 and 12. Thus, the composite cross section for excitation of the 2.73, 2.98, and 3.00 MeV levels is probably considerably higher than the measured values as is predicted by the calculated curve in Figure 13.

Likewise, the calculated cross sections for gamma production for Al^{27} are, for the most part, in agreement with the experimental values. Departures of experimental values from calculated values and

from other experimental values at closely neighboring neutron energies may possibly be accounted for, as mentioned previously, by sharp fluctuations in level excitation cross sections which are not calculable by the Hauser-Feshbach procedure.

As can be seen in Figure 29, the calculated cross section for excitation of the 0.847 MeV level of Fe^{56} agrees quite well with the experimental data at the lower energies. There appears, however, to be a tendency for disagreement beyond a neutron energy of 3 MeV where the theoretical prediction falls below the data. In this same energy region, a more pronounced departure from the experimental data occurs for the calculation of the cross section for excitation of the 2.085 MeV level (Fig. 30). Moreover, Figure 31 shows that the calculated cross section for excitation of the 2.657 MeV level lies below the experimental data. Although the optical model potential chosen for the calculations was shown in Reference 13 to fit the elastic scattering data very well, it is conceivable that another potential might be found through extensive parameter variations which would maintain the good elastic scattering fit while at the same time improving the fit to the inelastic scattering data. A difficulty here is that level excitation cross sections calculated with this new potential must not distrub appreciably the Fe^{56} gamma production cross sections calculated here, since, with the exception of the 2.272 MeV gamma ray (Fig. 40), these calculations, as can be seen in Figures 36 through 39, agree fairly well with experiment. The reason for the wide disgreement between the calculated and experimental cross section for the production of the 2.272 MeV gamma ray is not known. One can but conjecture that direct interaction effects, which are not predictable by the Hauser-Feshbach method, are operable in this instance.

It is of interest to compare the results presented here with those obtained recently by Kinney and Perey (Ref. 31). In addition to a few differences in the spins and parities adopted, the optical model parameters employed by these workers differ somewhat from those used in the present study. In particular, their potential does not contain a spin-orbit term. They do, however, introduce width fluctuation corrections to the level excitation cross sections, a refinement which is not made in the present calculations. The gamma production cross sections presented here are for the most part in agreement with theirs. They were also unable to account for the sharp increase in the 2.272 MeV gamma cross section which is evident in the experimental data at a neutron energy of about 3.5 MeV. However, in contrast to the results presented in the present study, they were able to fit the experimental cross section for the excitation of the 2.085 MeV level. Further investigation would be required to ascertain whether it is the width fluctuation corrections or their choice of potential parameters which leads to agreement in this particular case.

The calculated cross sections for excitation of the 2.615 and 3.475 MeV levels of Pb^{208} (Figs. 41 and 43) are in close agreement with the experimental values of Towle and Gilboy (Ref. 11). The calculated cross section for excitation of the 3.198 MeV level (Fig. 42) does not rise sharply enough to agree with the data points beyond 3.8 MeV.

Little can be said regarding the reliability of the calculated gamma production cross sections for Pb^{208} and the level excitation and gamma production cross sections for Si^{28}, since no experimental values for these quantities could be found in the literature.

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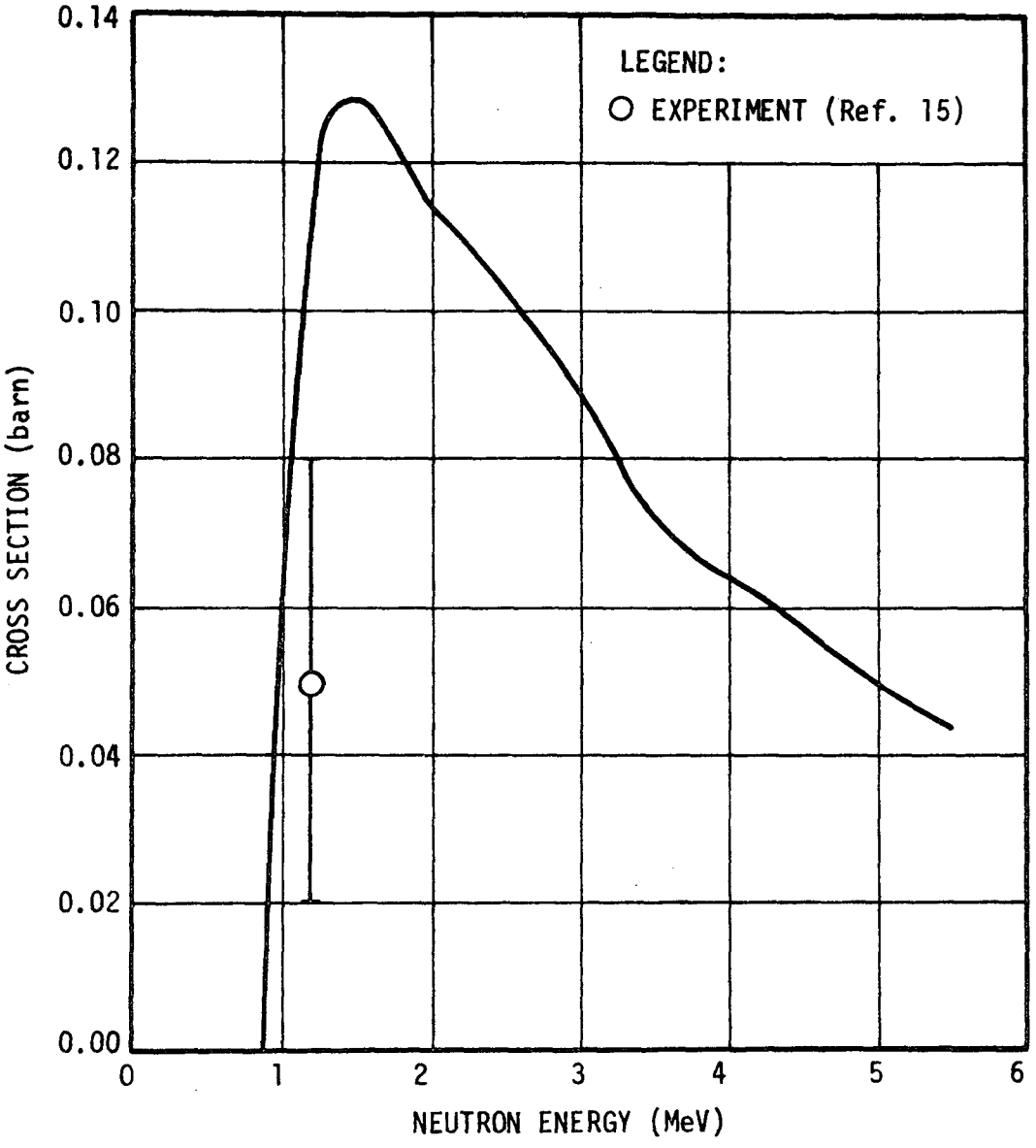

