NUCLEAR DATA AND MEASUREMENTS SERIES

ANL/NDM-145

A Neutron Spherical Optical-Statistical-Model Code: A User's Manual

by

R.D. Lawson and A.B. Smith

June 1999 (Revision I)

ARGONNE NATIONAL LABORATORY,
ARGONNE, ILLINOIS 60439, U.S.A.

Technology Development Division
Argonne national Laboratory
June 1, 1999

To: Donald L. Smith

From A. B. Smith

Subject: ANL/NDM-145, Revision-I

The original report was distributed about a year ago. It is the manual for a unique optical-statistical-model code. Since that time there has been user experience around the world, generally very encouraging. The code was extensively test using IBM, VAX-VMS, Lahey-PC and Microsoft-PC systems. However, it turns out that there are some other FORTRAN compilers used in Europe that had minor trouble with the code source. The problems were primarily associated with the order of EQUIVALENCE and DATA statements and with the citing of COMMON blocks. The current revision removes these problems. The revisions have no impact on the numerical results of the calculations. This revised report and the associated source diskette have received very limited distribution, particularly to the ORNL and NEA code centers. The attachments are the report and revised diskette. If you have a FORTRAN compiler on your PC you might try a test case or two.

Attachments

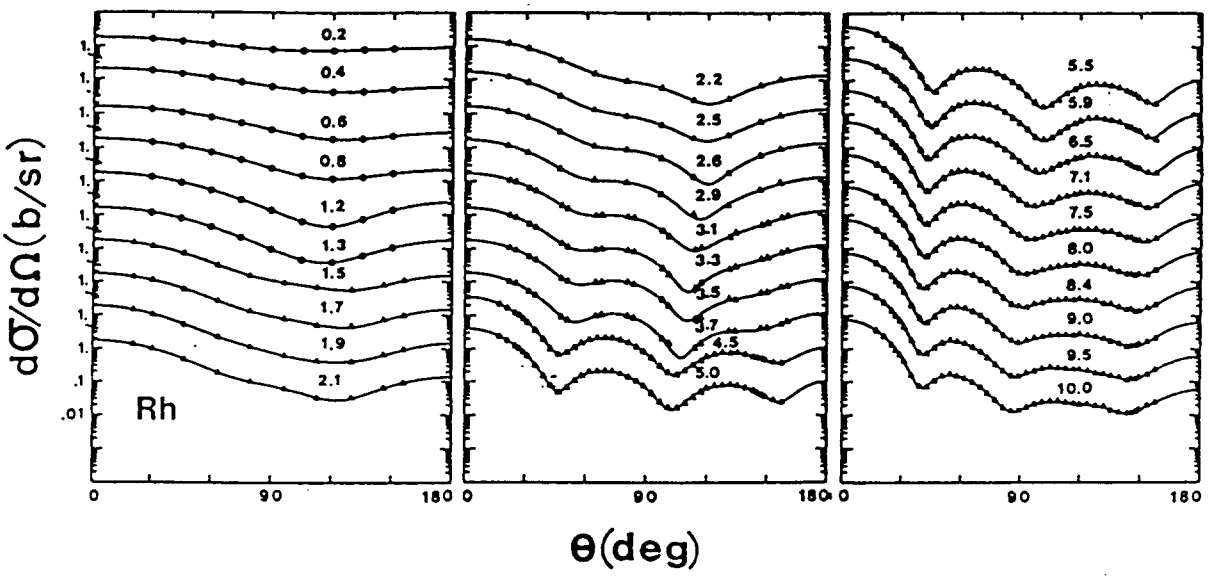
NUCLEAR DATA AND MEASUREMENTS SERIES

ANL/NDM-145

ABAREX
A NEUTRON SPHERICAL OPTICAL-STATISTICAL-MODEL CODE - A USER'S MANUAL

by
R. D. Lawson,
Edited and updated by A. B. Smith

REVISION-I, June, 1999



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PREFACE, REVISION-I, June 1999

This document and program was originally released in June of 1998. In the subsequent year a number of users in various parts of the world employed the program. Those experiences appear to have generally been very successful. However, there has been some feedback leading to the present revised form of the document and associated program. Problems were generally associated with FORTRAN compilers other than those cited in the original formulation, particularly in Europe. These problems are alleviated and/or removed by small adjustments of the FORTRAN source. As a consequence, compilation should now be routine on a wider spectrum of compilers. In no cases did the small modifications seem to make any difference in the calculation output for all of the test cases, or any other calculation.

Argonne
June, 1999

PREFACE

ABAREX is a very effective neutron spherical optical-statistical-model code that has found wide application in both applied and basic neutron physics. It is fast and is now effectively implemented on simple Personal Computers (PCs). It has unusual, and in some cases unique, capabilities that should not vanish as time passes and personnel leave the field. The objective of this document is a manual assuring the continued usefulness of ABAREX. It is an extension and updating of the document presented at the IAEA Trieste school by R. D. Lawson, and subsequently published by World Science Publishing (1). This revision includes the correction of errors reported by a number of individuals, and extended illustrative examples to aid the practitioner.

ABAREX was written over about a twenty-year period by P. A. Moldauer, particularly incorporating his development of the theory of compound-nucleus cross sections. The code has been extended and corrected by R. D. Lawson, and, more recently, by the present editor. Over the approximately quarter century of development, computational technology has grossly changed. The code was originally written to optimize storage requirements so as to expedite use on a large central computing facility. In the present version the code is arranged for operation on the VAX/VMS work station and the PC. The compilers used are the VAX/VMS on VAX systems (2) and the Lahey (3) and MS (4) compilers on the PC. All these are FORTRAN-77 compilers. If the PC compiler used has the VAX simulation option use it, though it does not have a critical effect. In the present form the code uses a version of the Racah and Clebsch-Gordon routine developed by S. Pieper (ANL) and the non-linear fitting routine of B. Garbow et al. (ANL). Known errors have been corrected, particularly as the result of suggestions by J. Raynal. The code is remarkably user-friendly.

The initial user instructions were set forth by Moldauer in a set of informal memoranda in the latter part of the 1970s. More detailed instructions are given in Ref. 1. As presently formulated, an extensive set of comment cards in the initial part of the program source should give considerable guidance to the user. Over a number of years the present editor has used the code literally thousands of times in a variety of contexts. In the course of this work a great number of comparisons were made with the results of other codes. The results of the various calculations are reasonably consistent given the different numerical procedures and somewhat different physical constants. This agreement gives confidence to the ABAREX calculations. Any changes and/or modifications from the document and the code as described in Ref. 1 are entirely the responsibility of the editor.