FIGURE 5. CROSS SECTION FOR EXCITATION OF THE 0.84 MeV LEVEL OF Al^{27}

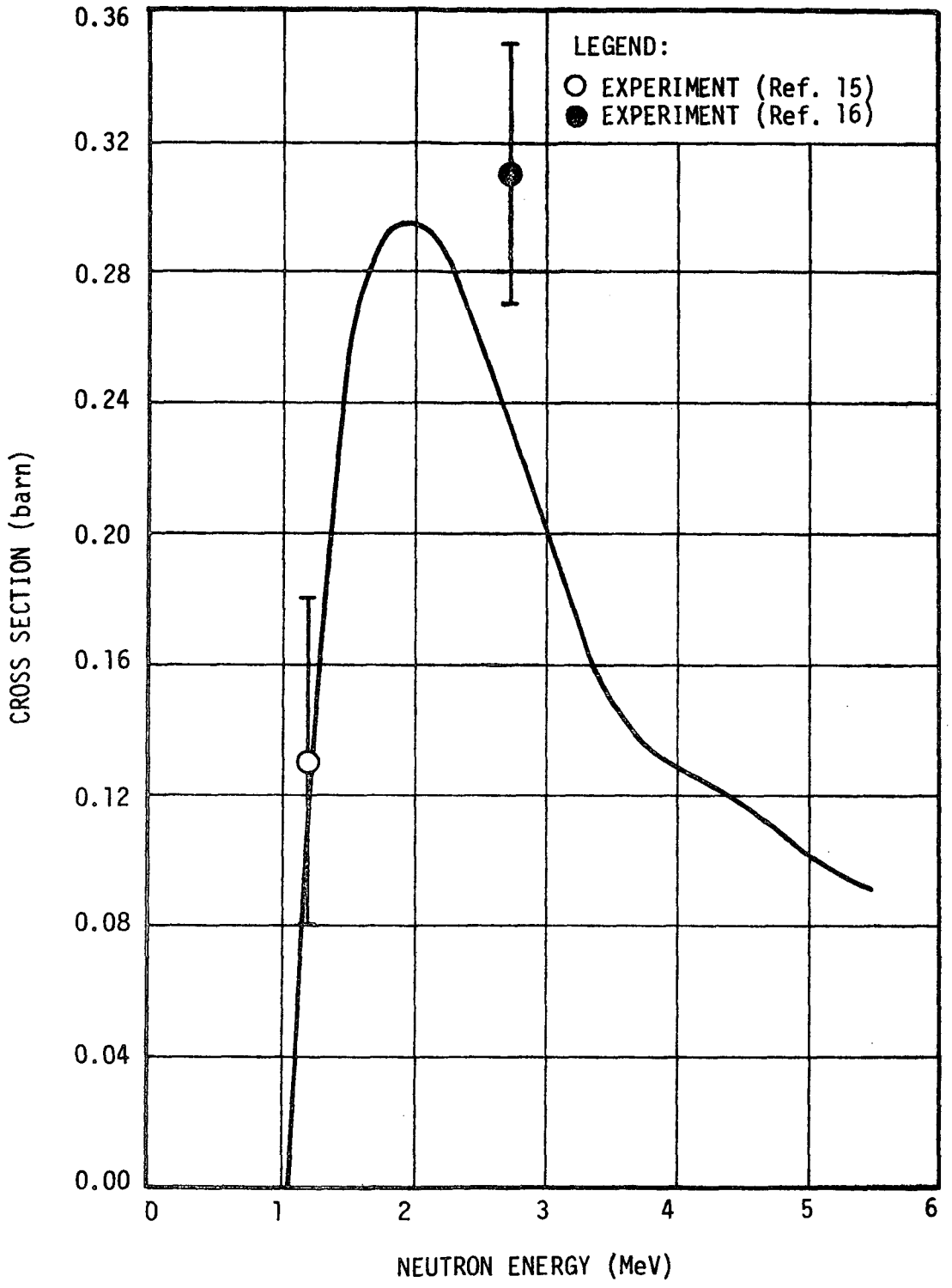

FIGURE 6. CROSS SECTION FOR EXCITATION OF THE 1.01 MeV LEVEL OF Al^{27}

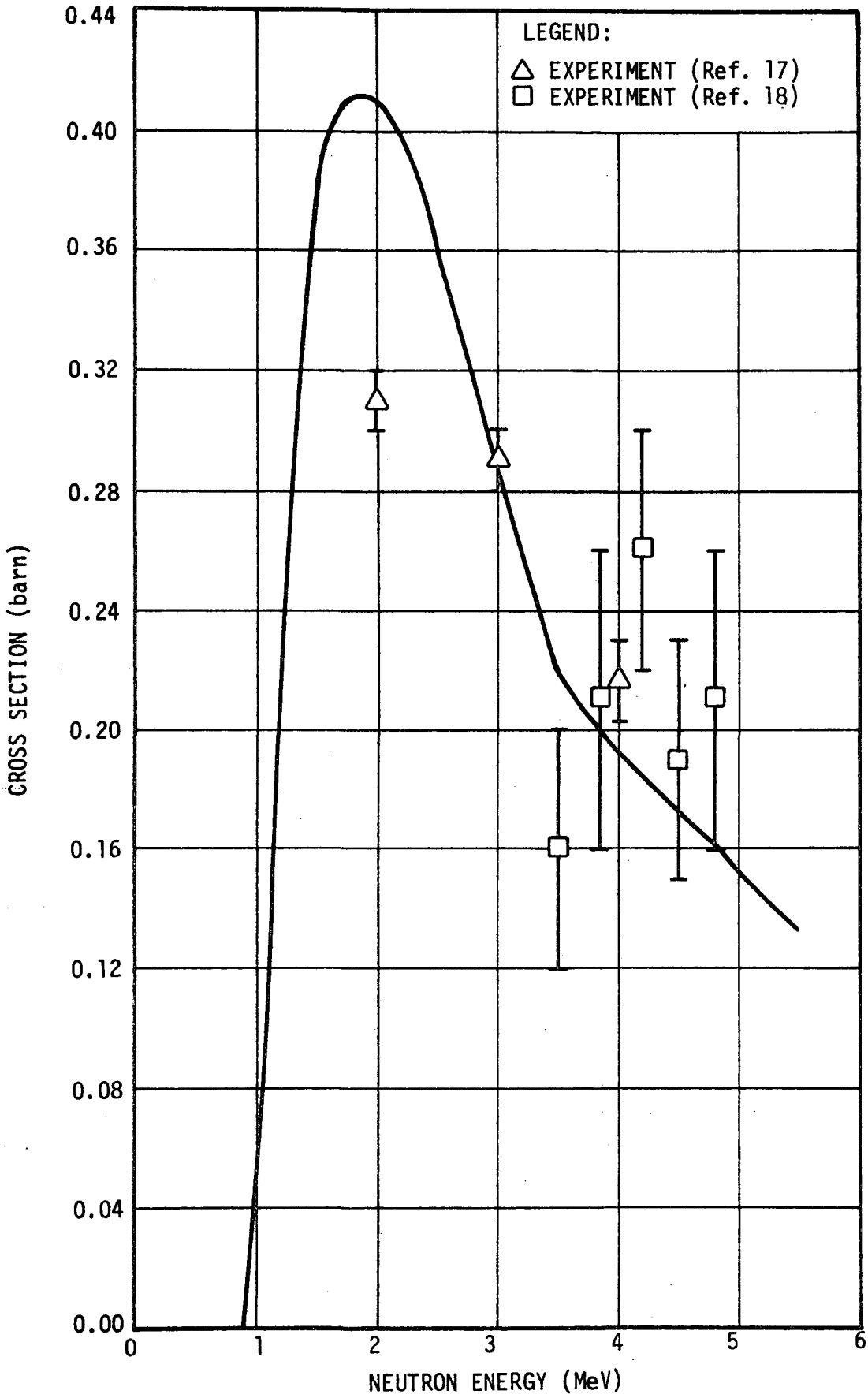

FIGURE 7. CROSS SECTION FOR EXCITATION OF THE 0.84 AND 1.01 MeV LEVELS OF Al^{27}

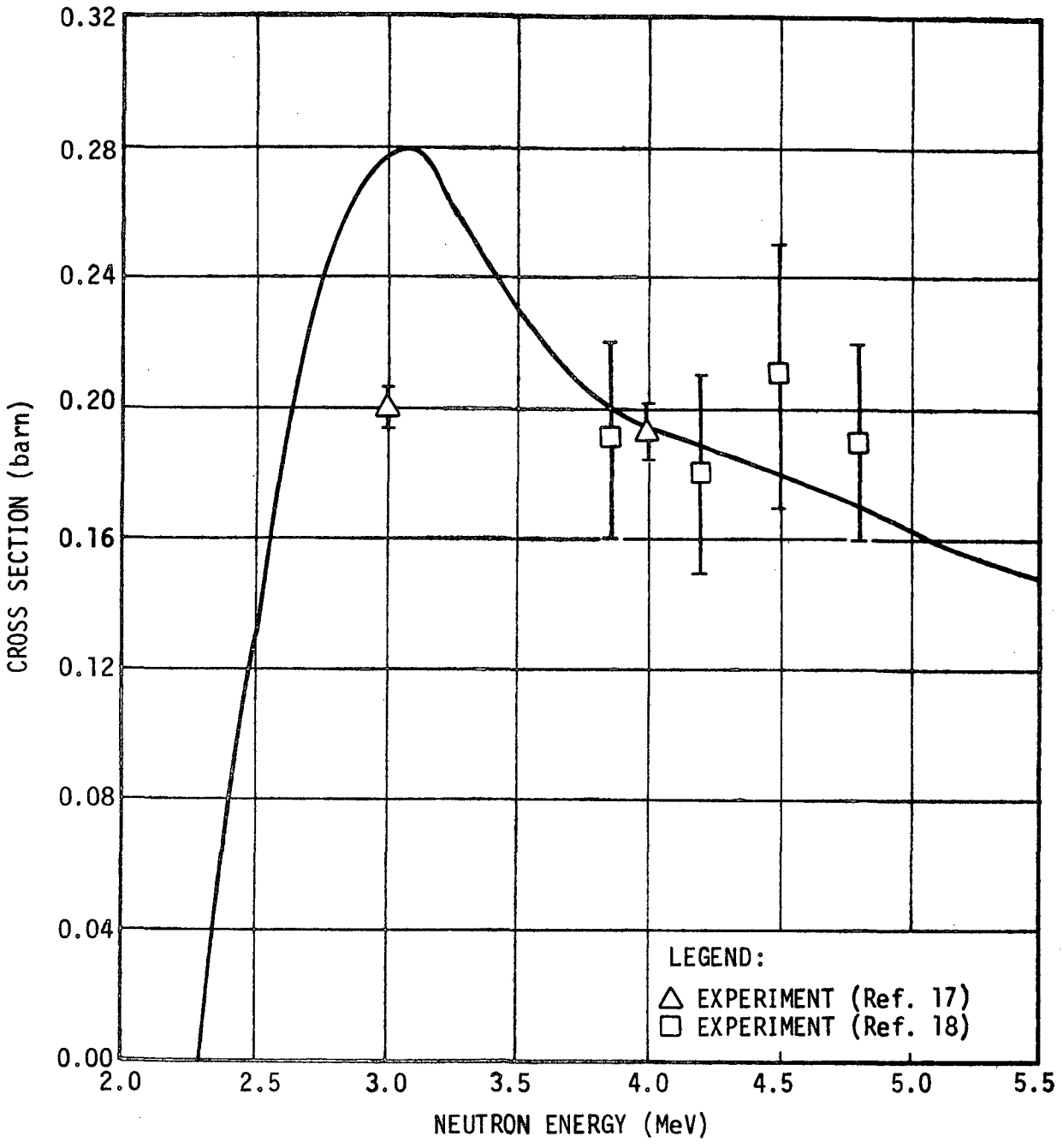

FIGURE 8. CROSS SECTION FOR EXCITATION OF THE 2.21 MeV LEVEL OF Al^{27}

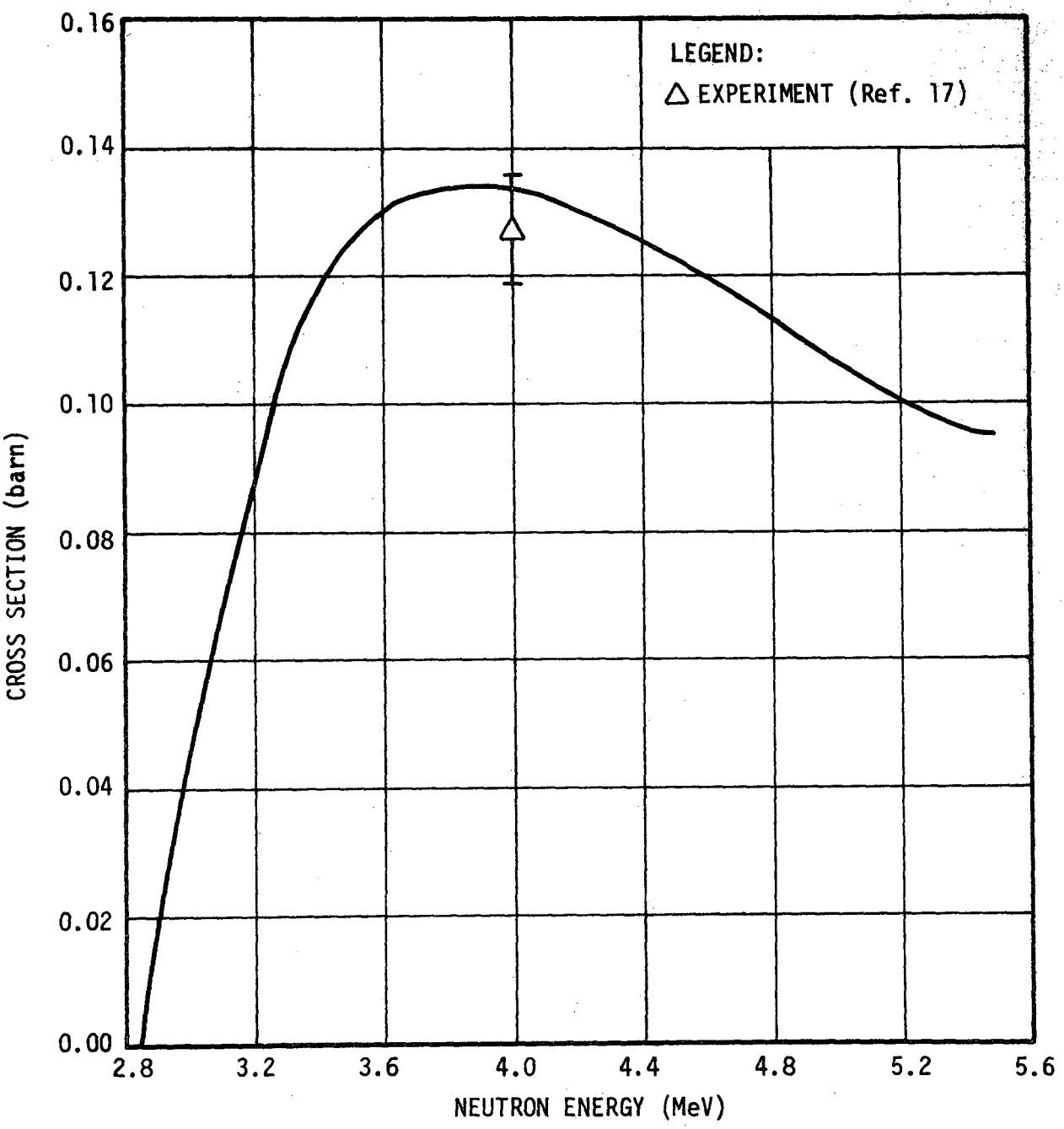

FIGURE 9. CROSS SECTION FOR EXCITATION OF THE 2.73 MeV LEVEL OF Al^{27}

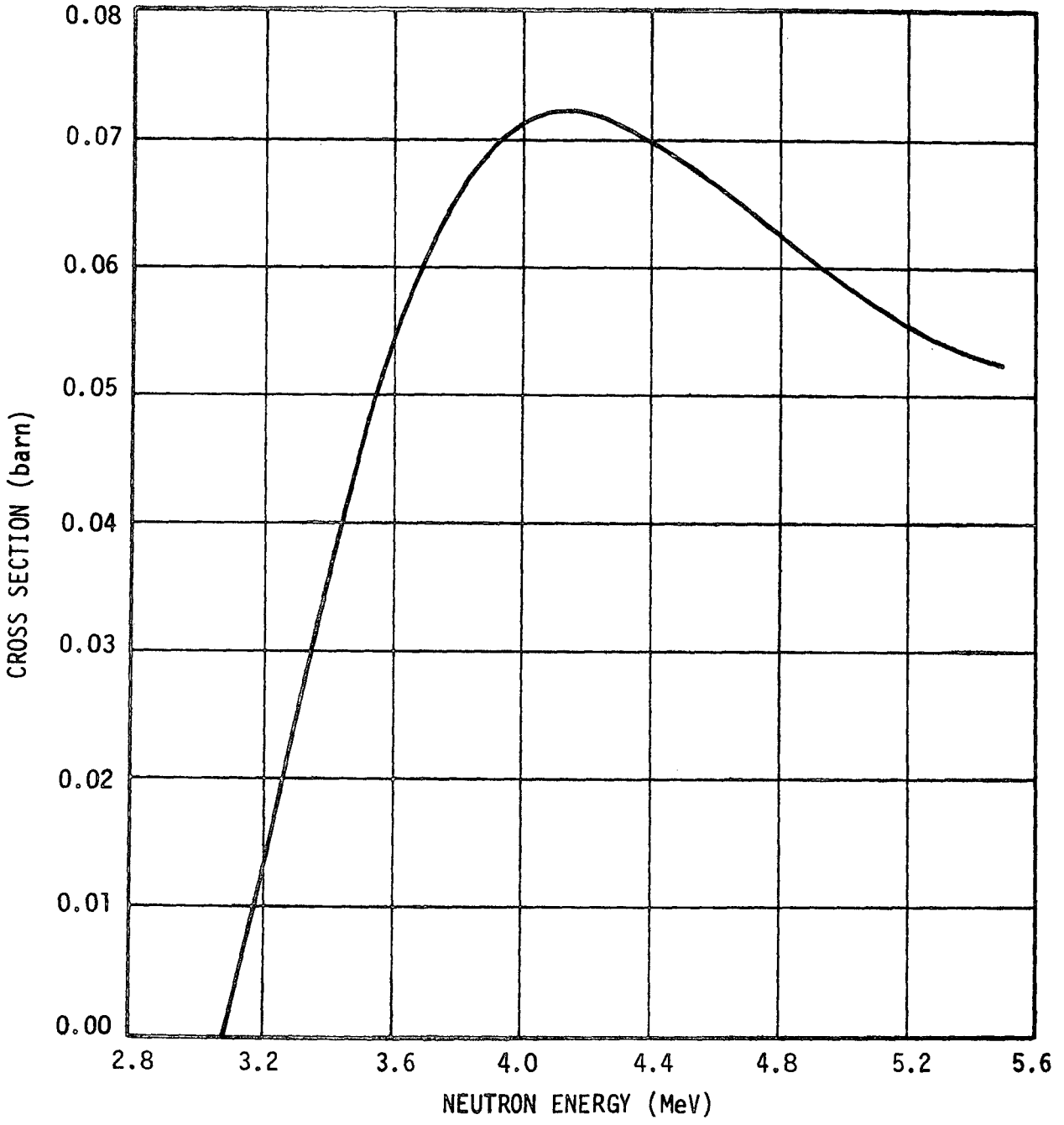

FIGURE 10. CROSS SECTION FOR EXCITATION OF THE 2.98 MeV LEVEL OF Al^{27}

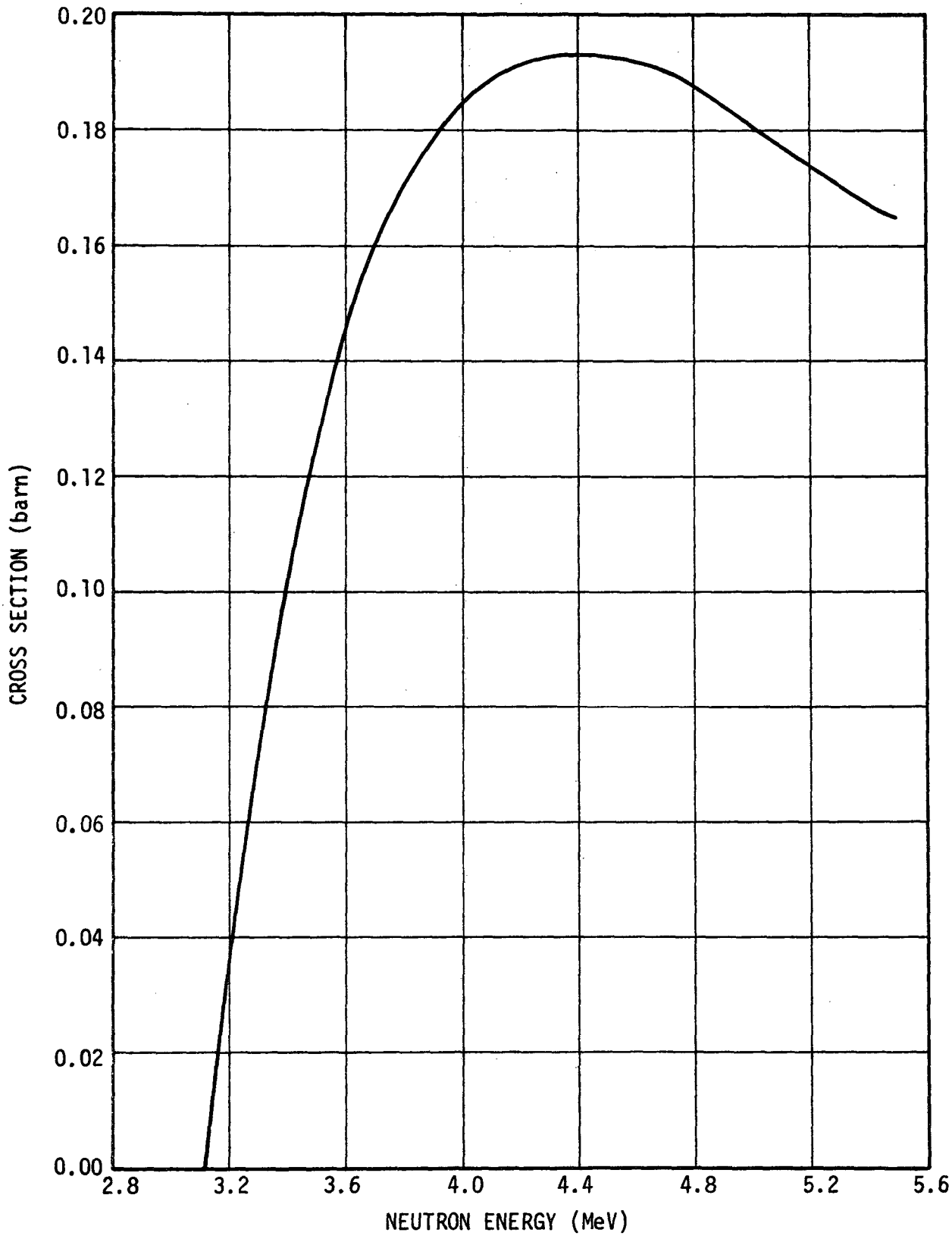

FIGURE 11. CROSS SECTION FOR EXCITATION OF THE 3.00 MeV LEVEL OF Al^{27}

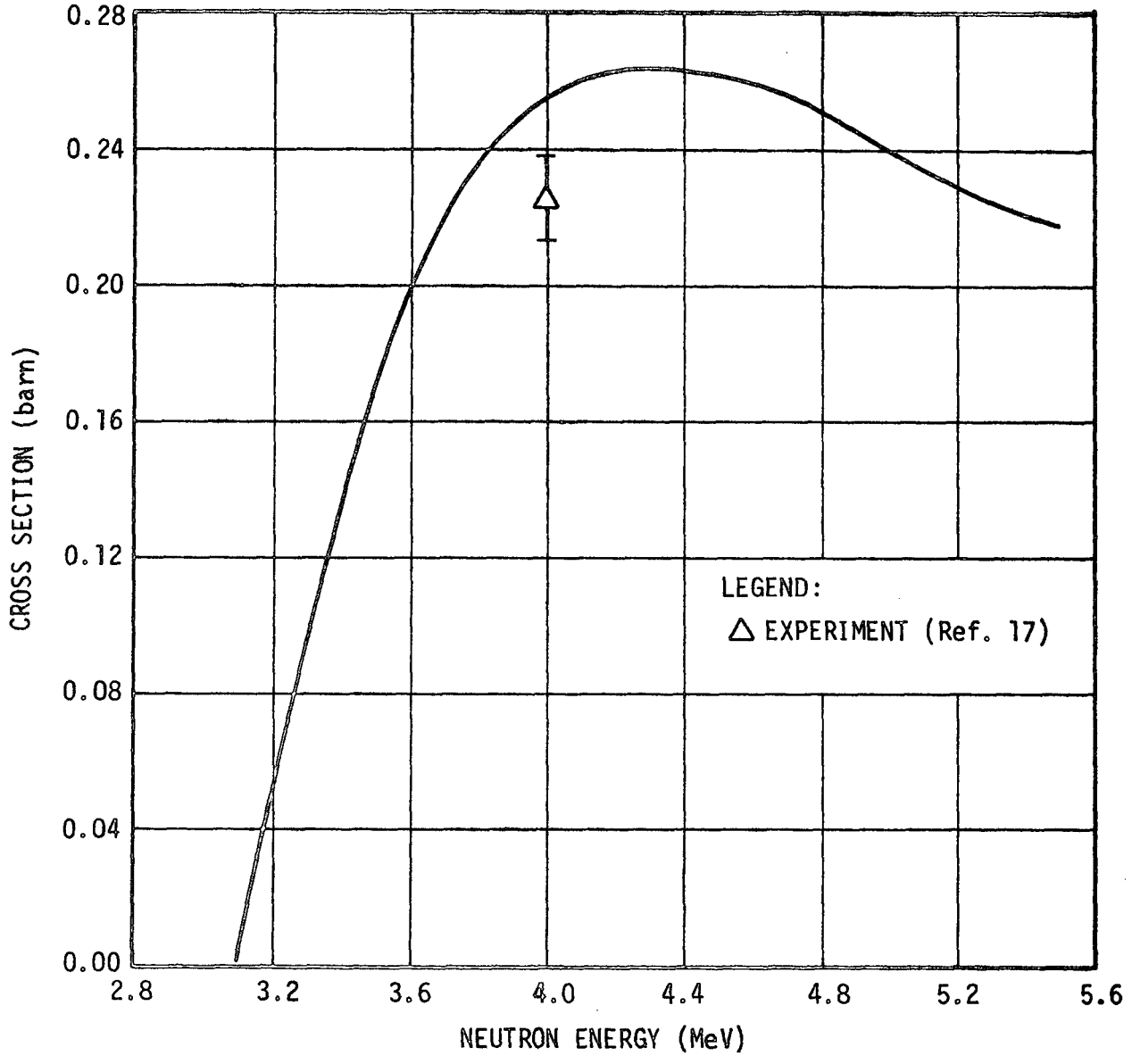

FIGURE 12. CROSS SECTION FOR EXCITATION OF THE 2.98 AND 3.00 MeV LEVELS OF Al^{27}

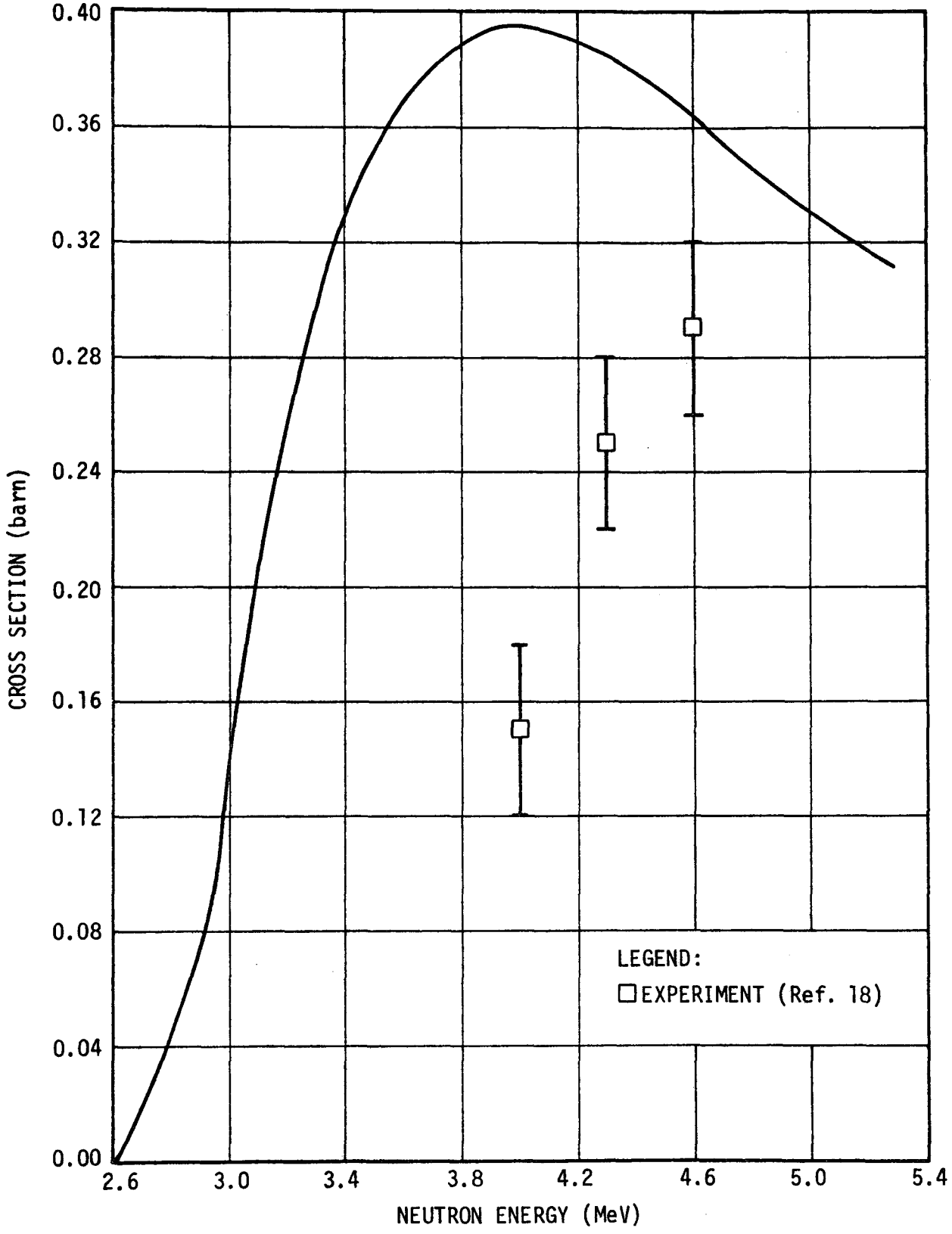

FIGURE 13. CROSS SECTION FOR EXCITATION OF THE 2.73, 2.98, AND 3.00 MeV LEVELS OF Al^{27}

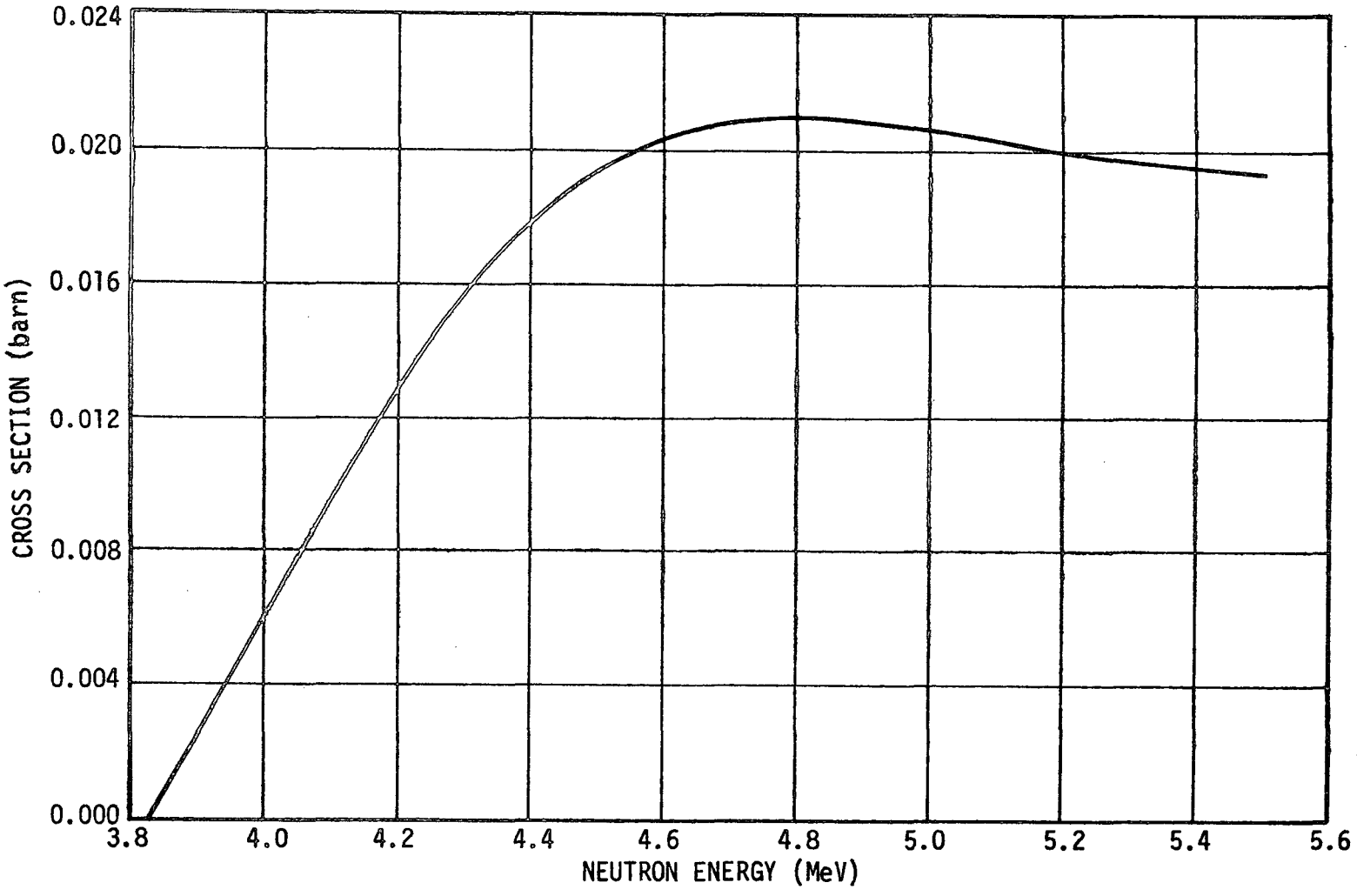

FIGURE 14. CROSS SECTION FOR EXCITATION OF THE 3.68 MeV LEVEL OF Al^{27}

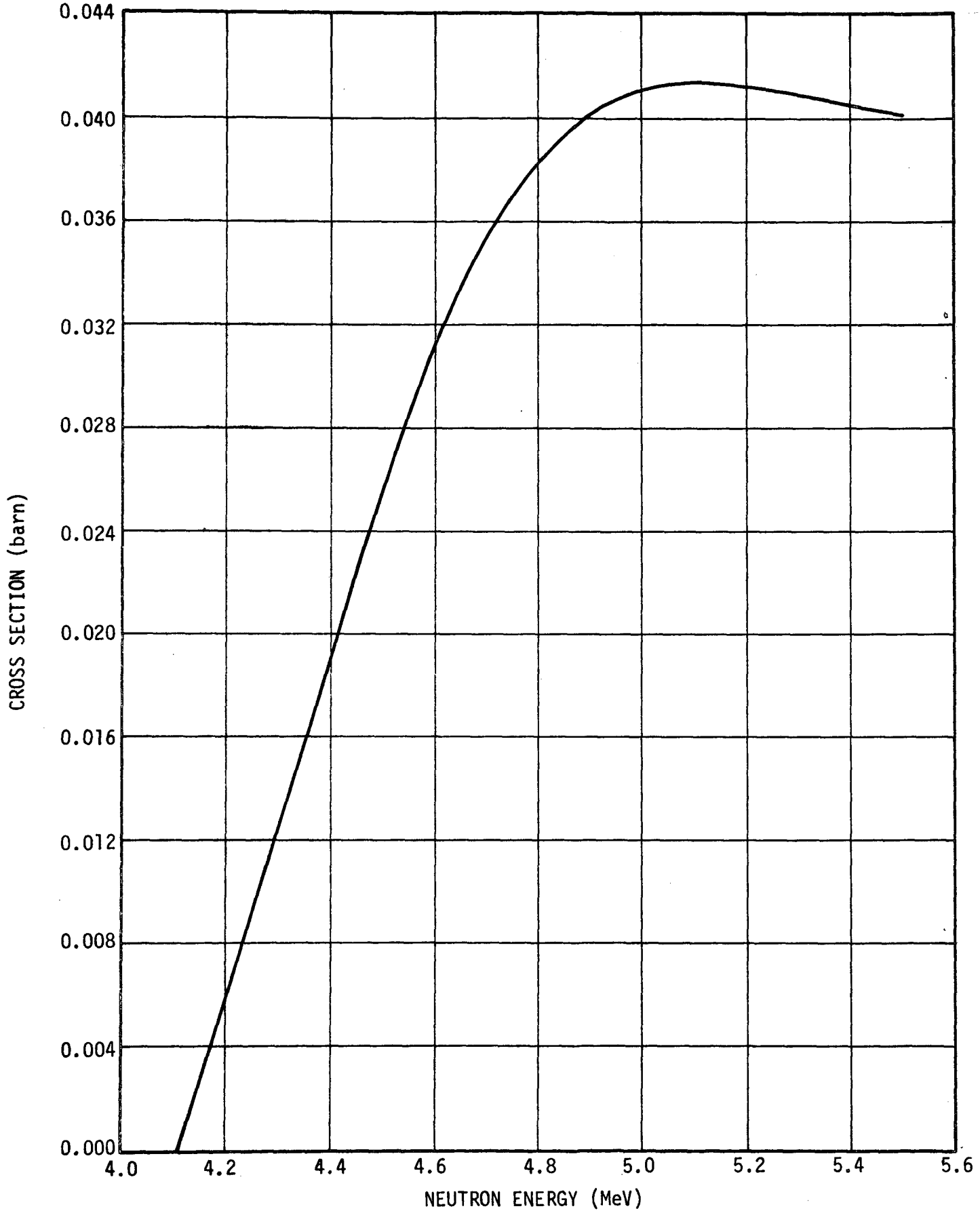

FIGURE 15. CROSS SECTION FOR EXCITATION OF THE 3.96 MeV LEVEL OF Al^{27}

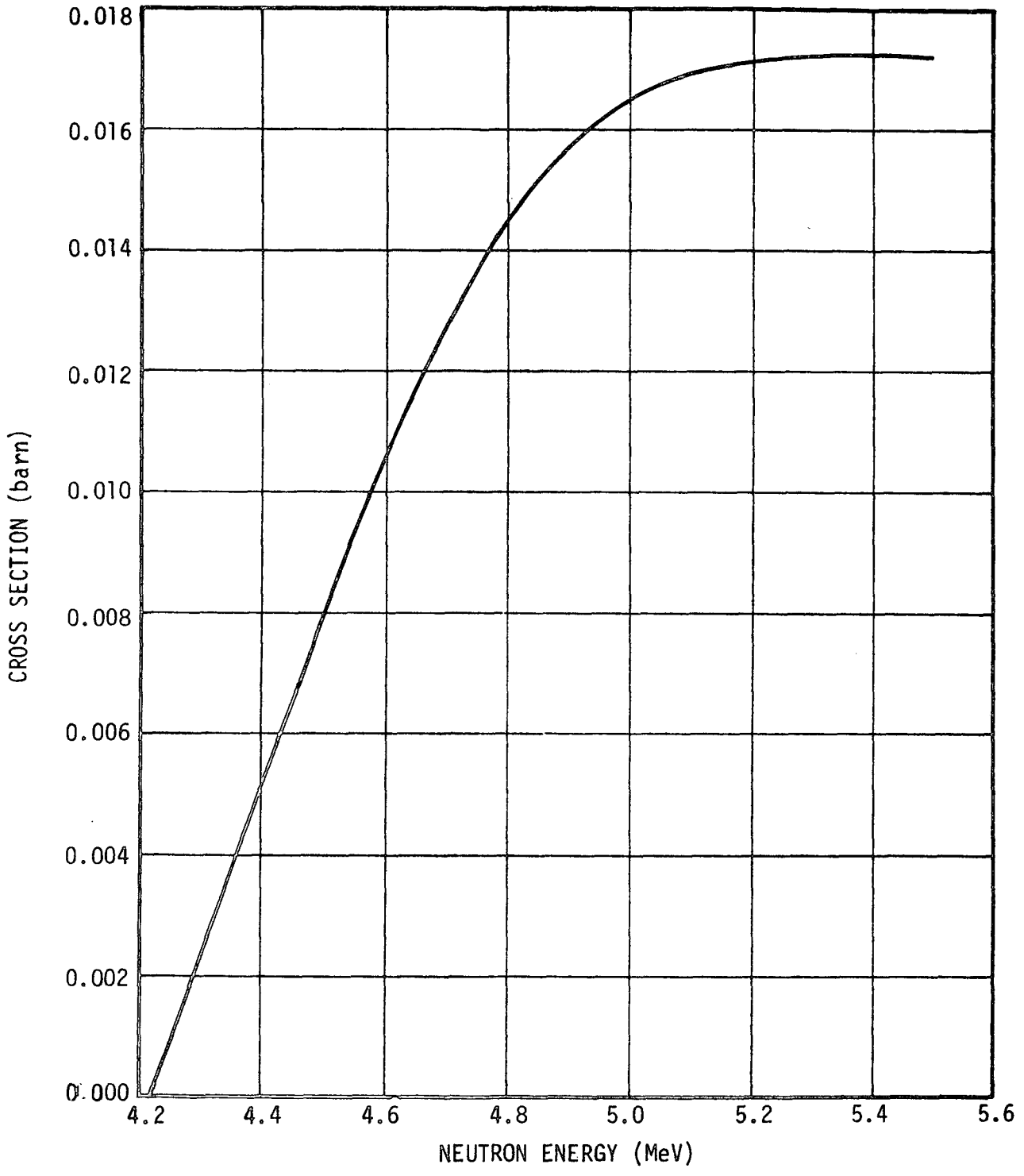

FIGURE 16. CROSS SECTION FOR EXCITATION OF THE 4.05 MeV LEVEL OF Al^{27}

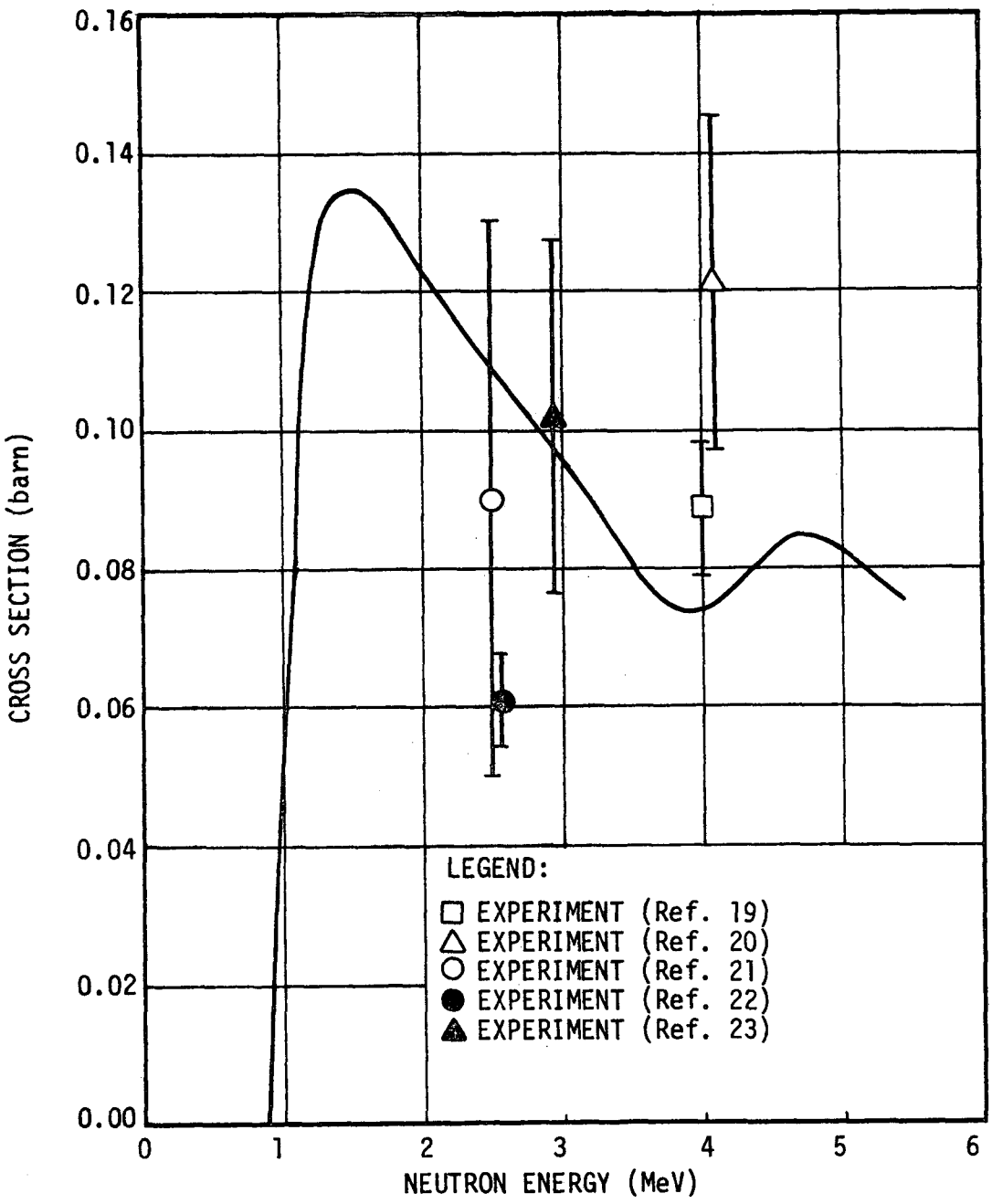

FIGURE 17. CROSS SECTION FOR PRODUCTION OF THE 0.84 MeV GAMMA TRANSITION FROM THE 0.84 MeV LEVEL TO THE GROUND LEVEL OF Al^{27}

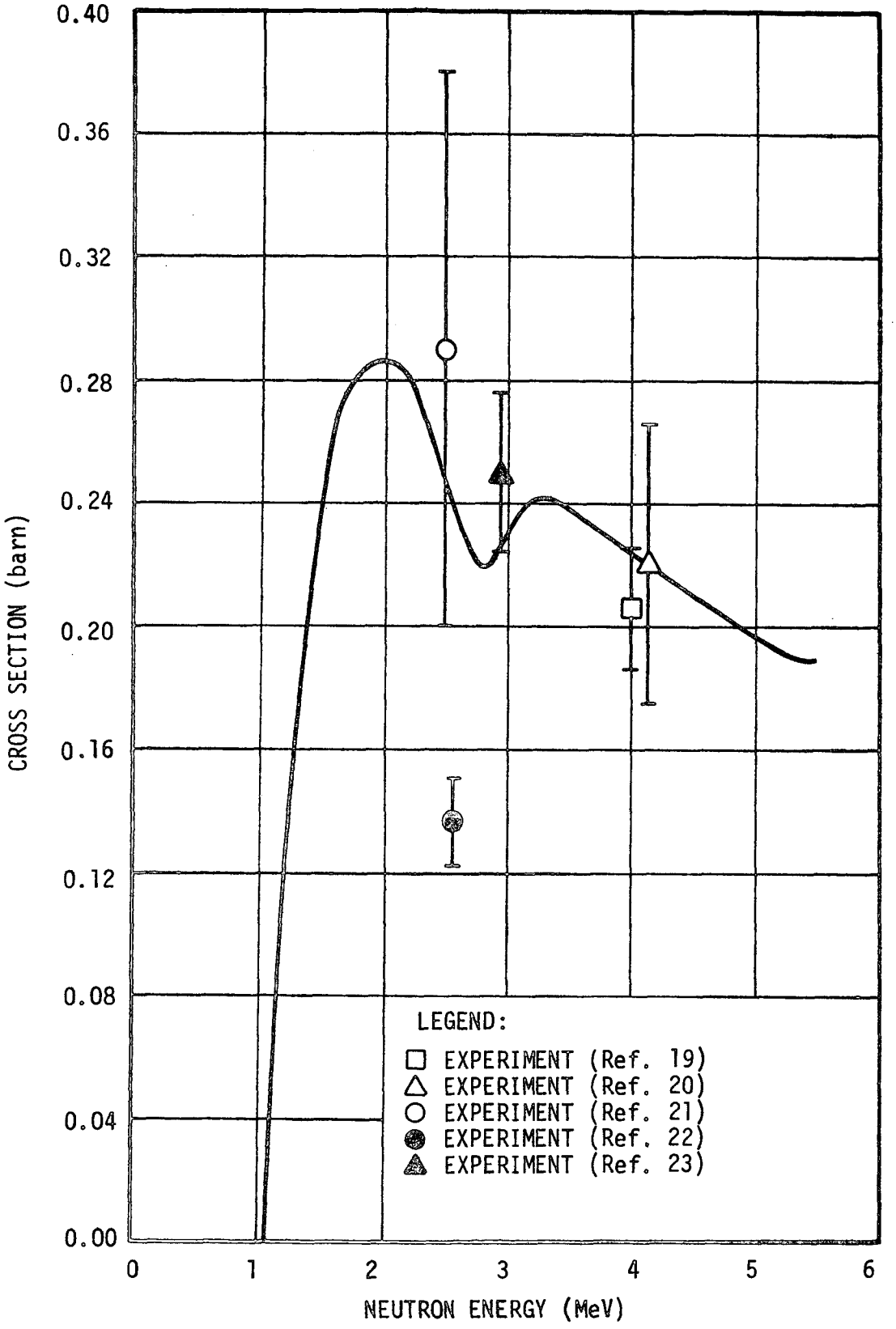

FIGURE 18. CROSS SECTION FOR PRODUCTION OF 1.01 MeV GAMMA TRANSITION FROM THE 1.01 MeV LEVEL TO THE GROUND LEVEL OF Al^{27}

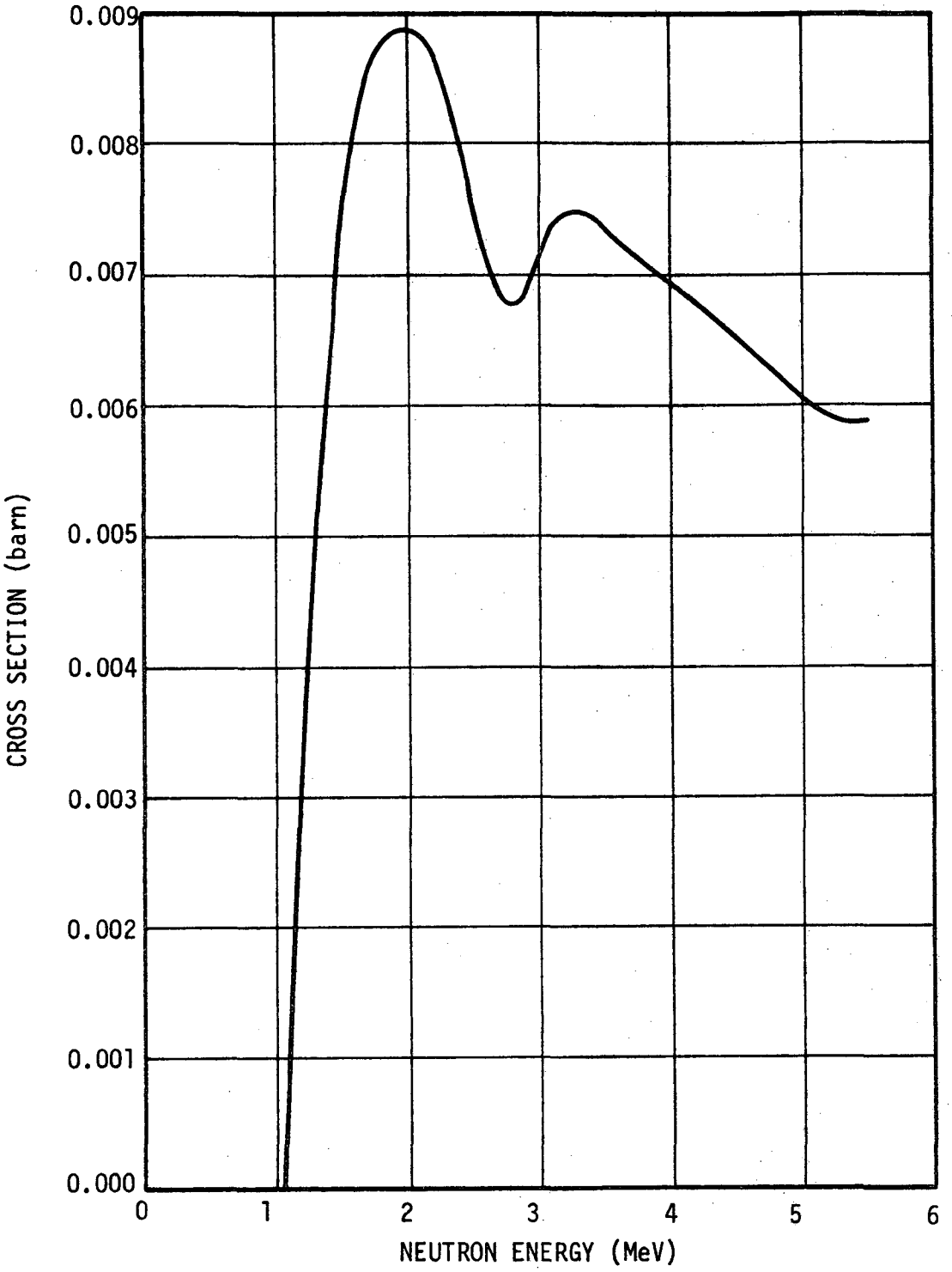

FIGURE 19. CROSS SECTION FOR PRODUCTION OF THE 0.17 MeV GAMMA TRANSITION FROM THE 1.01 MeV LEVEL TO THE 0.84 MeV LEVEL OF Al^{27}

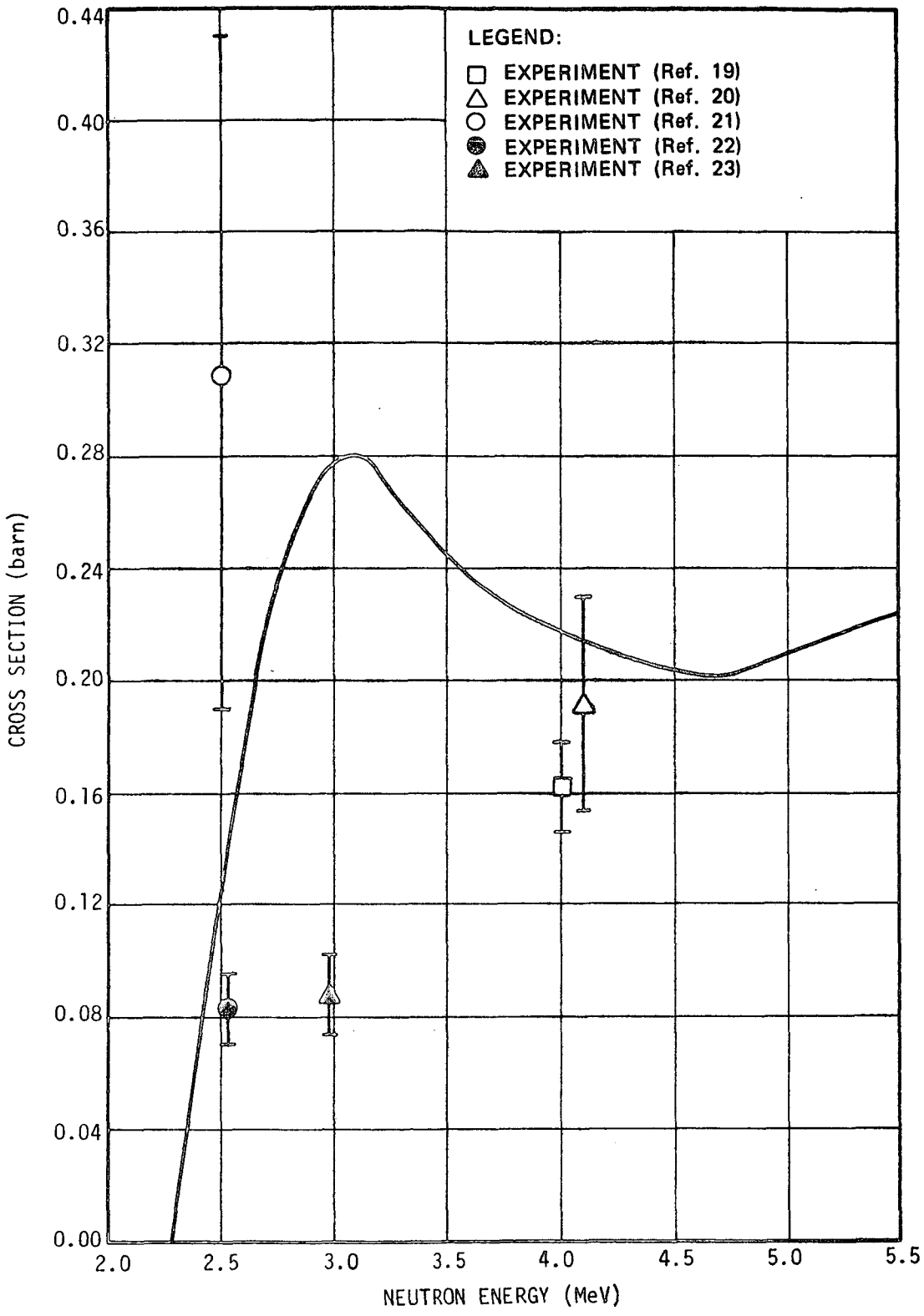

FIGURE 20. CROSS SECTION FOR PRODUCTION OF THE 2.21 MeV GAMMA TRANSITION FROM THE 2.21 MeV LEVEL TO THE GROUND LEVEL OF Al^{27}

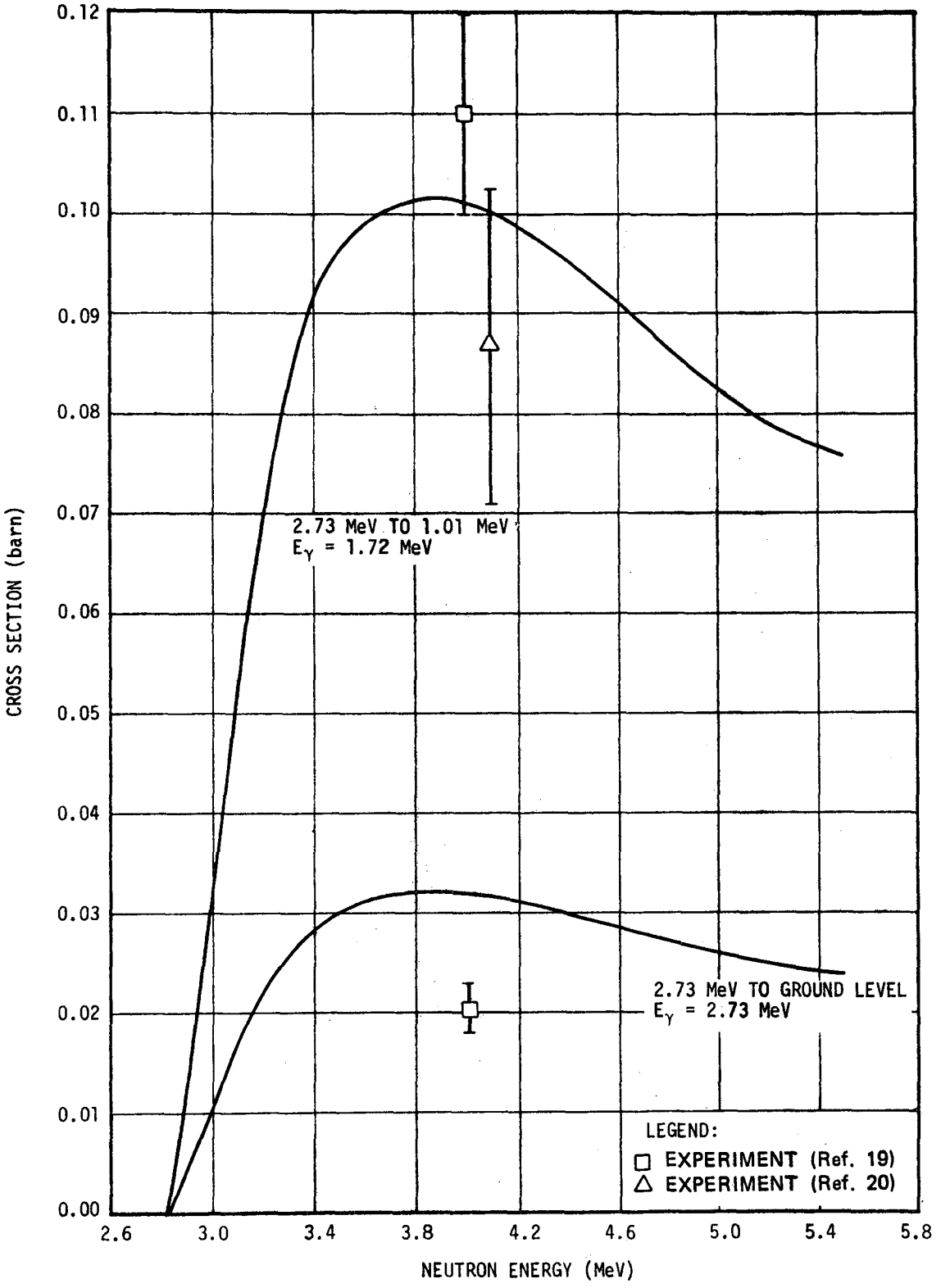

FIGURE 21. CROSS SECTION FOR PRODUCTION OF GAMMA TRANSITIONS FROM THE 2.73 MeV LEVEL TO THE 1.01 MeV LEVEL AND THE GROUND LEVEL OF Al^{27}

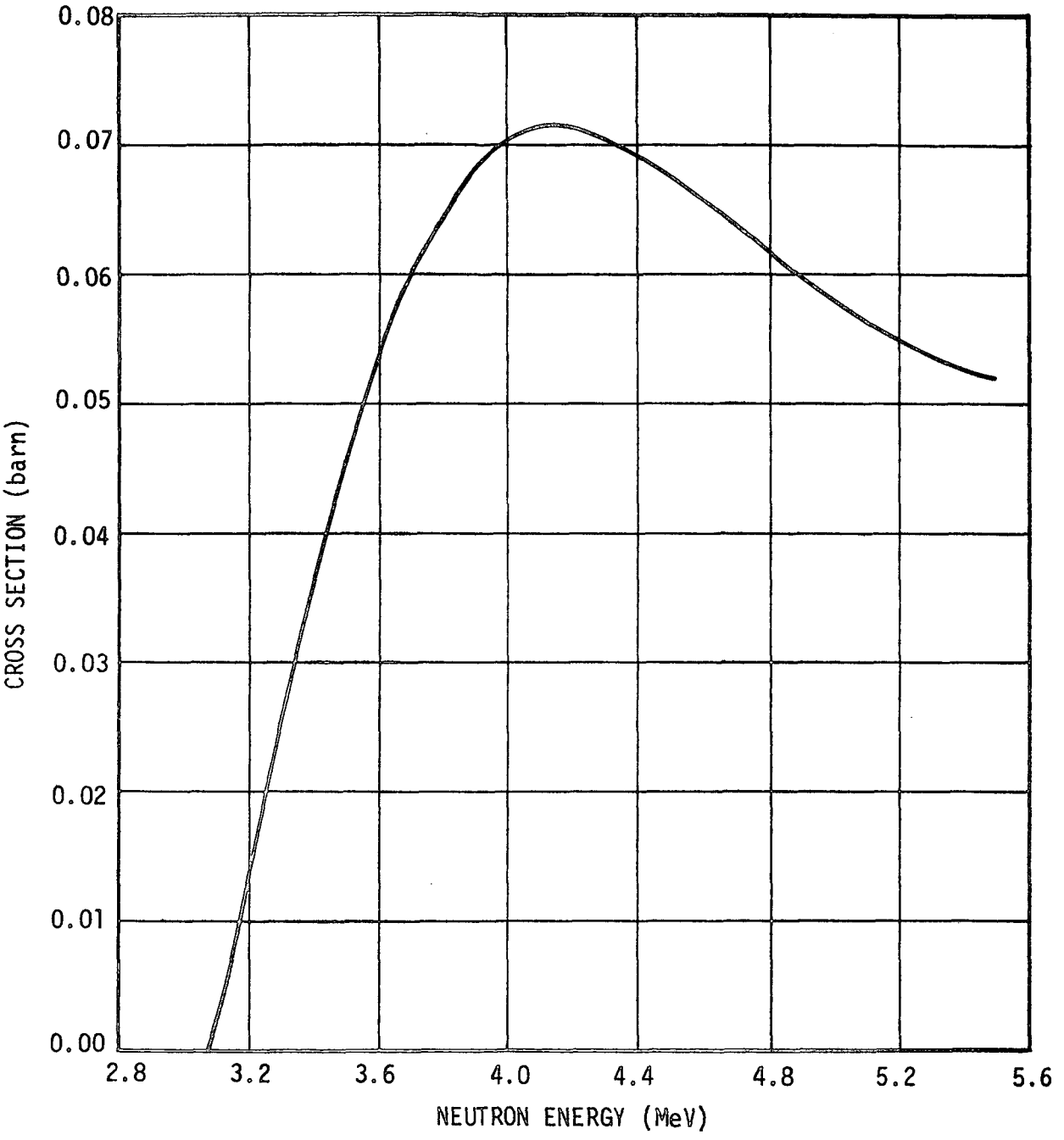

FIGURE 22. CROSS SECTION FOR PRODUCTION OF THE 2.98 MeV GAMMA TRANSITION FROM THE 2.98 MeV LEVEL TO THE GROUND LEVEL OF Al^{27}

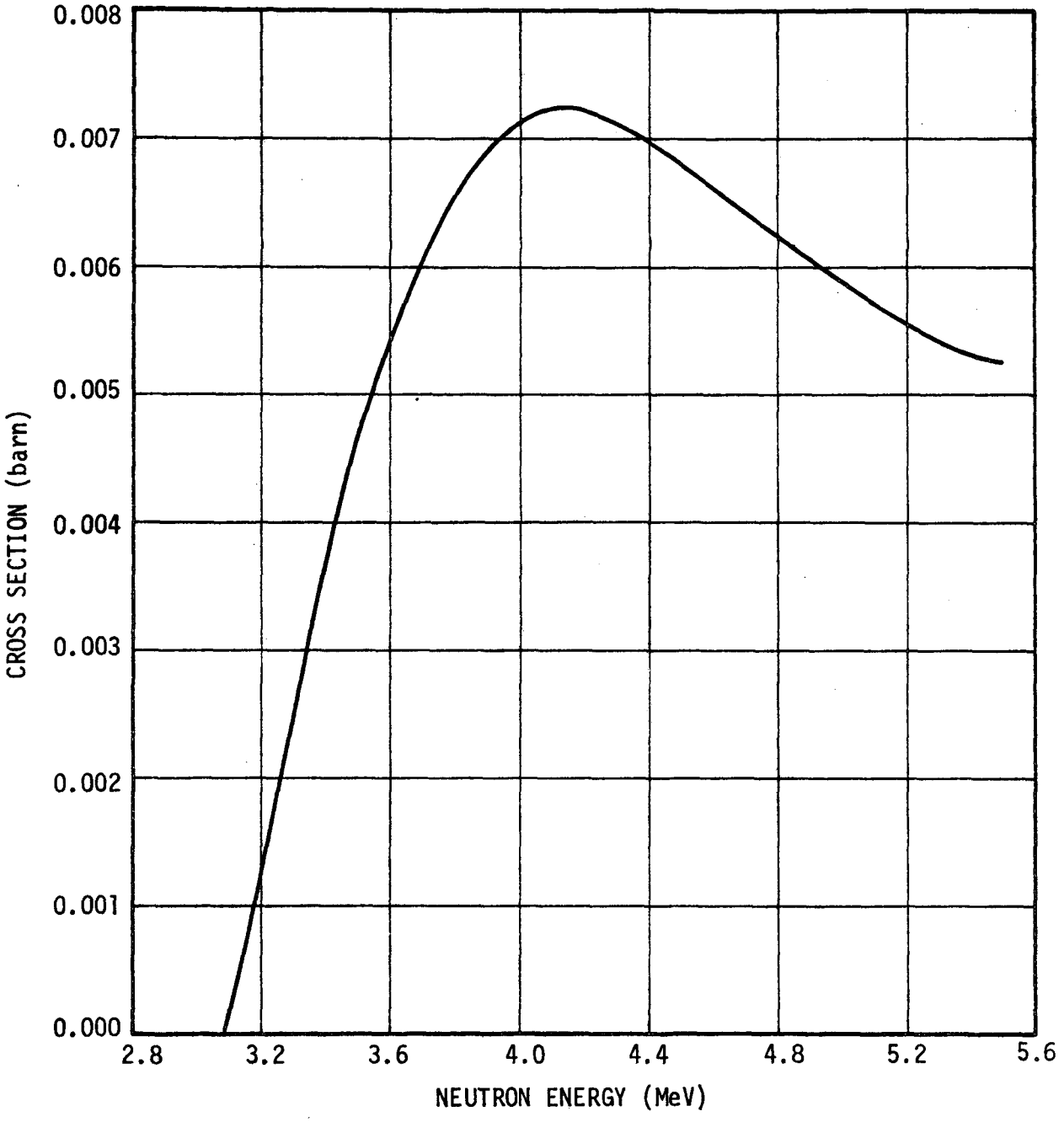

FIGURE 23. CROSS SECTION FOR PRODUCTION OF THE 2.14 MeV GAMMA TRANSITION FROM THE 2.98 MeV LEVEL TO THE 0.84 MeV LEVEL OF Al^{27}

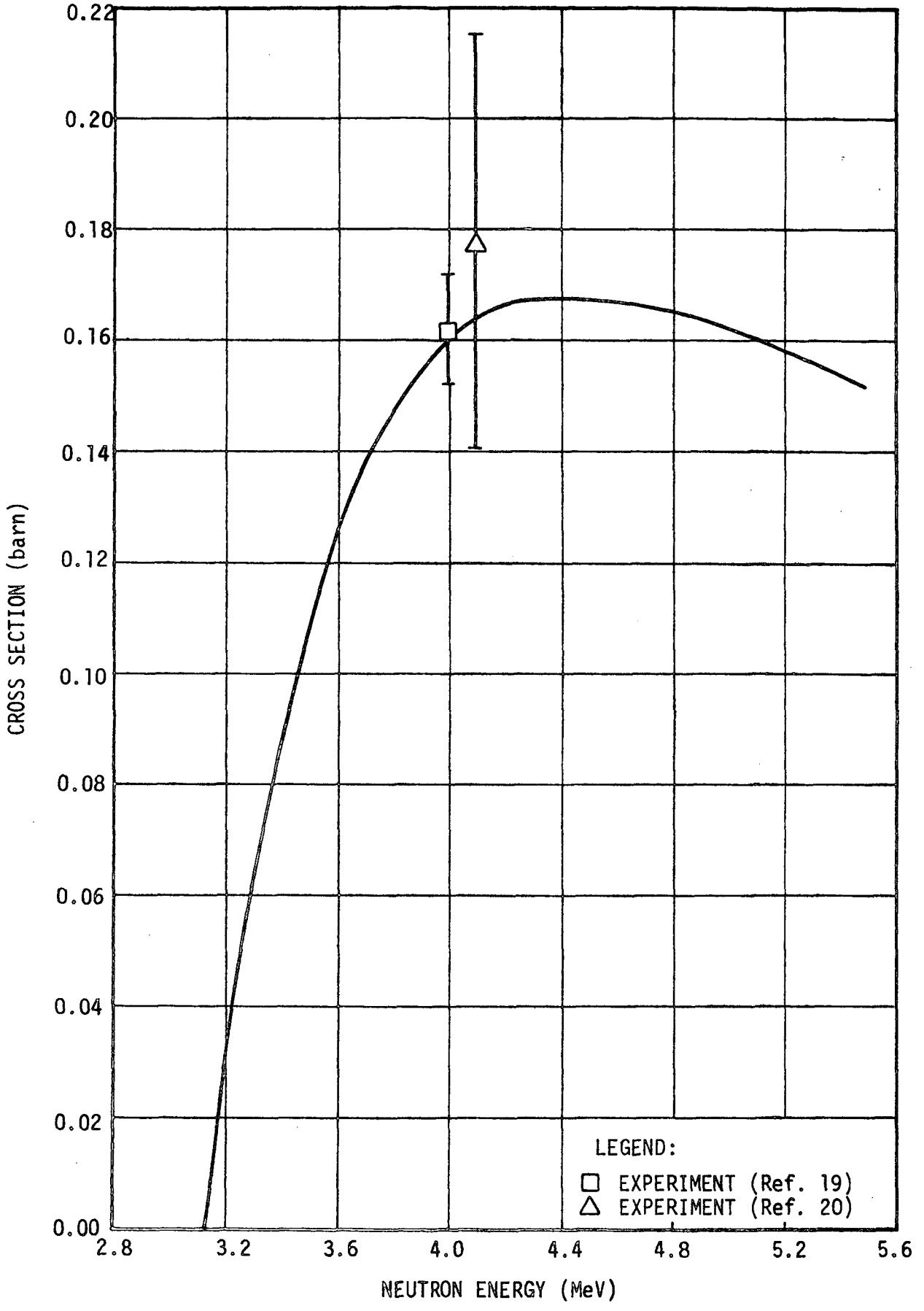

FIGURE 24. CROSS SECTION FOR PRODUCTION OF THE 3.00 MeV GAMMA TRANSITION FROM THE 3.00 MeV LEVEL TO THE GROUND LEVEL OF Al^{27}

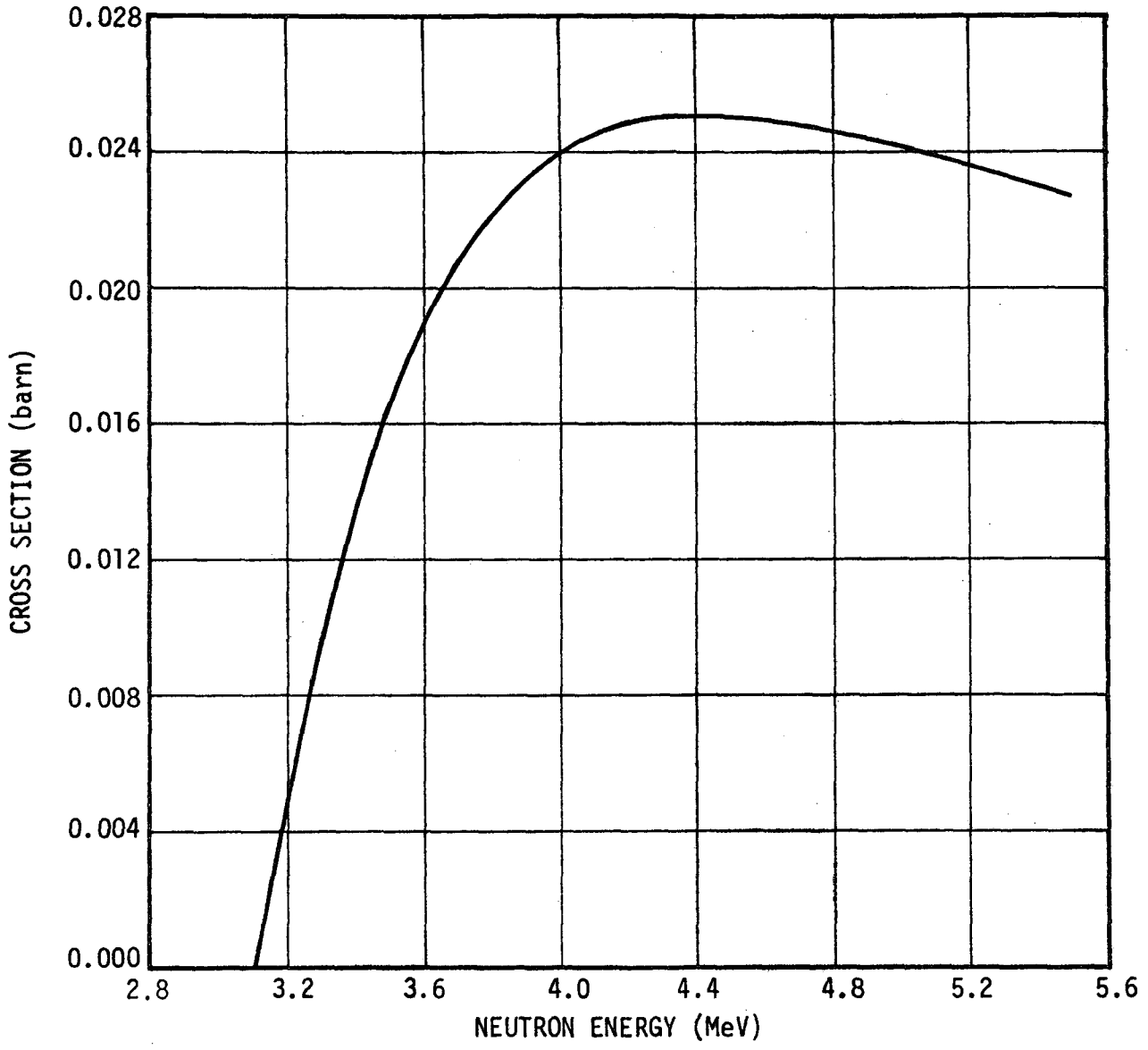

FIGURE 25. CROSS SECTION FOR PRODUCTION OF 0.79 MeV GAMMA TRANSITION FROM THE 3.00 MeV LEVEL TO THE 2.21 MeV LEVEL OF Al^{27}

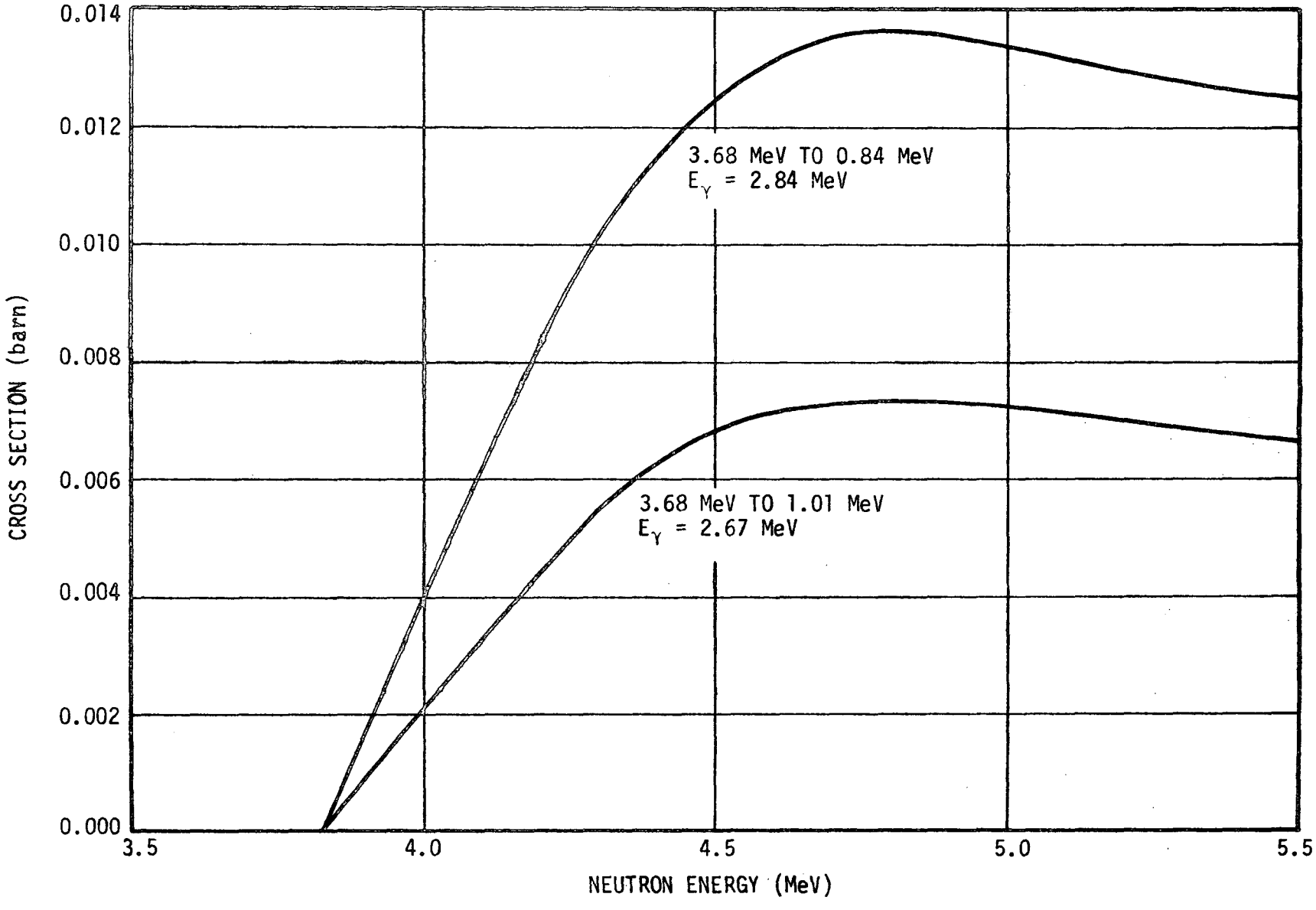

FIGURE 26. CROSS SECTION FOR PRODUCTION OF GAMMA TRANSITIONS FROM THE 3.68 MeV LEVEL TO THE 0.84 AND 1.01 MeV LEVELS OF Al^{27}

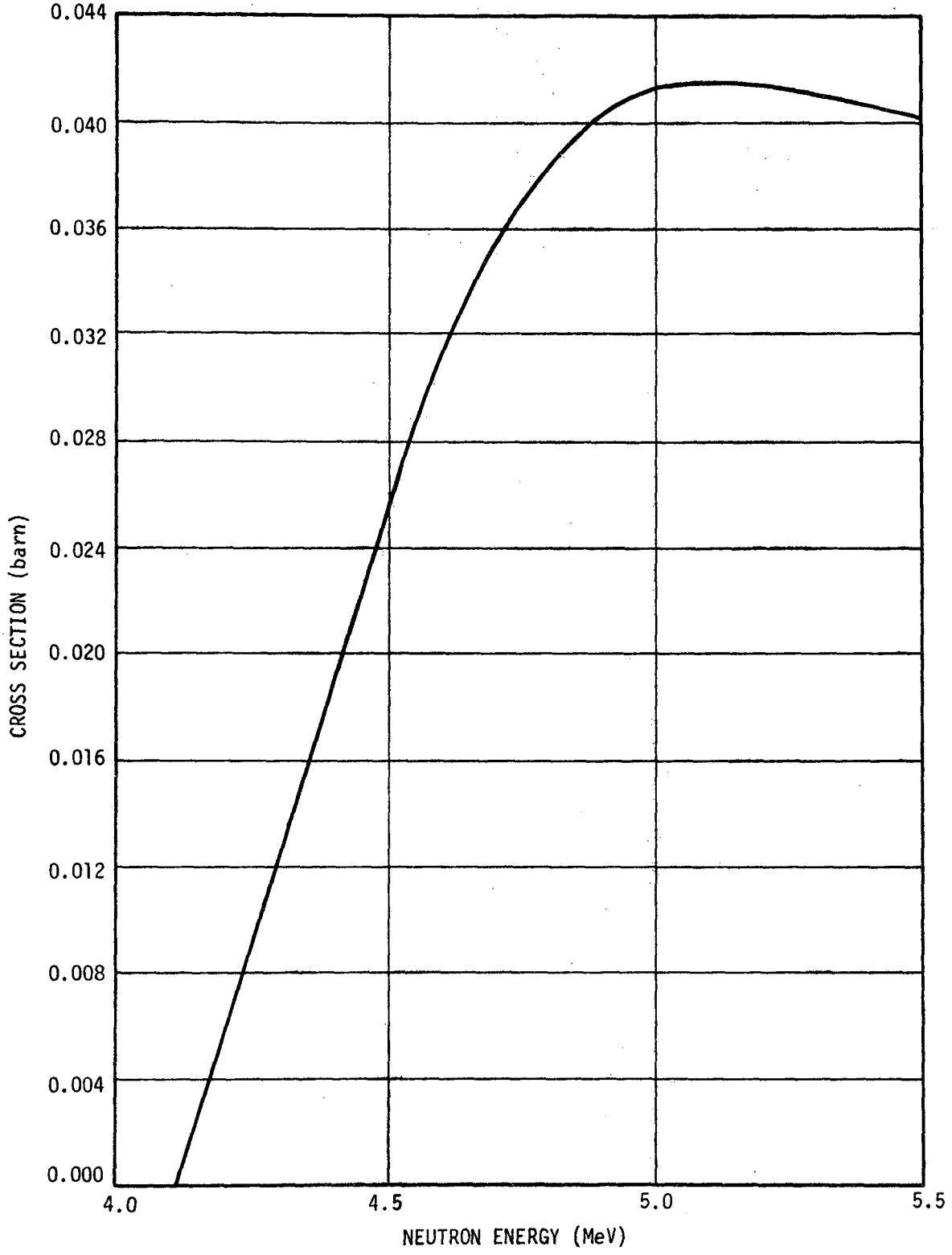

FIGURE 27. CROSS SECTION FOR PRODUCTION OF THE 3.96 MeV GAMMA TRANSITION FROM THE 3.96 MeV LEVEL TO THE GROUND LEVEL OF Al^{27}

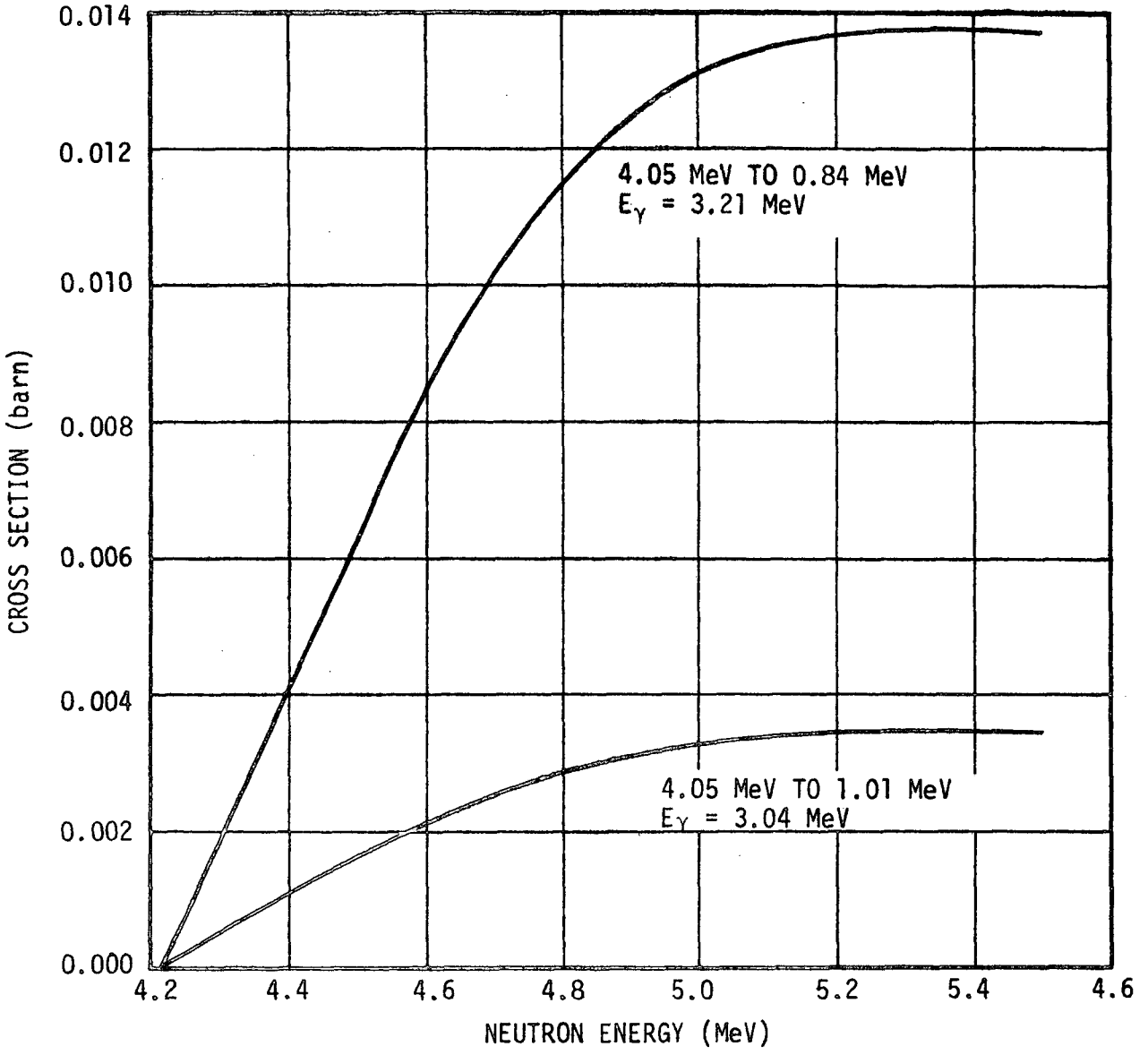

FIGURE 28. CROSS SECTION FOR PRODUCTION OF GAMMA TRANSITIONS FROM THE 4.05 MeV LEVEL TO THE 0.84 AND 1.01 MeV LEVELS OF Al^{27}

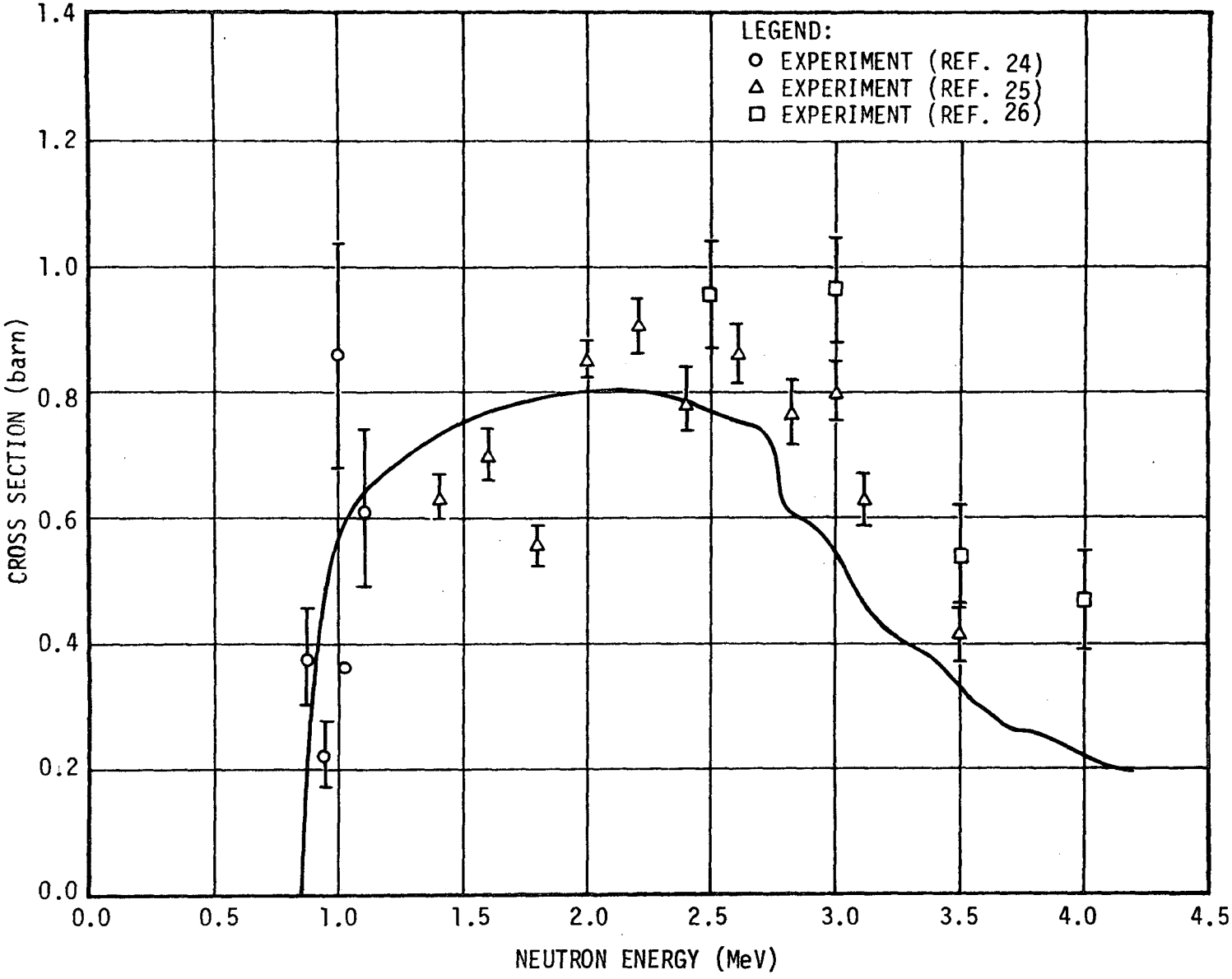

FIGURE 29. CROSS SECTION FOR EXCITATION OF THE 0.847 MeV LEVEL OF Fe^{56}

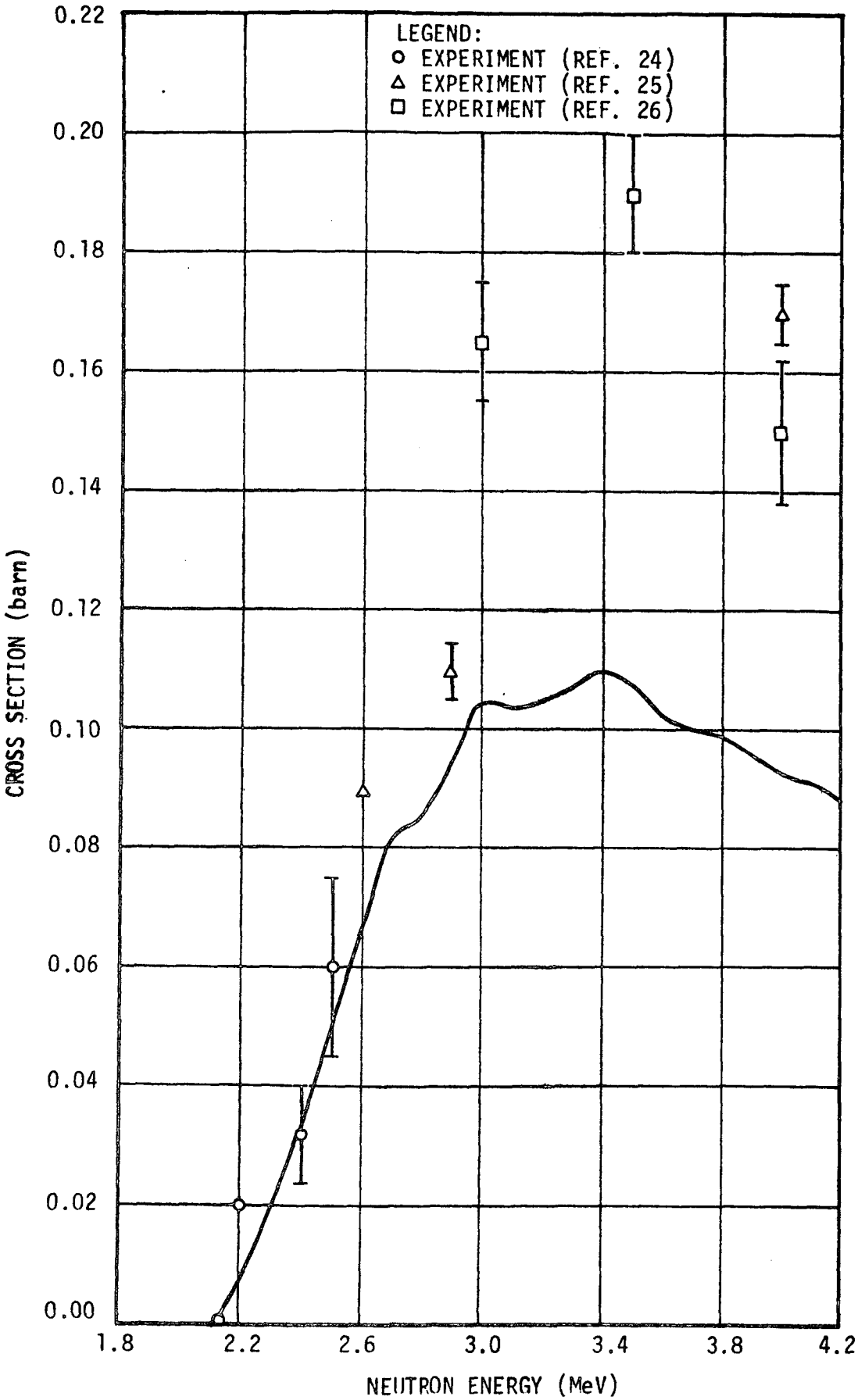

FIGURE 30. CROSS SECTION FOR EXCITATION OF THE 2.085 MeV LEVEL OF Fe^{56}

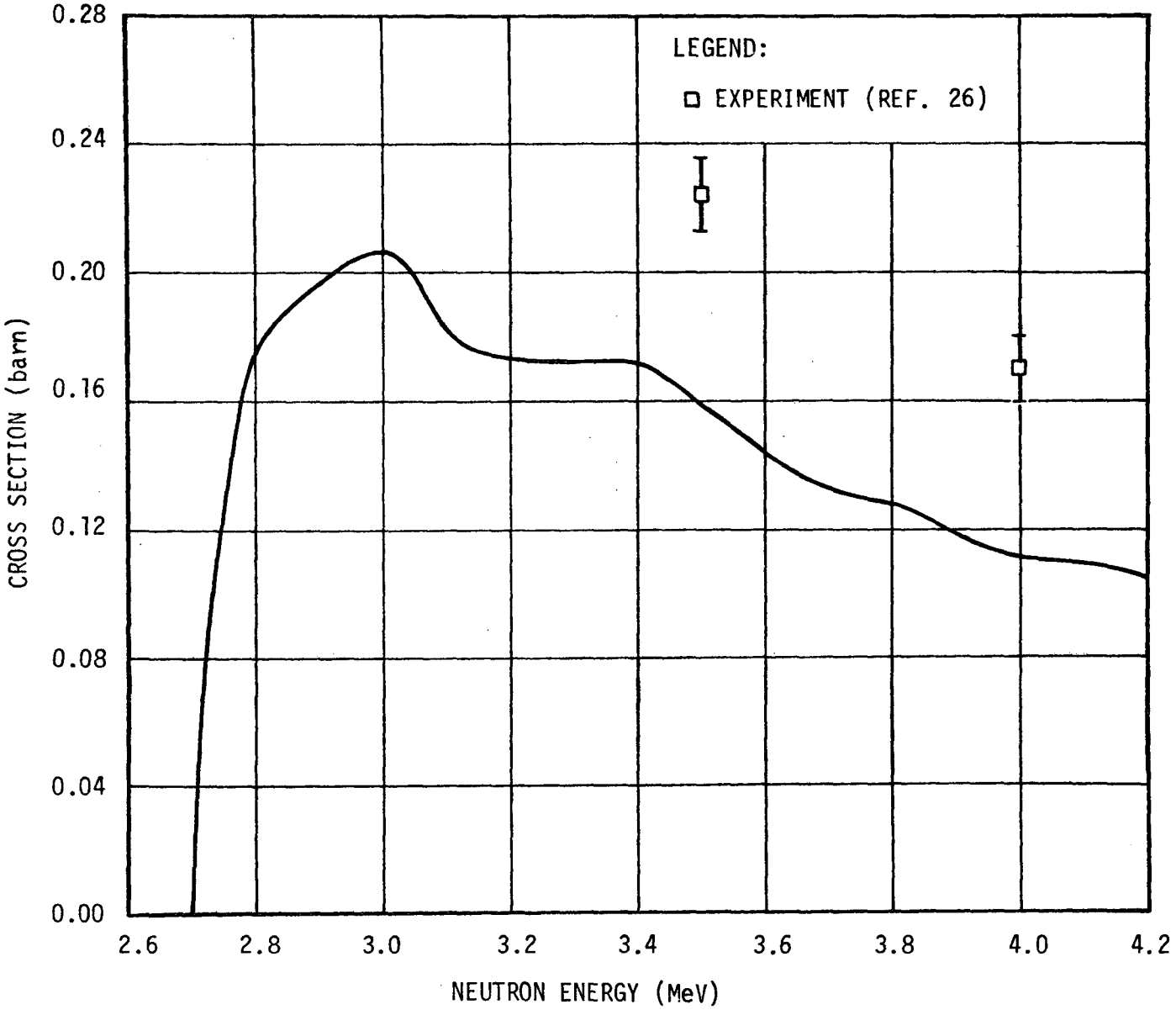

FIGURE 31. CROSS SECTION FOR EXCITATION OF THE 2.657 MeV LEVEL OF Fe^{56}

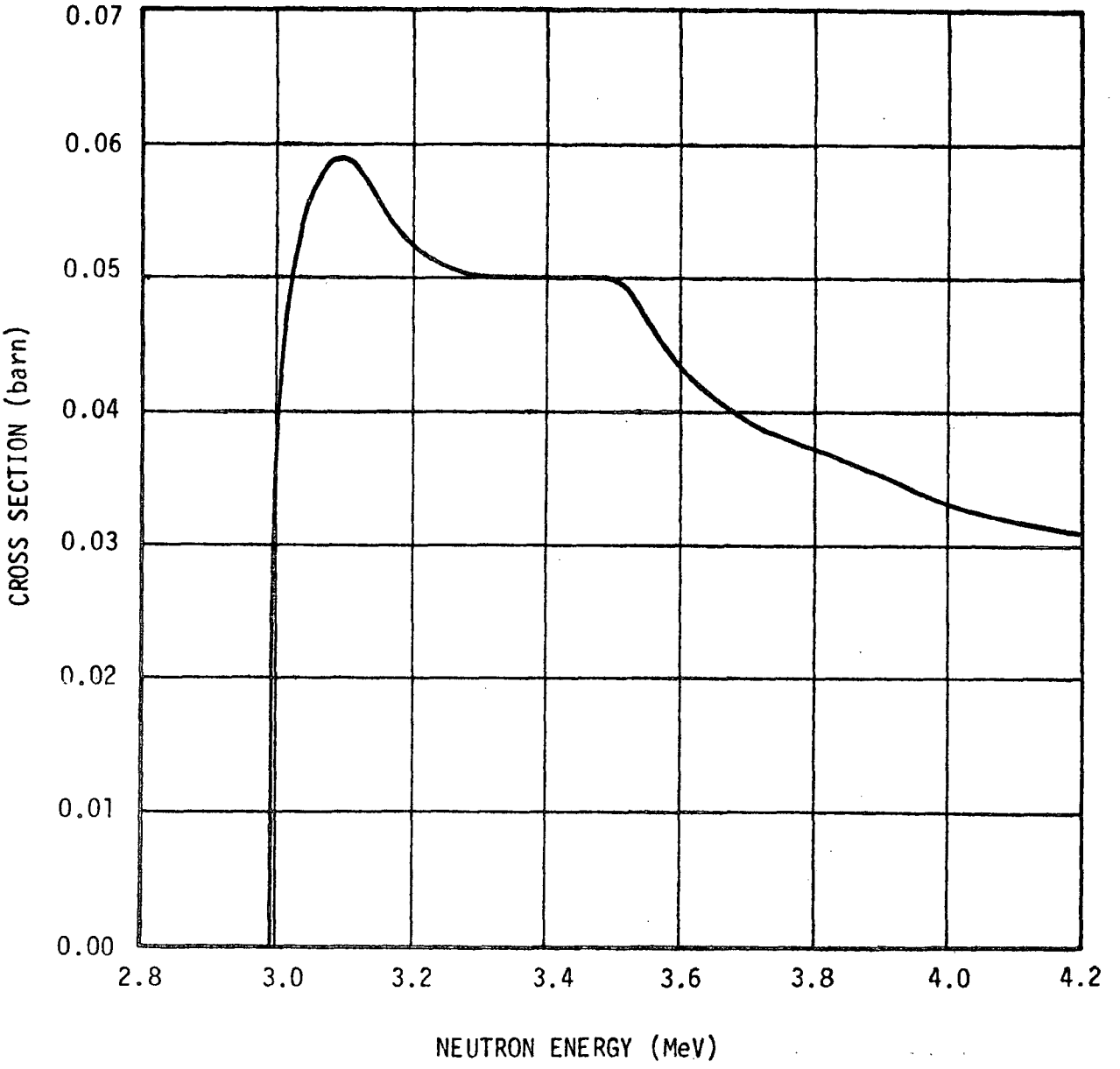

FIGURE 32. CROSS SECTION FOR EXCITATION OF THE 2.939 MeV LEVEL OF Fe^{56}

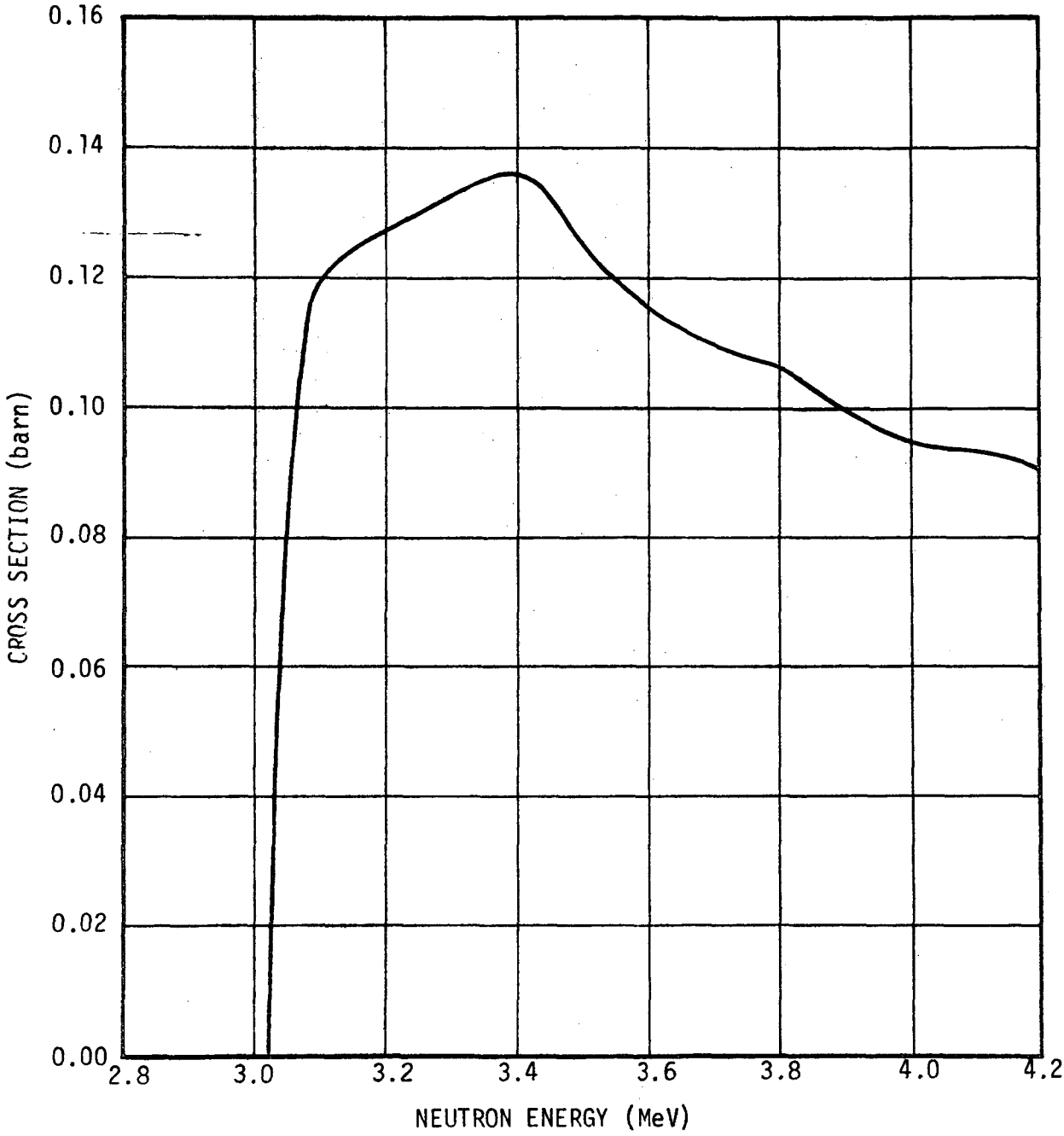

FIGURE 33. CROSS SECTION FOR EXCITATION OF THE 2.960 MeV LEVEL OF Fe^{56}

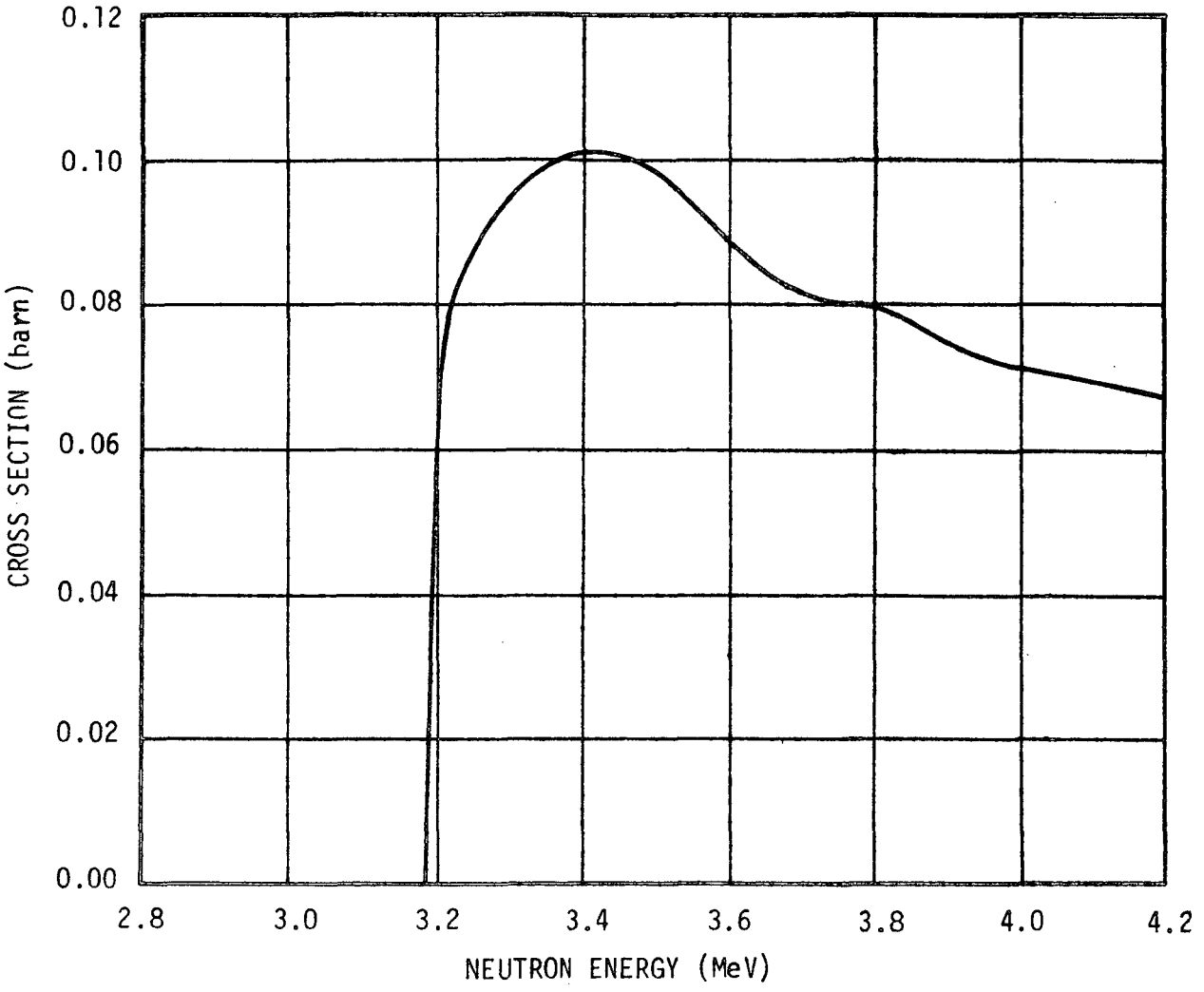

FIGURE 34. CROSS SECTION FOR EXCITATION OF THE 3.119 MeV LEVEL OF Fe^{56}

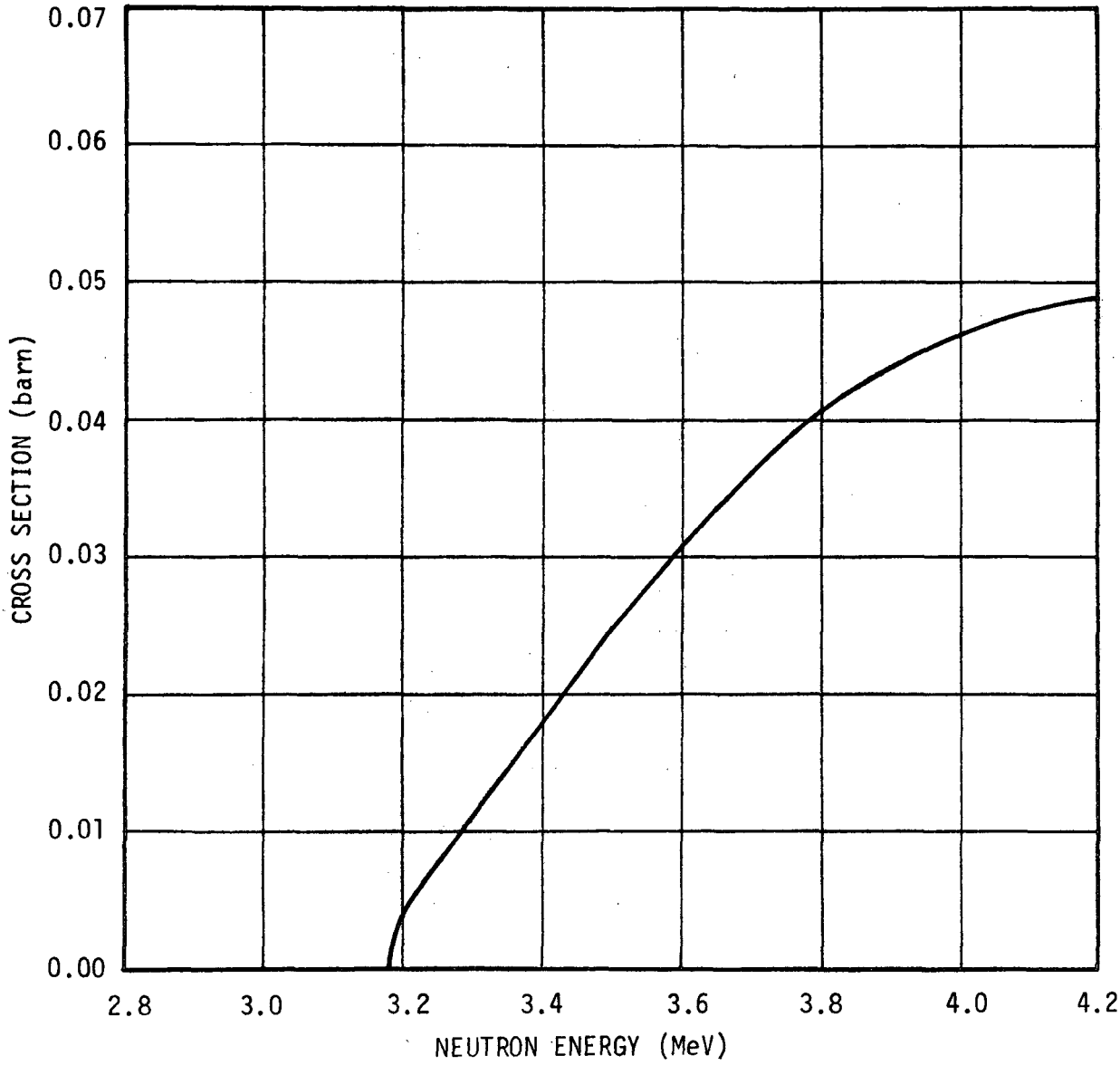

FIGURE 35. CROSS SECTION FOR EXCITATION OF THE 3.123 MeV LEVEL OF Fe^{56}

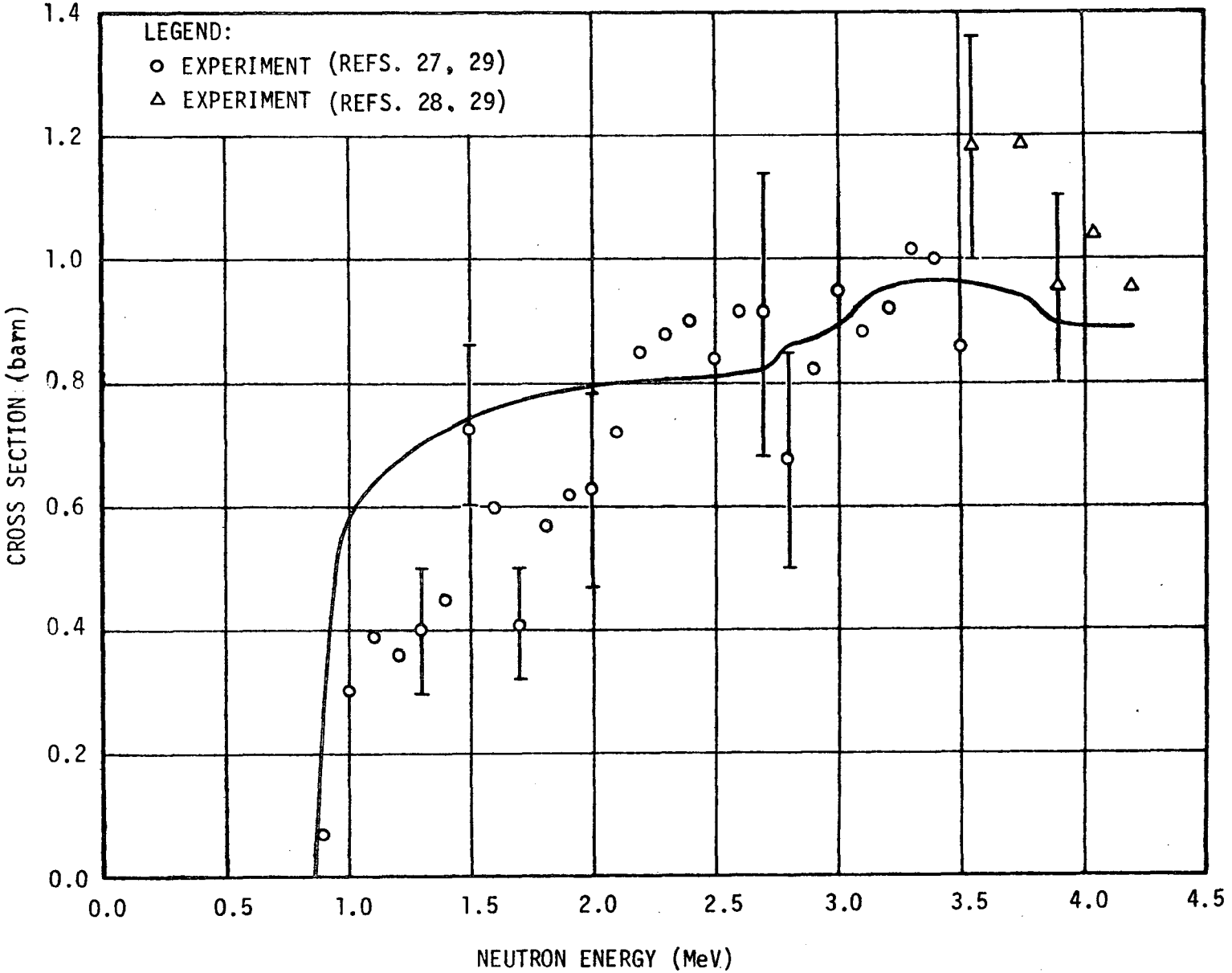

FIGURE 36. CROSS SECTION FOR PRODUCTION OF THE 0.847 MeV GAMMA TRANSITION FROM THE 0.847 MeV LEVEL TO THE GROUND LEVEL OF Fe^{56}

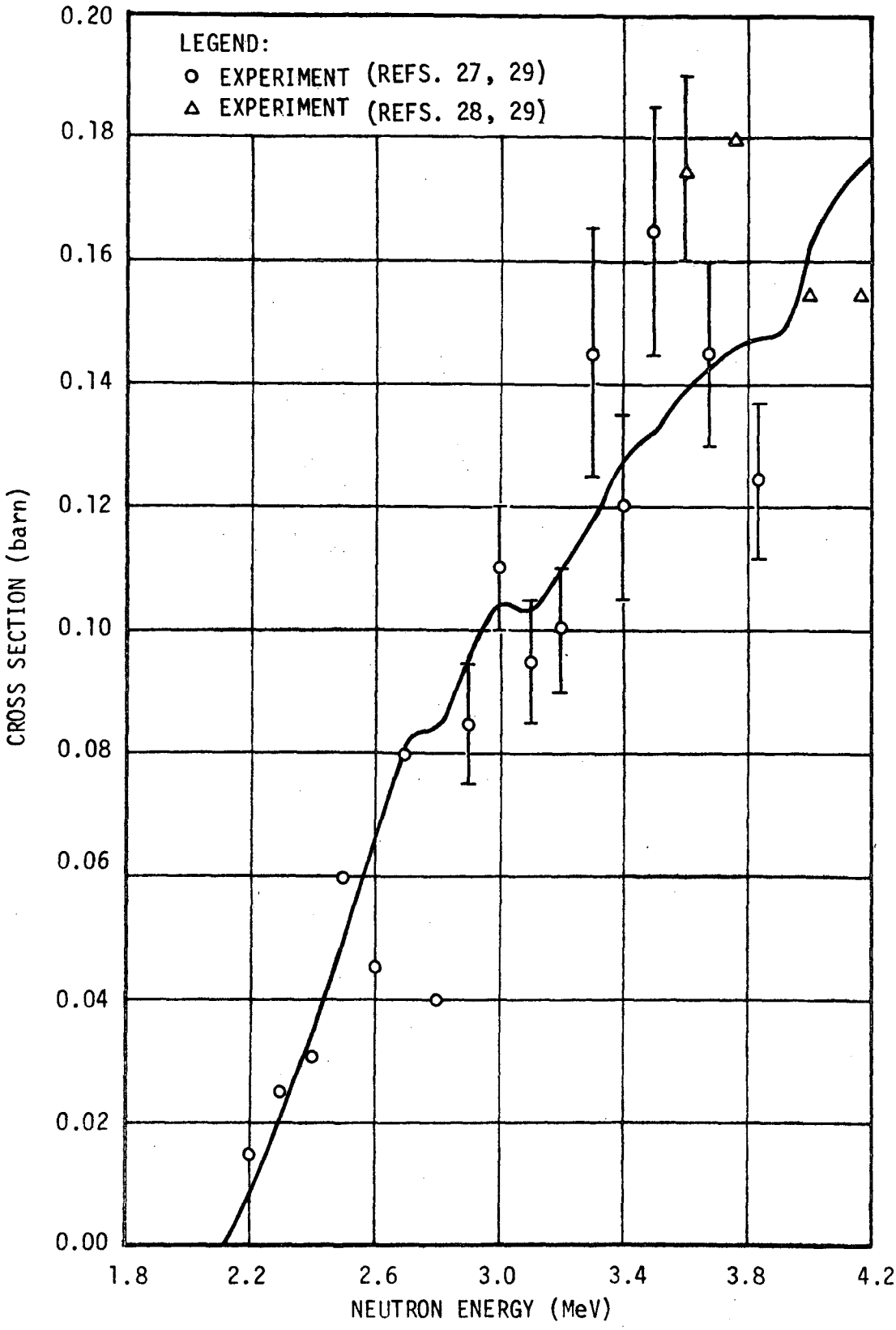

FIGURE 37. CROSS SECTION FOR PRODUCTION OF THE 1.238 MeV GAMMA TRANSITION FROM THE 2.085 MeV LEVEL TO THE 0.847 MeV LEVEL OF Fe^{56}