Argonne
June, 1998

ANL/NDM-145

ABAREX - A NEUTRON SPHERICAL OPTICAL-STATISTICAL-MODEL CODE - A USER'S MANUAL*

by
R. D. Lawson,
Edited and updated by A. B. Smith

REVISION-I

ABSTRACT

The contemporary version of the neutron spherical optical-statistical-model code ABAREX is summarized with the objective of providing detailed operational guidance for the user. The physical concepts involved are very briefly outlined. The code is described in some detail and a number of explicit examples are given. With this document one should very quickly become fluent with the use of ABAREX. While the code has operated on a number of computing systems, this version is specifically tailored for the VAX/VMS work station and/or the IBM-compatible personal computer.

This code and this document have been sent to the NEA Data Bank and the Radiation Shielding Information Center (ORNL). Interested users should contact one of these centers. Any suggestions, errors and/or corrections should be communicated to A. B. Smith, Technology Development Division, Bldg. 207, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439, USA.

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1. SYSTEM REQUIREMENTS AND EXPERIENCE

ABAREX is written in ANSI FORTRAN-77, with several VAX (IBM) extensions. It is explicitly formulated for VAX/VMS systems and IBM-compatible personal computers (PCs). Source compilation and linking should use VMS FORTRAN-77 on the VAX (2). For the PC either Lahey (3) or Microsoft (4) FORTRAN-77 can be used, and very possibly other PC FORTRAN compilers. The Lahey PC compiler has a VAX/VMS switch option ('/V') which should be used. The program has been extensively employed at VAX work stations, VAX central facilities, and with 286, 386, 486 and Pentium PCs. Older versions of the program have been used at a variety of central computing facilities, including IBM-3000 series machines and CDC machines. The program is largely machine independent. If exported to facilities other than cited above, modest modifications may be required. There is a VAX bit-check in the Subroutine CLEBSCH that may have to be adjusted, word-length constants in the fitting Subroutine LMDIF1 may need changing (there is guidance in the comments of the source listing), and the format of the little-used 'INPUT' option may vary with compilers. Users applying this program at diverse facilities, other than those cited above, should consult the relevant FORTRAN reference manuals. An effort has been made to make the program widely exportable.

The input/output of the program is described in detail in this document. In addition, the input is outlined in comment lines at the beginning of the source listing, as given in Appendix B. Throughout, extensive examples are given. Good examples are a valuable tutorial vehicle. All the program input is made through the file 'input', and all output through the file 'output'. Throughout this document the reader should note that 'input' (lower case) refers to the above input file, while 'INPUT' (upper case) denotes the IBM FORTRAN 'INPUT' order and keyword as defined subsequently.

No large computer code can be assured to be error free. However, this code has been very carefully considered and successfully used in thousands of applications. The results of calculations may differ from those of comparable codes by small amounts due to differing numerical procedures and/or physical assumptions. However, many facets of this code have been checked against comparable calculational results from PTOLEMY (5), SCAT2 (6), JUPITOR (7), ABACUS (8) and ECIS96 (9), particularly using the latter. The agreement between the various results is remarkably good. Even parameter-search procedures using ABAREX and ECIS96 lead to results in encouraging agreement despite the fact that very different non-linear fitting routines are used. However, the user should realize that there is a certain amount of "inbreeding" in nuclear model codes. They may often use the same numerical procedures and/or methods, and in many cases parts of one code are used in another.

ABAREX is a neutron code, no charged-particles are treated. It gives particular attention to compound-nucleus processes, and is designed for relatively low energies, e.g. for calculations at incident energies of less than or ≈ 30 - 40 MeV. The code is not relativistic and is not applicable (and may even fail) at high energies (e.g. at ≈ 100 MeV and above).

ABAREX was originally written for large central computing facilities at a time when storage was at a premium. There were large cost and time benefits to a compact code. Thus, ABAREX is very concise. The FORTRAN source is only ≈ 528 kilo-bytes long. The program is fast. All of the examples of this document run in a few seconds or less on a 150 MHz Pentium PC, and significant portions of those running times are in disk access rather than computation.

2. NOTES ON THE SPHERICAL OPTICAL MODEL

Consider the scattering of a neutron of mass m by a nucleus of mass M. The reduced mass of the system is

$$\mu = mM/(m+M) \qquad (1)$$

and the neutron center-of-mass energy, $E"$, is

$$E" = \{M/(m+M)\}E, \qquad (2)$$

where E is the incident energy in the laboratory coordinate system. If the spherical optical model is used to describe the scattering process the wave function for the relative motion takes the form

$$\Psi(r) = \sum_{\ell=0}^{\infty} r^{-1} \chi_\ell(r) Y_{\ell m}(\theta,\phi), \qquad (3)$$

where $Y_{\ell m}(\theta,\phi)$ is the spherical harmonic. $\chi_\ell(r)$ satisfies the radial wave equation

$$d^2\chi_\ell/dr^2 + [\ k^2 - \bar{U}(r) - \ell(\ell+1)/r^2\ ]\ \chi_\ell = 0, \qquad (4)$$

where

$$k^2 = 2\mu E"/\hbar^2 \qquad (5)$$

and

$$\bar{U}(r) = 2\mu U(r)/\hbar^2 \qquad (6)$$

with $U(r)$ the optical-model potential and $\hbar$ equal to Planck's constant divided by 2π. For large r the wave function in the

entrance channel with orbital angular momentum ℓ takes the form

$$\chi_\ell(r) \rightarrow exp(-i(kr-\tfrac{1}{2}\ell\pi)) - \eta_\ell exp(i(kr-\tfrac{1}{2}\ell\pi)), \qquad (7)$$

where the complex reflection factor, η_ℓ, is related to the complex phase shift, δ_ℓ, by

$$\eta_\ell = exp(2i\delta_\ell). \qquad (8)$$

If, for simplicity, we neglect the spin of the neutron, the contribution of the ℓth partial wave to the elastic-scattering cross section is given by

$$\sigma_{el}^{(\ell)} = \pi\lambda\!\!\!^{-2}(2\ell+1)|1-\eta_\ell|^2, \qquad (9)$$

and the reaction cross section is

$$\sigma_r^{(\ell)} = \pi\lambda\!\!\!^{-2}(2\ell+1)(1-|\eta_\ell|^2), \qquad (10)$$

where

$$\lambda\!\!\!^{-2} = 1/k^2. \qquad (11)$$

The total elastic and reaction cross sections are just the sum on ℓ of these partial wave contributions.

Turning to experimental data, it is clear from Fig. 1 that low energy neutron cross sections are highly fluctuating. However, the energy averaged cross section, also shown in Fig. 1, is a fairly smooth function of energy. Thus the experimental reflection factor, η_ℓ, must be a complicated and rapidly oscillating function of the energy of the incoming particle. However, the energy-averaged value,

$$\bar{\eta}_\ell(\varepsilon) = (\Delta E)^{-1}\int_{\varepsilon-\Delta E/2}^{\varepsilon+\Delta E/2}\eta_\ell(\varepsilon')d\varepsilon', \qquad (12)$$

should be a smooth function of the energy, ε, provided the interval ΔE contains many closely spaced resonances. In the same way, the average elastic and reaction cross sections in the energy interval ΔE are (10)

$$\bar{\sigma}_{el}^{(\ell)} = \pi\lambda\!\!\!^{-2}(2\ell+1)\overline{|1-\eta_\ell|^2}, \qquad (13)$$

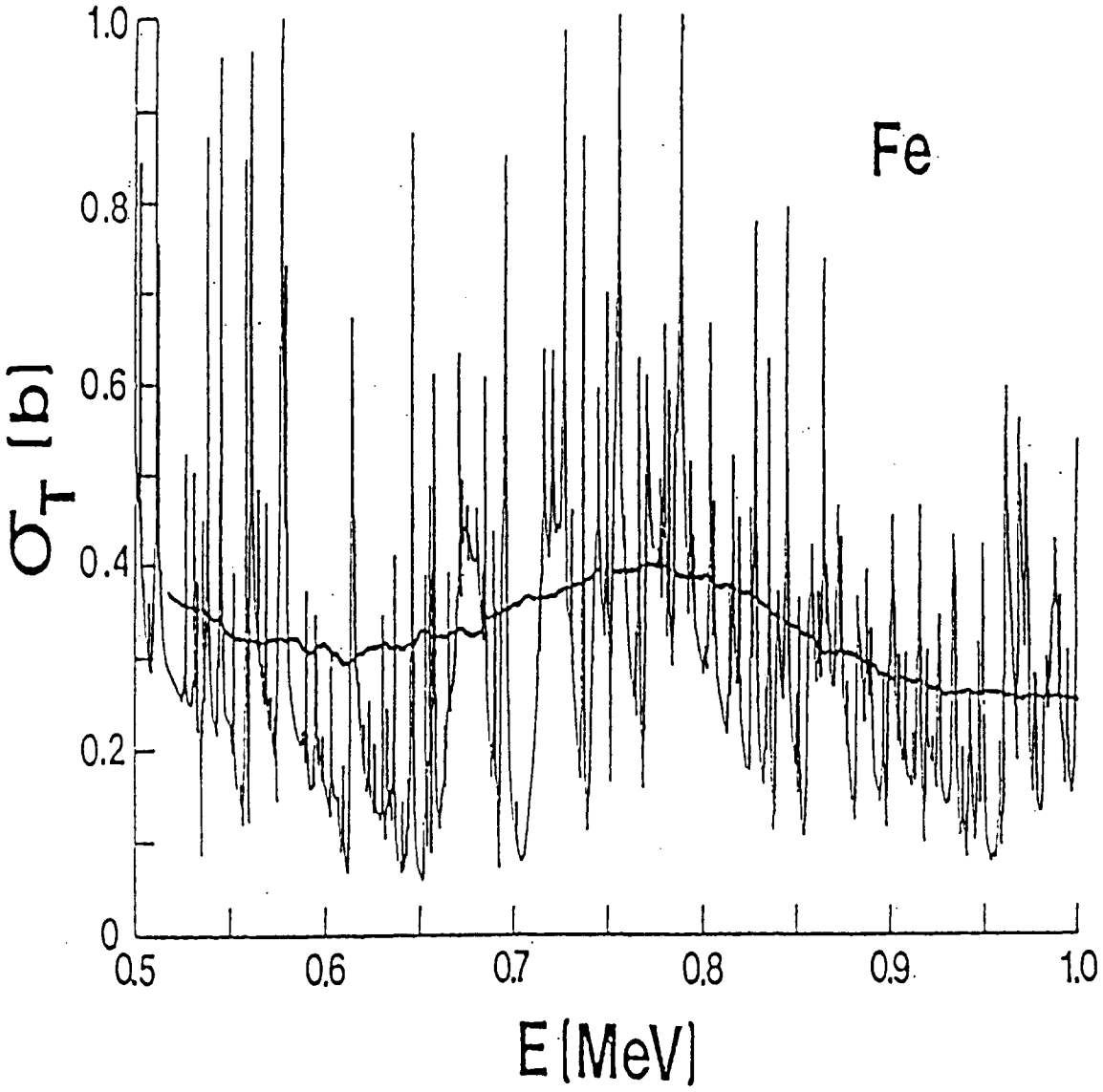

Fig. 1. High resolution total cross section measurements for neutrons incident on iron. The smooth curve is the energy-average cross section when the averaging interval is 200 keV.

and

$$\bar{\sigma}_r^{(\ell)} = \pi\lambda^2(2\ell+1)(1-\overline{|\eta_\ell|^2}). \qquad (14)$$

For the ℓth partial wave the average total cross section, $\bar{\sigma}_t^{(\ell)}$, which is the sum of the elastic and reaction cross sections, is

$$\bar{\sigma}_t^{(\ell)} = \pi\lambda^2(2\ell+1)\{|1-\bar{\eta}_\ell|^2+1-|\bar{\eta}_\ell|^2\}. \qquad (15)$$

We now divide the average elastic cross section into two parts, the "shape-elastic" cross section, $\bar{\sigma}_{se}^{(\ell)}$, and the "compound-elastic" cross section, $\bar{\sigma}_{ce}^{(\ell)}$, by writing

$$\bar{\sigma}_{se}^{(\ell)} = \pi\lambda^2(2\ell+1)|1-\bar{\eta}_\ell|^2 \qquad (16)$$

and

$$\bar{\sigma}_{ce}^{(\ell)} = \pi\lambda^2(2\ell+1)\{\overline{|\eta_\ell|^2}-|\bar{\eta}_\ell|^2\}. \qquad (17)$$

Furthermore, if we combine the compound-elastic and reaction cross sections into something called the absorption cross section (σ_{abs}), then

$$\sigma_{abs}^{(\ell)} = \bar{\sigma}_{ce}^{(\ell)} + \bar{\sigma}_r^{(\ell)} = \pi\lambda^2(2\ell+1)\{1-|\bar{\eta}_\ell|^2\}. \qquad (18)$$

Clearly, the total, the shape-elastic, and the absorption cross sections, given by Eqs. 15, 16, and 18, respectively, depend only on $\bar{\eta}_\ell$. It is only these quantities that the optical model, which describes the interaction of a neutron with a nucleus as the scattering by a complex one-body potential, can be expected to reproduce.