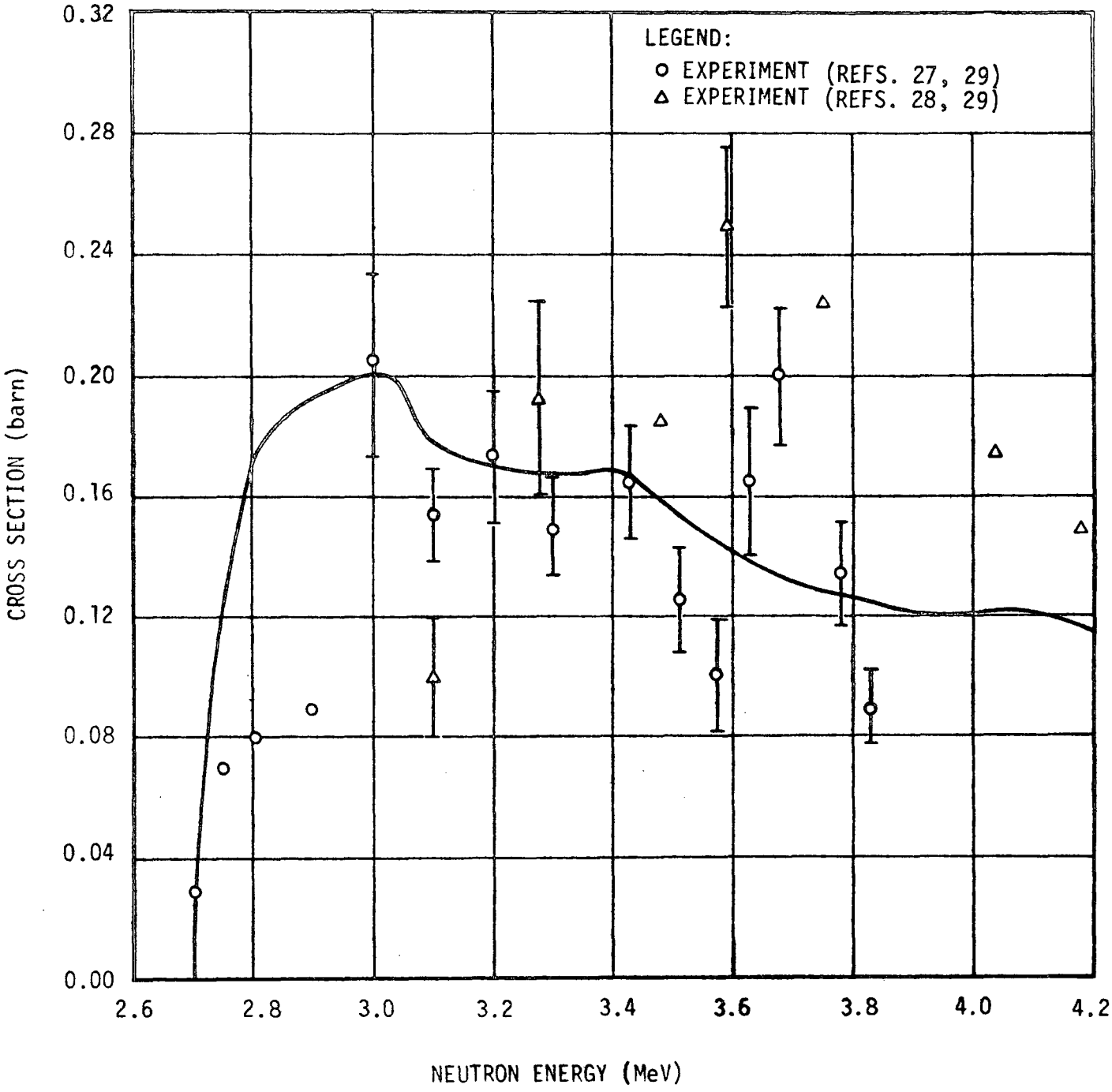

FIGURE 38. CROSS SECTION FOR PRODUCTION OF THE 1.810 MeV GAMMA TRANSITION FROM THE 2.657 MeV LEVEL TO THE 0.847 MeV LEVEL OF Fe^{56}

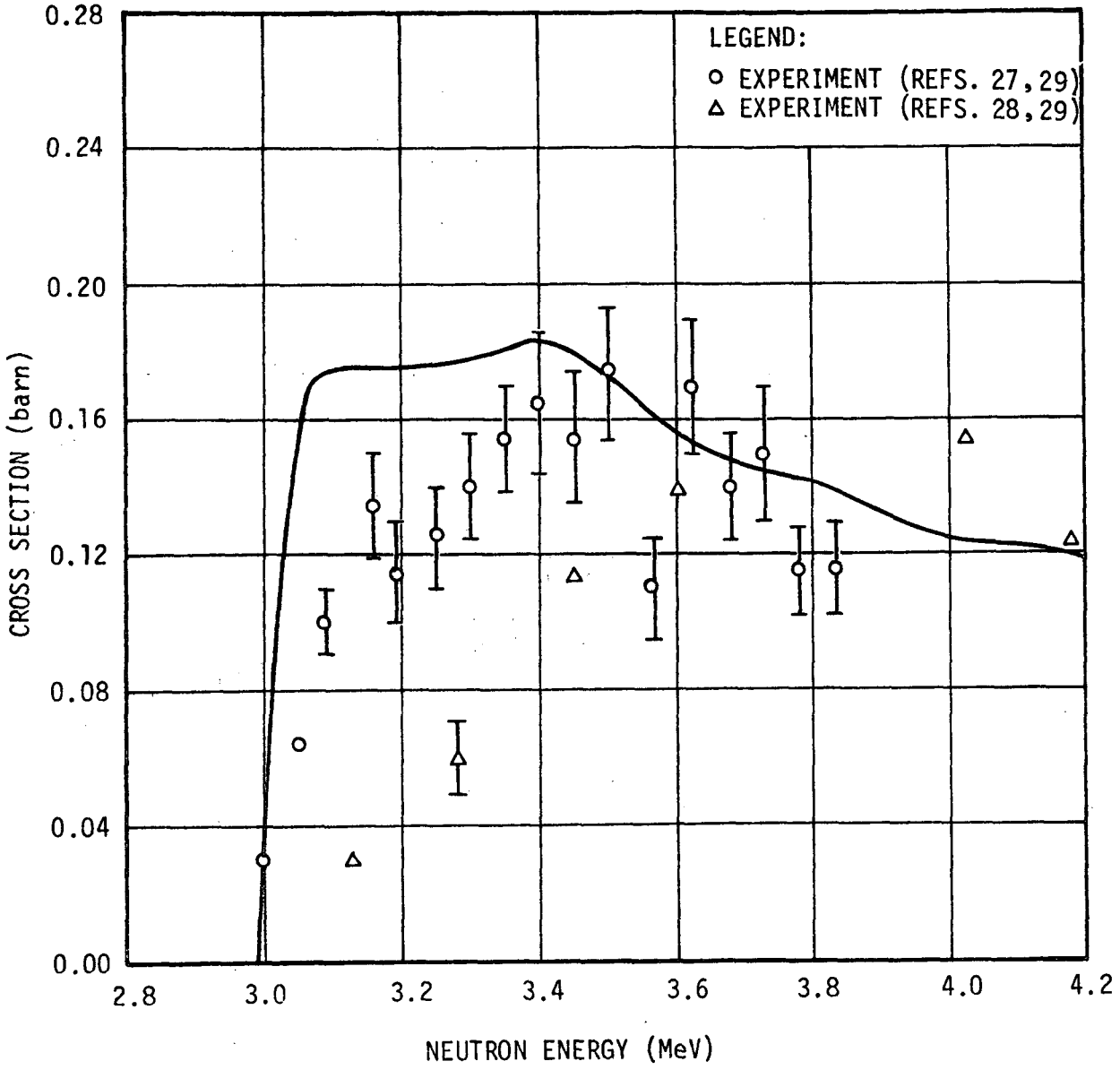

FIGURE 39. CROSS SECTION FOR PRODUCTION OF THE 2.092 AND 2.113 MeV GAMMA TRANSITIONS FROM THE 2.939 AND 2.960 MeV LEVELS TO THE 0.847 MeV LEVEL OF Fe^{56}

C.4

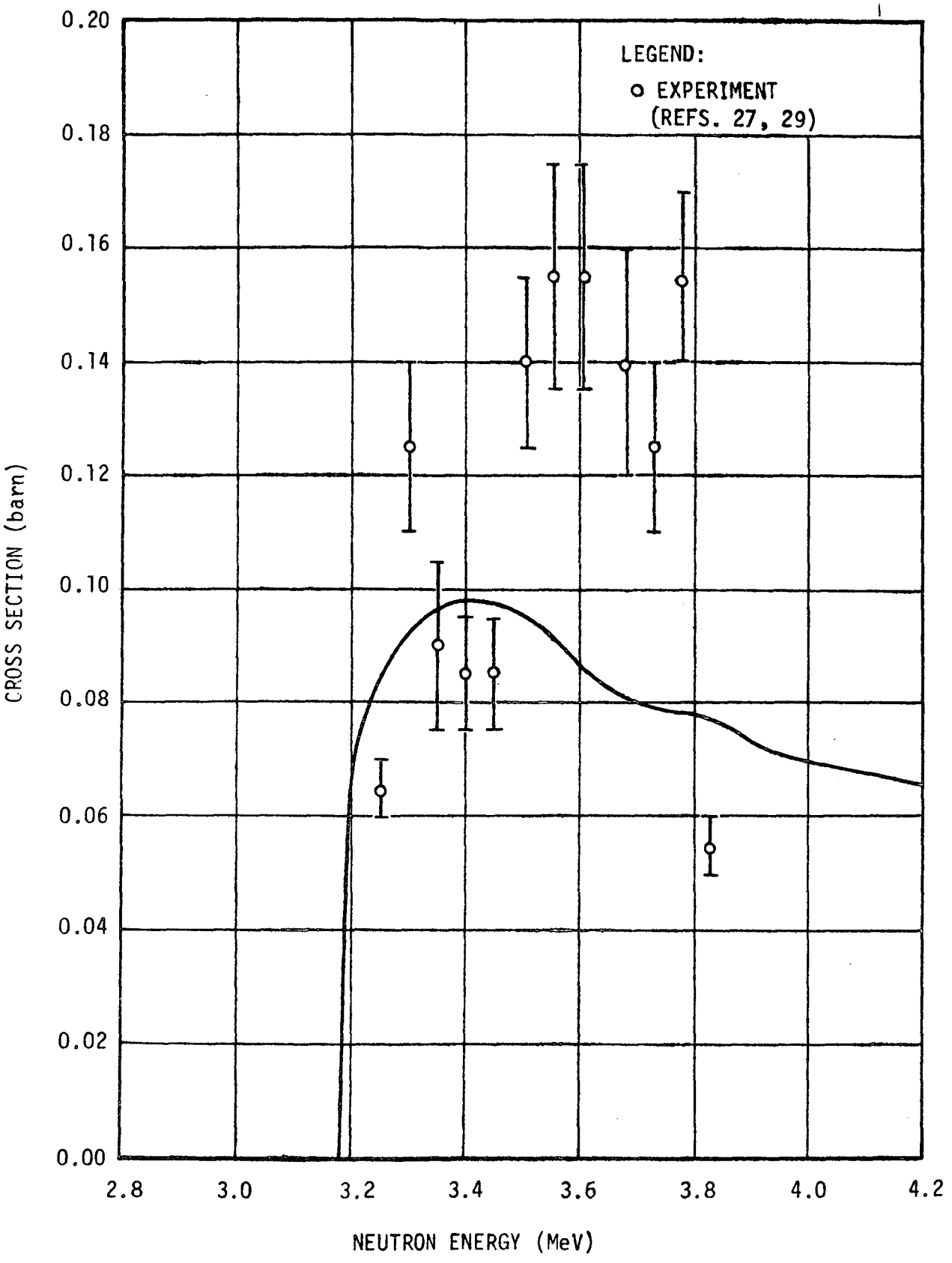

FIGURE 40. CROSS SECTION FOR PRODUCTION OF THE 2.272 MeV GAMMA TRANSITION FROM THE 3.119 MeV LEVEL TO THE 0.847 MeV LEVEL OF Fe^{56}

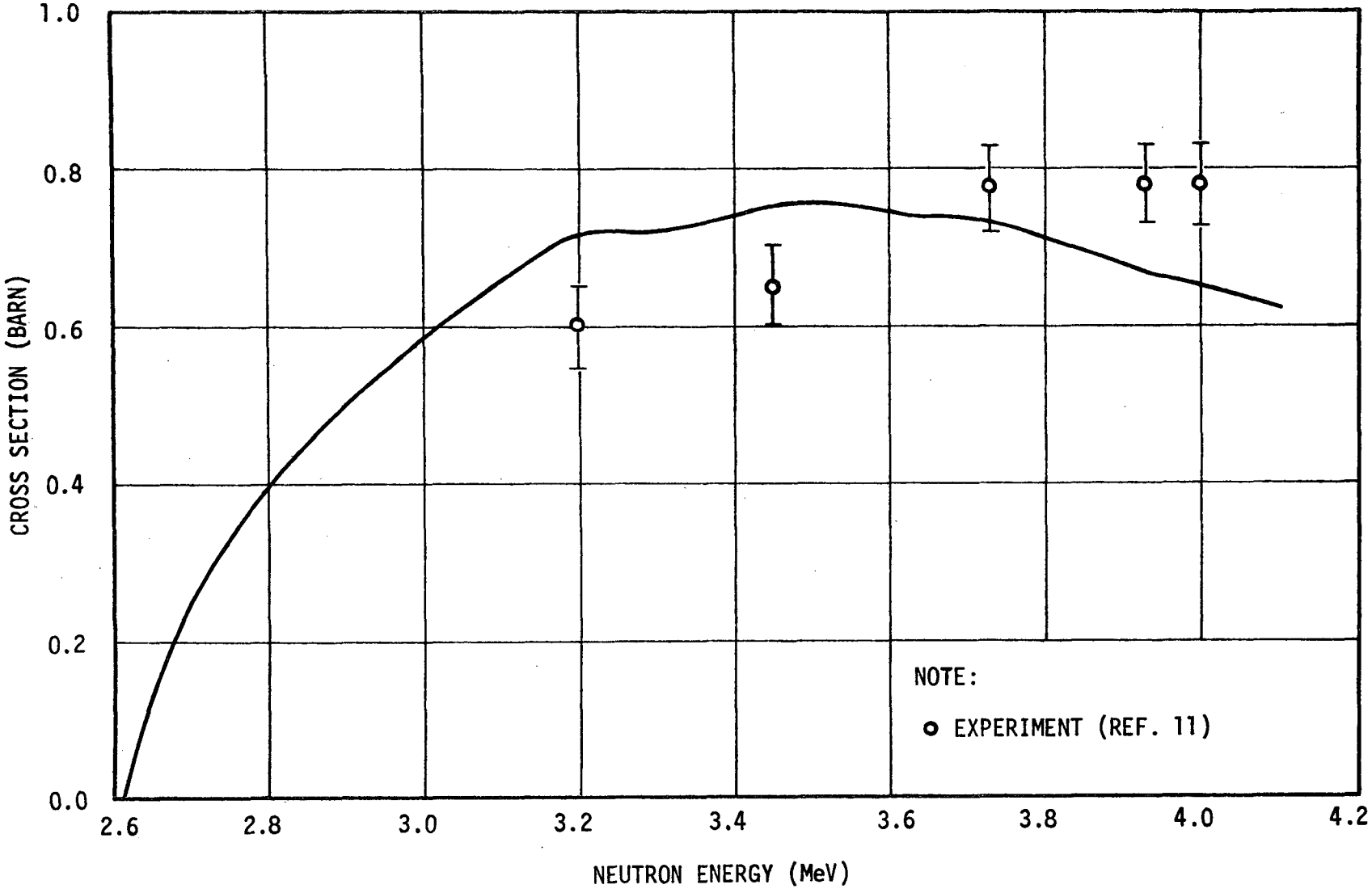

FIGURE 41. CROSS SECTION FOR EXCITATION OF THE 2.615 MeV LEVEL OF Pb^{208}

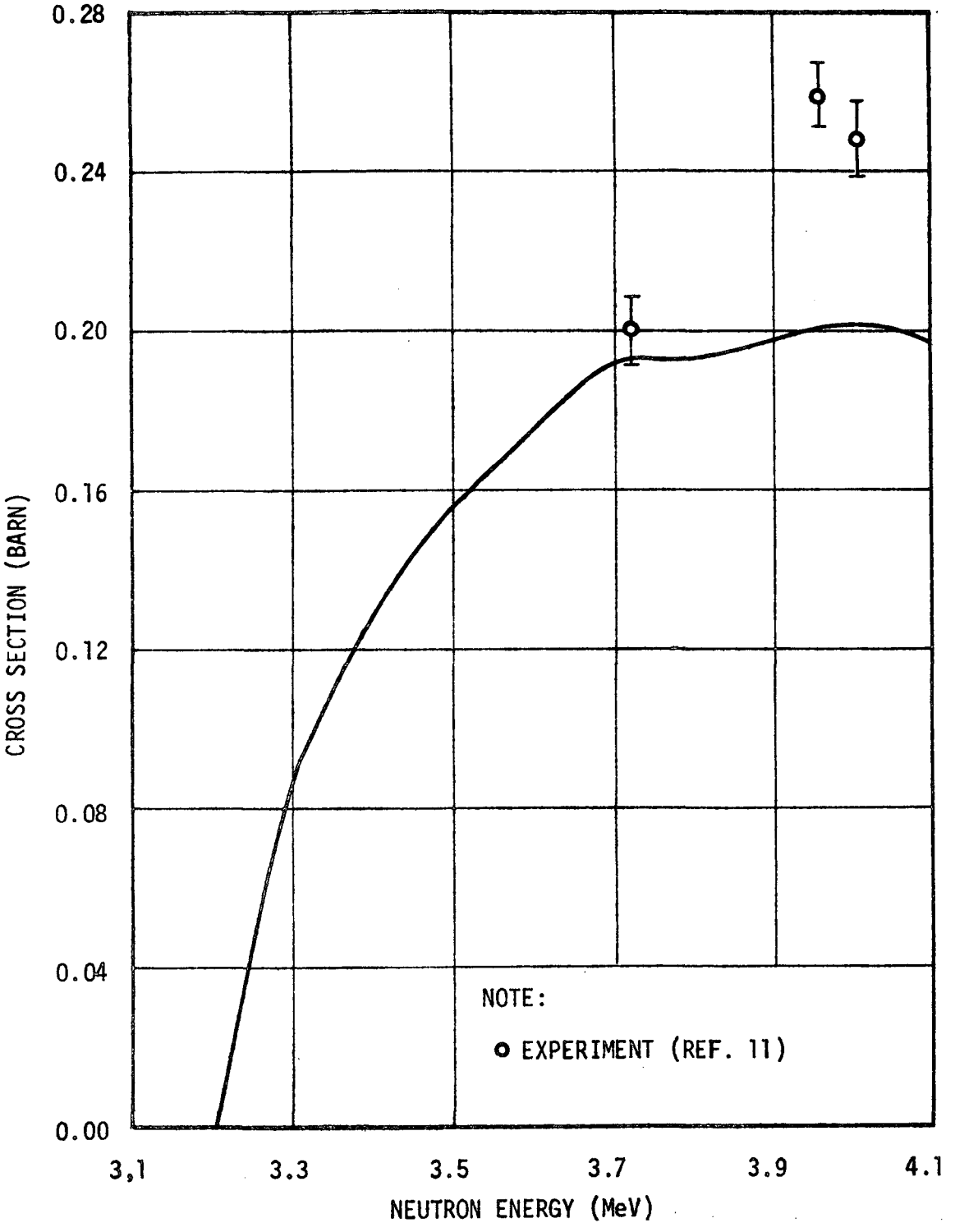

FIGURE 42. CROSS SECTION FOR EXCITATION OF THE 3.198 LEVEL OF Pb^{208}

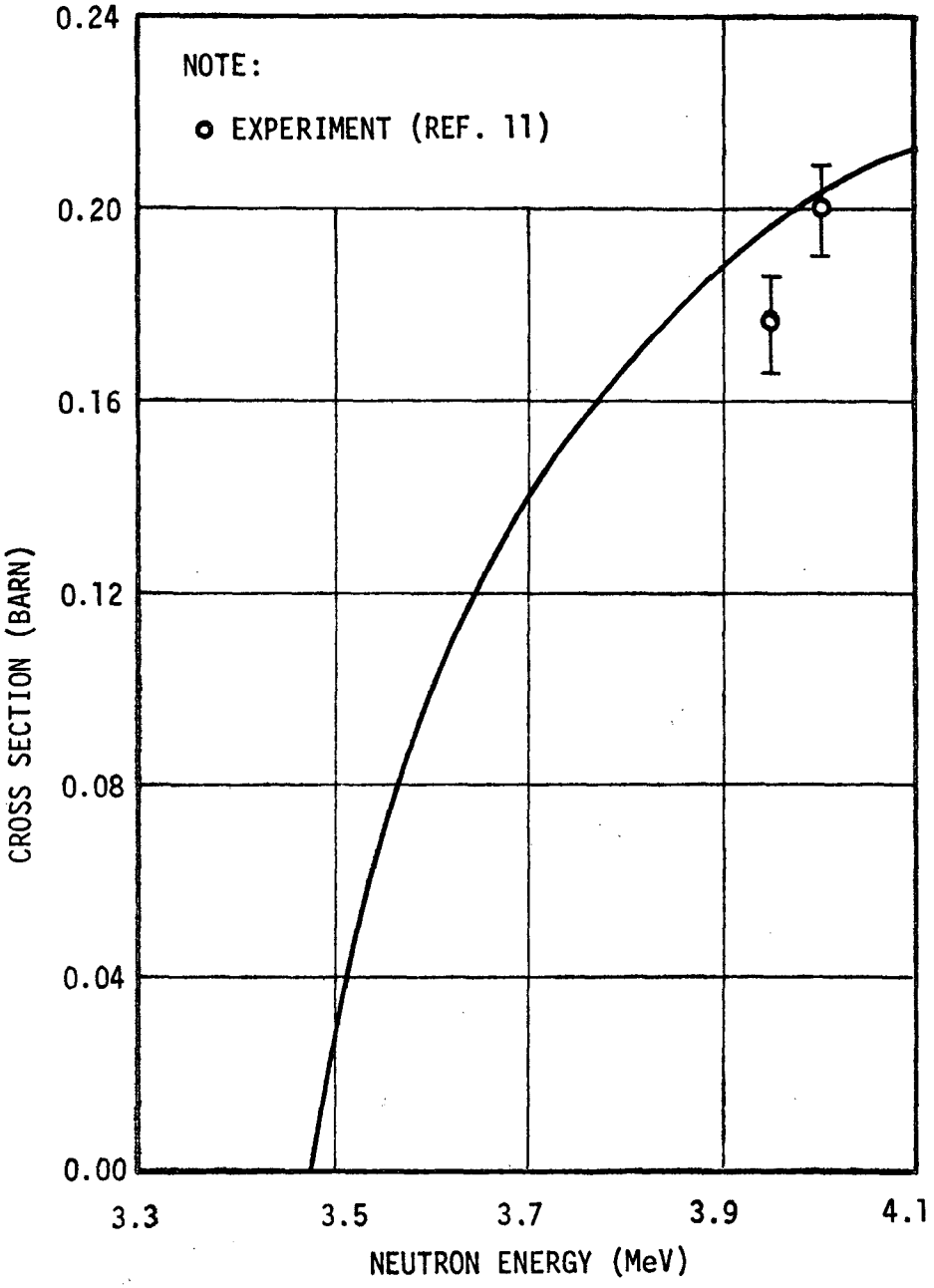

FIGURE 43. CROSS SECTION FOR EXCITATION OF THE 3.475 MeV LEVEL OF Pb^{208}

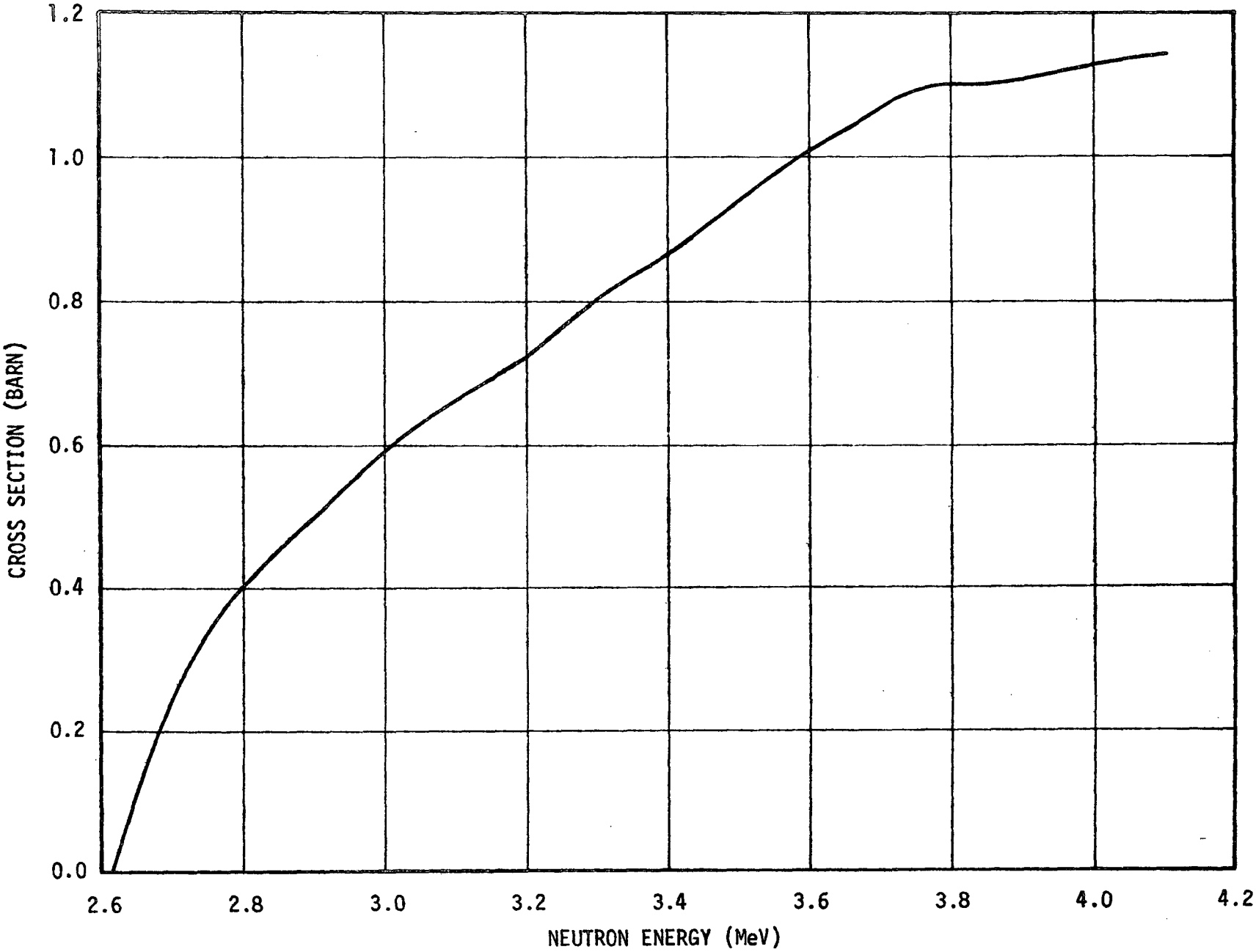

FIGURE 44. CROSS SECTION FOR PRODUCTION OF THE 2.615 MeV GAMMA TRANSITION FROM THE 2.615 MeV LEVEL TO THE GROUND LEVEL OF Pb^{208}

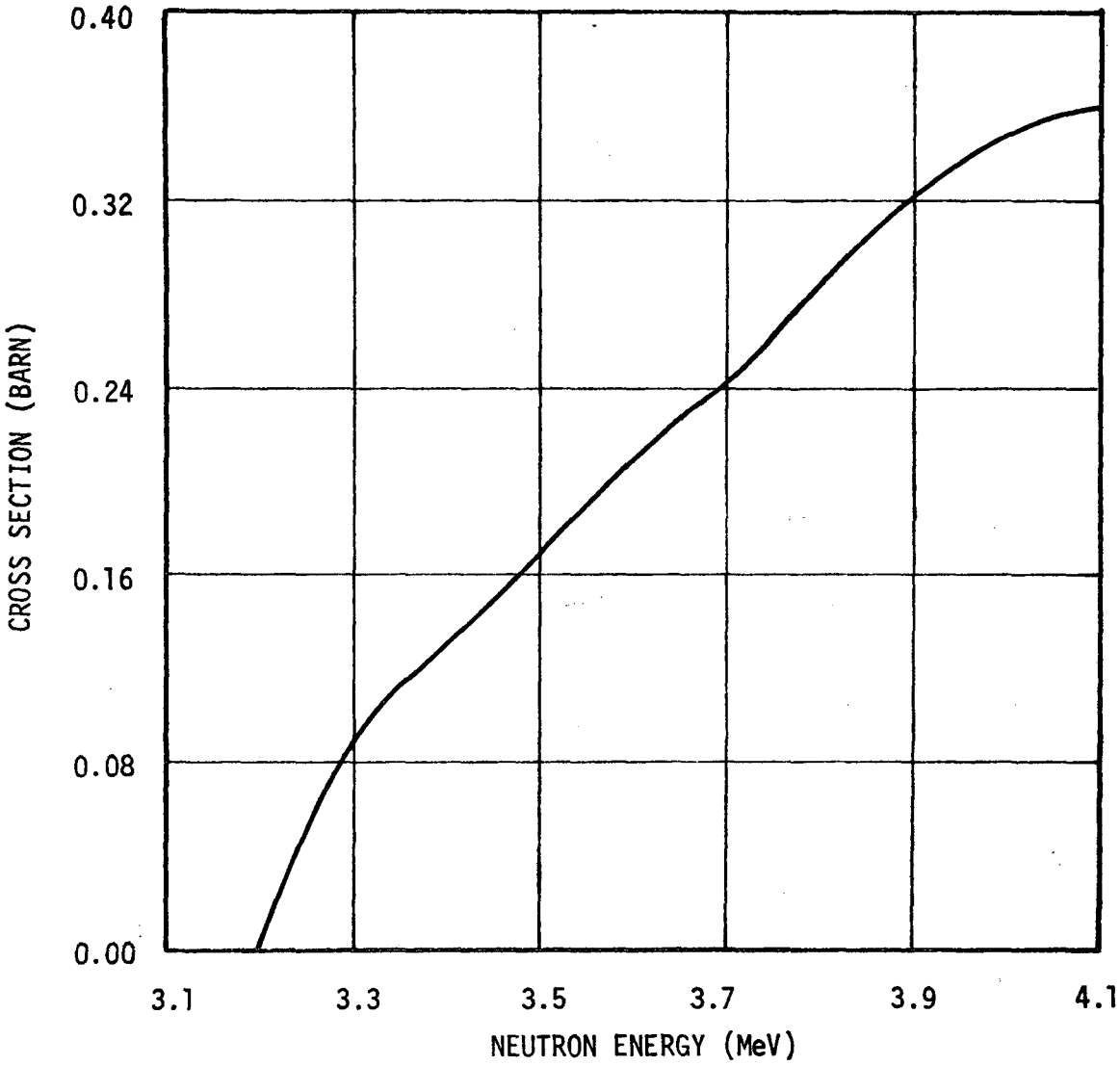

FIGURE 45. CROSS SECTION FOR PRODUCTION OF THE 0.583 GAMMA TRANSITION FROM THE 3.198 MeV LEVEL TO THE 2.615 LEVEL OF Pb^{208}

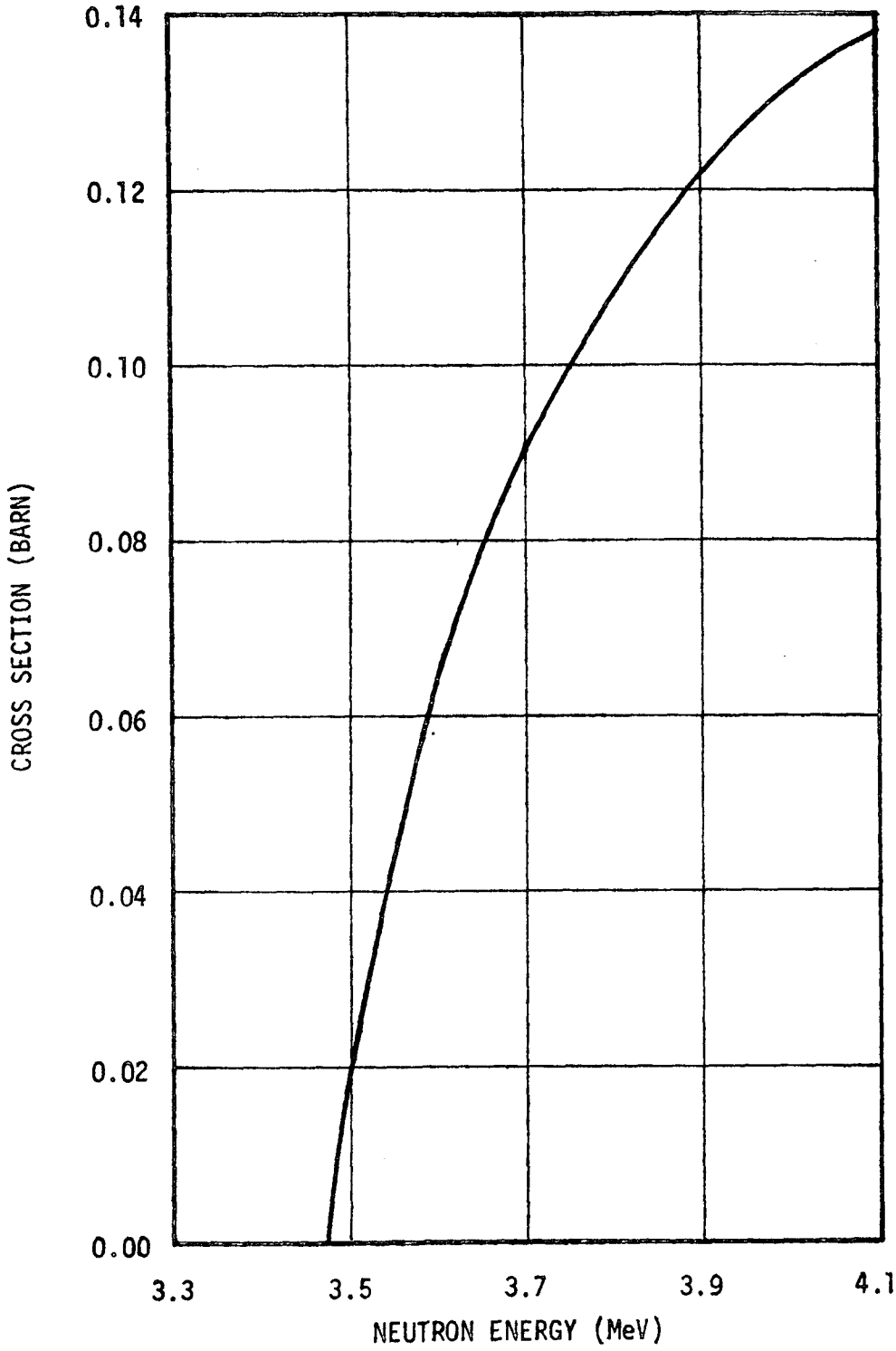

FIGURE 46. CROSS SECTION FOR PRODUCTION OF THE 0.860 MeV GAMMA TRANSITION FROM THE 3.475 MeV LEVEL TO THE 2.615 MeV LEVEL OF Pb^{208}

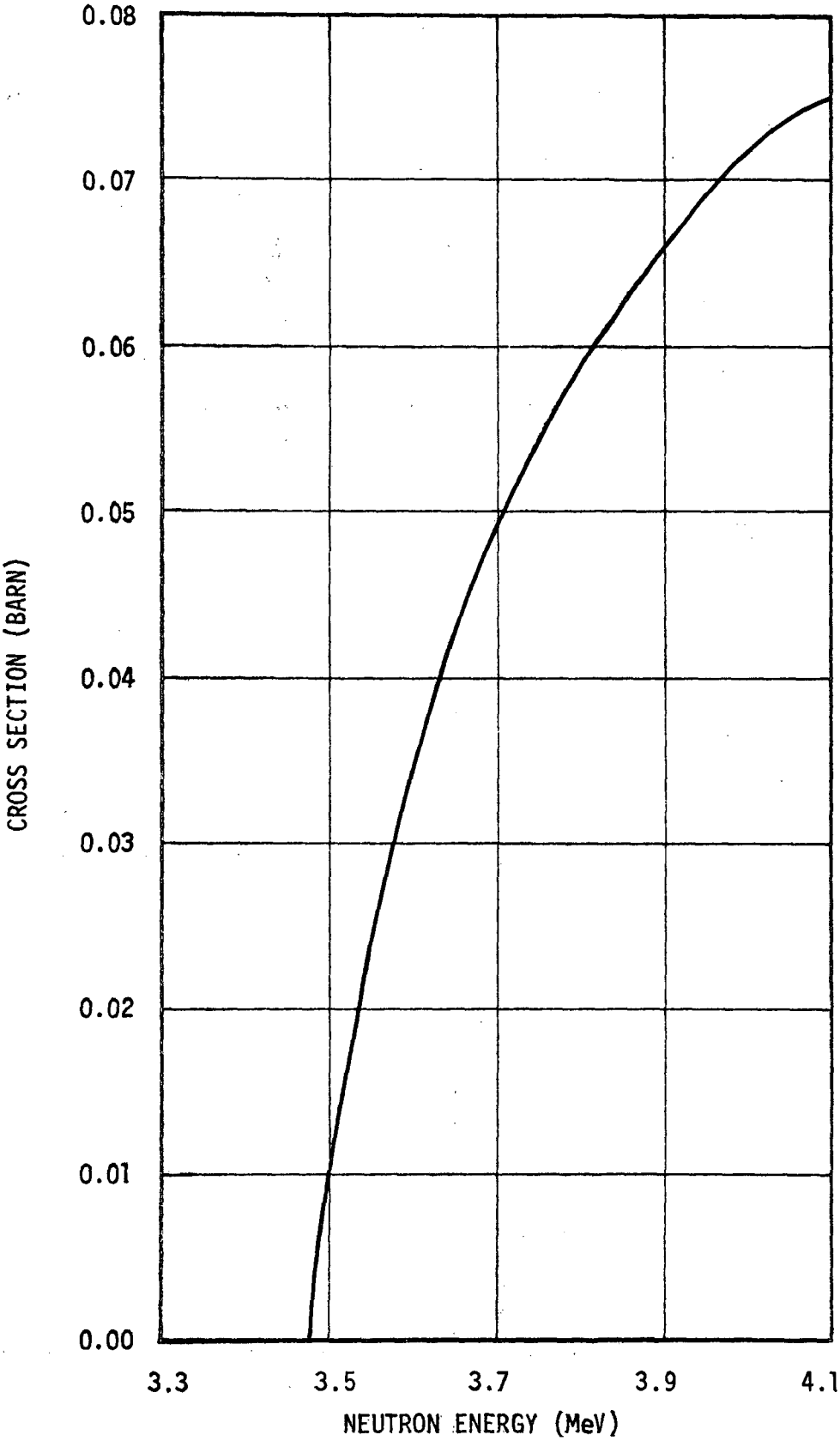

FIGURE 47. CROSS SECTION FOR PRODUCTION OF THE 0.277 MeV GAMMA TRANSITION FROM THE 3.475 MeV LEVEL TO THE 3.198 MeV LEVEL OF Pb^{208}