The program ABAREX computes the total, the shape-elastic (S.E.), and the absorption cross sections (given by Eqs. 15, 16,

and 18, respectively) for neutron scattering from nuclei using the spherical optical model. The calculated angular distributions are given in the laboratory coordinate system. It also has built into it prescriptions for dividing the absorption cross section into its compound-elastic part (C.E.) and into contributions to inelastic (and other) channels, and these will be discussed in Section 5. Input to the program is entered using a set of keyword records, which are discussed in detail in Section 7. With the exception of the SEARCH image, the format for all the keyword records is (A7,I3,7F10.4). All input energies are in MeV, all lengths are in fermis (10^{-13} cm), and all computed cross sections are in barns (b) or barns per steradian (b/sr).

3. POTENTIALS

In ABAREX the real optical-model potential is limited to a Woods-Saxon well

$$V(r) = -V_0/\{1 + exp((r-R_v)/a_v)\}, \qquad (19)$$

where V_0 and a_v are the strength and diffuseness of the potential, respectively, and the radius R_v is given by

$$R_v = r_v A^{\frac{1}{3}}, \qquad (20)$$

where A is the target mass. V_0, r_v, and a_v are entered on the REAL keyword image, discussed in Section 7.1.

Several options are available for the imaginary part of the optical-model potential. First, it can have the volume form given by Eq. 19. Alternatively either the surface-peaked derivative Woods-Saxon shape,

$$W(r) = -4\ W_0\ exp((r-R_w)/a_w)/\{1 + exp((r-R_w)/a_w)\}^2, \qquad (21)$$

or the surface-peaked Gaussian form,

$$W(r) = -W_0\{exp-((r-R_w)/a_w)^2\}, \qquad (22)$$

can be used, and R_w, the radius of imaginary interaction, is given by

$$R_w = r_w A^{\frac{1}{3}}. \qquad (23)$$

In addition, the imaginary potential can be the sum of one of either of these surface components, Eq. 21 or 22, and a volume Woods-Saxon term. However, in ABAREX the geometry, r_w and a_w, of both the surface and volume parts must be the same. The form of the imaginary potential, together with its strength, radius and diffuseness, are specified on the IMAG keyword image, discussed in Section 7.2.

ABAREX also allows for the inclusion of a spin-orbit term in the optical-model potential. Generally this is taken to have the Thomas form

$$V_{so}(r) = (2\underline{L}\cdot\underline{S})V_{so}(2/r)\{d/dr(1/(1 + exp((r-R_{so})/a_{so})))\}, \quad (24)$$

where V_{so} can be the sum of a real plus imaginary part and the radii of both are

$$R_{so} = r_{so}A^{\frac{1}{3}}. \quad (25)$$

The dot product of the orbital and spin angular momentum operators, $\underline{L}\cdot\underline{S}$, takes on the values

$$\begin{aligned} 2\underline{L}\cdot\underline{S}\phi_{jm} &= \ell\phi_{jm} && \text{when } j=\ell+\tfrac{1}{2} \\ &= -(\ell+1)\phi_{jm} && \text{when } j=\ell-\tfrac{1}{2}, \end{aligned} \quad (26)$$

where ϕ_{jm} is the wave function that arises when the orbital angular momentum, $Y_{\ell m}(\theta,\phi)$, and the neutron intrinsic spin eigenfunction, $\xi_{\frac{1}{2}\nu}$, are coupled to give total angular momentum j with z-component m,

$$\phi_{jm} = \sum_{\mu,\nu}(\ell\tfrac{1}{2}\mu\nu|jm)Y_{\ell\mu}(\theta,\phi)\xi_{\frac{1}{2}\nu}, \quad (27)$$

with $(\ell\frac{1}{2}\mu\nu|jm)$ the Clebsch-Gordan coefficient (11). The parameters of the spin-orbit potential are specified on the keyword image SO, discussed in Section 7.3. The code also allows for a spin-orbit form factor of the Woods-Saxon type, Eq. 19, but this is seldom used in optical-model calculations.

There is a fundamental dispersion relationship linking the real and imaginary optical-model potentials (12)

$$V(r,E) = V_{HF}(r,E) + \frac{P}{\pi}\int_{-\infty}^{\infty} \{W(r,E')/(E-E')\}dE', \qquad (28)$$

where $V(r,E)$ is the total real potential, $V_{HF}(r,E)$ is the Hartree-Fock contribution (which is taken to have the Woods-Saxon form given by Eq. 19), $W(r,E)$ is the total imaginary potential, and P is the principal-value integral. Thus, if the imaginary potential has a surface-peaked component, the real potential should also have a surface-peaked part. A surface real potential whose form and geometry are identical to either of the imaginary interactions, Eq. 21 or 22, can be included in ABAREX. The strength of this added real potential is specified on the keyword image DISP, discussed in Section 7.4. One can, of course, put in an arbitrary strength for this interaction. However, if one wishes to use the value predicted by the dispersion integral, Eq. 28, a method of estimating the magnitude of this added surface term is given in Ref. 13.

The order in which these keyword images are communicated to ABAREX is largely arbitrary. The last keyword image, however, must be the COMPUTE record, discussed in Section 7.10, which tells the program to begin the calculation. We now give several examples of how the various potentials are communicated to the code, and the results obtained with them.

3.1. DEFAULT CALCULATION

If no potentials are given, and only the COMPUTE image is submitted, the default calculation is carried out, namely the scattering of 0.8 MeV neutrons from ^{56}Fe Note that the keywords are always capitalized, i.e. COMPUTE, not compute or Compute. It is also noted that the keywords are truncated to two characters in the program. Thus, 'CO' is equivalent to COMPUTE, etc. The ABAREX input file is shown between the ***-----'s of the EXAMPLE 3.1. The numbers 123.... indicate the columns of the input image in these examples. The ABAREX output obtained by submitting this file follows in EXAMPLE 3.1 The first column in the printout contains printer carriage control symbols that may or may not appear on the users printer depending upon its nature and the software. They are not shown in the examples.

The first thing ABAREX prints is a copy of the 'input' file which, in this case, is merely the COMPUTE image. Next the mass numbers of the target and the projectile are given. In the default calculation, the exact values for the masses of ^{56}Fe and the neutron were used (14). In general, the rounded-off value for the target mass number is sufficient (e.g. 56 for ^{56}Fe) since the relative difference between this value and the exact one is quite small. However, it is important to retain the exact

neutron mass number since a round-off here would cause about a 1% error. The radial wave equation, Eq. 4, was numerically integrated from 0 to 15 fm (ASYMPTOPIA=15.0 FM) and 301 integration points were used. It should be noted that other codes may use slightly different mass constants, cutoff radii and/or integration steps. As a consequence, test cases may not exactly agree.

The default optical-model parameters for the real, imaginary, and spin-orbit potentials are given on the lines labelled REAL, IMAG, and SO, respectively. In the default option the real potential always has the Woods-Saxon form given by Eq. 19 and the parameters describing it are V_o=46 MeV, r_v=1.317 fm, and a_v=0.62 fm. In computing the radius of the real potential the mass number of ^{56}Fe, 55.9349 a.m.u., was used for A in Eq. 20. As discussed in Section 7.2, when the number "4" appears in column 10 of the IMAG image the imaginary potential has the derivative Woods-Saxon shape given by Eq 21 and the default parameters characterizing it are W_o=14 MeV, r_w=1.447 fm, and a_w=.25 fm. The "1" in column 10 of the SO image indicates that the Thomas term, Eq. 24, was used for the spin-orbit interaction with the default value of 7 MeV for the strength and geometry equal to that of the real potential. Finally, the entries "0" on the DISP image indicate that no surface real potential was included.

Under the heading VOLINT the absolute values of the volume integral per nucleon of the real (J_v) and imaginary (J_w) potentials are listed. Analytic expressions for these volume integrals have been obtained by Elton (15), and when $V(r)$ is the Woods-Saxon potential given by Eq. 19,

$$J_v = (4\pi/A) \int_0^\infty V(r) r^2 dr$$
$$= (4\pi V_o/3)\, r_v^3 \left[1 + (\pi a_v/R_v)^2 \right]. \qquad (29)$$

For the derivative Woods-Saxon well the volume integral, J_w, has the value

$$J_w = (4\pi/A) \int_0^\infty W(r) r^2 dr$$
$$= (16\pi W_o/A)\, R_w^2\, a_w \left[1 + \tfrac{1}{3}(\pi a_w/R_w)^2 \right]. \qquad (30)$$

The volume integral of the imaginary potential is calculated by the program only when the potential has the form given by Eq. 21. Next the laboratory and center-of-mass energies are listed, the latter being calculated by use of Eq. 2 with the mass numbers

given in the output. LAMBDA-BAR, the reduced wave length, is defined by Eq. 11 and its value, computed by use of Eqs. 1, 2, and 5, is listed. The statement "NEUTRON CHANNEL ... INTERNALLY" is unimportant in this problem, but will be discussed in detail in Section 5.2.

Under the heading TARGET LEVELS the properties of the various target levels considered in the scattering process are given. For the default calculation, only the ground state of ^{56}Fe, with spin 0 and positive parity, is considered. The maximum neutron ℓ-value, which is computed internally in the program, is also printed out.

Under the heading INTEGRATED CROSS SECTIONS IN BARNS the total, total absorption, and total shape-elastic cross sections are given. ABAREX uses the j-j coupling scheme, Eq. 27, to carry out the calculations, so that these three cross sections are the sum on j of the j-j analogs of Eqs 15, 18, and 16, respectively. In Sections 5.1 and 5.2 we shall discuss the algorithms by which the absorption cross section is divided into its compound-elastic part and the part going to other open channels. Suffice to say, for the moment, this division requires calculating the quantity ABAREX lists in the line labelled TOTAL COMPOUND, and this sometimes involves numerical approximations. It is clear that if this were calculated exactly, the quantity called TOTAL COMPOUND would be identical to the quantity labelled ABSORPTION. However, the numerical approximations, discussed in Section 5.2, lead to a TOTAL COMPOUND which is 0.00080 barns smaller, that is an error of approximately .05%. Since the elastic channel is the only one considered in this example, its integrated value should be equal to the total cross section. However, when the TOTAL COMPOUND is added to the SHAPE ELASTIC contribution a total elastic cross section which is about 0.02% smaller than the total cross section is obtained. Errors of this magnitude, brought about by these numerical approximations, also arise in calculations other than this test case.

Finally, the angular distribution of the elastic-scattering cross section is printed in 15° steps (the default step size) in the laboratory coordinate system. In the column headed S.E. the shape elastic contribution is given and under C.E. the compound elastic is tabulated. The last column gives the angular distribution for the total-elastic cross sections which is the sum of the S.E. and C.E. contributions.

3.2. INPUT OF POTENTIALS

In this example the scattering of 3.5 MeV neutrons by ^{58}Ni is considered. Instead of using the default values for the optical-model potential we take the interaction to be the sum of

four parts:

1) a real volume Woods-Saxon potential, Eq. 19, with strength, V_o=45.1 MeV, reduced radius, r_v=1.2975 fm, and diffuseness, a_v=0.638 fm,

2) an imaginary derivative-Woods-Saxon interaction, Eq. 21, characterized by W_o=11.3 MeV, r_w=1.302 fm, a_w=0.3344 fm,

3) a real spin-orbit potential of the Thomas form, Eq. 24, having V_{so}=5.5 MeV, r_{so}=1.005 fm, and a_{so}=0.65 fm,

4) a surface-peaked real potential, with form and geometry identical to that of the imaginary interaction (the only option available in ABAREX) and strength 0.3 W_o as input on the DISP image.

The method by which these potentials are communicated to the program is illustrated in EXAMPLE 3.2, and is discussed in Section 7.1, 7.2, 7.3, and 7.4.

The incident energy and the target mass number are given on the COMPUTE image, discussed in Section 7.10. (If the binding energy of ^{58}Ni had been taken into account then the number 58 in columns 21-30 would have become (5) 57.9353 a.m.u.) The other two entries on this image are 10.0 in columns 51-60 and 601.0 in columns 71-80. The 10.0 tells the program to print out the angular distributions in the laboratory coordinate system in 10^0 steps and the 601.0 specifies the number of integration points to be used in the calculation. (Actually, the default value of 301.0 is sufficient and this entry was included only to illustrate the use of the option.)

The format for all input images in this problem is (A7,I3,7F10.4), and the input file for the calculation is shown between the ****'s of Example 3.2, followed by the respective ABAREX output. The latter is easily understood from the discussion in Section 3.1.