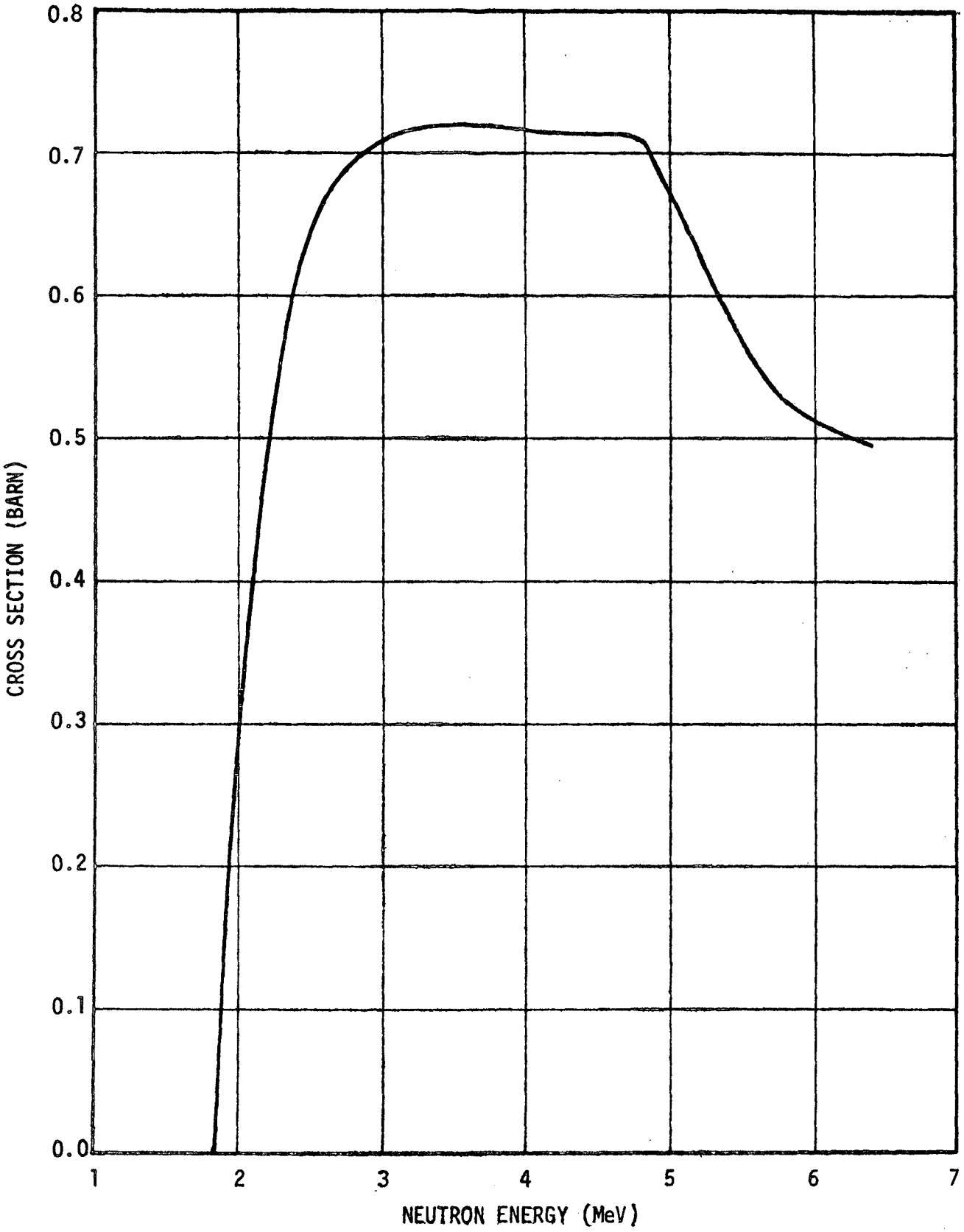

FIGURE 48. CROSS SECTION FOR EXCITATION OF THE 1.78 MeV LEVEL OF Si^{28}

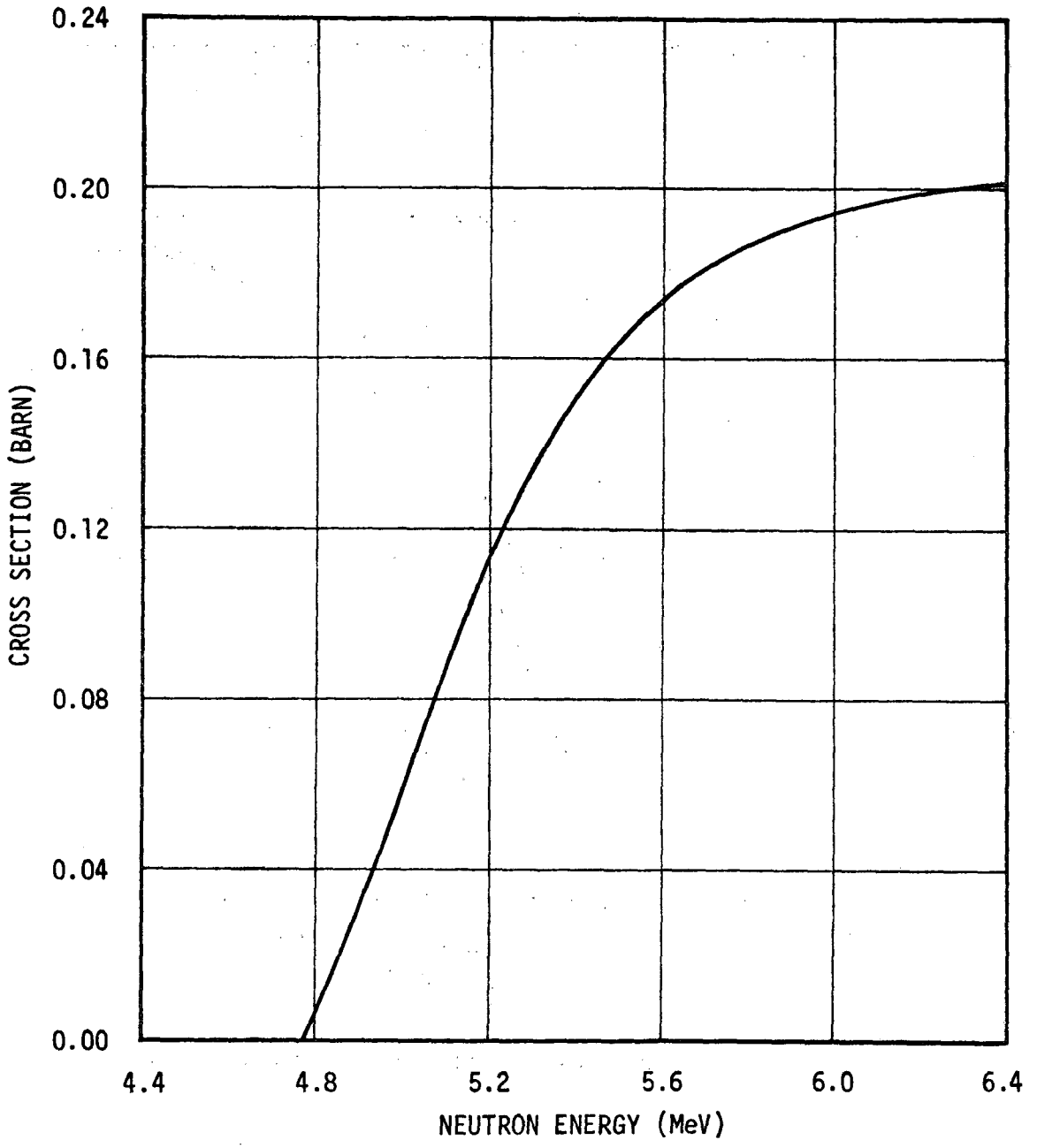

FIGURE 49. CROSS SECTION FOR EXCITATION OF THE 4.61 MeV LEVEL OF Si^{28}

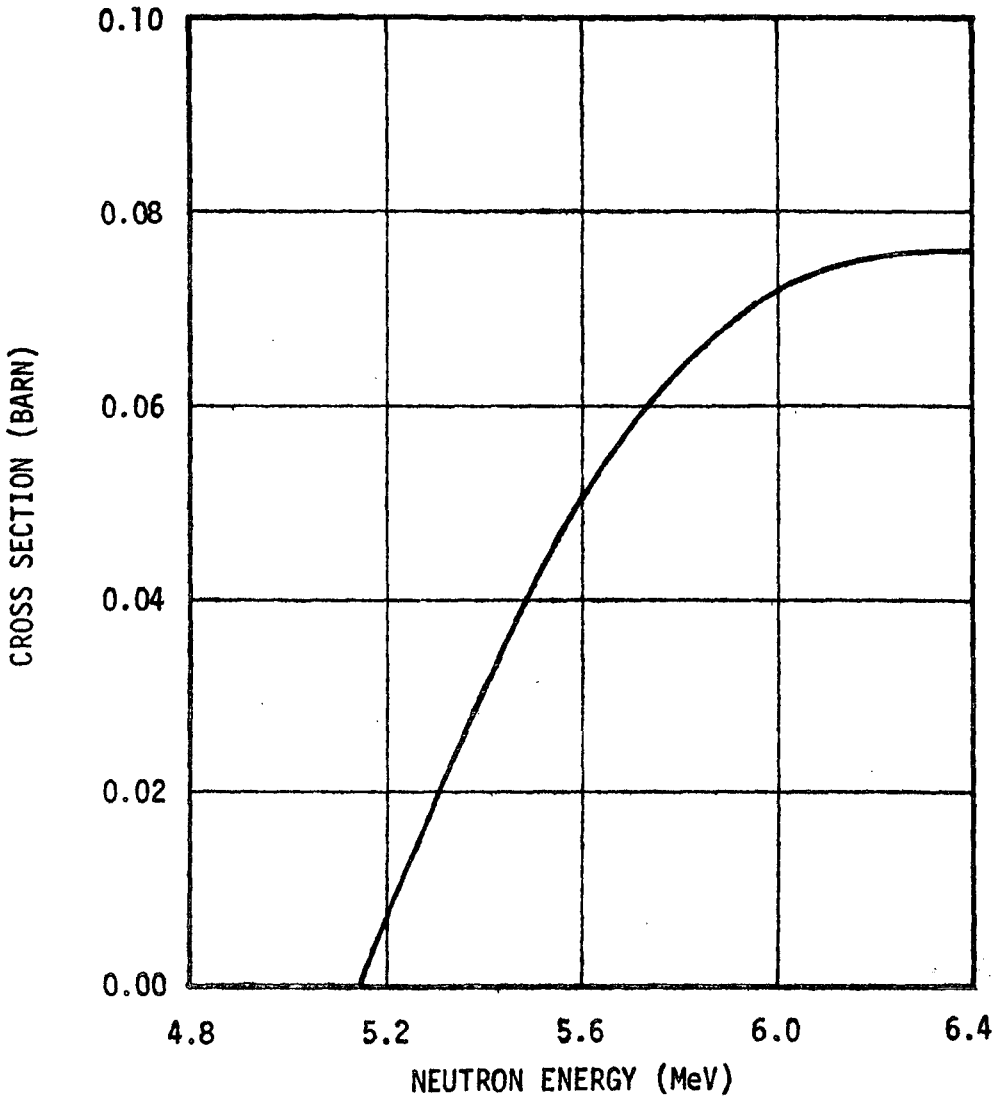

FIGURE 50. CROSS SECTION FOR EXCITATION OF THE 4.97 MeV LEVEL OF Si^{28}

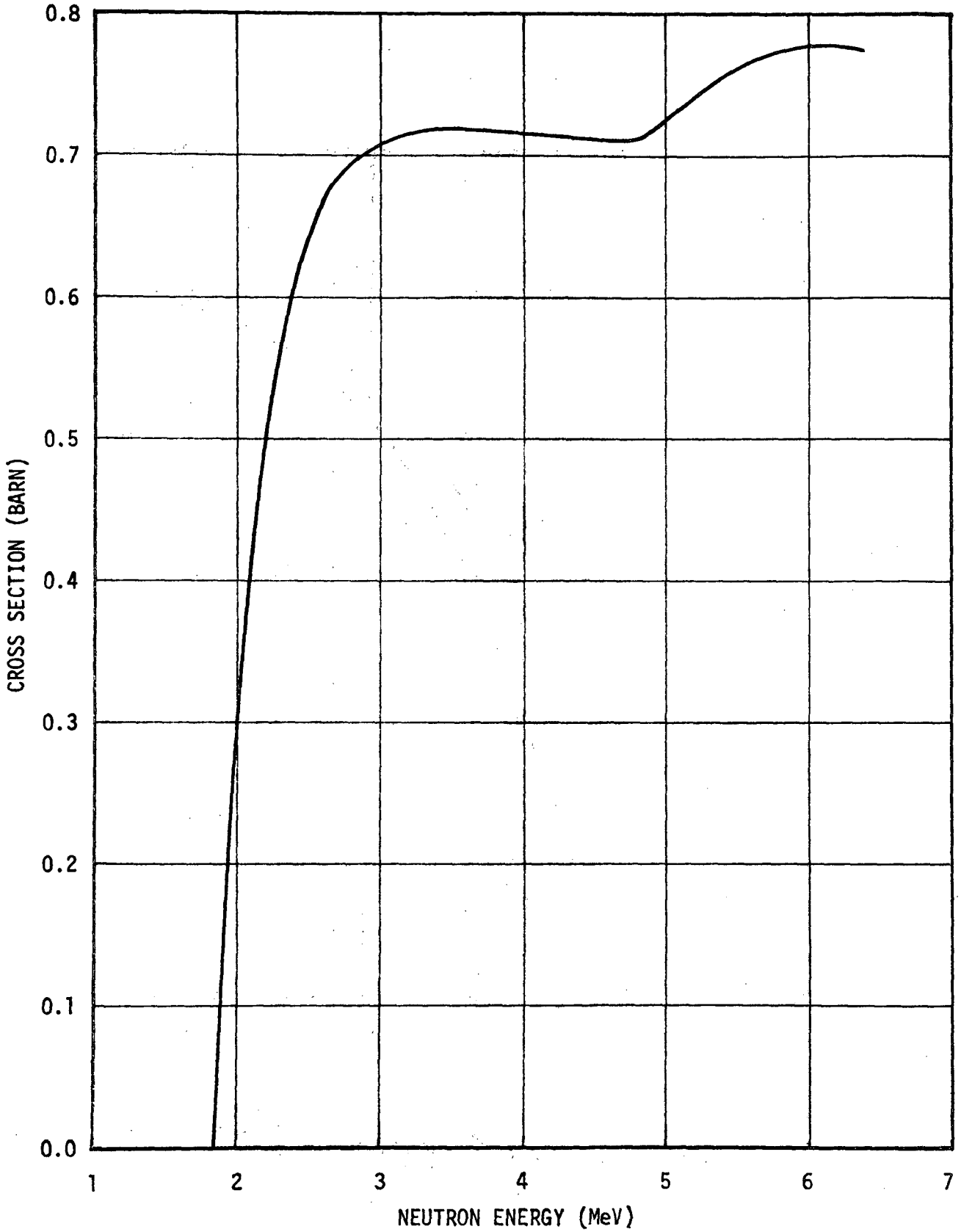

FIGURE 51. CROSS SECTION FOR PRODUCTION OF THE 1.78 MeV GAMMA TRANSITION FROM THE 1.78 MeV LEVEL TO THE GROUND LEVEL OF Si^{28}

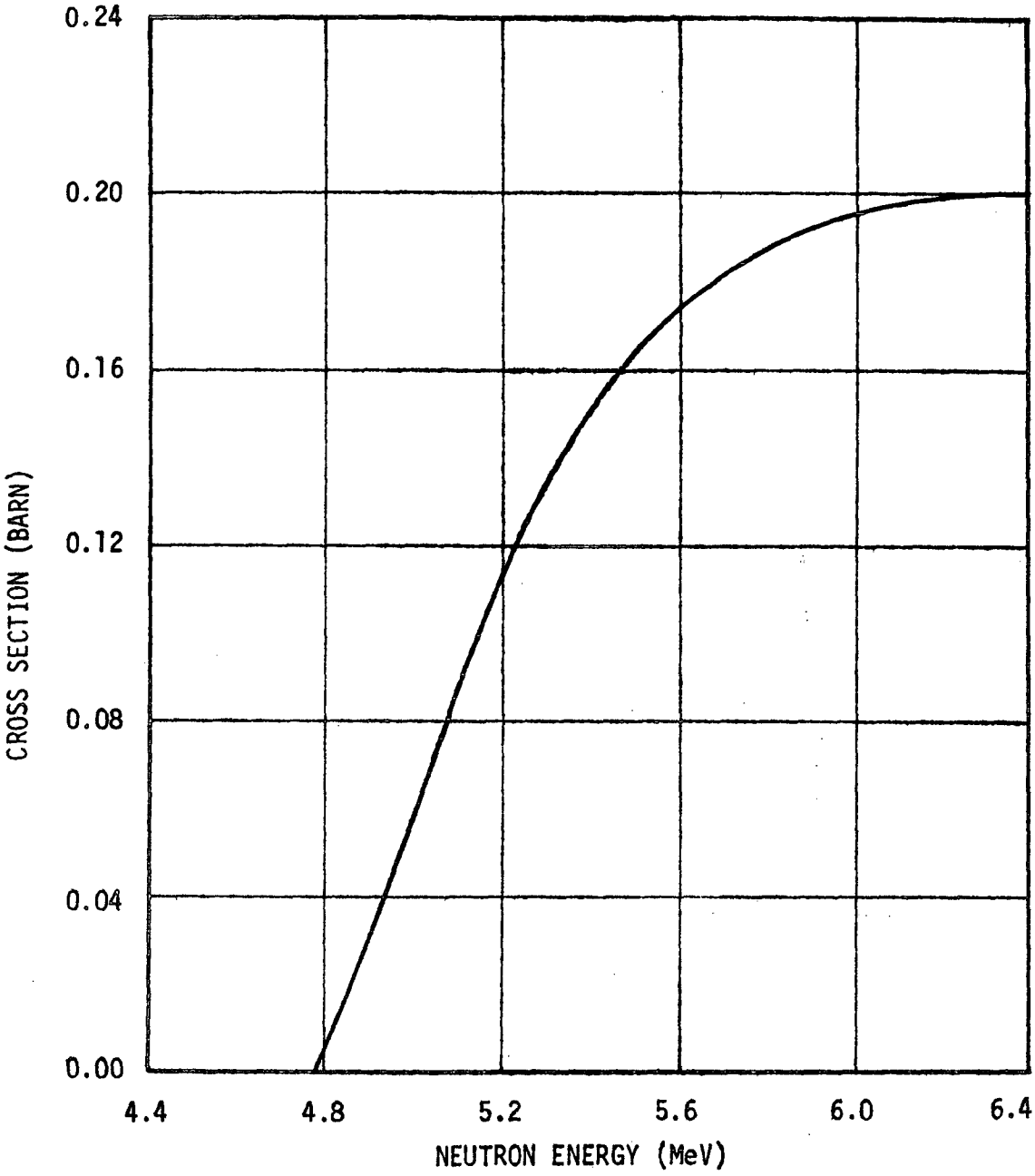

FIGURE 52. CROSS SECTION FOR PRODUCTION OF THE 2.83 MeV GAMMA TRANSITION FROM THE 4.61 MeV LEVEL TO THE 1.78 LEVEL OF Si^{28}

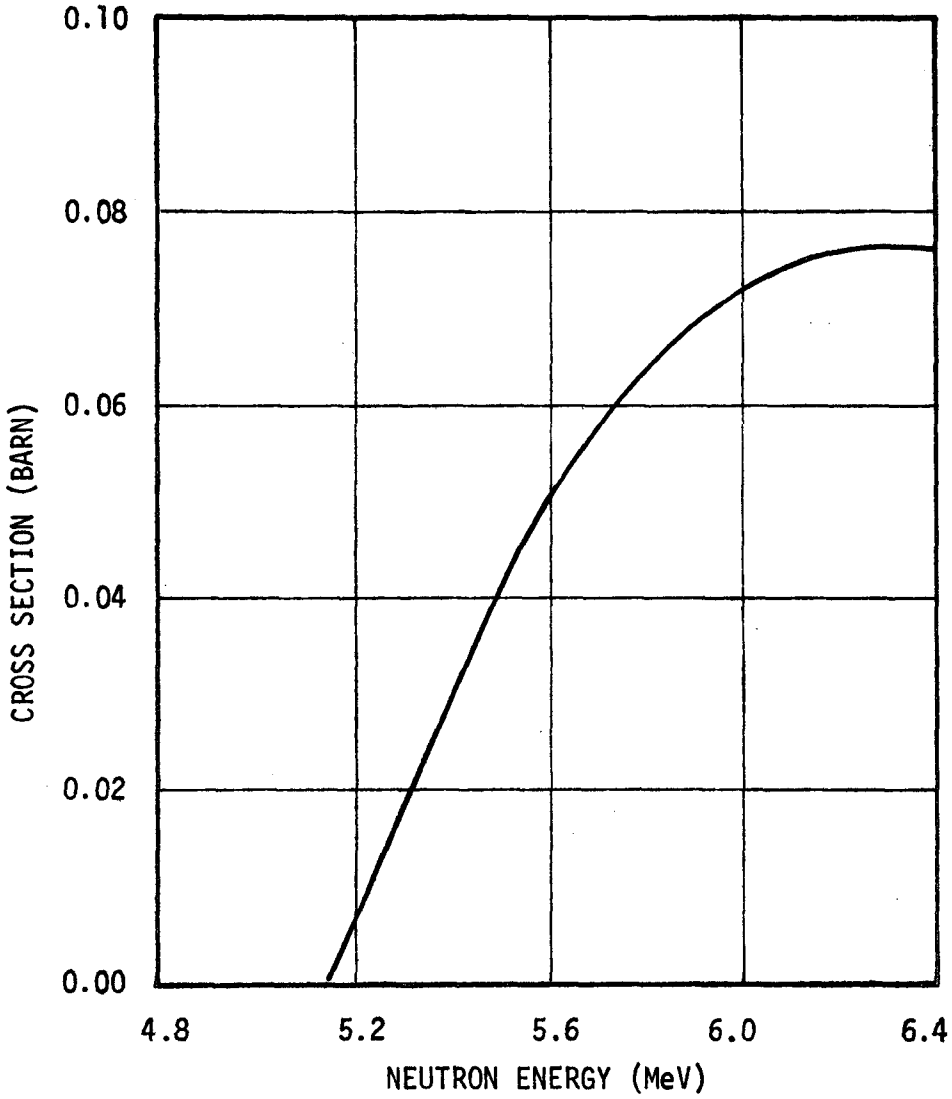

FIGURE 53. CROSS SECTION FOR PRODUCTION OF THE 3.19 MeV GAMMA TRANSITION FROM THE 4.97 MeV LEVEL TO THE 1.78 MeV LEVEL OF Si^{28}

APPENDIX A. LISTING OF GAMMA-RAY CASCADE COMPUTER PROGRAM

```
      DIMENSION EN(65),EA(65),SL(65,21),P(21,20),TERM(19),ELEV(21)
  161 READ(2,160) KMAX
  160 FORMAT(I5)
      IF(KMAX) 100,100,162
  162 WRITE(3,163) KMAX
  163 FORMAT(6H1KMAX=I3)
      DO 164 K=1,KMAX
      READ(2,165) K,EN(K),EA(K)
  165 FORMAT(I5,10X,F8.4,10X,F8.4)
  164 WRITE(3,166) K,EN(K),EA(K)
  166 FORMAT(3H K=I3,10X,7H EN(K)=F8.4,10X,7H EA(K)=F8.4)
      READ(2,167) N
  167 FORMAT(I5)
      WRITE(3,168) N
  168 FORMAT(3H N=I3)
      DO 172 I=2,N
      READ(2,173) I,ELEV(I)
  173 FORMAT(I5,10X,F8.4)
  172 WRITE(3,174) I,ELEV(I)
  174 FORMAT(3H I=I3,10X,9H ELEV(I)=F8.4)
      DO 169 I=2,N
      JLIM=I-1
      DO 169 J=1,JLIM
      READ(2,170) I,J,P(I,J)
  170 FORMAT(2I5,10X,F7.4)
  169 WRITE(3,171) I,J,P(I,J)
  171 FORMAT(3H I=I3,10X,3H J=I3,10X,8H P(I,J)=F7.4)
      ELEV(1)=0.
      DO 190 K=1,KMAX
      DO 175 I=2,N
      IF(ELEV(I)-EA(K))176,177,177
  176 READ(2,178) K,I,SL(K,I)
  178 FORMAT(2I5,10X,E10.3)
      WRITE(3,179) K,I,SL(K,I)
  179 FORMAT(3H K=I3,10X,3H I=I3,10X,9H SL(K,I)=E10.3)
      GO TO 175
  177 SL(K,I)=0.
  175 CONTINUE
  190 CONTINUE
      DO 222 I=2,N
      JLIM=I-1
      KLIM=N-I
      DO 222 J=1,JLIM
      IF(P(I,J))222,222,224
  224 EGAM=ELEV(I)-ELEV(J)
      WRITE(3,125) I,J,EGAM
  125 FORMAT(3H I=I3,5X,3H J=I3,5X,6H EGAM=F8.4)
      DO 223 K=1,KMAX
      IF(ELEV(I)-EA(K))122,223,223
```

```
122 IF(I-N)23,24,100
 24 SB=SL(K,N)
    GO TO 123
 23 SB=SL(K,I)
    DO 3 KK=1,KLIM
    M=I+KK
    IF(ELEV(M)-EA(K))180,123,123
180 IF(KK-1) 100,101,102
101 SB=SB+(SL(K,M)*P(M,I))
    GO TO 3
102 TERM(1)=P(M,I)
    SUM=TERM(1)
    DO 4 L=2,KK
    ML=I+L-1
    TERM(L)=P(M,ML)
    LLIM=L-1
    DO 5 LP=1,LLIM
    MLP=ML-LP+1
  5 TERM(L)=TERM(L)*P(MLP,MLP-1)
  4 SUM=SUM+TERM(L)
    SB=SB+(SL(K,M)*SUM)
  3 CONTINUE
123 SB=SB*P(I,J)
    WRITE(3,126) K,EN(K),SB
126 FORMAT(3H K=I3,10X,7H EN(K)=F7.3,10X,4H SB=E10.3)
223 CONTINUE
222 CONTINUE
    GO TO 161
100 CALL EXIT
    END
```

APPENDIX B. RESULTS OF Al^{27} CROSS SECTION CALCULATIONS IN TABULAR FORM

KMAX= 47

K= 1	EN(K)= 0.9000	EA(K)= 0.8676
K= 2	EN(K)= 1.0000	EA(K)= 0.9640
K= 3	EN(K)= 1.1000	EA(K)= 1.0604
K= 4	EN(K)= 1.2000	EA(K)= 1.1568
K= 5	EN(K)= 1.3000	EA(K)= 1.2532
K= 6	EN(K)= 1.4000	EA(K)= 1.3496
K= 7	EN(K)= 1.5000	EA(K)= 1.4460
K= 8	EN(K)= 1.6000	EA(K)= 1.5424
K= 9	EN(K)= 1.7000	EA(K)= 1.6388
K= 10	EN(K)= 1.8000	EA(K)= 1.7352
K= 11	EN(K)= 1.9000	EA(K)= 1.8316
K= 12	EN(K)= 2.0000	EA(K)= 1.9280
K= 13	EN(K)= 2.1000	EA(K)= 2.0244
K= 14	EN(K)= 2.2000	EA(K)= 2.1207
K= 15	EN(K)= 2.3000	EA(K)= 2.2171
K= 16	EN(K)= 2.4000	EA(K)= 2.3135
K= 17	EN(K)= 2.5000	EA(K)= 2.4099
K= 18	EN(K)= 2.6000	EA(K)= 2.5063
K= 19	EN(K)= 2.7000	EA(K)= 2.6027
K= 20	EN(K)= 2.8000	EA(K)= 2.6991
K= 21	EN(K)= 2.9000	EA(K)= 2.7955
K= 22	EN(K)= 3.0000	EA(K)= 2.8919
K= 23	EN(K)= 3.1000	EA(K)= 2.9883
K= 24	EN(K)= 3.2000	EA(K)= 3.0847
K= 25	EN(K)= 3.3000	EA(K)= 3.1811
K= 26	EN(K)= 3.4000	EA(K)= 3.2775
K= 27	EN(K)= 3.5000	EA(K)= 3.3739
K= 28	EN(K)= 3.6000	EA(K)= 3.4703
K= 29	EN(K)= 3.7000	EA(K)= 3.5667
K= 30	EN(K)= 3.8000	EA(K)= 3.6631
K= 31	EN(K)= 3.9000	EA(K)= 3.7595
K= 32	EN(K)= 4.0000	EA(K)= 3.8559
K= 33	EN(K)= 4.1000	EA(K)= 3.9523
K= 34	EN(K)= 4.2000	EA(K)= 4.0487
K= 35	EN(K)= 4.3000	EA(K)= 4.1451
K= 36	EN(K)= 4.4000	EA(K)= 4.2415
K= 37	EN(K)= 4.5000	EA(K)= 4.3379
K= 38	EN(K)= 4.6000	EA(K)= 4.4343
K= 39	EN(K)= 4.7000	EA(K)= 4.5307
K= 40	EN(K)= 4.8000	EA(K)= 4.6271
K= 41	EN(K)= 4.9000	EA(K)= 4.7235
K= 42	EN(K)= 5.0000	EA(K)= 4.8199
K= 43	EN(K)= 5.1000	EA(K)= 4.9163
K= 44	EN(K)= 5.2000	EA(K)= 5.0127
K= 45	EN(K)= 5.3000	EA(K)= 5.1091
K= 46	EN(K)= 5.4000	EA(K)= 5.2055
K= 47	EN(K)= 5.5000	EA(K)= 5.3019

```
N= 14
I=  2          ELEV(I)=  0.8400
I=  3          ELEV(I)=  1.0100
I=  4          ELEV(I)=  2.2100
I=  5          ELEV(I)=  2.7300
I=  6          ELEV(I)=  2.9800
I=  7          ELEV(I)=  3.0000
I=  8          ELEV(I)=  3.6800
I=  9          ELEV(I)=  3.9600
I= 10          ELEV(I)=  4.0500
I= 11          ELEV(I)=  4.4100
I= 12          ELEV(I)=  4.5100
I= 13          ELEV(I)=  4.8100
I= 14          ELEV(I)=  5.2500
```

```
I=  2    J=  1    P(I,J)= 1.0000
I=  3    J=  1    P(I,J)= 0.9700
I=  3    J=  2    P(I,J)= 0.0300
I=  4    J=  1    P(I,J)= 1.0000
I=  4    J=  2    P(I,J)= 0.0000
I=  4    J=  3    P(I,J)= 0.0000
I=  5    J=  1    P(I,J)= 0.2400
I=  5    J=  2    P(I,J)= 0.0000
I=  5    J=  3    P(I,J)= 0.7600
I=  5    J=  4    P(I,J)= 0.0000
I=  6    J=  1    P(I,J)= 0.9900
I=  6    J=  2    P(I,J)= 0.0100
I=  6    J=  3    P(I,J)= 0.0000
I=  6    J=  4    P(I,J)= 0.0000
I=  6    J=  5    P(I,J)= 0.0000
I=  7    J=  1    P(I,J)= 0.8700
I=  7    J=  2    P(I,J)= 0.0000
I=  7    J=  3    P(I,J)= 0.0000
I=  7    J=  4    P(I,J)= 0.1300
I=  7    J=  5    P(I,J)= 0.0000
I=  7    J=  6    P(I,J)= 0.0000
I=  8    J=  1    P(I,J)= 0.0000
I=  8    J=  2    P(I,J)= 0.6500
I=  8    J=  3    P(I,J)= 0.3500
I=  8    J=  4    P(I,J)= 0.0000
I=  8    J=  5    P(I,J)= 0.0000
I=  8    J=  6    P(I,J)= 0.0000
I=  8    J=  7    P(I,J)= 0.0000
I=  9    J=  1    P(I,J)= 1.0000
I=  9    J=  2    P(I,J)= 0.0000
I=  9    J=  3    P(I,J)= 0.0000
I=  9    J=  4    P(I,J)= 0.0000
I=  9    J=  5    P(I,J)= 0.0000
I=  9    J=  6    P(I,J)= 0.0000
I=  9    J=  7    P(I,J)= 0.0000
I=  9    J=  8    P(I,J)= 0.0000
I= 10    J=  1    P(I,J)= 0.0000
I= 10    J=  2    P(I,J)= 0.8000
I= 10    J=  3    P(I,J)= 0.2000
I= 10    J=  4    P(I,J)= 0.0000
I= 10    J=  5    P(I,J)= 0.0000
I= 10    J=  6    P(I,J)= 0.0000
I= 10    J=  7    P(I,J)= 0.0000
I= 10    J=  8    P(I,J)= 0.0000
I= 10    J=  9    P(I,J)= 0.0000
I= 11    J=  1    P(I,J)= 0.5500
I= 11    J=  2    P(I,J)= 0.0000
I= 11    J=  3    P(I,J)= 0.2500
I= 11    J=  4    P(I,J)= 0.2000
I= 11    J=  5    P(I,J)= 0.0000
```

```
I= 11    J=  6    P(I,J)= 0.0000
I= 11    J=  7    P(I,J)= 0.0000
I= 11    J=  8    P(I,J)= 0.0000
I= 11    J=  9    P(I,J)= 0.0000
I= 11    J= 10    P(I,J)= 0.0000
I= 12    J=  1    P(I,J)= 0.1000
I= 12    J=  2    P(I,J)= 0.0000
I= 12    J=  3    P(I,J)= 0.0000
I= 12    J=  4    P(I,J)= 0.6000
I= 12    J=  5    P(I,J)= 0.1000
I= 12    J=  6    P(I,J)= 0.0000
I= 12    J=  7    P(I,J)= 0.2000
I= 12    J=  8    P(I,J)= 0.0000
I= 12    J=  9    P(I,J)= 0.0000
I= 12    J= 10    P(I,J)= 0.0000
I= 12    J= 11    P(I,J)= 0.0000
I= 13    J=  1    P(I,J)= 0.4000
I= 13    J=  2    P(I,J)= 0.0000
I= 13    J=  3    P(I,J)= 0.2500
I= 13    J=  4    P(I,J)= 0.3500
I= 13    J=  5    P(I,J)= 0.0000
I= 13    J=  6    P(I,J)= 0.0000
I= 13    J=  7    P(I,J)= 0.0000
I= 13    J=  8    P(I,J)= 0.0000
I= 13    J=  9    P(I,J)= 0.0000
I= 13    J= 10    P(I,J)= 0.0000
I= 13    J= 11    P(I,J)= 0.0000
I= 13    J= 12    P(I,J)= 0.0000
I= 14    J=  1    P(I,J)= 0.1000
I= 14    J=  2    P(I,J)= 0.0000
I= 14    J=  3    P(I,J)= 0.7000
I= 14    J=  4    P(I,J)= 0.2000
I= 14    J=  5    P(I,J)= 0.0000
I= 14    J=  6    P(I,J)= 0.0000
I= 14    J=  7    P(I,J)= 0.0000
I= 14    J=  8    P(I,J)= 0.0000
I= 14    J=  9    P(I,J)= 0.0000
I= 14    J= 10    P(I,J)= 0.0000
I= 14    J= 11    P(I,J)= 0.0000
I= 14    J= 12    P(I,J)= 0.0000
I= 14    J= 13    P(I,J)= 0.0000
```