The states of ^{58}Ni considered in this calculation are listed in the ABAREX output under the heading TARGET LEVELS. Since the only property of the target communicated to the program was its mass number, A, ABAREX assumed that only the ground state was to be considered and that the default values for its spin (0), parity (+), and excitation energy (0.0) were to be used. Although there are nine states (16) in ^{58}Ni below a 3.5 MeV excitation energy, none of the other open channels, in which the neutron loses energy and leaves the nucleus in an excited state, were taken into account. Because of this, all of the compound

excitations go into the compound-elastic channel. As a consequence, the total elastic cross section, which is the sum of the shape-elastic and compound-elastic, is grossly overestimated. In Sections 5.1 and 5.2 we shall discuss how the neglected channels are taken into account.

3.3. ENERGY-DEPENDENT POTENTIALS

As discussed in Sections 7.1, 7.2, and 7.4, it is possible to give the real, imaginary, and surface-peaked real-potentials energy dependencies. For example, an energy-dependent real-potential strength of the form

$$V_o = V_r + V_1 E + V_2 E^2 \qquad (31)$$

can be used, where V_r, V_1, and V_2 are read in columns (11-20), (21-30) and (31-40), respectively, of the REAL image, discussed in Section 7.1. In a similar way, an energy dependence of the imaginary potential can be read from the IMAG image and, for the surface-peaked real potential, by making the appropriate entries on the DISP image, as discussed in Sections 7.2 and 7.4, respectively. In calculating the potential strengths using Eq. 31, and its analogs for the imaginary and surface peaked real potentials, ABAREX takes E to be the center-of-mass energy, E" of Eq. 2. In practice the difference between using the laboratory and center-of-mass energies for this purpose is generally negligible.

The easiest way to change the incident neutron energy is by use of the SCAN image, discussed in Section 7.7. When a "1" is placed in column 10 of the SCAN image, ABAREX will calculate cross sections from energy E_1, given in columns (11-20), to energy E_2, listed in columns (31-40), in energy steps, ΔE, given in columns (21-30). An alternative use of the SCAN image puts a "0" (or blank) in column 10 followed by the energies desired up to seven per image. These latter SCAN cards can be stacked to a maximum of 50 energies, but blanks can not occur in the list of energies as the scan will terminate when the first blank in the list is encountered.

In EXAMPLE 3.3, optical model calculations for the scattering of 3.5 and 4.5 MeV neutrons on ^{58}Ni are carried out. Both the real and imaginary potentials are taken to be energy dependent, the former decreasing and the latter increasing with increasing energy. The input file is given between the ****--------'s, and the ABAREX output immediately follows.

In this example the SCAN image was used to vary the incident neutron energy. The same result could have been obtained using the SCAN image with a "0" in column 10, followed by the energies

3.5 and 4.5 MeV in columns 11-20 and 21-30, respectively. If the FORTRAN used by the computer has the NAMELIST option, discussed in Section 7.11, there is a another way of altering the computational parameters. In this option the SCAN image is omitted, the COMPUTE image set to an energy of 3.5 MeV and immediately following the COMPUTE image, which initially ran the calculation for 3.5 MeV incident neutrons, the new energy is read in the form:

```
12345678901234567890123456789012345678901234567890

**************************************

INPUT
 &INPUT Z(1)=4.5,&END

**************************************
```

(In ABAREX the incident neutron energy is in the register Z(1).) The addition of these two images will lead to the same ABAREX output as given above. With the NAMELIST option any of the parameters listed in Section 7.11 can be changed.

It should be noted that the volume integrals of the real and imaginary potentials, listed in the output under VOLINT are calculated using the E=0 values of the potential strengths, that is with V_o = 46.15 MeV for J_v and W_o = 9.9 MeV for J_w in EXAMPLE 3.3.

As discussed in Section 3.2, the compound-elastic cross section in EXAMPLE 3.3 is grossly over estimated because none of the open channels corresponding to low-lying states in ^{58}Ni have been considered.

3.4. SURFACE PLUS VOLUME ABSORPTION

The example we now consider is the same as that in Section 3.2 except that there is no surface real potential and the imaginary interaction is the sum of a surface and volume contribution. Specifically, we use an imaginary optical-model potential which has a Gaussian surface component together with a Woods-Saxon volume absorption. The form of the surface absorption is given by Eq. 22 and the parameters of EXAMPLE 3.4 were taken to be W_o=11.3 MeV, r_w=1.302 fm and a_w=0.3344 fm. The only ABAREX option for the volume absorption is the Woods-Saxon potential of Eq. 19. The strength of this volume potential was taken to be 2.825 MeV with r_w and a_w having the above values.

As discussed in Section 7.2, an imaginary potential which is the sum of a Gaussian and Woods-Saxon well indicates that the index KIM, given in columns 8-10 of the IMAG image, should be 3.

(However, if KIM=2, a simple gaussian, and VIVOL is non-zero the program will set KIM=3 and give identical results to those obtained with KIM=3 at input. The same is true for the use of the Woods-Saxon-derivative well and the use of KIM=4 and =5.) The strength, reduced radius, and diffuseness of the surface peaked interactions are then given in columns 11-20, 41-50, and 51-60, respectively, and the strength of the volume absorption, VIVOL, is given in columns 61-70.

EXAMPLE 3.4 shows the input file for this calculation (between the ****--------'s), followed by the corresponding ABAREX output. The form of the output is identical to that discussed in Section 3.1. As mentioned before, the volume integral, J_w, of the imaginary potential is only calculated by the program when this interaction has the derivative Woods-Saxon form, Eq. 21. However, an expression for the volume integral of the Gaussian potential, Eq. 22, can be be easily obtained and is

$$J'_w = (4\pi/A) \int_0^\infty W(r) r^2 dr$$

$$= (\pi a_w W_o/A) \left[2a_w R_w exp(-(R_w/a_w)^2) + (2R_w^2 + a_w^2)\sqrt{\pi}\ [1 + erf(R_w/a_w)] \right], \qquad (32)$$

where $erf(x)$ is (17)

$$erf(x) = (2/\sqrt{\pi}) \int_0^x dt\ exp(-t^2). \qquad (33)$$

Note also that

$$J_{so} = \frac{4\pi}{3} \int_o^\infty V(r) \cdot r^2 \cdot dr \approx 2 \cdot R_{so} \cdot V_{so},$$

for the Thomas Spin-Orbit potential (18). The latter expression is seldom used.

In Section 7.2 a second way of communicating the volume-absorption strength to ABAREX is discussed. With the second alternative the sum of the surface and volume strengths is entered in columns 11-20 of the IMAG image and the ratio of the volume strength to the above total strength is entered in columns 71-80. For the case under discussion, the entry in columns 11-20 would become (11.3 + 2.825) = 14.125, the entry in columns 71-80 would be 2.825/14.125 = 0.2, and there would be no entry in columns 61-70.

Again, as discussed in Section 3.2, the compound-elastic cross section of EXAMPLE 3.4 is not realistic since no excited

states of ^{58}Ni were taken into account.

4. LOW ENERGY SCATTERING

If one writes the reflection factor, η_ℓ, in terms of its real and imaginary parts,

$$\eta_\ell = \eta_\ell^R + i\eta_\ell^I, \qquad (34)$$

and makes a similar decomposition for the phase shift, δ_ℓ, one sees that Eq. 8 can be written in the form

$$\eta_\ell^R + i\eta_\ell^I = \{exp(-2\delta_\ell^I)\}\{exp(2i\delta_\ell^R)\}, \qquad (35)$$

where the superscripts R and I indicate the real and imaginary parts of the functions. It, therefore, follows that

$$exp(-4\delta_\ell^I) = (\eta_\ell^R)^2 + (\eta_\ell^I)^2 . \qquad (36)$$

The transmission coefficient, T_ℓ, for the ℓth partial wave is defined to be

$$T_\ell = 1 - \{(\eta_\ell^R)^2 + (\eta_\ell^I)^2\}, \qquad (37)$$

so that

$$\begin{aligned} \delta_\ell^I &= -\tfrac{1}{4}\ell n(1 - T_\ell) \\ &\approx \tfrac{1}{4}T_\ell, \end{aligned} \qquad (38)$$

if T_ℓ is small. Similarly, from Eqs 35 and 37 it follows that

$$\delta_\ell^R = \tfrac{1}{2}\cos^{-1}\{\eta_\ell^R/\sqrt{(1-T_\ell)}\}. \qquad (39)$$

We now consider the form $\bar{\eta}_\ell$ takes when the cross section is written using the Breit-Wigner resonance formalism (10). For simplicity we consider low-energy scattering so that we can restrict the discussion to ℓ=0 partial waves. When the Breit-Wigner reflection coefficient, η_0, is averaged over an energy interval ΔE it becomes

$$\bar{\eta}_0 = \{exp(-2ikR')\}(1 - \pi\Gamma/D), \qquad (40)$$

provided Γ/D is small. In this expression Γ is the average width of an s-wave resonance and D is the average spacing between the resonances in the averaging interval. When Γ/D is small, comparison of Eqs. 35 and 40 shows that

$$R' = -\delta_0^R/k, \qquad (41)$$

and

$$\Gamma/D = (2/\pi)\delta_0^I. \qquad (42)$$

Since Γ/D depends on the energy at which Γ and D are measured, the quantity that is generally tabulated (19) is the s-wave strength function, S_0, which is defined to be

$$S_0 = (E_1/E)^{\frac{1}{2}}(\Gamma/D), \qquad (43)$$

where E is the average energy in the measurement interval, ΔE, and E_1 is a reference energy which is conventionally taken to be 1 eV.

We now examine how the s-wave strength function and R' come into the low-energy neutron total and shape-elastic cross sections. When Eq. 40, the Breit-Wigner value of $\bar{\eta}_0$, is inserted into Eq. 16 one finds that the shape-elastic cross section for small kR' becomes

$$\sigma_{se} = \pi\lambda^2 |exp(2ikR') - 1 + \pi\Gamma/D|^2$$
$$\approx \pi\lambda^2\{4k^2R'^2 + (\pi\Gamma/D)^2\}. \qquad (44)$$

Since $\lambda = 1/k$, and because Γ/D is small it follows that

$$\sigma_{se} \approx 4\pi R'^2, \qquad (45)$$

that is, at low energies the shape-elastic scattering is identical to the scattering from a hard sphere of radius R'. In the same way, an expression can be obtained for the total cross section at low energies and one finds

$$\sigma_t \approx 4\pi R'^2 + 2\pi^2 \lambda^2 \Gamma / D$$

$$\approx 4\pi R'^2 + 2\pi^2 \lambda^2 (E/E_1)^{\frac{1}{2}} S_0 , \qquad (46)$$

where Eq. 43 has been used in writing the second line of Eq. 46. Thus the total cross section at very low bombarding energies is the sum of a resonance contribution and the scattering from a hard sphere of radius R'.

When the transmission coefficient, T_0, is small, it follows from Eqs. 38, 42, and 43 that the s-wave strength function is

$$S_0 \approx (1/2\pi)(E_1/E)^{\frac{1}{2}} T_0 . \qquad (47)$$

The strength function for higher partial waves can also be measured and the generalization of Eq. 47, which takes into account the intrinsic spin of the neutron, is (19)

$$S_{j\ell} = \{1/(2\pi V_\ell)\}\{(2j+1)/(2(2\ell+1))\}(E_1/E)^{\frac{1}{2}} T_{j\ell}, \qquad (48)$$

where $j=\ell \pm \frac{1}{2}$. The penetration factor, V_ℓ, is given in Ref. 19 and has the value unity when $\ell=0$ and

$$V_1 = (kR)^2/(1+(kR)^2), \qquad (49)$$

when $\ell=1$, where $R = r_v A^{1/3}$ is the nuclear radius in Eq. 49. Clearly with these definitions the s-wave strength function given by Eq. 48 is identical to that given by Eq. 47. Experimental values for R' and the s- and p-wave strength functions are given in Ref. 19. Note that in this reference the tabulated p-wave strength function is the <u>sum</u> of the $j=\frac{1}{2}$ and $\frac{3}{2}$ values given by Eq. 48. ABAREX calculates R' and the s- and p-wave strength functions, defined by Eq. 48 and 49. <u>In order to have ABAREX print out these results the TRANSM image, described in Section 7.9, must be included in the input.</u>

4.1. STRENGTH FUNCTIONS

In this section we illustrate the calculation of the hard sphere scattering radius, R', and the s- and p-wave strength functions. The calculation is carried out for ^{58}Ni using the zero-energy spherical optical-model potential given in Table 3 of Ref. 20. EXAMPLE 4.1 shows the respective input file (between

the ***--------'s), followed by the corresponding ABAREX output.