K= 1	I= 2	SL(K,I)= 0.103E-01
K= 2	I= 2	SL(K,I)= 0.484E-01
K= 3	I= 2	SL(K,I)= 0.861E-01
K= 3	I= 3	SL(K,I)= 0.384E-01
K= 4	I= 2	SL(K,I)= 0.111E 00
K= 4	I= 3	SL(K,I)= 0.104E 00
K= 5	I= 2	SL(K,I)= 0.124E 00
K= 5	I= 3	SL(K,I)= 0.166E 00
K= 6	I= 2	SL(K,I)= 0.128E 00
K= 6	I= 3	SL(K,I)= 0.214E 00
K= 7	I= 2	SL(K,I)= 0.128E 00
K= 7	I= 3	SL(K,I)= 0.249E 00
K= 8	I= 2	SL(K,I)= 0.127E 00
K= 8	I= 3	SL(K,I)= 0.271E 00
K= 9	I= 2	SL(K,I)= 0.124E 00
K= 9	I= 3	SL(K,I)= 0.284E 00
K= 10	I= 2	SL(K,I)= 0.120E 00
K= 10	I= 3	SL(K,I)= 0.292E 00
K= 11	I= 2	SL(K,I)= 0.117E 00
K= 11	I= 3	SL(K,I)= 0.294E 00
K= 12	I= 2	SL(K,I)= 0.114E 00
K= 12	I= 3	SL(K,I)= 0.294E 00
K= 13	I= 2	SL(K,I)= 0.112E 00
K= 13	I= 3	SL(K,I)= 0.292E 00
K= 14	I= 2	SL(K,I)= 0.110E 00
K= 14	I= 3	SL(K,I)= 0.289E 00
K= 15	I= 2	SL(K,I)= 0.108E 00
K= 15	I= 3	SL(K,I)= 0.284E 00
K= 15	I= 4	SL(K,I)= 0.111E-01
K= 16	I= 2	SL(K,I)= 0.105E 00
K= 16	I= 3	SL(K,I)= 0.272E 00
K= 16	I= 4	SL(K,I)= 0.703E-01
K= 17	I= 2	SL(K,I)= 0.102E 00
K= 17	I= 3	SL(K,I)= 0.260E 00
K= 17	I= 4	SL(K,I)= 0.128E 00
K= 18	I= 2	SL(K,I)= 0.997E-01
K= 18	I= 3	SL(K,I)= 0.247E 00
K= 18	I= 4	SL(K,I)= 0.178E 00
K= 19	I= 2	SL(K,I)= 0.973E-01
K= 19	I= 3	SL(K,I)= 0.236E 00
K= 19	I= 4	SL(K,I)= 0.218E 00
K= 20	I= 2	SL(K,I)= 0.954E-01
K= 20	I= 3	SL(K,I)= 0.226E 00
K= 20	I= 4	SL(K,I)= 0.249E 00
K= 21	I= 2	SL(K,I)= 0.925E-01
K= 21	I= 3	SL(K,I)= 0.214E 00
K= 21	I= 4	SL(K,I)= 0.267E 00
K= 21	I= 5	SL(K,I)= 0.194E-01
K= 22	I= 2	SL(K,I)= 0.894E-01
K= 22	I= 3	SL(K,I)= 0.203E 00

```
K= 22    I=  4    SL(K,I)= 0.277E 00
K= 22    I=  5    SL(K,I)= 0.443E-01
K= 23    I=  2    SL(K,I)= 0.862E-01
K= 23    I=  3    SL(K,I)= 0.192E 00
K= 23    I=  4    SL(K,I)= 0.280E 00
K= 23    I=  5    SL(K,I)= 0.700E-01
K= 23    I=  6    SL(K,I)= 0.196E-02
K= 24    I=  2    SL(K,I)= 0.820E-01
K= 24    I=  3    SL(K,I)= 0.179E 00
K= 24    I=  4    SL(K,I)= 0.269E 00
K= 24    I=  5    SL(K,I)= 0.915E-01
K= 24    I=  6    SL(K,I)= 0.125E-01
K= 24    I=  7    SL(K,I)= 0.359E-01
K= 25    I=  2    SL(K,I)= 0.781E-01
K= 25    I=  3    SL(K,I)= 0.168E 00
K= 25    I=  4    SL(K,I)= 0.256E 00
K= 25    I=  5    SL(K,I)= 0.107E 00
K= 25    I=  6    SL(K,I)= 0.242E-01
K= 25    I=  7    SL(K,I)= 0.703E-01
K= 26    I=  2    SL(K,I)= 0.746E-01
K= 26    I=  3    SL(K,I)= 0.158E 00
K= 26    I=  4    SL(K,I)= 0.242E 00
K= 26    I=  5    SL(K,I)= 0.118E 00
K= 26    I=  6    SL(K,I)= 0.356E-01
K= 26    I=  7    SL(K,I)= 0.100E 00
K= 27    I=  2    SL(K,I)= 0.718E-01
K= 27    I=  3    SL(K,I)= 0.150E 00
K= 27    I=  4    SL(K,I)= 0.230E 00
K= 27    I=  5    SL(K,I)= 0.125E 00
K= 27    I=  6    SL(K,I)= 0.457E-01
K= 27    I=  7    SL(K,I)= 0.125E 00
K= 28    I=  2    SL(K,I)= 0.696E-01
K= 28    I=  3    SL(K,I)= 0.144E 00
K= 28    I=  4    SL(K,I)= 0.220E 00
K= 28    I=  5    SL(K,I)= 0.130E 00
K= 28    I=  6    SL(K,I)= 0.540E-01
K= 28    I=  7    SL(K,I)= 0.144E 00
K= 29    I=  2    SL(K,I)= 0.679E-01
K= 29    I=  3    SL(K,I)= 0.139E 00
K= 29    I=  4    SL(K,I)= 0.211E 00
K= 29    I=  5    SL(K,I)= 0.132E 00
K= 29    I=  6    SL(K,I)= 0.605E-01
K= 29    I=  7    SL(K,I)= 0.159E 00
K= 30    I=  2    SL(K,I)= 0.667E-01
K= 30    I=  3    SL(K,I)= 0.135E 00
K= 30    I=  4    SL(K,I)= 0.205E 00
K= 30    I=  5    SL(K,I)= 0.133E 00
K= 30    I=  6    SL(K,I)= 0.656E-01
K= 30    I=  7    SL(K,I)= 0.170E 00
K= 31    I=  2    SL(K,I)= 0.652E-01
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K= 31    I=  3    SL(K,I)= 0.132E 00
K= 31    I=  4    SL(K,I)= 0.199E 00
K= 31    I=  5    SL(K,I)= 0.133E 00
K= 31    I=  6    SL(K,I)= 0.690E-01
K= 31    I=  7    SL(K,I)= 0.178E 00
K= 31    I=  8    SL(K,I)= 0.250E-02
K= 32    I=  2    SL(K,I)= 0.640E-01
K= 32    I=  3    SL(K,I)= 0.129E 00
K= 32    I=  4    SL(K,I)= 0.195E 00
K= 32    I=  5    SL(K,I)= 0.133E 00
K= 32    I=  6    SL(K,I)= 0.711E-01
K= 32    I=  7    SL(K,I)= 0.184E 00
K= 32    I=  8    SL(K,I)= 0.581E-02
K= 33    I=  2    SL(K,I)= 0.630E-01
K= 33    I=  3    SL(K,I)= 0.127E 00
K= 33    I=  4    SL(K,I)= 0.191E 00
K= 33    I=  5    SL(K,I)= 0.132E 00
K= 33    I=  6    SL(K,I)= 0.723E-01
K= 33    I=  7    SL(K,I)= 0.189E 00
K= 33    I=  8    SL(K,I)= 0.949E-02
K= 34    I=  2    SL(K,I)= 0.615E-01
K= 34    I=  3    SL(K,I)= 0.124E 00
K= 34    I=  4    SL(K,I)= 0.188E 00
K= 34    I=  5    SL(K,I)= 0.130E 00
K= 34    I=  6    SL(K,I)= 0.722E-01
K= 34    I=  7    SL(K,I)= 0.191E 00
K= 34    I=  8    SL(K,I)= 0.129E-01
K= 34    I=  9    SL(K,I)= 0.578E-02
K= 35    I=  2    SL(K,I)= 0.599E-01
K= 35    I=  3    SL(K,I)= 0.121E 00
K= 35    I=  4    SL(K,I)= 0.185E 00
K= 35    I=  5    SL(K,I)= 0.128E 00
K= 35    I=  6    SL(K,I)= 0.712E-01
K= 35    I=  7    SL(K,I)= 0.193E 00
K= 35    I=  8    SL(K,I)= 0.157E-01
K= 35    I=  9    SL(K,I)= 0.122E-01
K= 35    I= 10    SL(K,I)= 0.237E-02
K= 36    I=  2    SL(K,I)= 0.584E-01
K= 36    I=  3    SL(K,I)= 0.118E 00
K= 36    I=  4    SL(K,I)= 0.182E 00
K= 36    I=  5    SL(K,I)= 0.125E 00
K= 36    I=  6    SL(K,I)= 0.698E-01
K= 36    I=  7    SL(K,I)= 0.193E 00
K= 36    I=  8    SL(K,I)= 0.178E-01
K= 36    I=  9    SL(K,I)= 0.190E-01
K= 36    I= 10    SL(K,I)= 0.506E-02
K= 37    I=  2    SL(K,I)= 0.572E-01
K= 37    I=  3    SL(K,I)= 0.116E 00
K= 37    I=  4    SL(K,I)= 0.180E 00
K= 37    I=  5    SL(K,I)= 0.123E 00
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K= 37        I=  6        SL(K,I)= 0.683E-01
K= 37        I=  7        SL(K,I)= 0.193E 00
K= 37        I=  8        SL(K,I)= 0.193E-01
K= 37        I=  9        SL(K,I)= 0.255E-01
K= 37        I= 10        SL(K,I)= 0.791E-02
K= 38        I=  2        SL(K,I)= 0.559E-01
K= 38        I=  3        SL(K,I)= 0.114E 00
K= 38        I=  4        SL(K,I)= 0.177E 00
K= 38        I=  5        SL(K,I)= 0.120E 00
K= 38        I=  6        SL(K,I)= 0.667E-01
K= 38        I=  7        SL(K,I)= 0.193E 00
K= 38        I=  8        SL(K,I)= 0.203E-01
K= 38        I=  9        SL(K,I)= 0.311E-01
K= 38        I= 10        SL(K,I)= 0.106E-01
K= 38        I= 11        SL(K,I)= 0.313E-02
K= 39        I=  2        SL(K,I)= 0.543E-01
K= 39        I=  3        SL(K,I)= 0.111E 00
K= 39        I=  4        SL(K,I)= 0.174E 00
K= 39        I=  5        SL(K,I)= 0.117E 00
K= 39        I=  6        SL(K,I)= 0.647E-01
K= 39        I=  7        SL(K,I)= 0.191E 00
K= 39        I=  8        SL(K,I)= 0.208E-01
K= 39        I=  9        SL(K,I)= 0.353E-01
K= 39        I= 10        SL(K,I)= 0.128E-01
K= 39        I= 11        SL(K,I)= 0.110E-01
K= 39        I= 12        SL(K,I)= 0.261E-02
K= 40        I=  2        SL(K,I)= 0.526E-01
K= 40        I=  3        SL(K,I)= 0.107E 00
K= 40        I=  4        SL(K,I)= 0.170E 00
K= 40        I=  5        SL(K,I)= 0.113E 00
K= 40        I=  6        SL(K,I)= 0.626E-01
K= 40        I=  7        SL(K,I)= 0.188E 00
K= 40        I=  8        SL(K,I)= 0.210E-01
K= 40        I=  9        SL(K,I)= 0.382E-01
K= 40        I= 10        SL(K,I)= 0.144E-01
K= 40        I= 11        SL(K,I)= 0.198E-01
K= 40        I= 12        SL(K,I)= 0.999E-02
K= 41        I=  2        SL(K,I)= 0.511E-01
K= 41        I=  3        SL(K,I)= 0.104E 00
K= 41        I=  4        SL(K,I)= 0.167E 00
K= 41        I=  5        SL(K,I)= 0.110E 00
K= 41        I=  6        SL(K,I)= 0.606E-01
K= 41        I=  7        SL(K,I)= 0.185E 00
K= 41        I=  8        SL(K,I)= 0.209E-01
K= 41        I=  9        SL(K,I)= 0.401E-01
K= 41        I= 10        SL(K,I)= 0.156E-01
K= 41        I= 11        SL(K,I)= 0.286E-01
K= 41        I= 12        SL(K,I)= 0.183E-01
K= 42        I=  2        SL(K,I)= 0.495E-01
K= 42        I=  3        SL(K,I)= 0.102E 00
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```
K= 42    I=  4    SL(K,I)= 0.163E 00
K= 42    I=  5    SL(K,I)= 0.106E 00
K= 42    I=  6    SL(K,I)= 0.588E-01
K= 42    I=  7    SL(K,I)= 0.181E 00
K= 42    I=  8    SL(K,I)= 0.207E-01
K= 42    I=  9    SL(K,I)= 0.411E-01
K= 42    I= 10    SL(K,I)= 0.164E-01
K= 42    I= 11    SL(K,I)= 0.365E-01
K= 42    I= 12    SL(K,I)= 0.266E-01
K= 42    I= 13    SL(K,I)= 0.138E-02
K= 43    I=  2    SL(K,I)= 0.479E-01
K= 43    I=  3    SL(K,I)= 0.986E-01
K= 43    I=  4    SL(K,I)= 0.159E 00
K= 43    I=  5    SL(K,I)= 0.103E 00
K= 43    I=  6    SL(K,I)= 0.570E-01
K= 43    I=  7    SL(K,I)= 0.178E 00
K= 43    I=  8    SL(K,I)= 0.203E-01
K= 43    I=  9    SL(K,I)= 0.414E-01
K= 43    I= 10    SL(K,I)= 0.169E-01
K= 43    I= 11    SL(K,I)= 0.429E-01
K= 43    I= 12    SL(K,I)= 0.341E-01
K= 43    I= 13    SL(K,I)= 0.756E-02
K= 44    I=  2    SL(K,I)= 0.465E-01
K= 44    I=  3    SL(K,I)= 0.960E-01
K= 44    I=  4    SL(K,I)= 0.156E 00
K= 44    I=  5    SL(K,I)= 0.100E 00
K= 44    I=  6    SL(K,I)= 0.555E-01
K= 44    I=  7    SL(K,I)= 0.174E 00
K= 44    I=  8    SL(K,I)= 0.200E-01
K= 44    I=  9    SL(K,I)= 0.412E-01
K= 44    I= 10    SL(K,I)= 0.171E-01
K= 44    I= 11    SL(K,I)= 0.477E-01
K= 44    I= 12    SL(K,I)= 0.402E-01
K= 44    I= 13    SL(K,I)= 0.144E-01
K= 45    I=  2    SL(K,I)= 0.453E-01
K= 45    I=  3    SL(K,I)= 0.937E-01
K= 45    I=  4    SL(K,I)= 0.153E 00
K= 45    I=  5    SL(K,I)= 0.981E-01
K= 45    I=  6    SL(K,I)= 0.543E-01
K= 45    I=  7    SL(K,I)= 0.171E 00
K= 45    I=  8    SL(K,I)= 0.197E-01
K= 45    I=  9    SL(K,I)= 0.409E-01
K= 45    I= 10    SL(K,I)= 0.172E-01
K= 45    I= 11    SL(K,I)= 0.513E-01
K= 45    I= 12    SL(K,I)= 0.450E-01
K= 45    I= 13    SL(K,I)= 0.216E-01
K= 46    I=  2    SL(K,I)= 0.442E-01
K= 46    I=  3    SL(K,I)= 0.918E-01
K= 46    I=  4    SL(K,I)= 0.151E 00
K= 46    I=  5    SL(K,I)= 0.964E-01
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K= 46	I= 6	SL(K,I)= 0.534E-01
K= 46	I= 7	SL(K,I)= 0.168E 00
K= 46	I= 8	SL(K,I)= 0.195E-01
K= 46	I= 9	SL(K,I)= 0.406E-01
K= 46	I= 10	SL(K,I)= 0.173E-01
K= 46	I= 11	SL(K,I)= 0.538E-01
K= 46	I= 12	SL(K,I)= 0.487E-01
K= 46	I= 13	SL(K,I)= 0.282E-01
K= 47	I= 2	SL(K,I)= 0.432E-01
K= 47	I= 3	SL(K,I)= 0.898E-01
K= 47	I= 4	SL(K,I)= 0.149E 00
K= 47	I= 5	SL(K,I)= 0.948E-01
K= 47	I= 6	SL(K,I)= 0.526E-01
K= 47	I= 7	SL(K,I)= 0.165E 00
K= 47	I= 8	SL(K,I)= 0.193E-01
K= 47	I= 9	SL(K,I)= 0.401E-01
K= 47	I= 10	SL(K,I)= 0.172E-01
K= 47	I= 11	SL(K,I)= 0.552E-01
K= 47	I= 12	SL(K,I)= 0.511E-01
K= 47	I= 13	SL(K,I)= 0.339E-01
K= 47	I= 14	SL(K,I)= 0.319E-02

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I=  2      J=  1      EGAM=  0.8400
K=  1          EN(K)=  0.900          SB= 0.103E-01
K=  2          EN(K)=  1.000          SB= 0.484E-01
K=  3          EN(K)=  1.100          SB= 0.872E-01
K=  4          EN(K)=  1.200          SB= 0.114E 00
K=  5          EN(K)=  1.300          SB= 0.128E 00
K=  6          EN(K)=  1.400          SB= 0.134E 00
K=  7          EN(K)=  1.500          SB= 0.135E 00
K=  8          EN(K)=  1.600          SB= 0.135E 00
K=  9          EN(K)=  1.700          SB= 0.132E 00
K= 10          EN(K)=  1.800          SB= 0.128E 00
K= 11          EN(K)=  1.900          SB= 0.125E 00
K= 12          EN(K)=  2.000          SB= 0.122E 00
K= 13          EN(K)=  2.100          SB= 0.120E 00
K= 14          EN(K)=  2.200          SB= 0.118E 00
K= 15          EN(K)=  2.300          SB= 0.116E 00
K= 16          EN(K)=  2.400          SB= 0.113E 00
K= 17          EN(K)=  2.500          SB= 0.109E 00
K= 18          EN(K)=  2.600          SB= 0.107E 00
K= 19          EN(K)=  2.700          SB= 0.104E 00
K= 20          EN(K)=  2.800          SB= 0.102E 00
K= 21          EN(K)=  2.900          SB= 0.993E-01
K= 22          EN(K)=  3.000          SB= 0.965E-01
K= 23          EN(K)=  3.100          SB= 0.935E-01
K= 24          EN(K)=  3.200          SB= 0.895E-01
K= 25          EN(K)=  3.300          SB= 0.858E-01
K= 26          EN(K)=  3.400          SB= 0.823E-01
K= 27          EN(K)=  3.500          SB= 0.796E-01
K= 28          EN(K)=  3.600          SB= 0.774E-01
K= 29          EN(K)=  3.700          SB= 0.756E-01
K= 30          EN(K)=  3.800          SB= 0.744E-01
K= 31          EN(K)=  3.900          SB= 0.745E-01
K= 32          EN(K)=  4.000          SB= 0.754E-01
K= 33          EN(K)=  4.100          SB= 0.768E-01
K= 34          EN(K)=  4.200          SB= 0.774E-01
K= 35          EN(K)=  4.300          SB= 0.794E-01
K= 36          EN(K)=  4.400          SB= 0.813E-01
K= 37          EN(K)=  4.500          SB= 0.832E-01
K= 38          EN(K)=  4.600          SB= 0.846E-01
K= 39          EN(K)=  4.700          SB= 0.850E-01
K= 40          EN(K)=  4.800          SB= 0.846E-01
K= 41          EN(K)=  4.900          SB= 0.839E-01
K= 42          EN(K)=  5.000          SB= 0.827E-01
K= 43          EN(K)=  5.100          SB= 0.811E-01
K= 44          EN(K)=  5.200          SB= 0.796E-01
K= 45          EN(K)=  5.300          SB= 0.783E-01
K= 46          EN(K)=  5.400          SB= 0.771E-01
K= 47          EN(K)=  5.500          SB= 0.759E-01
I=  3      J=  1      EGAM=  1.0100
K=  3          EN(K)=  1.100          SB= 0.372E-01
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K=  4          EN(K)=  1.200          SB= 0.100E 00
K=  5          EN(K)=  1.300          SB= 0.161E 00
K=  6          EN(K)=  1.400          SB= 0.207E 00
K=  7          EN(K)=  1.500          SB= 0.241E 00
K=  8          EN(K)=  1.600          SB= 0.262E 00
K=  9          EN(K)=  1.700          SB= 0.275E 00
K= 10          EN(K)=  1.800          SB= 0.283E 00
K= 11          EN(K)=  1.900          SB= 0.285E 00
K= 12          EN(K)=  2.000          SB= 0.285E 00
K= 13          EN(K)=  2.100          SB= 0.283E 00
K= 14          EN(K)=  2.200          SB= 0.280E 00
K= 15          EN(K)=  2.300          SB= 0.275E 00
K= 16          EN(K)=  2.400          SB= 0.263E 00
K= 17          EN(K)=  2.500          SB= 0.252E 00
K= 18          EN(K)=  2.600          SB= 0.239E 00
K= 19          EN(K)=  2.700          SB= 0.228E 00
K= 20          EN(K)=  2.800          SB= 0.219E 00
K= 21          EN(K)=  2.900          SB= 0.221E 00
K= 22          EN(K)=  3.000          SB= 0.229E 00
K= 23          EN(K)=  3.100          SB= 0.237E 00
K= 24          EN(K)=  3.200          SB= 0.241E 00
K= 25          EN(K)=  3.300          SB= 0.241E 00
K= 26          EN(K)=  3.400          SB= 0.240E 00
K= 27          EN(K)=  3.500          SB= 0.237E 00
K= 28          EN(K)=  3.600          SB= 0.235E 00
K= 29          EN(K)=  3.700          SB= 0.232E 00
K= 30          EN(K)=  3.800          SB= 0.228E 00
K= 31          EN(K)=  3.900          SB= 0.226E 00
K= 32          EN(K)=  4.000          SB= 0.225E 00
K= 33          EN(K)=  4.100          SB= 0.223E 00
K= 34          EN(K)=  4.200          SB= 0.220E 00
K= 35          EN(K)=  4.300          SB= 0.217E 00
K= 36          EN(K)=  4.400          SB= 0.213E 00
K= 37          EN(K)=  4.500          SB= 0.211E 00
K= 38          EN(K)=  4.600          SB= 0.208E 00
K= 39          EN(K)=  4.700          SB= 0.206E 00
K= 40          EN(K)=  4.800          SB= 0.201E 00
K= 41          EN(K)=  4.900          SB= 0.199E 00
K= 42          EN(K)=  5.000          SB= 0.196E 00
K= 43          EN(K)=  5.100          SB= 0.193E 00
K= 44          EN(K)=  5.200          SB= 0.192E 00
K= 45          EN(K)=  5.300          SB= 0.190E 00
K= 46          EN(K)=  5.400          SB= 0.189E 00
K= 47          EN(K)=  5.500          SB= 0.190E 00
I=  3     J=  2       EGAM=  0.1700
K=  3          EN(K)=  1.100          SB= 0.115E-02
K=  4          EN(K)=  1.200          SB= 0.311E-02
K=  5          EN(K)=  1.300          SB= 0.497E-02
K=  6          EN(K)=  1.400          SB= 0.641E-02
K=  7          EN(K)=  1.500          SB= 0.746E-02
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K=  8          EN(K)=  1.600          SB= 0.812E-02
K=  9          EN(K)=  1.700          SB= 0.851E-02
K= 10          EN(K)=  1.800          SB= 0.875E-02
K= 11          EN(K)=  1.900          SB= 0.881E-02
K= 12          EN(K)=  2.000          SB= 0.881E-02
K= 13          EN(K)=  2.100          SB= 0.875E-02
K= 14          EN(K)=  2.200          SB= 0.867E-02
K= 15          EN(K)=  2.300          SB= 0.851E-02
K= 16          EN(K)=  2.400          SB= 0.815E-02
K= 17          EN(K)=  2.500          SB= 0.779E-02
K= 18          EN(K)=  2.600          SB= 0.740E-02
K= 19          EN(K)=  2.700          SB= 0.707E-02
K= 20          EN(K)=  2.800          SB= 0.677E-02
K= 21          EN(K)=  2.900          SB= 0.686E-02
K= 22          EN(K)=  3.000          SB= 0.710E-02
K= 23          EN(K)=  3.100          SB= 0.735E-02
K= 24          EN(K)=  3.200          SB= 0.745E-02
K= 25          EN(K)=  3.300          SB= 0.747E-02
K= 26          EN(K)=  3.400          SB= 0.743E-02
K= 27          EN(K)=  3.500          SB= 0.734E-02
K= 28          EN(K)=  3.600          SB= 0.728E-02
K= 29          EN(K)=  3.700          SB= 0.717E-02
K= 30          EN(K)=  3.800          SB= 0.708E-02
K= 31          EN(K)=  3.900          SB= 0.701E-02
K= 32          EN(K)=  4.000          SB= 0.696E-02
K= 33          EN(K)=  4.100          SB= 0.691E-02
K= 34          EN(K)=  4.200          SB= 0.681E-02
K= 35          EN(K)=  4.300          SB= 0.672E-02
K= 36          EN(K)=  4.400          SB= 0.660E-02
K= 37          EN(K)=  4.500          SB= 0.653E-02
K= 38          EN(K)=  4.600          SB= 0.645E-02
K= 39          EN(K)=  4.700          SB= 0.637E-02
K= 40          EN(K)=  4.800          SB= 0.624E-02
K= 41          EN(K)=  4.900          SB= 0.615E-02
K= 42          EN(K)=  5.000          SB= 0.607E-02
K= 43          EN(K)=  5.100          SB= 0.599E-02
K= 44          EN(K)=  5.200          SB= 0.593E-02
K= 45          EN(K)=  5.300          SB= 0.590E-02
K= 46          EN(K)=  5.400          SB= 0.587E-02
K= 47          EN(K)=  5.500          SB= 0.589E-02
I=  4     J=  1        EGAM=  2.2100
K= 15          EN(K)=  2.300          SB= 0.111E-01
K= 16          EN(K)=  2.400          SB= 0.703E-01
K= 17          EN(K)=  2.500          SB= 0.128E 00
K= 18          EN(K)=  2.600          SB= 0.178E 00
K= 19          EN(K)=  2.700          SB= 0.218E 00
K= 20          EN(K)=  2.800          SB= 0.249E 00
K= 21          EN(K)=  2.900          SB= 0.267E 00
K= 22          EN(K)=  3.000          SB= 0.277E 00
K= 23          EN(K)=  3.100          SB= 0.280E 00
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K= 24          EN(K)=  3.200          SB= 0.273E 00
K= 25          EN(K)=  3.300          SB= 0.265E 00
K= 26          EN(K)=  3.400          SB= 0.254E 00
K= 27          EN(K)=  3.500          SB= 0.246E 00
K= 28          EN(K)=  3.600          SB= 0.238E 00
K= 29          EN(K)=  3.700          SB= 0.231E 00
K= 30          EN(K)=  3.800          SB= 0.227E 00
K= 31          EN(K)=  3.900          SB= 0.222E 00
K= 32          EN(K)=  4.000          SB= 0.218E 00
K= 33          EN(K)=  4.100          SB= 0.215E 00
K= 34          EN(K)=  4.200          SB= 0.212E 00
K= 35          EN(K)=  4.300          SB= 0.210E 00
K= 36          EN(K)=  4.400          SB= 0.207E 00
K= 37          EN(K)=  4.500          SB= 0.205E 00
K= 38          EN(K)=  4.600          SB= 0.202E 00
K= 39          EN(K)=  4.700          SB= 0.202E 00
K= 40          EN(K)=  4.800          SB= 0.204E 00
K= 41          EN(K)=  4.900          SB= 0.207E 00
K= 42          EN(K)=  5.000          SB= 0.210E 00
K= 43          EN(K)=  5.100          SB= 0.213E 00
K= 44          EN(K)=  5.200          SB= 0.217E 00
K= 45          EN(K)=  5.300          SB= 0.220E 00
K= 46          EN(K)=  5.400          SB= 0.222E 00
K= 47          EN(K)=  5.500          SB= 0.224E 00
I=  5     J=  1        EGAM=  2.7300
K= 21          EN(K)=  2.900          SB= 0.465E-02
K= 22          EN(K)=  3.000          SB= 0.106E-01
K= 23          EN(K)=  3.100          SB= 0.167E-01
K= 24          EN(K)=  3.200          SB= 0.219E-01
K= 25          EN(K)=  3.300          SB= 0.256E-01
K= 26          EN(K)=  3.400          SB= 0.283E-01
K= 27          EN(K)=  3.500          SB= 0.300E-01
K= 28          EN(K)=  3.600          SB= 0.311E-01
K= 29          EN(K)=  3.700          SB= 0.316E-01
K= 30          EN(K)=  3.800          SB= 0.319E-01
K= 31          EN(K)=  3.900          SB= 0.319E-01
K= 32          EN(K)=  4.000          SB= 0.319E-01
K= 33          EN(K)=  4.100          SB= 0.316E-01
K= 34          EN(K)=  4.200          SB= 0.311E-01
K= 35          EN(K)=  4.300          SB= 0.307E-01
K= 36          EN(K)=  4.400          SB= 0.300E-01
K= 37          EN(K)=  4.500          SB= 0.295E-01
K= 38          EN(K)=  4.600          SB= 0.287E-01
K= 39          EN(K)=  4.700          SB= 0.281E-01
K= 40          EN(K)=  4.800          SB= 0.273E-01
K= 41          EN(K)=  4.900          SB= 0.268E-01
K= 42          EN(K)=  5.000          SB= 0.260E-01
K= 43          EN(K)=  5.100          SB= 0.255E-01
K= 44          EN(K)=  5.200          SB= 0.249E-01
K= 45          EN(K)=  5.300          SB= 0.246E-01
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K= 46          EN(K)=  5.400          SB= 0.243E-01
K= 47          EN(K)=  5.500          SB= 0.239E-01
I=  5     J=  3      EGAM=  1.7199
K= 21          EN(K)=  2.900          SB= 0.147E-01
K= 22          EN(K)=  3.000          SB= 0.336E-01
K= 23          EN(K)=  3.100          SB= 0.531E-01
K= 24          EN(K)=  3.200          SB= 0.695E-01
K= 25          EN(K)=  3.300          SB= 0.813E-01
K= 26          EN(K)=  3.400          SB= 0.896E-01
K= 27          EN(K)=  3.500          SB= 0.950E-01
K= 28          EN(K)=  3.600          SB= 0.988E-01
K= 29          EN(K)=  3.700          SB= 0.100E 00
K= 30          EN(K)=  3.800          SB= 0.101E 00
K= 31          EN(K)=  3.900          SB= 0.101E 00
K= 32          EN(K)=  4.000          SB= 0.101E 00
K= 33          EN(K)=  4.100          SB= 0.100E 00
K= 34          EN(K)=  4.200          SB= 0.988E-01
K= 35          EN(K)=  4.300          SB= 0.972E-01
K= 36          EN(K)=  4.400          SB= 0.950E-01
K= 37          EN(K)=  4.500          SB= 0.934E-01
K= 38          EN(K)=  4.600          SB= 0.911E-01
K= 39          EN(K)=  4.700          SB= 0.891E-01
K= 40          EN(K)=  4.800          SB= 0.866E-01
K= 41          EN(K)=  4.900          SB= 0.849E-01
K= 42          EN(K)=  5.000          SB= 0.825E-01
K= 43          EN(K)=  5.100          SB= 0.808E-01
K= 44          EN(K)=  5.200          SB= 0.790E-01
K= 45          EN(K)=  5.300          SB= 0.779E-01
K= 46          EN(K)=  5.400          SB= 0.769E-01
K= 47          EN(K)=  5.500          SB= 0.759E-01
I=  6     J=  1      EGAM=  2.9800
K= 23          EN(K)=  3.100          SB= 0.194E-02
K= 24          EN(K)=  3.200          SB= 0.123E-01
K= 25          EN(K)=  3.300          SB= 0.239E-01
K= 26          EN(K)=  3.400          SB= 0.352E-01
K= 27          EN(K)=  3.500          SB= 0.452E-01
K= 28          EN(K)=  3.600          SB= 0.534E-01
K= 29          EN(K)=  3.700          SB= 0.598E-01
K= 30          EN(K)=  3.800          SB= 0.649E-01
K= 31          EN(K)=  3.900          SB= 0.683E-01
K= 32          EN(K)=  4.000          SB= 0.703E-01
K= 33          EN(K)=  4.100          SB= 0.715E-01
K= 34          EN(K)=  4.200          SB= 0.714E-01
K= 35          EN(K)=  4.300          SB= 0.704E-01
K= 36          EN(K)=  4.400          SB= 0.691E-01
K= 37          EN(K)=  4.500          SB= 0.676E-01
K= 38          EN(K)=  4.600          SB= 0.660E-01
K= 39          EN(K)=  4.700          SB= 0.640E-01
K= 40          EN(K)=  4.800          SB= 0.619E-01
K= 41          EN(K)=  4.900          SB= 0.599E-01
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K= 42          EN(K)=  5.000          SB= 0.582E-01
K= 43          EN(K)=  5.100          SB= 0.564E-01
K= 44          EN(K)=  5.200          SB= 0.549E-01
K= 45          EN(K)=  5.300          SB= 0.537E-01
K= 46          EN(K)=  5.400          SB= 0.528E-01
K= 47          EN(K)=  5.500          SB= 0.520E-01
I=  6     J=  2       EGAM=  2.1399
K= 23          EN(K)=  3.100          SB= 0.195E-04
K= 24          EN(K)=  3.200          SB= 0.124E-03
K= 25          EN(K)=  3.300          SB= 0.242E-03
K= 26          EN(K)=  3.400          SB= 0.356E-03
K= 27          EN(K)=  3.500          SB= 0.456E-03
K= 28          EN(K)=  3.600          SB= 0.540E-03
K= 29          EN(K)=  3.700          SB= 0.604E-03
K= 30          EN(K)=  3.800          SB= 0.655E-03
K= 31          EN(K)=  3.900          SB= 0.689E-03
K= 32          EN(K)=  4.000          SB= 0.711E-03
K= 33          EN(K)=  4.100          SB= 0.722E-03
K= 34          EN(K)=  4.200          SB= 0.721E-03
K= 35          EN(K)=  4.300          SB= 0.712E-03
K= 36          EN(K)=  4.400          SB= 0.697E-03
K= 37          EN(K)=  4.500          SB= 0.682E-03
K= 38          EN(K)=  4.600          SB= 0.666E-03
K= 39          EN(K)=  4.700          SB= 0.646E-03
K= 40          EN(K)=  4.800          SB= 0.625E-03
K= 41          EN(K)=  4.900          SB= 0.606E-03
K= 42          EN(K)=  5.000          SB= 0.588E-03
K= 43          EN(K)=  5.100          SB= 0.570E-03
K= 44          EN(K)=  5.200          SB= 0.555E-03
K= 45          EN(K)=  5.300          SB= 0.542E-03
K= 46          EN(K)=  5.400          SB= 0.533E-03
K= 47          EN(K)=  5.500          SB= 0.526E-03
I=  7     J=  1       EGAM=  3.0000
K= 24          EN(K)=  3.200          SB= 0.312E-01
K= 25          EN(K)=  3.300          SB= 0.611E-01
K= 26          EN(K)=  3.400          SB= 0.869E-01
K= 27          EN(K)=  3.500          SB= 0.108E 00
K= 28          EN(K)=  3.600          SB= 0.125E 00
K= 29          EN(K)=  3.700          SB= 0.138E 00
K= 30          EN(K)=  3.800          SB= 0.147E 00
K= 31          EN(K)=  3.900          SB= 0.154E 00
K= 32          EN(K)=  4.000          SB= 0.160E 00
K= 33          EN(K)=  4.100          SB= 0.164E 00
K= 34          EN(K)=  4.200          SB= 0.166E 00
K= 35          EN(K)=  4.300          SB= 0.167E 00
K= 36          EN(K)=  4.400          SB= 0.167E 00
K= 37          EN(K)=  4.500          SB= 0.167E 00
K= 38          EN(K)=  4.600          SB= 0.167E 00
K= 39          EN(K)=  4.700          SB= 0.166E 00
K= 40          EN(K)=  4.800          SB= 0.165E 00
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K= 41          EN(K)=  4.900          SB= 0.164E 00
K= 42          EN(K)=  5.000          SB= 0.162E 00
K= 43          EN(K)=  5.100          SB= 0.160E 00
K= 44          EN(K)=  5.200          SB= 0.158E 00
K= 45          EN(K)=  5.300          SB= 0.156E 00
K= 46          EN(K)=  5.400          SB= 0.154E 00
K= 47          EN(K)=  5.500          SB= 0.152E 00
I=  7     J=  4       EGAM=  0.7900
K= 24          EN(K)=  3.200          SB= 0.466E-02
K= 25          EN(K)=  3.300          SB= 0.913E-02
K= 26          EN(K)=  3.400          SB= 0.130E-01
K= 27          EN(K)=  3.500          SB= 0.162E-01
K= 28          EN(K)=  3.600          SB= 0.187E-01
K= 29          EN(K)=  3.700          SB= 0.206E-01
K= 30          EN(K)=  3.800          SB= 0.220E-01
K= 31          EN(K)=  3.900          SB= 0.231E-01
K= 32          EN(K)=  4.000          SB= 0.239E-01
K= 33          EN(K)=  4.100          SB= 0.245E-01
K= 34          EN(K)=  4.200          SB= 0.248E-01
K= 35          EN(K)=  4.300          SB= 0.250E-01
K= 36          EN(K)=  4.400          SB= 0.250E-01
K= 37          EN(K)=  4.500          SB= 0.250E-01
K= 38          EN(K)=  4.600          SB= 0.250E-01
K= 39          EN(K)=  4.700          SB= 0.248E-01
K= 40          EN(K)=  4.800          SB= 0.246E-01
K= 41          EN(K)=  4.900          SB= 0.245E-01
K= 42          EN(K)=  5.000          SB= 0.242E-01
K= 43          EN(K)=  5.100          SB= 0.240E-01
K= 44          EN(K)=  5.200          SB= 0.236E-01
K= 45          EN(K)=  5.300          SB= 0.233E-01
K= 46          EN(K)=  5.400          SB= 0.231E-01
K= 47          EN(K)=  5.500          SB= 0.227E-01
I=  8     J=  2       EGAM=  2.8400
K= 31          EN(K)=  3.900          SB= 0.162E-02
K= 32          EN(K)=  4.000          SB= 0.377E-02
K= 33          EN(K)=  4.100          SB= 0.616E-02
K= 34          EN(K)=  4.200          SB= 0.838E-02
K= 35          EN(K)=  4.300          SB= 0.102E-01
K= 36          EN(K)=  4.400          SB= 0.115E-01
K= 37          EN(K)=  4.500          SB= 0.125E-01
K= 38          EN(K)=  4.600          SB= 0.131E-01
K= 39          EN(K)=  4.700          SB= 0.135E-01
K= 40          EN(K)=  4.800          SB= 0.136E-01
K= 41          EN(K)=  4.900          SB= 0.135E-01
K= 42          EN(K)=  5.000          SB= 0.134E-01
K= 43          EN(K)=  5.100          SB= 0.131E-01
K= 44          EN(K)=  5.200          SB= 0.130E-01
K= 45          EN(K)=  5.300          SB= 0.128E-01
K= 46          EN(K)=  5.400          SB= 0.126E-01
K= 47          EN(K)=  5.500          SB= 0.125E-01
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I=  8      J=  3      EGAM=  2.6700
K= 31       EN(K)=  3.900          SB= 0.874E-03
K= 32       EN(K)=  4.000          SB= 0.203E-02
K= 33       EN(K)=  4.100          SB= 0.332E-02
K= 34       EN(K)=  4.200          SB= 0.451E-02
K= 35       EN(K)=  4.300          SB= 0.549E-02
K= 36       EN(K)=  4.400          SB= 0.622E-02
K= 37       EN(K)=  4.500          SB= 0.675E-02
K= 38       EN(K)=  4.600          SB= 0.710E-02
K= 39       EN(K)=  4.700          SB= 0.727E-02
K= 40       EN(K)=  4.800          SB= 0.734E-02
K= 41       EN(K)=  4.900          SB= 0.731E-02
K= 42       EN(K)=  5.000          SB= 0.724E-02
K= 43       EN(K)=  5.100          SB= 0.710E-02
K= 44       EN(K)=  5.200          SB= 0.699E-02
K= 45       EN(K)=  5.300          SB= 0.689E-02
K= 46       EN(K)=  5.400          SB= 0.682E-02
K= 47       EN(K)=  5.500          SB= 0.675E-02
I=  9      J=  1      EGAM=  3.9600
K= 34       EN(K)=  4.200          SB= 0.578E-02
K= 35       EN(K)=  4.300          SB= 0.122E-01
K= 36       EN(K)=  4.400          SB= 0.190E-01
K= 37       EN(K)=  4.500          SB= 0.255E-01
K= 38       EN(K)=  4.600          SB= 0.311E-01
K= 39       EN(K)=  4.700          SB= 0.353E-01
K= 40       EN(K)=  4.800          SB= 0.382E-01
K= 41       EN(K)=  4.900          SB= 0.401E-01
K= 42       EN(K)=  5.000          SB= 0.411E-01
K= 43       EN(K)=  5.100          SB= 0.414E-01
K= 44       EN(K)=  5.200          SB= 0.412E-01
K= 45       EN(K)=  5.300          SB= 0.409E-01
K= 46       EN(K)=  5.400          SB= 0.406E-01
K= 47       EN(K)=  5.500          SB= 0.401E-01
I= 10      J=  2      EGAM=  3.2099
K= 35       EN(K)=  4.300          SB= 0.189E-02
K= 36       EN(K)=  4.400          SB= 0.404E-02
K= 37       EN(K)=  4.500          SB= 0.632E-02
K= 38       EN(K)=  4.600          SB= 0.847E-02
K= 39       EN(K)=  4.700          SB= 0.102E-01
K= 40       EN(K)=  4.800          SB= 0.115E-01
K= 41       EN(K)=  4.900          SB= 0.124E-01
K= 42       EN(K)=  5.000          SB= 0.131E-01
K= 43       EN(K)=  5.100          SB= 0.135E-01
K= 44       EN(K)=  5.200          SB= 0.136E-01
K= 45       EN(K)=  5.300          SB= 0.137E-01
K= 46       EN(K)=  5.400          SB= 0.138E-01
K= 47       EN(K)=  5.500          SB= 0.137E-01
I= 10      J=  3      EGAM=  3.0399
K= 35       EN(K)=  4.300          SB= 0.474E-03
K= 36       EN(K)=  4.400          SB= 0.101E-02
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K= 37          EN(K)=  4.500          SB= 0.158E-02
K= 38          EN(K)=  4.600          SB= 0.211E-02
K= 39          EN(K)=  4.700          SB= 0.255E-02
K= 40          EN(K)=  4.800          SB= 0.288E-02
K= 41          EN(K)=  4.900          SB= 0.312E-02
K= 42          EN(K)=  5.000          SB= 0.327E-02
K= 43          EN(K)=  5.100          SB= 0.337E-02
K= 44          EN(K)=  5.200          SB= 0.341E-02
K= 45          EN(K)=  5.300          SB= 0.343E-02
K= 46          EN(K)=  5.400          SB= 0.345E-02
K= 47          EN(K)=  5.500          SB= 0.343E-02
I= 11     J=  1       EGAM=  4.4100
K= 38          EN(K)=  4.600          SB= 0.172E-02
K= 39          EN(K)=  4.700          SB= 0.604E-02
K= 40          EN(K)=  4.800          SB= 0.108E-01
K= 41          EN(K)=  4.900          SB= 0.157E-01
K= 42          EN(K)=  5.000          SB= 0.200E-01
K= 43          EN(K)=  5.100          SB= 0.235E-01
K= 44          EN(K)=  5.200          SB= 0.262E-01
K= 45          EN(K)=  5.300          SB= 0.282E-01
K= 46          EN(K)=  5.400          SB= 0.295E-01
K= 47          EN(K)=  5.500          SB= 0.303E-01
I= 11     J=  3       EGAM=  3.4000
K= 38          EN(K)=  4.600          SB= 0.782E-03
K= 39          EN(K)=  4.700          SB= 0.275E-02
K= 40          EN(K)=  4.800          SB= 0.495E-02
K= 41          EN(K)=  4.900          SB= 0.715E-02
K= 42          EN(K)=  5.000          SB= 0.912E-02
K= 43          EN(K)=  5.100          SB= 0.107E-01
K= 44          EN(K)=  5.200          SB= 0.119E-01
K= 45          EN(K)=  5.300          SB= 0.128E-01
K= 46          EN(K)=  5.400          SB= 0.134E-01
K= 47          EN(K)=  5.500          SB= 0.138E-01
I= 11     J=  4       EGAM=  2.2000
K= 38          EN(K)=  4.600          SB= 0.625E-03
K= 39          EN(K)=  4.700          SB= 0.219E-02
K= 40          EN(K)=  4.800          SB= 0.396E-02
K= 41          EN(K)=  4.900          SB= 0.571E-02
K= 42          EN(K)=  5.000          SB= 0.729E-02
K= 43          EN(K)=  5.100          SB= 0.857E-02
K= 44          EN(K)=  5.200          SB= 0.953E-02
K= 45          EN(K)=  5.300          SB= 0.102E-01
K= 46          EN(K)=  5.400          SB= 0.107E-01
K= 47          EN(K)=  5.500          SB= 0.110E-01
I= 12     J=  1       EGAM=  4.5100
K= 39          EN(K)=  4.700          SB= 0.261E-03
K= 40          EN(K)=  4.800          SB= 0.998E-03
K= 41          EN(K)=  4.900          SB= 0.182E-02
K= 42          EN(K)=  5.000          SB= 0.266E-02
K= 43          EN(K)=  5.100          SB= 0.340E-02
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K= 44          EN(K)=  5.200          SB= 0.401E-02
K= 45          EN(K)=  5.300          SB= 0.449E-02
K= 46          EN(K)=  5.400          SB= 0.487E-02
K= 47          EN(K)=  5.500          SB= 0.510E-02
I= 12     J=  4       EGAM=  2.3000
K= 39          EN(K)=  4.700          SB= 0.156E-02
K= 40          EN(K)=  4.800          SB= 0.599E-02
K= 41          EN(K)=  4.900          SB= 0.109E-01
K= 42          EN(K)=  5.000          SB= 0.159E-01
K= 43          EN(K)=  5.100          SB= 0.204E-01
K= 44          EN(K)=  5.200          SB= 0.241E-01
K= 45          EN(K)=  5.300          SB= 0.269E-01
K= 46          EN(K)=  5.400          SB= 0.292E-01
K= 47          EN(K)=  5.500          SB= 0.306E-01
I= 12     J=  5       EGAM=  1.7799
K= 39          EN(K)=  4.700          SB= 0.261E-03
K= 40          EN(K)=  4.800          SB= 0.998E-03
K= 41          EN(K)=  4.900          SB= 0.182E-02
K= 42          EN(K)=  5.000          SB= 0.266E-02
K= 43          EN(K)=  5.100          SB= 0.340E-02
K= 44          EN(K)=  5.200          SB= 0.401E-02
K= 45          EN(K)=  5.300          SB= 0.449E-02
K= 46          EN(K)=  5.400          SB= 0.487E-02
K= 47          EN(K)=  5.500          SB= 0.510E-02
I= 12     J=  7       EGAM=  1.5099
K= 39          EN(K)=  4.700          SB= 0.522E-03
K= 40          EN(K)=  4.800          SB= 0.199E-02
K= 41          EN(K)=  4.900          SB= 0.365E-02
K= 42          EN(K)=  5.000          SB= 0.532E-02
K= 43          EN(K)=  5.100          SB= 0.681E-02
K= 44          EN(K)=  5.200          SB= 0.803E-02
K= 45          EN(K)=  5.300          SB= 0.899E-02
K= 46          EN(K)=  5.400          SB= 0.974E-02
K= 47          EN(K)=  5.500          SB= 0.102E-01
I= 13     J=  1       EGAM=  4.8100
K= 42          EN(K)=  5.000          SB= 0.551E-03
K= 43          EN(K)=  5.100          SB= 0.302E-02
K= 44          EN(K)=  5.200          SB= 0.576E-02
K= 45          EN(K)=  5.300          SB= 0.863E-02
K= 46          EN(K)=  5.400          SB= 0.112E-01
K= 47          EN(K)=  5.500          SB= 0.135E-01
I= 13     J=  3       EGAM=  3.7999
K= 42          EN(K)=  5.000          SB= 0.345E-03
K= 43          EN(K)=  5.100          SB= 0.189E-02
K= 44          EN(K)=  5.200          SB= 0.360E-02
K= 45          EN(K)=  5.300          SB= 0.540E-02
K= 46          EN(K)=  5.400          SB= 0.705E-02
K= 47          EN(K)=  5.500          SB= 0.847E-02
I= 13     J=  4       EGAM=  2.6000
K= 42          EN(K)=  5.000          SB= 0.482E-03
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K= 43          EN(K)=  5.100          SB= 0.264E-02
K= 44          EN(K)=  5.200          SB= 0.504E-02
K= 45          EN(K)=  5.300          SB= 0.755E-02
K= 46          EN(K)=  5.400          SB= 0.986E-02
K= 47          EN(K)=  5.500          SB= 0.118E-01
I= 14     J=  1       EGAM=  5.2500
K= 47          EN(K)=  5.500          SB= 0.318E-03
I= 14     J=  3       EGAM=  4.2400
K= 47          EN(K)=  5.500          SB= 0.223E-02
I= 14     J=  4       EGAM=  3.0400
K= 47          EN(K)=  5.500          SB= 0.637E-03
```

APPENDIX C. RESULTS OF Fe^{56} CROSS SECTION CALCULATIONS IN TABULAR FORM

KMAX= 33

K= 1	EN(K)= 1.0000	EA(K)= 0.9823
K= 2	EN(K)= 1.1000	EA(K)= 1.0805
K= 3	EN(K)= 1.2000	EA(K)= 1.1788
K= 4	EN(K)= 1.3000	EA(K)= 1.2770
K= 5	EN(K)= 1.4000	EA(K)= 1.3752
K= 6	EN(K)= 1.5000	EA(K)= 1.4735
K= 7	EN(K)= 1.6000	EA(K)= 1.5717
K= 8	EN(K)= 1.7000	EA(K)= 1.6699
K= 9	EN(K)= 1.8000	EA(K)= 1.7681
K= 10	EN(K)= 1.9000	EA(K)= 1.8664
K= 11	EN(K)= 2.0000	EA(K)= 1.9646
K= 12	EN(K)= 2.1000	EA(K)= 2.0628
K= 13	EN(K)= 2.2000	EA(K)= 2.1611
K= 14	EN(K)= 2.3000	EA(K)= 2.2593
K= 15	EN(K)= 2.4000	EA(K)= 2.3575
K= 16	EN(K)= 2.5000	EA(K)= 2.4558
K= 17	EN(K)= 2.6000	EA(K)= 2.5540
K= 18	EN(K)= 2.7000	EA(K)= 2.6522
K= 19	EN(K)= 2.8000	EA(K)= 2.7504
K= 20	EN(K)= 2.9000	EA(K)= 2.8487
K= 21	EN(K)= 3.0000	EA(K)= 2.9469
K= 22	EN(K)= 3.1000	EA(K)= 3.0451
K= 23	EN(K)= 3.2000	EA(K)= 3.1434
K= 24	EN(K)= 3.3000	EA(K)= 3.2416
K= 25	EN(K)= 3.4000	EA(K)= 3.3398
K= 26	EN(K)= 3.5000	EA(K)= 3.4381
K= 27	EN(K)= 3.6000	EA(K)= 3.5363
K= 28	EN(K)= 3.7000	EA(K)= 3.6345
K= 29	EN(K)= 3.8000	EA(K)= 3.7327
K= 30	EN(K)= 3.9000	EA(K)= 3.8310
K= 31	EN(K)= 4.0000	EA(K)= 3.9292
K= 32	EN(K)= 4.1000	EA(K)= 4.0274
K= 33	EN(K)= 4.2000	EA(K)= 4.1257

N= 19

I= 2	ELEV(I)= 0.8470
I= 3	ELEV(I)= 2.0850
I= 4	ELEV(I)= 2.6570
I= 5	ELEV(I)= 2.9390
I= 6	ELEV(I)= 2.9600
I= 7	ELEV(I)= 3.1190
I= 8	ELEV(I)= 3.1230
I= 9	ELEV(I)= 3.3690
I= 10	ELEV(I)= 3.3860
I= 11	ELEV(I)= 3.4450
I= 12	ELEV(I)= 3.4500
I= 13	ELEV(I)= 3.5990
I= 14	ELEV(I)= 3.6050
I= 15	ELEV(I)= 3.7470
I= 16	ELEV(I)= 3.8290
I= 17	ELEV(I)= 3.8560
I= 18	ELEV(I)= 4.0490
I= 19	ELEV(I)= 4.1000

I = 2	J = 1	P(I,J) = 1.0000
I = 3	J = 1	P(I,J) = 0.0000
I = 3	J = 2	P(I,J) = 1.0000
I = 4	J = 1	P(I,J) = 0.0200
I = 4	J = 2	P(I,J) = 0.9800
I = 4	J = 3	P(I,J) = 0.0000
I = 5	J = 1	P(I,J) = 0.0000
I = 5	J = 2	P(I,J) = 1.0000
I = 5	J = 3	P(I,J) = 0.0000
I = 5	J = 4	P(I,J) = 0.0000
I = 6	J = 1	P(I,J) = 0.0200
I = 6	J = 2	P(I,J) = 0.9800
I = 6	J = 3	P(I,J) = 0.0000
I = 6	J = 4	P(I,J) = 0.0000
I = 6	J = 5	P(I,J) = 0.0000
I = 7	J = 1	P(I,J) = 0.0300
I = 7	J = 2	P(I,J) = 0.9700
I = 7	J = 3	P(I,J) = 0.0000
I = 7	J = 4	P(I,J) = 0.0000
I = 7	J = 5	P(I,J) = 0.0000
I = 7	J = 6	P(I,J) = 0.0000
I = 8	J = 1	P(I,J) = 0.0000
I = 8	J = 2	P(I,J) = 0.0000
I = 8	J = 3	P(I,J) = 1.0000
I = 8	J = 4	P(I,J) = 0.0000
I = 8	J = 5	P(I,J) = 0.0000
I = 8	J = 6	P(I,J) = 0.0000
I = 8	J = 7	P(I,J) = 0.0000
I = 9	J = 1	P(I,J) = 0.1600
I = 9	J = 2	P(I,J) = 0.8400
I = 9	J = 3	P(I,J) = 0.0000
I = 9	J = 4	P(I,J) = 0.0000
I = 9	J = 5	P(I,J) = 0.0000
I = 9	J = 6	P(I,J) = 0.0000
I = 9	J = 7	P(I,J) = 0.0000
I = 9	J = 8	P(I,J) = 0.0000
I = 10	J = 1	P(I,J) = 0.0000
I = 10	J = 2	P(I,J) = 0.0000
I = 10	J = 3	P(I,J) = 0.0000
I = 10	J = 4	P(I,J) = 0.0000
I = 10	J = 5	P(I,J) = 0.0000
I = 10	J = 6	P(I,J) = 0.0000
I = 10	J = 7	P(I,J) = 0.0000
I = 10	J = 8	P(I,J) = 0.0000
I = 10	J = 9	P(I,J) = 0.0000
I = 11	J = 1	P(I,J) = 0.0000
I = 11	J = 2	P(I,J) = 0.7800
I = 11	J = 3	P(I,J) = 0.1900
I = 11	J = 4	P(I,J) = 0.0300
I = 11	J = 5	P(I,J) = 0.0000

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I= 11    J=  6    P(I,J)= 0.0000
I= 11    J=  7    P(I,J)= 0.0000
I= 11    J=  8    P(I,J)= 0.0000
I= 11    J=  9    P(I,J)= 0.0000
I= 11    J= 10    P(I,J)= 0.0000
I= 12    J=  1    P(I,J)= 0.4600
I= 12    J=  2    P(I,J)= 0.5400
I= 12    J=  3    P(I,J)= 0.0000
I= 12    J=  4    P(I,J)= 0.0000
I= 12    J=  5    P(I,J)= 0.0000
I= 12    J=  6    P(I,J)= 0.0000
I= 12    J=  7    P(I,J)= 0.0000
I= 12    J=  8    P(I,J)= 0.0000
I= 12    J=  9    P(I,J)= 0.0000
I= 12    J= 10    P(I,J)= 0.0000
I= 12    J= 11    P(I,J)= 0.0000
I= 13    J=  1    P(I,J)= 0.0000
I= 13    J=  2    P(I,J)= 1.0000
I= 13    J=  3    P(I,J)= 0.0000
I= 13    J=  4    P(I,J)= 0.0000
I= 13    J=  5    P(I,J)= 0.0000
I= 13    J=  6    P(I,J)= 0.0000
I= 13    J=  7    P(I,J)= 0.0000
I= 13    J=  8    P(I,J)= 0.0000
I= 13    J=  9    P(I,J)= 0.0000
I= 13    J= 10    P(I,J)= 0.0000
I= 13    J= 11    P(I,J)= 0.0000
I= 13    J= 12    P(I,J)= 0.0000
I= 14    J=  1    P(I,J)= 0.4900
I= 14    J=  2    P(I,J)= 0.5100
I= 14    J=  3    P(I,J)= 0.0000
I= 14    J=  4    P(I,J)= 0.0000
I= 14    J=  5    P(I,J)= 0.0000
I= 14    J=  6    P(I,J)= 0.0000
I= 14    J=  7    P(I,J)= 0.0000
I= 14    J=  8    P(I,J)= 0.0000
I= 14    J=  9    P(I,J)= 0.0000
I= 14    J= 10    P(I,J)= 0.0000
I= 14    J= 11    P(I,J)= 0.0000
I= 14    J= 12    P(I,J)= 0.0000
I= 14    J= 13    P(I,J)= 0.0000
I= 15    J=  1    P(I,J)= 0.0000
I= 15    J=  2    P(I,J)= 0.0000
I= 15    J=  3    P(I,J)= 0.0000
I= 15    J=  4    P(I,J)= 0.0000
I= 15    J=  5    P(I,J)= 0.0000
I= 15    J=  6    P(I,J)= 0.0000
I= 15    J=  7    P(I,J)= 0.0000
I= 15    J=  8    P(I,J)= 0.0000
I= 15    J=  9    P(I,J)= 0.0000
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I= 15    J= 10    P(I,J)= 0.0000
I= 15    J= 11    P(I,J)= 0.0000
I= 15    J= 12    P(I,J)= 0.0000
I= 15    J= 13    P(I,J)= 0.0000
I= 15    J= 14    P(I,J)= 0.0000
I= 16    J=  1    P(I,J)= 0.0800
I= 16    J=  2    P(I,J)= 0.6400
I= 16    J=  3    P(I,J)= 0.0000
I= 16    J=  4    P(I,J)= 0.2800
I= 16    J=  5    P(I,J)= 0.0000
I= 16    J=  6    P(I,J)= 0.0000
I= 16    J=  7    P(I,J)= 0.0000
I= 16    J=  8    P(I,J)= 0.0000
I= 16    J=  9    P(I,J)= 0.0000
I= 16    J= 10    P(I,J)= 0.0000
I= 16    J= 11    P(I,J)= 0.0000
I= 16    J= 12    P(I,J)= 0.0000
I= 16    J= 13    P(I,J)= 0.0000
I= 16    J= 14    P(I,J)= 0.0000
I= 16    J= 15    P(I,J)= 0.0000
I= 17    J=  1    P(I,J)= 0.0000
I= 17    J=  2    P(I,J)= 0.0700
I= 17    J=  3    P(I,J)= 0.9200
I= 17    J=  4    P(I,J)= 0.0000
I= 17    J=  5    P(I,J)= 0.0000
I= 17    J=  6    P(I,J)= 0.0000
I= 17    J=  7    P(I,J)= 0.0000
I= 17    J=  8    P(I,J)= 0.0100
I= 17    J=  9    P(I,J)= 0.0000
I= 17    J= 10    P(I,J)= 0.0000
I= 17    J= 11    P(I,J)= 0.0000
I= 17    J= 12    P(I,J)= 0.0000
I= 17    J= 13    P(I,J)= 0.0000
I= 17    J= 14    P(I,J)= 0.0000
I= 17    J= 15    P(I,J)= 0.0000
I= 17    J= 16    P(I,J)= 0.0000
I= 18    J=  1    P(I,J)= 0.0000
I= 18    J=  2    P(I,J)= 0.8000
I= 18    J=  3    P(I,J)= 0.2000
I= 18    J=  4    P(I,J)= 0.0000
I= 18    J=  5    P(I,J)= 0.0000
I= 18    J=  6    P(I,J)= 0.0000
I= 18    J=  7    P(I,J)= 0.0000
I= 18    J=  8    P(I,J)= 0.0000
I= 18    J=  9    P(I,J)= 0.0000
I= 18    J= 10    P(I,J)= 0.0000
I= 18    J= 11    P(I,J)= 0.0000
I= 18    J= 12    P(I,J)= 0.0000
I= 18    J= 13    P(I,J)= 0.0000
I= 18    J= 14    P(I,J)= 0.0000
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I= 18          J= 15          P(I,J)= 0.0000
I= 18          J= 16          P(I,J)= 0.0000
I= 18          J= 17          P(I,J)= 0.0000
I= 19          J=  1          P(I,J)= 0.0000
I= 19          J=  2          P(I,J)= 0.6200
I= 19          J=  3          P(I,J)= 0.2900
I= 19          J=  4          P(I,J)= 0.0000
I= 19          J=  5          P(I,J)= 0.0000
I= 19          J=  6          P(I,J)= 0.0000
I= 19          J=  7          P(I,J)= 0.0000
I= 19          J=  8          P(I,J)= 0.0900
I= 19          J=  9          P(I,J)= 0.0000
I= 19          J= 10          P(I,J)= 0.0000
I= 19          J= 11          P(I,J)= 0.0000
I= 19          J= 12          P(I,J)= 0.0000
I= 19          J= 13          P(I,J)= 0.0000
I= 19          J= 14          P(I,J)= 0.0000
I= 19          J= 15          P(I,J)= 0.0000
I= 19          J= 16          P(I,J)= 0.0000
I= 19          J= 17          P(I,J)= 0.0000
I= 19          J= 18          P(I,J)= 0.0000
```

K= 1	I= 2	SL(K,I)= 0.576E 00
K= 2	I= 2	SL(K,I)= 0.626E 00
K= 3	I= 2	SL(K,I)= 0.666E 00
K= 4	I= 2	SL(K,I)= 0.698E 00
K= 5	I= 2	SL(K,I)= 0.724E 00
K= 6	I= 2	SL(K,I)= 0.745E 00
K= 7	I= 2	SL(K,I)= 0.762E 00
K= 8	I= 2	SL(K,I)= 0.774E 00
K= 9	I= 2	SL(K,I)= 0.784E 00
K= 10	I= 2	SL(K,I)= 0.792E 00
K= 11	I= 2	SL(K,I)= 0.797E 00
K= 12	I= 2	SL(K,I)= 0.801E 00
K= 13	I= 2	SL(K,I)= 0.796E 00
K= 13	I= 3	SL(K,I)= 0.819E-02
K= 14	I= 2	SL(K,I)= 0.788E 00
K= 14	I= 3	SL(K,I)= 0.202E-01
K= 15	I= 2	SL(K,I)= 0.778E 00
K= 15	I= 3	SL(K,I)= 0.342E-01
K= 16	I= 2	SL(K,I)= 0.767E 00
K= 16	I= 3	SL(K,I)= 0.498E-01
K= 17	I= 2	SL(K,I)= 0.754E 00
K= 17	I= 3	SL(K,I)= 0.659E-01
K= 18	I= 2	SL(K,I)= 0.742E 00
K= 18	I= 3	SL(K,I)= 0.817E-01
K= 19	I= 2	SL(K,I)= 0.608E 00
K= 19	I= 3	SL(K,I)= 0.841E-01
K= 19	I= 4	SL(K,I)= 0.177E 00
K= 20	I= 2	SL(K,I)= 0.586E 00
K= 20	I= 3	SL(K,I)= 0.941E-01
K= 20	I= 4	SL(K,I)= 0.197E 00
K= 21	I= 2	SL(K,I)= 0.553E 00
K= 21	I= 3	SL(K,I)= 0.104E 00
K= 21	I= 4	SL(K,I)= 0.207E 00
K= 21	I= 5	SL(K,I)= 0.343E-01
K= 22	I= 2	SL(K,I)= 0.470E 00
K= 22	I= 3	SL(K,I)= 0.103E 00
K= 22	I= 4	SL(K,I)= 0.181E 00
K= 22	I= 5	SL(K,I)= 0.589E-01
K= 22	I= 6	SL(K,I)= 0.119E 00
K= 23	I= 2	SL(K,I)= 0.423E 00
K= 23	I= 3	SL(K,I)= 0.105E 00
K= 23	I= 4	SL(K,I)= 0.174E 00
K= 23	I= 5	SL(K,I)= 0.524E-01
K= 23	I= 6	SL(K,I)= 0.127E 00
K= 23	I= 7	SL(K,I)= 0.680E-01
K= 23	I= 8	SL(K,I)= 0.411E-02
K= 24	I= 2	SL(K,I)= 0.397E 00
K= 24	I= 3	SL(K,I)= 0.107E 00
K= 24	I= 4	SL(K,I)= 0.173E 00
K= 24	I= 5	SL(K,I)= 0.504E-01

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K= 24    I=  6    SL(K,I)= 0.132E 00
K= 24    I=  7    SL(K,I)= 0.945E-01
K= 24    I=  8    SL(K,I)= 0.109E-01
K= 25    I=  2    SL(K,I)= 0.380E 00
K= 25    I=  3    SL(K,I)= 0.110E 00
K= 25    I=  4    SL(K,I)= 0.173E 00
K= 25    I=  5    SL(K,I)= 0.504E-01
K= 25    I=  6    SL(K,I)= 0.136E 00
K= 25    I=  7    SL(K,I)= 0.101E 00
K= 25    I=  8    SL(K,I)= 0.182E-01
K= 26    I=  2    SL(K,I)= 0.343E 00
K= 26    I=  3    SL(K,I)= 0.107E 00
K= 26    I=  4    SL(K,I)= 0.159E 00
K= 26    I=  5    SL(K,I)= 0.498E-01
K= 26    I=  6    SL(K,I)= 0.126E 00
K= 26    I=  7    SL(K,I)= 0.986E-01
K= 26    I=  8    SL(K,I)= 0.253E-01
K= 26    I=  9    SL(K,I)= 0.718E-01
K= 26    I= 10    SL(K,I)= 0.339E-03
K= 27    I=  2    SL(K,I)= 0.302E 00
K= 27    I=  3    SL(K,I)= 0.102E 00
K= 27    I=  4    SL(K,I)= 0.144E 00
K= 27    I=  5    SL(K,I)= 0.431E-01
K= 27    I=  6    SL(K,I)= 0.116E 00
K= 27    I=  7    SL(K,I)= 0.889E-01
K= 27    I=  8    SL(K,I)= 0.308E-01
K= 27    I=  9    SL(K,I)= 0.754E-01
K= 27    I= 10    SL(K,I)= 0.115E-02
K= 27    I= 11    SL(K,I)= 0.334E-01
K= 27    I= 12    SL(K,I)= 0.588E-01
K= 28    I=  2    SL(K,I)= 0.274E 00
K= 28    I=  3    SL(K,I)= 0.996E-01
K= 28    I=  4    SL(K,I)= 0.134E 00
K= 28    I=  5    SL(K,I)= 0.387E-01
K= 28    I=  6    SL(K,I)= 0.110E 00
K= 28    I=  7    SL(K,I)= 0.824E-01
K= 28    I=  8    SL(K,I)= 0.361E-01
K= 28    I=  9    SL(K,I)= 0.748E-01
K= 28    I= 10    SL(K,I)= 0.198E-02
K= 28    I= 11    SL(K,I)= 0.386E-01
K= 28    I= 12    SL(K,I)= 0.606E-01
K= 28    I= 13    SL(K,I)= 0.157E-01
K= 28    I= 14    SL(K,I)= 0.406E-01
K= 29    I=  2    SL(K,I)= 0.258E 00
K= 29    I=  3    SL(K,I)= 0.988E-01
K= 29    I=  4    SL(K,I)= 0.129E 00
K= 29    I=  5    SL(K,I)= 0.369E-01
K= 29    I=  6    SL(K,I)= 0.107E 00
K= 29    I=  7    SL(K,I)= 0.802E-01
K= 29    I=  8    SL(K,I)= 0.408E-01
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K= 29    I=  9    SL(K,I)= 0.762E-01
K= 29    I= 10    SL(K,I)= 0.278E-02
K= 29    I= 11    SL(K,I)= 0.435E-01
K= 29    I= 12    SL(K,I)= 0.617E-01
K= 29    I= 13    SL(K,I)= 0.202E-01
K= 29    I= 14    SL(K,I)= 0.558E-01
K= 30    I=  2    SL(K,I)= 0.236E 00
K= 30    I=  3    SL(K,I)= 0.958E-01
K= 30    I=  4    SL(K,I)= 0.120E 00
K= 30    I=  5    SL(K,I)= 0.352E-01
K= 30    I=  6    SL(K,I)= 0.100E 00
K= 30    I=  7    SL(K,I)= 0.754E-01
K= 30    I=  8    SL(K,I)= 0.441E-01
K= 30    I=  9    SL(K,I)= 0.726E-01
K= 30    I= 10    SL(K,I)= 0.354E-02
K= 30    I= 11    SL(K,I)= 0.457E-01
K= 30    I= 12    SL(K,I)= 0.595E-01
K= 30    I= 13    SL(K,I)= 0.214E-01
K= 30    I= 14    SL(K,I)= 0.559E-01
K= 30    I= 15    SL(K,I)= 0.425E-01
K= 30    I= 16    SL(K,I)= 0.111E-01
K= 31    I=  2    SL(K,I)= 0.218E 00
K= 31    I=  3    SL(K,I)= 0.922E-01
K= 31    I=  4    SL(K,I)= 0.112E 00
K= 31    I=  5    SL(K,I)= 0.334E-01
K= 31    I=  6    SL(K,I)= 0.943E-01
K= 31    I=  7    SL(K,I)= 0.717E-01
K= 31    I=  8    SL(K,I)= 0.459E-01
K= 31    I=  9    SL(K,I)= 0.698E-01
K= 31    I= 10    SL(K,I)= 0.432E-02
K= 31    I= 11    SL(K,I)= 0.468E-01
K= 31    I= 12    SL(K,I)= 0.580E-01
K= 31    I= 13    SL(K,I)= 0.217E-01
K= 31    I= 14    SL(K,I)= 0.550E-01
K= 31    I= 15    SL(K,I)= 0.456E-01
K= 31    I= 16    SL(K,I)= 0.385E-01
K= 31    I= 17    SL(K,I)= 0.181E-01
K= 32    I=  2    SL(K,I)= 0.208E 00
K= 32    I=  3    SL(K,I)= 0.912E-01
K= 32    I=  4    SL(K,I)= 0.109E 00
K= 32    I=  5    SL(K,I)= 0.323E-01
K= 32    I=  6    SL(K,I)= 0.928E-01
K= 32    I=  7    SL(K,I)= 0.700E-01
K= 32    I=  8    SL(K,I)= 0.482E-01
K= 32    I=  9    SL(K,I)= 0.704E-01
K= 32    I= 10    SL(K,I)= 0.503E-02
K= 32    I= 11    SL(K,I)= 0.500E-01
K= 32    I= 12    SL(K,I)= 0.576E-01
K= 32    I= 13    SL(K,I)= 0.217E-01
K= 32    I= 14    SL(K,I)= 0.569E-01
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K= 32          I= 15          SL(K,I)= 0.486E-01
K= 32          I= 16          SL(K,I)= 0.435E-01
K= 32          I= 17          SL(K,I)= 0.238E-01
K= 33          I=  2          SL(K,I)= 0.197E 00
K= 33          I=  3          SL(K,I)= 0.883E-01
K= 33          I=  4          SL(K,I)= 0.104E 00
K= 33          I=  5          SL(K,I)= 0.309E-01
K= 33          I=  6          SL(K,I)= 0.895E-01
K= 33          I=  7          SL(K,I)= 0.679E-01
K= 33          I=  8          SL(K,I)= 0.490E-01
K= 33          I=  9          SL(K,I)= 0.693E-01
K= 33          I= 10          SL(K,I)= 0.566E-02
K= 33          I= 11          SL(K,I)= 0.507E-01
K= 33          I= 12          SL(K,I)= 0.568E-01
K= 33          I= 13          SL(K,I)= 0.214E-01
K= 33          I= 14          SL(K,I)= 0.570E-01
K= 33          I= 15          SL(K,I)= 0.494E-01
K= 33          I= 16          SL(K,I)= 0.450E-01
K= 33          I= 17          SL(K,I)= 0.265E-01
K= 33          I= 18          SL(K,I)= 0.148E-01
K= 33          I= 19          SL(K,I)= 0.101E-01
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I=  2      J=  1      EGAM=  0.8470
K=  1        EN(K)=  1.000        SB= 0.576E 00
K=  2        EN(K)=  1.100        SB= 0.626E 00
K=  3        EN(K)=  1.200        SB= 0.666E 00
K=  4        EN(K)=  1.300        SB= 0.698E 00
K=  5        EN(K)=  1.400        SB= 0.724E 00
K=  6        EN(K)=  1.500        SB= 0.745E 00
K=  7        EN(K)=  1.600        SB= 0.762E 00
K=  8        EN(K)=  1.700        SB= 0.774E 00
K=  9        EN(K)=  1.800        SB= 0.784E 00
K= 10        EN(K)=  1.900        SB= 0.792E 00
K= 11        EN(K)=  2.000        SB= 0.797E 00
K= 12        EN(K)=  2.100        SB= 0.801E 00
K= 13        EN(K)=  2.200        SB= 0.804E 00
K= 14        EN(K)=  2.300        SB= 0.808E 00
K= 15        EN(K)=  2.400        SB= 0.812E 00
K= 16        EN(K)=  2.500        SB= 0.816E 00
K= 17        EN(K)=  2.600        SB= 0.819E 00
K= 18        EN(K)=  2.700        SB= 0.823E 00
K= 19        EN(K)=  2.800        SB= 0.865E 00
K= 20        EN(K)=  2.900        SB= 0.873E 00
K= 21        EN(K)=  3.000        SB= 0.894E 00
K= 22        EN(K)=  3.100        SB= 0.925E 00
K= 23        EN(K)=  3.200        SB= 0.945E 00
K= 24        EN(K)=  3.300        SB= 0.955E 00
K= 25        EN(K)=  3.400        SB= 0.959E 00
K= 26        EN(K)=  3.500        SB= 0.960E 00
K= 27        EN(K)=  3.600        SB= 0.946E 00
K= 28        EN(K)=  3.700        SB= 0.936E 00
K= 29        EN(K)=  3.800        SB= 0.931E 00
K= 30        EN(K)=  3.900        SB= 0.894E 00
K= 31        EN(K)=  4.000        SB= 0.888E 00
K= 32        EN(K)=  4.100        SB= 0.886E 00
K= 33        EN(K)=  4.200        SB= 0.888E 00
I=  3      J=  2      EGAM=  1.2379
K= 13        EN(K)=  2.200        SB= 0.819E-02
K= 14        EN(K)=  2.300        SB= 0.202E-01
K= 15        EN(K)=  2.400        SB= 0.342E-01
K= 16        EN(K)=  2.500        SB= 0.498E-01
K= 17        EN(K)=  2.600        SB= 0.659E-01
K= 18        EN(K)=  2.700        SB= 0.817E-01
K= 19        EN(K)=  2.800        SB= 0.841E-01
K= 20        EN(K)=  2.900        SB= 0.941E-01
K= 21        EN(K)=  3.000        SB= 0.104E 00
K= 22        EN(K)=  3.100        SB= 0.103E 00
K= 23        EN(K)=  3.200        SB= 0.109E 00
K= 24        EN(K)=  3.300        SB= 0.117E 00
K= 25        EN(K)=  3.400        SB= 0.128E 00
K= 26        EN(K)=  3.500        SB= 0.132E 00
K= 27        EN(K)=  3.600        SB= 0.139E 00
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K= 28          EN(K)=  3.700          SB= 0.143E 00
K= 29          EN(K)=  3.800          SB= 0.147E 00
K= 30          EN(K)=  3.900          SB= 0.148E 00
K= 31          EN(K)=  4.000          SB= 0.163E 00
K= 32          EN(K)=  4.100          SB= 0.170E 00
K= 33          EN(K)=  4.200          SB= 0.177E 00
I=  4     J=  1       EGAM=  2.6570
K= 19          EN(K)=  2.800          SB= 0.353E-02
K= 20          EN(K)=  2.900          SB= 0.394E-02
K= 21          EN(K)=  3.000          SB= 0.413E-02
K= 22          EN(K)=  3.100          SB= 0.362E-02
K= 23          EN(K)=  3.200          SB= 0.347E-02
K= 24          EN(K)=  3.300          SB= 0.345E-02
K= 25          EN(K)=  3.400          SB= 0.345E-02
K= 26          EN(K)=  3.500          SB= 0.317E-02
K= 27          EN(K)=  3.600          SB= 0.290E-02
K= 28          EN(K)=  3.700          SB= 0.270E-02
K= 29          EN(K)=  3.800          SB= 0.260E-02
K= 30          EN(K)=  3.900          SB= 0.248E-02
K= 31          EN(K)=  4.000          SB= 0.248E-02
K= 32          EN(K)=  4.100          SB= 0.245E-02
K= 33          EN(K)=  4.200          SB= 0.236E-02
I=  4     J=  2       EGAM=  1.8099
K= 19          EN(K)=  2.800          SB= 0.173E 00
K= 20          EN(K)=  2.900          SB= 0.193E 00
K= 21          EN(K)=  3.000          SB= 0.202E 00
K= 22          EN(K)=  3.100          SB= 0.177E 00
K= 23          EN(K)=  3.200          SB= 0.170E 00
K= 24          EN(K)=  3.300          SB= 0.169E 00
K= 25          EN(K)=  3.400          SB= 0.169E 00
K= 26          EN(K)=  3.500          SB= 0.155E 00
K= 27          EN(K)=  3.600          SB= 0.142E 00
K= 28          EN(K)=  3.700          SB= 0.132E 00
K= 29          EN(K)=  3.800          SB= 0.127E 00
K= 30          EN(K)=  3.900          SB= 0.121E 00
K= 31          EN(K)=  4.000          SB= 0.121E 00
K= 32          EN(K)=  4.100          SB= 0.120E 00
K= 33          EN(K)=  4.200          SB= 0.115E 00
I=  5     J=  2       EGAM=  2.0920
K= 21          EN(K)=  3.000          SB= 0.343E-01
K= 22          EN(K)=  3.100          SB= 0.589E-01
K= 23          EN(K)=  3.200          SB= 0.524E-01
K= 24          EN(K)=  3.300          SB= 0.504E-01
K= 25          EN(K)=  3.400          SB= 0.504E-01
K= 26          EN(K)=  3.500          SB= 0.498E-01
K= 27          EN(K)=  3.600          SB= 0.431E-01
K= 28          EN(K)=  3.700          SB= 0.387E-01
K= 29          EN(K)=  3.800          SB= 0.369E-01
K= 30          EN(K)=  3.900          SB= 0.352E-01
K= 31          EN(K)=  4.000          SB= 0.334E-01
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K= 32          EN(K)=  4.100          SB= 0.323E-01
K= 33          EN(K)=  4.200          SB= 0.309E-01
I=  6     J=   1       EGAM=  2.9600
K= 22          EN(K)=  3.100          SB= 0.237E-02
K= 23          EN(K)=  3.200          SB= 0.253E-02
K= 24          EN(K)=  3.300          SB= 0.264E-02
K= 25          EN(K)=  3.400          SB= 0.271E-02
K= 26          EN(K)=  3.500          SB= 0.252E-02
K= 27          EN(K)=  3.600          SB= 0.231E-02
K= 28          EN(K)=  3.700          SB= 0.219E-02
K= 29          EN(K)=  3.800          SB= 0.214E-02
K= 30          EN(K)=  3.900          SB= 0.199E-02
K= 31          EN(K)=  4.000          SB= 0.188E-02
K= 32          EN(K)=  4.100          SB= 0.185E-02
K= 33          EN(K)=  4.200          SB= 0.178E-02
I=  6     J=   2       EGAM=  2.1129
K= 22          EN(K)=  3.100          SB= 0.116E 00
K= 23          EN(K)=  3.200          SB= 0.124E 00
K= 24          EN(K)=  3.300          SB= 0.129E 00
K= 25          EN(K)=  3.400          SB= 0.133E 00
K= 26          EN(K)=  3.500          SB= 0.123E 00
K= 27          EN(K)=  3.600          SB= 0.113E 00
K= 28          EN(K)=  3.700          SB= 0.107E 00
K= 29          EN(K)=  3.800          SB= 0.104E 00
K= 30          EN(K)=  3.900          SB= 0.979E-01
K= 31          EN(K)=  4.000          SB= 0.924E-01
K= 32          EN(K)=  4.100          SB= 0.909E-01
K= 33          EN(K)=  4.200          SB= 0.877E-01
I=  7     J=   1       EGAM=  3.1190
K= 23          EN(K)=  3.200          SB= 0.203E-02
K= 24          EN(K)=  3.300          SB= 0.283E-02
K= 25          EN(K)=  3.400          SB= 0.302E-02
K= 26          EN(K)=  3.500          SB= 0.295E-02
K= 27          EN(K)=  3.600          SB= 0.266E-02
K= 28          EN(K)=  3.700          SB= 0.247E-02
K= 29          EN(K)=  3.800          SB= 0.240E-02
K= 30          EN(K)=  3.900          SB= 0.226E-02
K= 31          EN(K)=  4.000          SB= 0.215E-02
K= 32          EN(K)=  4.100          SB= 0.209E-02
K= 33          EN(K)=  4.200          SB= 0.203E-02
I=  7     J=   2       EGAM=  2.2720
K= 23          EN(K)=  3.200          SB= 0.659E-01
K= 24          EN(K)=  3.300          SB= 0.916E-01
K= 25          EN(K)=  3.400          SB= 0.979E-01
K= 26          EN(K)=  3.500          SB= 0.956E-01
K= 27          EN(K)=  3.600          SB= 0.862E-01
K= 28          EN(K)=  3.700          SB= 0.799E-01
K= 29          EN(K)=  3.800          SB= 0.777E-01
K= 30          EN(K)=  3.900          SB= 0.731E-01
K= 31          EN(K)=  4.000          SB= 0.695E-01
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K= 32          EN(K)=  4.100          SB= 0.678E-01
K= 33          EN(K)=  4.200          SB= 0.658E-01
I=  8     J=  3       EGAM=  1.0380
K= 23          EN(K)=  3.200          SB= 0.411E-02
K= 24          EN(K)=  3.300          SB= 0.109E-01
K= 25          EN(K)=  3.400          SB= 0.182E-01
K= 26          EN(K)=  3.500          SB= 0.253E-01
K= 27          EN(K)=  3.600          SB= 0.308E-01
K= 28          EN(K)=  3.700          SB= 0.361E-01
K= 29          EN(K)=  3.800          SB= 0.408E-01
K= 30          EN(K)=  3.900          SB= 0.441E-01
K= 31          EN(K)=  4.000          SB= 0.460E-01
K= 32          EN(K)=  4.100          SB= 0.484E-01
K= 33          EN(K)=  4.200          SB= 0.501E-01
I=  9     J=  1       EGAM=  3.3690
K= 26          EN(K)=  3.500          SB= 0.114E-01
K= 27          EN(K)=  3.600          SB= 0.120E-01
K= 28          EN(K)=  3.700          SB= 0.119E-01
K= 29          EN(K)=  3.800          SB= 0.121E-01
K= 30          EN(K)=  3.900          SB= 0.116E-01
K= 31          EN(K)=  4.000          SB= 0.111E-01
K= 32          EN(K)=  4.100          SB= 0.112E-01
K= 33          EN(K)=  4.200          SB= 0.110E-01
I=  9     J=  2       EGAM=  2.5220
K= 26          EN(K)=  3.500          SB= 0.603E-01
K= 27          EN(K)=  3.600          SB= 0.633E-01
K= 28          EN(K)=  3.700          SB= 0.628E-01
K= 29          EN(K)=  3.800          SB= 0.640E-01
K= 30          EN(K)=  3.900          SB= 0.609E-01
K= 31          EN(K)=  4.000          SB= 0.586E-01
K= 32          EN(K)=  4.100          SB= 0.591E-01
K= 33          EN(K)=  4.200          SB= 0.582E-01
I= 11     J=  2       EGAM=  2.5980
K= 27          EN(K)=  3.600          SB= 0.260E-01
K= 28          EN(K)=  3.700          SB= 0.301E-01
K= 29          EN(K)=  3.800          SB= 0.339E-01
K= 30          EN(K)=  3.900          SB= 0.356E-01
K= 31          EN(K)=  4.000          SB= 0.365E-01
K= 32          EN(K)=  4.100          SB= 0.389E-01
K= 33          EN(K)=  4.200          SB= 0.395E-01
I= 11     J=  3       EGAM=  1.3600
K= 27          EN(K)=  3.600          SB= 0.634E-02
K= 28          EN(K)=  3.700          SB= 0.733E-02
K= 29          EN(K)=  3.800          SB= 0.826E-02
K= 30          EN(K)=  3.900          SB= 0.868E-02
K= 31          EN(K)=  4.000          SB= 0.889E-02
K= 32          EN(K)=  4.100          SB= 0.950E-02
K= 33          EN(K)=  4.200          SB= 0.963E-02
I= 11     J=  4       EGAM=  0.7880
K= 27          EN(K)=  3.600          SB= 0.100E-02
```

```
K= 28          EN(K)=  3.700          SB= 0.115E-02
K= 29          EN(K)=  3.800          SB= 0.130E-02
K= 30          EN(K)=  3.900          SB= 0.137E-02
K= 31          EN(K)=  4.000          SB= 0.140E-02
K= 32          EN(K)=  4.100          SB= 0.150E-02
K= 33          EN(K)=  4.200          SB= 0.152E-02
I= 12     J=  1       EGAM=  3.4500
K= 27          EN(K)=  3.600          SB= 0.270E-01
K= 28          EN(K)=  3.700          SB= 0.278E-01
K= 29          EN(K)=  3.800          SB= 0.283E-01
K= 30          EN(K)=  3.900          SB= 0.273E-01
K= 31          EN(K)=  4.000          SB= 0.266E-01
K= 32          EN(K)=  4.100          SB= 0.264E-01
K= 33          EN(K)=  4.200          SB= 0.261E-01
I= 12     J=  2       EGAM=  2.6030
K= 27          EN(K)=  3.600          SB= 0.317E-01
K= 28          EN(K)=  3.700          SB= 0.327E-01
K= 29          EN(K)=  3.800          SB= 0.333E-01
K= 30          EN(K)=  3.900          SB= 0.321E-01
K= 31          EN(K)=  4.000          SB= 0.313E-01
K= 32          EN(K)=  4.100          SB= 0.311E-01
K= 33          EN(K)=  4.200          SB= 0.306E-01
I= 13     J=  2       EGAM=  2.7520
K= 28          EN(K)=  3.700          SB= 0.157E-01
K= 29          EN(K)=  3.800          SB= 0.202E-01
K= 30          EN(K)=  3.900          SB= 0.214E-01
K= 31          EN(K)=  4.000          SB= 0.217E-01
K= 32          EN(K)=  4.100          SB= 0.217E-01
K= 33          EN(K)=  4.200          SB= 0.214E-01
I= 14     J=  1       EGAM=  3.6050
K= 28          EN(K)=  3.700          SB= 0.198E-01
K= 29          EN(K)=  3.800          SB= 0.273E-01
K= 30          EN(K)=  3.900          SB= 0.273E-01
K= 31          EN(K)=  4.000          SB= 0.269E-01
K= 32          EN(K)=  4.100          SB= 0.278E-01
K= 33          EN(K)=  4.200          SB= 0.279E-01
I= 14     J=  2       EGAM=  2.7579
K= 28          EN(K)=  3.700          SB= 0.207E-01
K= 29          EN(K)=  3.800          SB= 0.284E-01
K= 30          EN(K)=  3.900          SB= 0.285E-01
K= 31          EN(K)=  4.000          SB= 0.280E-01
K= 32          EN(K)=  4.100          SB= 0.290E-01
K= 33          EN(K)=  4.200          SB= 0.290E-01
I= 16     J=  1       EGAM=  3.8290
K= 30          EN(K)=  3.900          SB= 0.888E-03
K= 31          EN(K)=  4.000          SB= 0.307E-02
K= 32          EN(K)=  4.100          SB= 0.347E-02
K= 33          EN(K)=  4.200          SB= 0.359E-02
I= 16     J=  2       EGAM=  2.9820
K= 30          EN(K)=  3.900          SB= 0.710E-02
```

APPENDIX D. RESULTS OF Pb^{208} CROSS SECTION CALCULATIONS IN TABULAR FORM

```
KMAX= 15
K=  1          EN(K)=  2.7000          EA(K)=  2.6870
K=  2          EN(K)=  2.8000          EA(K)=  2.7865
K=  3          EN(K)=  2.9000          EA(K)=  2.8860
K=  4          EN(K)=  3.0000          EA(K)=  2.9855
K=  5          EN(K)=  3.1000          EA(K)=  3.0850
K=  6          EN(K)=  3.2000          EA(K)=  3.1846
K=  7          EN(K)=  3.3000          EA(K)=  3.2841
K=  8          EN(K)=  3.4000          EA(K)=  3.3836
K=  9          EN(K)=  3.5000          EA(K)=  3.4831
K= 10          EN(K)=  3.6000          EA(K)=  3.5826
K= 11          EN(K)=  3.7000          EA(K)=  3.6821
K= 12          EN(K)=  3.8000          EA(K)=  3.7817
K= 13          EN(K)=  3.9000          EA(K)=  3.8812
K= 14          EN(K)=  4.0000          EA(K)=  3.9807
K= 15          EN(K)=  4.1000          EA(K)=  4.0802
```

```
N=  9

I=  2          ELEV(I)=  2.6150

I=  3          ELEV(I)=  3.1980

I=  4          ELEV(I)=  3.4750

I=  5          ELEV(I)=  3.7080

I=  6          ELEV(I)=  3.7500

I=  7          ELEV(I)=  3.9200

I=  8          ELEV(I)=  3.9610

I=  9          ELEV(I)=  3.9990
```

I= 2	J= 1	P(I,J)= 1.0000
I= 3	J= 1	P(I,J)= 0.0000
I= 3	J= 2	P(I,J)= 1.0000
I= 4	J= 1	P(I,J)= 0.0000
I= 4	J= 2	P(I,J)= 0.6490
I= 4	J= 3	P(I,J)= 0.3510
I= 5	J= 1	P(I,J)= 0.0000
I= 5	J= 2	P(I,J)= 0.0160
I= 5	J= 3	P(I,J)= 0.9700
I= 5	J= 4	P(I,J)= 0.0140
I= 6	J= 1	P(I,J)= 0.0000
I= 6	J= 2	P(I,J)= 0.0000
I= 6	J= 3	P(I,J)= 0.0000
I= 6	J= 4	P(I,J)= 0.0000
I= 6	J= 5	P(I,J)= 0.0000
I= 7	J= 1	P(I,J)= 0.0000
I= 7	J= 2	P(I,J)= 0.0000
I= 7	J= 3	P(I,J)= 0.6140
I= 7	J= 4	P(I,J)= 0.0000
I= 7	J= 5	P(I,J)= 0.3860
I= 7	J= 6	P(I,J)= 0.0000
I= 8	J= 1	P(I,J)= 0.0000
I= 8	J= 2	P(I,J)= 0.0000
I= 8	J= 3	P(I,J)= 0.6910
I= 8	J= 4	P(I,J)= 0.0210
I= 8	J= 5	P(I,J)= 0.2880
I= 8	J= 6	P(I,J)= 0.0000
I= 8	J= 7	P(I,J)= 0.0000
I= 9	J= 1	P(I,J)= 0.0000
I= 9	J= 2	P(I,J)= 1.0000
I= 9	J= 3	P(I,J)= 0.0000
I= 9	J= 4	P(I,J)= 0.0000
I= 9	J= 5	P(I,J)= 0.0000
I= 9	J= 6	P(I,J)= 0.0000
I= 9	J= 7	P(I,J)= 0.0000
I= 9	J= 8	P(I,J)= 0.0000

C. 5

K= 1	I= 2	SL(K,I)= 0.241E 00
K= 2	I= 2	SL(K,I)= 0.396E 00
K= 3	I= 2	SL(K,I)= 0.499E 00
K= 4	I= 2	SL(K,I)= 0.587E 00
K= 5	I= 2	SL(K,I)= 0.657E 00
K= 6	I= 2	SL(K,I)= 0.718E 00
K= 7	I= 2	SL(K,I)= 0.722E 00
K= 7	I= 3	SL(K,I)= 0.902E-01
K= 8	I= 2	SL(K,I)= 0.743E 00
K= 8	I= 3	SL(K,I)= 0.129E 00
K= 9	I= 2	SL(K,I)= 0.753E 00
K= 9	I= 3	SL(K,I)= 0.157E 00
K= 9	I= 4	SL(K,I)= 0.283E-01
K= 10	I= 2	SL(K,I)= 0.741E 00
K= 10	I= 3	SL(K,I)= 0.175E 00
K= 10	I= 4	SL(K,I)= 0.100E 00
K= 11	I= 2	SL(K,I)= 0.736E 00
K= 11	I= 3	SL(K,I)= 0.193E 00
K= 11	I= 4	SL(K,I)= 0.142E 00
K= 12	I= 2	SL(K,I)= 0.707E 00
K= 12	I= 3	SL(K,I)= 0.194E 00
K= 12	I= 4	SL(K,I)= 0.167E 00
K= 12	I= 5	SL(K,I)= 0.336E-01
K= 12	I= 6	SL(K,I)= 0.477E-01
K= 13	I= 2	SL(K,I)= 0.676E 00
K= 13	I= 3	SL(K,I)= 0.199E 00
K= 13	I= 4	SL(K,I)= 0.187E 00
K= 13	I= 5	SL(K,I)= 0.555E-01
K= 13	I= 6	SL(K,I)= 0.982E-01
K= 14	I= 2	SL(K,I)= 0.651E 00
K= 14	I= 3	SL(K,I)= 0.203E 00
K= 14	I= 4	SL(K,I)= 0.203E 00
K= 14	I= 5	SL(K,I)= 0.719E-01
K= 14	I= 6	SL(K,I)= 0.132E 00
K= 14	I= 7	SL(K,I)= 0.154E-02
K= 14	I= 8	SL(K,I)= 0.408E-02
K= 15	I= 2	SL(K,I)= 0.622E 00
K= 15	I= 3	SL(K,I)= 0.197E 00
K= 15	I= 4	SL(K,I)= 0.212E 00
K= 15	I= 5	SL(K,I)= 0.820E-01
K= 15	I= 6	SL(K,I)= 0.159E 00
K= 15	I= 7	SL(K,I)= 0.455E-02
K= 15	I= 8	SL(K,I)= 0.119E-01
K= 15	I= 9	SL(K,I)= 0.238E-01

```
I=  2      J=  1      EGAM=  2.6150
K=  1       EN(K)=  2.700          SB= 0.241E 00
K=  2       EN(K)=  2.800          SB= 0.396E 00
K=  3       EN(K)=  2.900          SB= 0.499E 00
K=  4       EN(K)=  3.000          SB= 0.587E 00
K=  5       EN(K)=  3.100          SB= 0.657E 00
K=  6       EN(K)=  3.200          SB= 0.718E 00
K=  7       EN(K)=  3.300          SB= 0.812E 00
K=  8       EN(K)=  3.400          SB= 0.871E 00
K=  9       EN(K)=  3.500          SB= 0.938E 00
K= 10       EN(K)=  3.600          SB= 0.101E 01
K= 11       EN(K)=  3.700          SB= 0.107E 01
K= 12       EN(K)=  3.800          SB= 0.110E 01
K= 13       EN(K)=  3.900          SB= 0.111E 01
K= 14       EN(K)=  4.000          SB= 0.113E 01
K= 15       EN(K)=  4.100          SB= 0.114E 01
I=  3      J=  2      EGAM=  0.5830
K=  7       EN(K)=  3.300          SB= 0.902E-01
K=  8       EN(K)=  3.400          SB= 0.129E 00
K=  9       EN(K)=  3.500          SB= 0.166E 00
K= 10       EN(K)=  3.600          SB= 0.210E 00
K= 11       EN(K)=  3.700          SB= 0.242E 00
K= 12       EN(K)=  3.800          SB= 0.285E 00
K= 13       EN(K)=  3.900          SB= 0.318E 00
K= 14       EN(K)=  4.000          SB= 0.348E 00
K= 15       EN(K)=  4.100          SB= 0.362E 00
I=  4      J=  2      EGAM=  0.8600
K=  9       EN(K)=  3.500          SB= 0.183E-01
K= 10       EN(K)=  3.600          SB= 0.648E-01
K= 11       EN(K)=  3.700          SB= 0.921E-01
K= 12       EN(K)=  3.800          SB= 0.108E 00
K= 13       EN(K)=  3.900          SB= 0.121E 00
K= 14       EN(K)=  4.000          SB= 0.132E 00
K= 15       EN(K)=  4.100          SB= 0.138E 00
I=  4      J=  3      EGAM=  0.2770
K=  9       EN(K)=  3.500          SB= 0.993E-02
K= 10       EN(K)=  3.600          SB= 0.350E-01
K= 11       EN(K)=  3.700          SB= 0.498E-01
K= 12       EN(K)=  3.800          SB= 0.587E-01
K= 13       EN(K)=  3.900          SB= 0.659E-01
K= 14       EN(K)=  4.000          SB= 0.716E-01
K= 15       EN(K)=  4.100          SB= 0.749E-01
I=  5      J=  2      EGAM=  1.0930
K= 12       EN(K)=  3.800          SB= 0.537E-03
K= 13       EN(K)=  3.900          SB= 0.887E-03
K= 14       EN(K)=  4.000          SB= 0.117E-02
K= 15       EN(K)=  4.100          SB= 0.139E-02
I=  5      J=  3      EGAM=  0.5099
K= 12       EN(K)=  3.800          SB= 0.325E-01
K= 13       EN(K)=  3.900          SB= 0.538E-01
```

```
K= 14          EN(K)=  4.000          SB= 0.714E-01
K= 15          EN(K)=  4.100          SB= 0.845E-01
I=  5     J=   4       EGAM=  0.2329
K= 12          EN(K)=  3.800          SB= 0.470E-03
K= 13          EN(K)=  3.900          SB= 0.776E-03
K= 14          EN(K)=  4.000          SB= 0.103E-02
K= 15          EN(K)=  4.100          SB= 0.122E-02
I=  7     J=   3       EGAM=  0.7219
K= 14          EN(K)=  4.000          SB= 0.945E-03
K= 15          EN(K)=  4.100          SB= 0.279E-02
I=  7     J=   5       EGAM=  0.2119
K= 14          EN(K)=  4.000          SB= 0.594E-03
K= 15          EN(K)=  4.100          SB= 0.175E-02
I=  8     J=   3       EGAM=  0.7630
K= 14          EN(K)=  4.000          SB= 0.281E-02
K= 15          EN(K)=  4.100          SB= 0.822E-02
I=  8     J=   4       EGAM=  0.4860
K= 14          EN(K)=  4.000          SB= 0.856E-04
K= 15          EN(K)=  4.100          SB= 0.249E-03
I=  8     J=   5       EGAM=  0.2530
K= 14          EN(K)=  4.000          SB= 0.117E-02
K= 15          EN(K)=  4.100          SB= 0.342E-02
I=  9     J=   2       EGAM=  1.3840
K= 15          EN(K)=  4.100          SB= 0.238E-01
```

APPENDIX E. RESULTS OF Si^{28} CROSS SECTION CALCULATIONS IN TABULAR FORM

KMAX= 46

K= 1	EN(K)= 1.9000	EA(K)= 1.8339
K= 2	EN(K)= 2.0000	EA(K)= 1.9304
K= 3	EN(K)= 2.1000	EA(K)= 2.0270
K= 4	EN(K)= 2.2000	EA(K)= 2.1235
K= 5	EN(K)= 2.3000	EA(K)= 2.2200
K= 6	EN(K)= 2.4000	EA(K)= 2.3165
K= 7	EN(K)= 2.5000	EA(K)= 2.4130
K= 8	EN(K)= 2.6000	EA(K)= 2.5096
K= 9	EN(K)= 2.7000	EA(K)= 2.6061
K= 10	EN(K)= 2.8000	EA(K)= 2.7026
K= 11	EN(K)= 2.9000	EA(K)= 2.7991
K= 12	EN(K)= 3.0000	EA(K)= 2.8957
K= 13	EN(K)= 3.1000	EA(K)= 2.9922
K= 14	EN(K)= 3.2000	EA(K)= 3.0887
K= 15	EN(K)= 3.3000	EA(K)= 3.1852
K= 16	EN(K)= 3.4000	EA(K)= 3.2817
K= 17	EN(K)= 3.5000	EA(K)= 3.3783
K= 18	EN(K)= 3.6000	EA(K)= 3.4748
K= 19	EN(K)= 3.7000	EA(K)= 3.5713
K= 20	EN(K)= 3.8000	EA(K)= 3.6678
K= 21	EN(K)= 3.9000	EA(K)= 3.7644
K= 22	EN(K)= 4.0000	EA(K)= 3.8609
K= 23	EN(K)= 4.1000	EA(K)= 3.9574
K= 24	EN(K)= 4.2000	EA(K)= 4.0539
K= 25	EN(K)= 4.3000	EA(K)= 4.1504
K= 26	EN(K)= 4.4000	EA(K)= 4.2470
K= 27	EN(K)= 4.5000	EA(K)= 4.3435
K= 28	EN(K)= 4.6000	EA(K)= 4.4400
K= 29	EN(K)= 4.7000	EA(K)= 4.5365
K= 30	EN(K)= 4.8000	EA(K)= 4.6330
K= 31	EN(K)= 4.9000	EA(K)= 4.7296
K= 32	EN(K)= 5.0000	EA(K)= 4.8261
K= 33	EN(K)= 5.1000	EA(K)= 4.9226
K= 34	EN(K)= 5.2000	EA(K)= 5.0191
K= 35	EN(K)= 5.3000	EA(K)= 5.1157
K= 36	EN(K)= 5.4000	EA(K)= 5.2122
K= 37	EN(K)= 5.5000	EA(K)= 5.3087
K= 38	EN(K)= 5.6000	EA(K)= 5.4052
K= 39	EN(K)= 5.7000	EA(K)= 5.5017
K= 40	EN(K)= 5.8000	EA(K)= 5.5983
K= 41	EN(K)= 5.9000	EA(K)= 5.6948
K= 42	EN(K)= 6.0000	EA(K)= 5.7913
K= 43	EN(K)= 6.1000	EA(K)= 5.8878
K= 44	EN(K)= 6.2000	EA(K)= 5.9844
K= 45	EN(K)= 6.3000	EA(K)= 6.0809
K= 46	EN(K)= 6.4000	EA(K)= 6.1774

```
N=  4

I=  2          ELEV(I)=  1.7800

I=  3          ELEV(I)=  4.6100

I=  4          ELEV(I)=  4.9700
```

```
I=  2          J=  1          P(I,J)= 1.0000
I=  3          J=  1          P(I,J)= 0.0000
I=  3          J=  2          P(I,J)= 1.0000
I=  4          J=  1          P(I,J)= 0.0000
I=  4          J=  2          P(I,J)= 1.0000
I=  4          J=  3          P(I,J)= 0.0000
```

```
K=  1          I=  2          SL(K,I)= 0.136E 00
K=  2          I=  2          SL(K,I)= 0.286E 00
K=  3          I=  2          SL(K,I)= 0.411E 00
K=  4          I=  2          SL(K,I)= 0.505E 00
K=  5          I=  2          SL(K,I)= 0.572E 00
K=  6          I=  2          SL(K,I)= 0.618E 00
K=  7          I=  2          SL(K,I)= 0.649E 00
K=  8          I=  2          SL(K,I)= 0.671E 00
K=  9          I=  2          SL(K,I)= 0.686E 00
K= 10          I=  2          SL(K,I)= 0.697E 00
K= 11          I=  2          SL(K,I)= 0.704E 00
K= 12          I=  2          SL(K,I)= 0.709E 00
K= 13          I=  2          SL(K,I)= 0.713E 00
K= 14          I=  2          SL(K,I)= 0.715E 00
K= 15          I=  2          SL(K,I)= 0.717E 00
K= 16          I=  2          SL(K,I)= 0.718E 00
K= 17          I=  2          SL(K,I)= 0.719E 00
K= 18          I=  2          SL(K,I)= 0.718E 00
K= 19          I=  2          SL(K,I)= 0.717E 00
K= 20          I=  2          SL(K,I)= 0.717E 00
K= 21          I=  2          SL(K,I)= 0.716E 00
K= 22          I=  2          SL(K,I)= 0.716E 00
K= 23          I=  2          SL(K,I)= 0.715E 00
K= 24          I=  2          SL(K,I)= 0.714E 00
K= 25          I=  2          SL(K,I)= 0.714E 00
K= 26          I=  2          SL(K,I)= 0.713E 00
K= 27          I=  2          SL(K,I)= 0.713E 00
K= 28          I=  2          SL(K,I)= 0.713E 00
K= 29          I=  2          SL(K,I)= 0.713E 00
K= 30          I=  2          SL(K,I)= 0.708E 00
K= 30          I=  3          SL(K,I)= 0.515E-02
K= 31          I=  2          SL(K,I)= 0.690E 00
K= 31          I=  3          SL(K,I)= 0.287E-01
K= 32          I=  2          SL(K,I)= 0.668E 00
K= 32          I=  3          SL(K,I)= 0.587E-01
K= 33          I=  2          SL(K,I)= 0.646E 00
K= 33          I=  3          SL(K,I)= 0.880E-01
K= 34          I=  2          SL(K,I)= 0.622E 00
K= 34          I=  3          SL(K,I)= 0.114E 00
K= 34          I=  4          SL(K,I)= 0.745E-02
K= 35          I=  2          SL(K,I)= 0.600E 00
K= 35          I=  3          SL(K,I)= 0.134E 00
K= 35          I=  4          SL(K,I)= 0.182E-01
K= 36          I=  2          SL(K,I)= 0.579E 00
K= 36          I=  3          SL(K,I)= 0.151E 00
K= 36          I=  4          SL(K,I)= 0.297E-01
K= 37          I=  2          SL(K,I)= 0.562E 00
K= 37          I=  3          SL(K,I)= 0.164E 00
K= 37          I=  4          SL(K,I)= 0.406E-01
K= 38          I=  2          SL(K,I)= 0.547E 00
```

```
K= 38          I=  3          SL(K,I)= 0.173E 00
K= 38          I=  4          SL(K,I)= 0.501E-01
K= 39          I=  2          SL(K,I)= 0.535E 00
K= 39          I=  3          SL(K,I)= 0.181E 00
K= 39          I=  4          SL(K,I)= 0.578E-01
K= 40          I=  2          SL(K,I)= 0.526E 00
K= 40          I=  3          SL(K,I)= 0.186E 00
K= 40          I=  4          SL(K,I)= 0.637E-01
K= 41          I=  2          SL(K,I)= 0.519E 00
K= 41          I=  3          SL(K,I)= 0.191E 00
K= 41          I=  4          SL(K,I)= 0.683E-01
K= 42          I=  2          SL(K,I)= 0.513E 00
K= 42          I=  3          SL(K,I)= 0.194E 00
K= 42          I=  4          SL(K,I)= 0.715E-01
K= 43          I=  2          SL(K,I)= 0.508E 00
K= 43          I=  3          SL(K,I)= 0.197E 00
K= 43          I=  4          SL(K,I)= 0.737E-01
K= 44          I=  2          SL(K,I)= 0.504E 00
K= 44          I=  3          SL(K,I)= 0.199E 00
K= 44          I=  4          SL(K,I)= 0.751E-01
K= 45          I=  2          SL(K,I)= 0.500E 00
K= 45          I=  3          SL(K,I)= 0.200E 00
K= 45          I=  4          SL(K,I)= 0.759E-01
K= 46          I=  2          SL(K,I)= 0.497E 00
K= 46          I=  3          SL(K,I)= 0.202E 00
K= 46          I=  4          SL(K,I)= 0.762E-01
```

```
I=  2       J=  1       EGAM=  1.7800
K=  1            EN(K)=  1.900          SB= 0.136E 00
K=  2            EN(K)=  2.000          SB= 0.286E 00
K=  3            EN(K)=  2.100          SB= 0.411E 00
K=  4            EN(K)=  2.200          SB= 0.505E 00
K=  5            EN(K)=  2.300          SB= 0.572E 00
K=  6            EN(K)=  2.400          SB= 0.618E 00
K=  7            EN(K)=  2.500          SB= 0.649E 00
K=  8            EN(K)=  2.600          SB= 0.671E 00
K=  9            EN(K)=  2.700          SB= 0.686E 00
K= 10            EN(K)=  2.800          SB= 0.697E 00
K= 11            EN(K)=  2.900          SB= 0.704E 00
K= 12            EN(K)=  3.000          SB= 0.709E 00
K= 13            EN(K)=  3.100          SB= 0.713E 00
K= 14            EN(K)=  3.200          SB= 0.715E 00
K= 15            EN(K)=  3.300          SB= 0.717E 00
K= 16            EN(K)=  3.400          SB= 0.718E 00
K= 17            EN(K)=  3.500          SB= 0.719E 00
K= 18            EN(K)=  3.600          SB= 0.718E 00
K= 19            EN(K)=  3.700          SB= 0.717E 00
K= 20            EN(K)=  3.800          SB= 0.717E 00
K= 21            EN(K)=  3.900          SB= 0.716E 00
K= 22            EN(K)=  4.000          SB= 0.716E 00
K= 23            EN(K)=  4.100          SB= 0.715E 00
K= 24            EN(K)=  4.200          SB= 0.714E 00
K= 25            EN(K)=  4.300          SB= 0.714E 00
K= 26            EN(K)=  4.400          SB= 0.713E 00
K= 27            EN(K)=  4.500          SB= 0.713E 00
K= 28            EN(K)=  4.600          SB= 0.713E 00
K= 29            EN(K)=  4.700          SB= 0.713E 00
K= 30            EN(K)=  4.800          SB= 0.713E 00
K= 31            EN(K)=  4.900          SB= 0.718E 00
K= 32            EN(K)=  5.000          SB= 0.726E 00
K= 33            EN(K)=  5.100          SB= 0.733E 00
K= 34            EN(K)=  5.200          SB= 0.743E 00
K= 35            EN(K)=  5.300          SB= 0.752E 00
K= 36            EN(K)=  5.400          SB= 0.759E 00
K= 37            EN(K)=  5.500          SB= 0.766E 00
K= 38            EN(K)=  5.600          SB= 0.770E 00
K= 39            EN(K)=  5.700          SB= 0.773E 00
K= 40            EN(K)=  5.800          SB= 0.775E 00
K= 41            EN(K)=  5.900          SB= 0.778E 00
K= 42            EN(K)=  6.000          SB= 0.778E 00
K= 43            EN(K)=  6.100          SB= 0.778E 00
K= 44            EN(K)=  6.200          SB= 0.778E 00
K= 45            EN(K)=  6.300          SB= 0.775E 00
K= 46            EN(K)=  6.400          SB= 0.775E 00
I=  3       J=  2       EGAM=  2.8299
K= 30            EN(K)=  4.800          SB= 0.515E-02
K= 31            EN(K)=  4.900          SB= 0.287E-01
```

```
K= 32          EN(K)=  5.000          SB= 0.587E-01
K= 33          EN(K)=  5.100          SB= 0.880E-01
K= 34          EN(K)=  5.200          SB= 0.114E 00
K= 35          EN(K)=  5.300          SB= 0.134E 00
K= 36          EN(K)=  5.400          SB= 0.151E 00
K= 37          EN(K)=  5.500          SB= 0.164E 00
K= 38          EN(K)=  5.600          SB= 0.173E 00
K= 39          EN(K)=  5.700          SB= 0.181E 00
K= 40          EN(K)=  5.800          SB= 0.186E 00
K= 41          EN(K)=  5.900          SB= 0.191E 00
K= 42          EN(K)=  6.000          SB= 0.194E 00
K= 43          EN(K)=  6.100          SB= 0.197E 00
K= 44          EN(K)=  6.200          SB= 0.199E 00
K= 45          EN(K)=  6.300          SB= 0.200E 00
K= 46          EN(K)=  6.400          SB= 0.202E 00
I=  4     J=  2       EGAM=  3.1899
K= 34          EN(K)=  5.200          SB= 0.745E-02
K= 35          EN(K)=  5.300          SB= 0.182E-01
K= 36          EN(K)=  5.400          SB= 0.297E-01
K= 37          EN(K)=  5.500          SB= 0.406E-01
K= 38          EN(K)=  5.600          SB= 0.501E-01
K= 39          EN(K)=  5.700          SB= 0.578E-01
K= 40          EN(K)=  5.800          SB= 0.637E-01
K= 41          EN(K)=  5.900          SB= 0.683E-01
K= 42          EN(K)=  6.000          SB= 0.715E-01
K= 43          EN(K)=  6.100          SB= 0.737E-01
K= 44          EN(K)=  6.200          SB= 0.751E-01
K= 45          EN(K)=  6.300          SB= 0.759E-01
K= 46          EN(K)=  6.400          SB= 0.762E-01
```

SECTION V. COMPUTER PROGRAM FOR ADAPTATION OF NEUTRON INELASTIC SCATTERING SPECTRAL DATA

TABLE OF CONTENTS

INTRODUCTION

The purpose of this program is to provide inelastic neutron spectrum probability tables for direct input in the H01 code of the COHORT procedure. In the present version this code provides separate inelastic neutron spectrum probability tables for secondary neutrons from inelastic scattering (n, n') reactions, (n, 2n) reactions and (n, 3n) reactions. The probability values are obtained from data given in File 5 of the ENDF/B Version I data tapes. The probability tables are punched on cards for direct input into H01 and are also printed for examination. This code is written in FORTRAN IV for the IBM-7094 and is based on the SPCT2 code written by James Price and Karl Warkentin of Radiation Research Associates, Inc., Fort Worth, Texas.

CODE DESCRIPTION

Secondary energy distributions, expressed as normalized probability distributions, are given in File 5 of the ENDF/B, Version I data tapes. The file is divided into sections, each giving the data for a particular reaction type. The sections are ordered by increasing reaction type number (MT). Data is available for inelastic (MT = 4), (n, 2n)(MT = 16), (n, 3n) (MT = 17) and fission (MT = 18) reactions, if smooth cross sections for these reactions are given in File. 3. The present code extracts the data for reactions MT = 4, 16 and 17. Reaction 18 could be included by modifying Statement No. 2222 to include MM = 4.

Inelastic energy distributions are given in File 5 as discrete levels (LF = 3) plus a Maxwellian distribution with an arbitrary temperature (LF = 9), or with a constant temperature (LF = 8).

The Maxwellian distribution is given by the equation

$$N(E') = \left(\frac{E'}{\theta^2}\right) \exp\left(-\frac{E'}{\theta}\right)$$

where $N(E')$ is the number of inelastic neutrons per unit energy interval having energy E', and θ is the nuclear temperature used in defining a continuum for the particular energy range considered. As mentioned in the previous paragraph, θ may either be constant (LF = 8), or a function of incident neutron energy (LF = 9).

For input incident energies exactly equal to the incident energies tabulated on the ENDF/B tapes, the excitation probability distributions are extracted directly from the tape. For incident energies in the range of the values tabulated on the ENDF/B tapes, the excitation

probability distributions are interpolated from the tabulated data according to the interpolation mode specified on the ENDF/B tapes (Subroutine INTRP).

For incident energies above those tabulated on the tape, the excitation probability distributions are calculated for pseudo-excitation levels which are distributed over the continuum and used to approximate the continuum. For these calculations it is assumed that the energy of the scattered neutron is not dependent upon the scattering angle and that the recoil energy of the target nucleus is negligible. In order to approximate the continuum of excitation levels with discrete levels, it is assumed that neutrons with energies close to E' will leave the scattering nucleus in pseudo-excitation level EL such that

$$EL = E_o - (E' - \Delta E')$$

where E_o is the incident neutron energy, E' is the most probable energy of the scattered neutron and $\Delta E'$ is a measure of the spread of actual E' values about the most probable E' value. That is, after a neutron of energy E_o has excited level EL, the secondary neutrons will have energies between $E_o - EL - \Delta E$ and $E_o - EL + \Delta E$, so that the minimum secondary neutron energy, E_ℓ' is $E_o - EL - \Delta E$.

The cumulative probability, $P[E_o, EL(N)]$, for excitation of pseudo-energy level EL(N) for an incident neutron energy E_o is given by

$$P(E') = \frac{\int_{E_\ell'}^{E_o} N(E')\, dE'}{\int_{0}^{E_o} N(E')\, dE'}$$

where E_ℓ' is the lower limit on the energy of the scattered neutron after excitation of pseudo-energy level EL(N). If ΔE is taken as 1/2 [EL(N+1) - EL(N)] then E_ℓ' is given by $E_\ell' = E_o - 1/2[EL(N) + EL(N+1)]$ and

$$P(E') = P[E_o, EL(N)] = \frac{\left(\frac{BL}{\theta} + 1\right) \exp\left(-\frac{BL}{\theta}\right) - \left(\frac{E_o}{\theta} + 1\right) \exp\left(-\frac{E_o}{\theta}\right)}{1 - \left(\frac{E_o}{\theta} + 1\right) \exp\left(-\frac{E_o}{\theta}\right)}$$

where

$$BL = E_o - \frac{1}{2}[EL(N) + EL(N+1)] .$$

The number of pseudo-excitation levels, EL(K), used to define the continuum for each element is determined by the input parameter, NPPE(I), which is set equal to MAXL in the primary DO LOOP of the routine, and by the number (=NK-1) of tabulated discrete-energy levels on the ENDF/B tapes. The first level is set equal to 0.0 [EL(1) = 0.0]. The first (NK-1) tabulated discrete-energy levels [THETA(I)] are used next.

$$[EL(2) = THETA(1), EL(3) = THETA(2) \ldots .$$

$$EL(NK) = THETA(NK-1) .$$

Then the energy range between the highest incident energy, EP(KEBM1), and the highest tabulated discrete-energy level, EL(NK), is divided into NPPE-NK equally spaced energy levels, giving a total of NK discrete-energy levels (including EL(1) = 0.0) and NPPE-NK pseudo-energy levels.

A different set of incident energy groups may be input for each element. However, in COHORT the discrete-energy levels must be the

same for all incident energies for a given element. To eliminate the probability of a neutron with an energy at the lower end of the group from being able to excite an excitation level which may be excited only by neutrons with incident energies near the top of the group, it is necessary to set the incident energy which represents each input incident energy group as being equal to the lower bound of the group rather than some average incident energy.

The H01 library six input format requires that the upper bounds of the incident energy groups be listed in descending order for each element and that the energy excitation levels be listed in ascending order for each element. It further requires that the inelastic scattering probabilities for each element be listed for each excitation level in ascending order for the maximum incident energy first, and then for each successive incident energy in descending order. That is, the probabilities are to be entered for each excitation level for the highest neutron incident energy group, then for each excitation level for the next highest incident energy group, and so on. Probabilities are to be cumulative probabilities, so the input probability of exciting the second level, for example, should actually be the sum of the probabilities for exciting the first two levels.

The probabilities for exciting each discrete-energy level and each pseudo-energy level are calculated separately and then accumulated and normalized immediately before printout so that the output of the present routine is in the format required for H01 input.

The data for each element are calculated and printed out separately, first for reaction MT = 4, then for MT = 16 and MT = 17 when the data are available.

TABLE 1. INPUT CARDS

FIRST CARD:

- ID(I) I = 1, 20 20A4 FORMAT This card simply describes the problem.

NEXT CARD:

ND(1)	ND(2)	ND(3)	ND(4)	(Symbol)
1 to 5	6 to 10	11 to 15	16 to 20	(Card Columns)
I5	I5	I5	I5	

- ND(1) is the number of sets of input incident energy groups. If a different set of energy groups is to be used for each material, ND(1) must be set equal to ND(2). If the same set of energy groups is to be used for each material, ND(1) should be set equal to 1 .

- ND(2) is the number of materials to be considered and must not exceed ten (10).

- ND(3) is an integer which determines whether to use a new set of incident energy groups for each material or to use the same set for each material.

  ND(3) = 0 for same set
  ND(3) = 1 for new sets for each material

- ND(4) is the energy super-group number. A separate problem must be run for each super-group.

NEXT CARD(S):

MAT*(1),	NTP(1),	MATNP(1),	MATN*(2),	NTP(2)	MATNP(2), . . .
1 to 5	6 to 10	11 to 15	16 to 20	21 to 25	26 to 30
I5	I5	I5	I5	I5	I5

or MATN*(I), NTP(I), MATNP(I), I=1, ND(2), 12I5 FORMAT

*The MATN numbers must be in ascending order for each tape.

- MATN is the material number used on the ENDF/B tapes

- NTP(I) is the logical unit number of the ENDF/B tape containing the data for material MATN(I)

- MATNP(I) is the integer defining the order of material MATN(I) in the COHORT input.

TABLE 1 - Continued

NEXT CARD:

NEPM(1)	NEPM(2)	.....	NEPM[ND(2)]
1 to 5	6 to 10	.....	
I5	I5	.....	I5

or NEPM(I) I = 1, ND(2), 12I5 FORMAT, ND(2) $\leq$ 10

- NEPM(I) is one plus the number of energy groups in incident energy group set I. That is, incident energy group set I will consist of NEPM(I)-1 energy groups.

  Each NEPM value must not exceed one hundred (100).

NEXT CARD:

NPPE(1)	NPPE(2)	.....	NPPE[ND(2)]
1 to 5	6 to 10	.....	
I5	I5	.....	I5

or NPPE(I), I = 1, ND(2), 12I5 FORMAT, ND(2) $\leq$ 10

- NPPE(I) is the total number of excitation levels for material MATN(I) to be considered for each incident energy. NPPE(I) must not exceed forty-nine (49).

NEXT CARD(S):

EE(1,1)	EE(1,2)	EE(1,3)	.....	EE[1,NEPM(1)]
1 to 10	11 to 20	21 to 30	.....	
E10.5	E10.5	E10.5	.....	E10.5
EE(2,1)	II(2,2)	EE(2,3)	.....	EE[2,NEPM(2)]
1 to 10	11 to 20	21 to 30	.....	
E10.5	E10.5	E10.5	.....	E10.5

⋮

or EE(I,K), K=1,NEPM(I), I=1,ND(2), FORMAT 8E10.5

NOTE:	IF ND(3)=0	I=1	K=1,NEPM(1)
	IF ND(3)=1	I=1,ND(2)	K=1,NEPM(I)

- EE(I,K) is the Kth memeber of the input incident energy group set for material MATN(I). That is, EE(I,K) for K=1 to NEPM(I) is the complete set of input incident energy groups for material MATN(I).

TABLE 1 - Concluded

- These energies must be input in eV in ascending order for each MATN(I). Energies for each material must start on a new card.

NOTE: All the EE(I,K) are read in but in the calculation procedure, the upper bound is not used; that is, EE[I,NEPM(I)] is not considered.

TABLE 2. PRINTED OUTPUT

FIRST LINE

ID(I) I=1, 20 FORMAT 20A4 Problem Description
(Same as card input)

NEXT LINE

ND(1)	ND(2)	ND(3)	ND(4)	
1 to 5	6 to 10	11 to 15	16 to 20	Columns

(Same as card input)

NEXT LINE(S)

MATN(I) NTP(I) MATNP(I) I=1, ND(2)
FORMAT 12I5

(Same as card input)

NEXT LINE(S)

EE(I,K) K=1, NEPM(I)
I=1, ND(2) FORMAT 8E10.5
(Same as card input)

NEXT LINE(S)

Programmed error messages or data unavailability messages possibly

FIRST LINE OF PUNCH SUBROUTINE OUTPUT

CROSS SECTIONS FROM ENDF/B TAPES

NEXT LINE

6	KEBM1	MATPP	ND(4)	MAXL	N1	...	MATP	06001
5	4 to 8	9 to 13	14 to 18	19 to 23	24 to 28	...	61 to 64	65 to 70

Pertinent input parameters and material number for first material considered. (See H01 Library Six Input Data Format - CARD A).

NEXT LINE(S)

EL(I) I=1, MAXL FORMAT 6E10.3

Excitation level for material MATP in MeV, listed in ascending energy order.

TABLE 2 - Continued

For example, if MAXL = 9, output would be

EL(1)	EL(2)	EL(3)	EL(4)	EL(5)	EL(6)
EL(7)	EL(8)	EL(MAXL)			
1 to 10	11 to 20	21 to 30	31 to 40	41 to 50	51 to 60

where EL(1) < EL(2) < ... < EL(MAXL)

NEXT LINE(S)

EPUN(K) K=1, KEBM1 FORMAT 6E10.3

Input incident energies used in the calculations for material MATP in MeV, listed in descending energy order.

For example, if KEBM1 = 8, output would be

EPUN(1)	EPUN(2)	EPUN(3)	EPUN(4)	EPUN(5)	EPUN(6)
EPUN(7)	EPUN(KEBM1)				
1 to 10	11 to 20	21 to 30	31 to 40	41 to 50	51 to 60

where EPUN(1) > EPUN(2) > ... > EPUN(KEBM1)

NEXT LINE

MT FORMAT I5

Number identifying the type reaction considered.

NEXT LINE(S)

PP (JJ, KK) KK=1, MAXL
JJ=KEBM1, 1 FORMAT 6E10.3

Normalized, accumulated probability for obtaining an inelastically scattered neutron from any of the excitation levels through level EL(KK), assuming an incident neutron energy EPUN(JJ) and reaction MT printed immediately above.

Note that the subscript JJ begins at KEBM1 and decreases and that the subscript KK is allowed to vary throughout its range prior to changing the JJ subscript.

For example, if MAXL = 9 and KEBM1 = 8, the output would be:

TABLE 2 - Concluded

KEBM1

PP(8,1)	PP(8,2)	. . . . .	PP(8,6)
PP(8,7)	PP(8,8)	PP(8,MAXL)	
PP(7,1)	PP(7,2)	. . . . .	PP(7,6)
PP(7,7)	PP(7,8)	PP(7,MAXL)	
⋮	⋮	⋮	
PP(1,1)	PP(1,2)	. . . . .	PP(1,3)
PP(1,7)	PP(1,8)	PP(1,MAXL)	
1 to 10	11 to 20	21 to 30	51 to 60

where PP(7,6) is the probability of a neutron with incident energy EPUN(7) being inelastically scattered from either excitation level EL(1), EL(2), EL(3), EL(4), EL(5), or EL(6).

The probabilities are printed out for each MT reaction type for material MATP. Then the routine goes to the next material number, reads the pertinent data on the ENDF/B tapes, calculates the probabilities and prints the output data for the new material MATP as above, beginning with the first line of the PUNCH subroutine output.

TABLE 3. ERROR MESSAGE DESCRIPTION

Error Number	Description
1	The number of discrete energy levels for one element is greater than 49.
2	The number of regions having different interpolation schemes is greater than 10 for one of the discrete energy levels.
3	The number of incident energies for one discrete level is greater than 100.
4	The number of energy regions having different interpolation schemes for the energy dependent nuclear temperature is greater than 10.
5	The number of energies for which nuclear temperatures are given is greater than 50.

In addition to the above errors, some problems which may be encountered with the ENDF/B tape data are anticipated and descriptive messages are printed out when these problems are encountered.

OPERATING INSTRUCTIONS

The present code is written in FORTRAN IV for the IBM-7094. The card input, IN, is assigned logical unit number 5, while the print output, IO, is assigned logical unit number 6. The IN assignment routine. The IO assignment is made at the beginning of the main routine and at the beginning of the PUNCH subroutine. The ENDF/B tape input, INPT, is assigned logical unit number NTP(I) for material MATN(I) and is read in on punched cards as part of the card input. The data for input directly into the H01 code is punched on cards with the punched output, IOT, assigned logical unit number 7 in the PUNCH subroutine.

Any changes in the logical unit numbers should be made through the above mentioned assignment statements.

The input incident energies should be read in eV in ascending energy order. In the ENDF/B tabulated data, the tabulated incident energies are often specified to five decimal places at break points in the interpolation schemes.

Although the punched data output is in the correct format for H01 input, the H01 routine does not provide for identification of reaction type (MT number). The punched card output does have MT identification cards. Therefore some sorting of output cards must be performed before using the cards as input into H01.

As now written the present program requires nearly 15,000 words in common. The maximum common capacity of the 7094 is approximately 32,000 words. If large arrays of EE, ESUB and PROB are to be read simultaneously, it may be necessary to do the problem in parts.

The primary dimension restrictions are:

- Number of incident energy groups must not exceed 25 for each material
- Total number of excitation levels for each material must not exceed 100
- Total number of tabulated discrete energy levels must not exceed 50.

```
      DIMENSION THETA (50), EE(10,25)
      COMMON  PP(25,100), NEPM(10), NPPE(10), EL(100)
      COMMONID(20), ND(10), E(25), MATN(10), NTP(10)
      COMMON  MATNP(10), LFP(50), NBT(50,10), INT(50,10)
       COMMON     NBT1(10), INT1(10), ESUB(50,100), PROB(50,100), NPN(50)
      COMMON    NR1(50), TEMP(100), ESUB1(100), PRO(50)
       COMMON    AWR,NK,NPP,NR,MAXL
      COMMON NMT(4)
       IO=6
       IN=5
       READ(IN,151) (ID(I),I=1,20)
      WRITE(IO,10) (ID(I),I=1,20)
   10  FORMAT (20A4)
  151  FORMAT (1H1, 20A4)
       READ (IN,12) (ND(I),I=1,10)
       WRITE (IO,12) (ND(I), I=1,10)
   12  FORMAT (1215)
       NMAT=ND(2)
       READ (IN,12) (MATN(I),NTP(I),MATNP(I), I=1,NMAT)
       WRITE (IO,12) (MATN(I),NTP(I),MATNP(I), I=1,NMAT)
       READ (IN,12) (NEPM(I),I=1,NMAT)
       READ (IN,12) (NPPE(I),I=1,NMAT)
       N=ND(1)
       DO 13 I=1,N
       KEB=NEPM(I)
       READ (IN,14) (EE(I,K),K=1,KEB)
   13  WRITE(IO,14) (EE(I,K),K=1,KEB)
   14  FORMAT(8E10.3)
C       DETERMINE  IF NEW ENERGY GROUPS GIVEN FOR EACH MATERIAL
C
       IF(ND(3)) 142,142,145
  142   KEB= NEPM(1)
       DO 144  K= 1,KEB
  144   E(K)= EE(1,K)
  145   DO 90  MAT= 1,NMAT
       KEB= NEPM(MAT)
       KEBM1 = KEB-1
       MAXL =NPPE(MAT)
      MATP = MATN(MAT)
      NTAP = NTP(MAT)
      MATPP =MATNP(MAT)
       IF (MATP) 15,15,17
   15   CALL PUNCH (MATP,MATPP,0,MAT)
       GO TO 90
   17  IF(ND(3)) 166,168,166
  166    N=NEPM(MAT)
      DO 167 K=1,N
  167   E(K)= EE(MAT,K)
  168   NMT(1)=4
       NMT(2)=16
       NMT(3)=17
       NMT(4)=18
 2222  DO 901   MM=1,3
       MT=NMT(MM)

C
C       DETERMINE IF INELASTIC DATA IS ON ENDF/B TAPE
C
```

```
      CALL SRCH (MATP,5,MT,NTAP,I2, I15, THETA)
      IF (I15-3) 5000,5001,5000
 5000 IF (I2) 20,20,18
   18 WRITE (I0,19) MATP
   19 FORMAT (1H1,50HINELASTIC SCATTERING CROSS SECTIONS NOT GIVEN FOR
     1 I5 )
 5001 GO TO 90
C
C     START PROBABILITY CALCULATIONS
C
   20 NKM1= NK-1
      EL(1) =0.0
         DO 202 I=2,NK
  202 EL(I)=THETA(I-1)
         ER= E(KEBM1)- EL(NK)
       NL=MAXL-NK
       DELE = ER/FLOAT(NL)
       NODL= NK+1
          DO 205  L=NODL,MAXL
      EL(L)= EL(L-1)+DELE
  205      CONTINUE
      DO 70  J= 1,KEBM1
      EP= E(J)
       IF(EP-ESUB(1,1)) 21,25,25
   21 LLMAX =1
      PP(J,1)=0.0
      DO 3000 KK=2,MAXL
 3000 PP(J,KK)=0.0
      GO TO 70
   25 IF (EP-ESUB(NK,1)) 31,55,55
   31 KK=1
      DO 48 I=1,NKM1
      KK= KK+1
      IF (EP-ESUB(I,1)) 29,2900,30
   30 WRITE (I0,12) MAT,J,I,KK
      N=NPN(I)
      DO 32 K=2,N
      IF (EP-ESUB(I,K)) 35,33,32
   32 CONTINUE
      K=N
   33 PRO(KK)=  PROB(I,K)
      GO TO 41
   35 LN=NR1(I)
      DO 36 JL=1,LN
      IF (K-NBT(I,JL)) 37,37,36
   36 CONTINUE
      INTP=INT(I,LN)
      GO TO 40
   37 INTP= INT(I,JL)
   40 CALL INTRP(INTP,PROB(I,K-1),PROB(I,K),ESUB(I,K-1),ESUB(I,K),EP,P)
      PRO(KK)= P
   41 LLMAX= KK+1
      IF(I-NKM1) 48,45,45
```

```
   48 CONTINUE
      GO TO 70
   45 DO 4500 K=LLMAX,MAXL
 4500 PRO(K)=0.0
      GO TO 8000
   29 DO 291 M=KK,MAXL
  291 PRO(M)=0.0
      GO TO 9000
 2900 PRO(KK)=PROB(I,1)
      NN=KK+1
      DO 2901 KK=NN,MAXL
 2901 PRO(KK)=0.0
 8000 PP(J,1)=0.0
      DO 8003 K=2,MAXL
 8003 PP(J,K)=PP(J,K-1)+PRO(K)
      IF (PP(J,MAXL)-1.0) 8005,70,8005
 8005 DO 8006 K=2,MAXL
 8006 PP(J,K)=PP(J,K)/PP(J,MAXL)
      GO TO 70
   55 IF(LFP(NK)-5) 449,60,449
  449 IF(LFP(NK)-8)  56,58,60
   56 WRITE (10,57) MATPP
   57 FORMAT (1H ,38HMAXWELLIAN DISTRIBUTION NOT GIVEN FOR , I5 )
      GO TO 70
   58 THET = THETA(NK)
      IF (THET-0.0) 59,560,59
  560 WRITE (10,570)
  570 FORMAT (1H1,13HTHETA(NK)=0.0)
      GO TO 70
   59 JAP = J
      CALL MAXW (EP,JAP,THET)
      GO TO 70
   60 DO 62 K=2,NPP
      IF(EP- ESUBI(K)) 65,63,62
   62 CONTINUE
   63 THETA(NK)=TEMP(K)
      GO TO 58
   65 DO 66  LO=1,NR
      IF (K-NBTI(LO)) 67,67,66
   66 CONTINUE
      INTP=INTI(NR)
      GO TO 68
   67 INTP= INTI(LO)
   68 CALL INTRP(INTP,TEMP(K-1),TEMP(K),ESUBI(K-1),ESUBI(K),EP,THET)
      GO TO 59
   70 CONTINUE
      CALL PUNCH (MATP,MATPP,1,MAT)
  901 CONTINUE
   90 CONTINUE
  100 STOP
      END
```

```
      SUBROUTINE INTRP (MM,Y1,Y2,X1,X2,U1,V)
      DIMENSION Y(2),X(2),U(1),V(1)
      M=2
      I=1
      Y(1)= Y1
      Y(2)= Y2
      X(1)= X1
      X(2)= X2
      U(1)= U1
      IF(MM-1)  2000,202,2000
  202 V(I)= Y(M-1)
C       Y IS  CONSTANT
      GO TO 300
 2000 IF(MM-2)    203,2001,203
 2001 V(I)=(Y(M)-Y(M-1))/(X(M)-X(M-1))*(U(I)-X(M-1))+Y(M-1)
C       Y LINEAR IN X
      GO TO 300
  203 IF(MM-3) 204,2002,204
 2002 AX= ALOG(X(M))
      BX= ALOG(X(M-1))
      CX= ALOG(U(I))
      V(I)= (Y(M)-Y(M-1))/(AX-BX)*(CX-BX) + Y(M-1)
C       Y LINEAR IN  LN X
      GO TO 300
  204 IF(Y(M)) 2001,2001,2003
 2003 IF(Y(M-1))  2001,2001,2004
 2004 IF(MM-4)  205,2005,205
 2005 AY= ALOG(Y(M))
      BY= ALOG(Y(M-1))
      V(I)= (AY-BY)/(X(M)-X(M-1))*(U(I)-X(M-1))+ BY
      V(I)= EXP(V(I))
C       LN Y LINEAR IN X
      GO TO 300
  205 AY= ALOG(Y(M))
      BY= ALOG(Y(M-1))
      AX= ALOG(X(M))
      BX= ALOG(X(M-1))
      CX= ALOG(U(I))
      V(I)=(AY-BY)/(AX-BX)*(CX-BX)+BY
      V(I)= EXP(V(I))
C         LN Y LINEAR IN LN X
  300 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MAXW(EP,J,THET)
      COMMON  PP(25,100), NEPM(10), NPPE(10), EL(100)
      COMMONID(20), ND(10), E(25), MATN(10), NTP(10)
      COMMON  MATNP(10), LFP(50), NBT(50,10), INT(50,10)
       COMMON     NBTI(10), INTI(10), ESUB(50,100), PROB(50,100), NPN(50)
      COMMON    NR1(50), TEMP(100), ESUB1(100), PRO(50)
       COMMON    AWR,NK,NPP,NR,MAXL
      COMMON NMT(4)
C
C     PREPARES CUMULATIVE PROBABILITY  FOR EXCITING  PSEUDO STATES FOR
C     A GIVEN INCIDENT NEUTRON ENERGY  WHEN THE  ENERGY DISTRIBUTION
C     OF THE INELASTIC NEUTRON  IS MAXWELLIAN
C
C     MAXL IS THE MAXIMUM NUMBER OF LEVELS
C     EP IS THE INCIDENT ENERGY
C
C
      DO 120  L=2,MAXL
      IF (L-MAXL) 65,66,66
   65 BL = EP- 0.5*(EL(L) + EL(L+1))
      GO  TO  67
   66 BL = 0.0
   67 BU = EP
   85 IF(BL)    90,  90,  100
   90 BL = 0.0
  100 PRO  (L)  =(EXP(-BL/THET     )*(BL/THET       +1.0)-EXP(-BU/THET )*
     1(BU/THET     +1.0))/(1.0-EXP(-DU/THET)*(BU/THET+1.0 ) )
      IF(BL - 0.0001)     110, 110, 120
  110 LMAX = L
      GO TO 130
  120 CONTINUE
  130 IF(MAXL - LMAX)    190,  190, 170
  170 LLMAX = LMAX+1
      DO 180    L =  LLMAX, MAXL
  180 PRO(L) = 1.0
  190 PP(J,1)= 0.0
      DO 200  KK  = 2,MAXL
      PP(J,KK) = PRO(KK)
  200 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE  SRCH ( IA,IB,IC,INPT, I2,I15, THETA)
      DIMENSION THETA(50)
      COMMON  PP(25,100), NEPM(10), NPPE(10), EL(100)
      COMMONID(20), ND(10), E(25), MATN(10), NTP(10)
      COMMON  MATNP(10), LFP(50), NBT(50,10), INT(50,10)
       COMMON    NBTI(10), INTI(10), ESUB(50,100), PROB(50,100), NPN(50)
      COMMON   NRI(50), TEMP(100), ESUBI(100), PRO(50)
       COMMON   AWR,NK,NPP,NR,MAXL
      COMMON NMT(4)
      I15=0
      I2 = 0
    7 READ(INPT,14)  ITN,NC,MT
   14 FORMAT(66X,I4,I2,I3)
      IF(ITN-IA)  7,15,7
   15 IF(NC-IB)   7,16,7
   16 IF(MT-IC)  7,18,17
   17 I2  =  1
      RETURN
C
C     READ INELASTIC DATA
C
   18 BACKSPACE INPT
      READ (INPT,19) ZA,AWR,L1,L2,NK
   19 FORMAT(2E11.3,4I11,I4,I2,I3 )
      IF(NK-49) 195,1995,1995
 1995 II = 1
      GO TO 500
  195 DO 49 I=1,NK
      READ(INPT,19) C1,THETA(I),L1,LF,NR,NPP
      IF(NR-10)  197,1997,1997
 1997 II = 2
      GO TO 500
  197 IF(NPP-275)  198,1998,1998
 1998 II = 3
      GO TO 500
  198 NPN(I) = NPP
      NRI(I) = NR
      LFP(I) =  LF
      GO TO(50,50,20,50,20,50,50,20,20,50 ),LF
   20 READ(INPT,22) (NBT (I,K),  INT(I,K), K = 1,NR  )
   22 FORMAT(6I11)
      READ(INPT,23)  (ESUB(I,K),PROB(I,K), K=1,NPP   )
   23 FORMAT (3(E11.4,F11.4))
      IF(LF-5)  3900,30,3900
 3900 IF(LF-9)   49,30,50
C
   30 READ(INPT,19) C1,C2,L1,L2,NR,NPP
      IF(NR-10)  302,3020,3020
 3020 II =  4
      GO TO 500
  302 IF(NPP-275) 304,3040,3040
```

```
 3040 II =  5
      GO TO  500
  304 READ(INPT,22)(NBTI(  K),INTI(    K),  K = 1,NR   )
      READ(INPT,23) (ESUBI( K), TEMP(  K),K=1,NPP )
C
   49 CONTINUE
C
      GO TO  60
  500 WRITE(6,501)  II
  501 FORMAT (1H1,13HERROR NUMBER , I3 )
      II5 = 3
      GO TO 60
   50 I2  =  1
   60 RETURN
      END
```

```
      SUBROUTINE PUNCH    (MATP,MATPP,NI,MAT)
      DIMENSION EPUN(100)
      COMMON  PP(25,100), NEPM(10), NPPE(10), EL(100)
      COMMON ID(20), ND(10), E(25), MATN(10), NTP(10)
      COMMON  MATNP(10), LFP(50), NBT(50,10), INT(50,10)
       COMMON     NBTI(10), INTI(10), ESUB(50,100), PROB(50,100), NPN(50)
      COMMON    NR1(50), TEMP(100), ESUB1(100), PRO(50)
       COMMON    AWR,NK,NPP,NR,MAXL
      COMMON NMT(4)
      IO    =  6
      IOT   =    7
      KEB   =    NEPM(MAT)
      KEBM1   =  KEB-1
      NMAT   =   ND(2)
      IF (MT-4)   1135, 1134, 1135
 1135 IF (MT-16)   1138, 1146, 1136
 1136 IF (MT-17)   1138, 1147, 1138
 1138 WRITE (IOT, 1139) MT
 1139 FORMAT (1H_, 20H ILLEGAL  REACTION    MT=,I5)
      GO TO 1178
 1134 WRITE (IOT, 1144) MT
 1144 FORMAT (1H_, 24 H INELASTIC-(N,NPRIME)-MT=,I5)
      GO TO 1178
 1146 WRITE (IOT,1156) MT
 1156 FORMAT (1H_, 19H (N,2N)-REACTION-MT=,I5)
      GO TO 1178
 1147 WRITE (IOT,1157) MT
 1157 FORMAT (1H_, 19H (N,3N)-REACTION-MT=,I5)
      GO TO 1178
 1178 WRITE(IOT,10)   KEBM1    , MATPP, ND(4),   MAXL, NI,   MATP
   10 FORMAT (1H ,4H0006, 5I5, 32X, I4, 6H 60001)
      IF   (NI)   355,355,20
   20 DO   24 I = 1,MAXL
   24 EL(I) =  EL(I) * 1.0E-06
      WRITE(IOT,26) (EL(I), I=1,MAXL)
   26 FORMAT (1H , E9.3, 5E10.3)
      DO   27   I   = 1,KEBM1
      K=KEB-I
   27 EPUN(K)=E(I)*1.0E-06
      WRITE (IOT,26) (EPUN(K), K=1,KEBM1)
      DO   35   J   =   1,KEBM1
      JJ =   KEB-J
   35 WRITE(IOT,26) (PP(JJ,KK), KK=1,MAXL )
  355 WRITE(IO,36)
   36 FORMAT (1H1,33HCROSS SECTIONS FROM ENDF/B TAPES )
      IF (MT-4)   1105, 1104, 1105
 1105 IF (MT-16)   1108, 1116, 1106
 1106 IF (MT-17)   1108, 1117, 1108
 1108 WRITE (IO   , 1109) MT
 1109 FORMAT (1H_, 20H ILLEGAL-REACTION  MT=,I5)
      GO TO 1128
 1104 WRITE (IO, 1114) MT
 1114 FORMAT (1H_, 24H  INELASTIC-(N,NPRIME)-MT=,I5)
      GO TO 1128
```

```
1116  WRITE (IO, 1126) MT
1126  FORMAT (1H___, 19H (N,2N)-REACTION-MT=,I5)
      GO TO 1128
1117  WRITE (IO, 1127)  MT
1127  FORMAT (1H___, 19H (N,3N)-REACTION-MT=,I5)
      GO TO 1128
1128  WRITE(IO ,40) KEBM1 .    , MATPP,  ND(4), MAXL, N1, MATP
  40  FORMAT (1H ,3H   6, 515, 32X, 14,6HC400C1)
      IF   (1.1)        100,100,41
  41  WRITE(IO ,56) (EL(I), I = 1,MAXL )
  56  FORMAT(1H ,         6E1C.3 )
      WRITE (IO,56) (EPUN(K),K=1,KEBM1)
      DO   7?   J  =  1,KEBM1
      JJ   = KEB-J
  70  WRITE(IO , 56)   (PP(JJ,KK),   KK=1,MAXL   )
 100  CONTINUE
      RETURN
      END
```