The calculated strength functions are given in the column headed STR.FN. in the ABAREX output. The s-wave value, $S_o = 2.336 \times 10^{-4}$, is listed in the line which starts with 0 and columns headed L and J, respectively, which are the ℓ and j values of the neutron partial wave. This result is in excellent agreement with the experimental value (19), $S_o = (2.8 \pm 0.6) \times 10^{-4}$. The predicted p-wave strength function is also listed in the column headed STR.FN., the $j=\frac{1}{2}$ value being given on the line beginning 1 and 1/2 and the $j=\frac{3}{2}$ on the line beginning 1 and 3/2. The sum of these two predicted values, $S_1 = (0.1926+0.5894)\times10^{-4} = 0.782\times10^{-4}$ is the quantity that should be compared with the experimental value (19), $S_1 = (0.5 \pm 0.1)\times10^{-4}$. In view of the difficulty in extracting p-wave strength functions from the experimental data, theory and experiment are in reasonable agreement. Finally, the predicted hard sphere radius, R', is in the same line as the s-wave strength function in the column headed R-PRIME. The predicted value, $R' = 6.547$ fm, is somewhat smaller than the experimentally-deduced value (19), $R' = (8.0 \pm 0.5)$ fm.

When the TRANSM image is included, the real and imaginary parts of the reflection factors, $\eta_{j\ell}$, are printed under the heading ETA, and under T the transmission coefficients, Eq. 37, are given. For the very low energy considered in this problem (100 eV), only the $\ell=0$ partial wave is important. Using the printed values of η_0 and T_0, together with Eqs. 15, 16, and 19, it is easy to verify the values given under INTEGRATED CROSS SECTION IN BARNS for the TOTAL, ABSORPTION, and SHAPE ELASTIC cross sections. As discussed in Section 5.2, the approximations involved in calculating the quantity labelled TOTAL COMPOUND lead to a cross section which is 0.082 barns smaller than the ABSORPTION value, that is a discrepancy of 0.084%.

The quantities NU(+) and NU(-), which will be discussed below in Section 5.2, are calculated using Eq. 84. The printout also contains the quantities γ^2/D and R_∞ as defined in Ref. 21. These latter two quantities will not be discussed here.

4.2. (n,γ) AND RADIATIVE CAPTURE

At low energies the emission of gamma rays can become important when a neutron interacts with a spherical nucleus. In this section we shall consider two possibilities that occur when a neutron, incident on a target with mass number A, is captured and the compound $(A+1)$ nucleon system is formed in a highly excited state:

i) Radiative Capture - The compound state decays by the emission of one or more gamma rays finally ending up in the nuclear ground state of the $(A+1)$ nucleus.

ii) (n,γ) Reaction - The (n,γ) cross section is defined here as the radiative capture cross section plus that for gamma emission followed by neutron decay so that the final nucleus has the mass A. Since there is a finite probability of neutron emission, the (n,γ) cross section will always be $\geq$ that for radiative capture.

To include these processes in the optical-model calculation, the input file must contain the CAPTURE image, discussed in Section 7.8. In EXAMPLE 4.2 the default problem of Section 3.1 was used, including the CAPTURE image. The target nucleus is ^{56}Fe, so that the Z of the target, which is read in columns (8-10) of the CAPTURE card, is 26. The average radiative width to level spacing ratio for s-wave neutrons, which is read in columns (11-20), can be obtained from Ref. 19, and for ^{56}Fe is $S_{\gamma_0} = 0.5\text{x}10^{-4}$. (Actually S_{γ_0} for the compound nucleus ^{57}Fe should be used. However, since the calculated result will be compared with the data on elemental Fe, which is $\approx$ 91% ^{56}Fe, this value is a reasonable approximation.) The neutron binding energy can be obtained from the binding energy tables (14) and is 7.65 MeV. The default value, 20, is taken for the gamma-ray width fluctuation degrees of freedom, discussed in Section 5.2. Values of EGD and GGD, which characterize the $E1$ giant-dipole resonance energy and width, are given by Berman and Fultz (22). (The values, 17.4 MeV and 4.4 MeV, are the averages of the giant dipole energy and width for the neighboring nucleus ^{60}Ni.) Finally, the default values for the level density parameter, SA=a, and the spin cut off parameter, SG = σ, discussed in Section 5 and by Gilbert and Cameron (23), have been used. The TRANSM image was included so that the reflection factors, η_{jl}, would be printed. The input file and ABAREX output are given in EXAMPLE 4.2.

In calculating the (n,γ) and radiative capture cross sections, ABAREX uses the $E1$ giant-dipole model of Brink and Axel (21,24), provided the giant-dipole energy, EGD, is positive. In this theory the average partial width of an electric dipole

transition with energy, ε, is proportional to the Lorentzian form,

$$\Gamma_\gamma \propto \varepsilon^4/\{(\varepsilon^2 - EGD^2)^2 + (\varepsilon GGD)^2\}. \qquad (50)$$

The total radiative width is obtained by weighting this quantity by the density of states, $\rho(\varepsilon)$, and integrating from 0 to $(BN + E'')$, where BN is the neutron binding energy and E'' is the center-of-mass energy of the incident neutron, given by Eq. 2 (we shall discuss $\rho(\varepsilon)$ in more detail in Section 5). As discussed in Ref. 21, the proportionality factor in Eq. 50 is determined by the photo-nuclear dipole sum rule, and, as shown by Levinger and Bethe (25), this sum rule should be multiplied by the factor $(1 + 0.8x)$, where x is the fraction of exchange force present in the two-body nuclear force. In ABAREX, x is set equal to 0.5. If an experimental value is known for S_{γ_0}, as it is for ^{56}Fe, the radiative width is normalized to the value read in columns (11-20) of the capture image. For the present calculation the predicted (n,γ) and radiative capture cross sections are identical at 11.06 mb, when the transmission coefficients for the second chance neutrons are calculated using the Black Nucleus Approximation. As discussed in Section 7.8, if S_{γ_0} is read in with a negative sign the transmission coefficients for the second chance neutrons are calculated using the optical model and this option gives results identical with those just quoted. Experimentally (26) the capture cross section of Fe is 5.3 mb at 800 keV, that is almost a factor of two smaller than the theoretical prediction. If the default values were used for all parameters in the capture calculation, the binding energy and the giant dipole width would be BN = 8 MeV and GGD = 5 MeV, and the giant dipole energy would be calculated from the expression

$$EGD = \{163\sqrt{((A + 1 - NZ)NZ)}\}/(A + 1)^{\frac{4}{3}}, \qquad (51)$$

where A = 56 and NZ =26 refer to the mass number and charge of the target. In this case the predicted values for the (n,γ) and radiative capture cross sections are 4.79 mb and 4.78 mb, respectively, when the Black Nucleus Approximation is made in calculating the transmission coefficients for second chance neutrons.

Generally, ABAREX uses the Brink-Axel theory in calculating the radiative cross sections. However, if the input value of the giant-dipole energy is negative then instead of taking Γ_γ proportional to the Lorentzian form, Eq. 50, it is taken proportional to E^3. When this is done, the (n,γ) and radiative capture cross sections in EXAMPLE 4.2 become 10.51 mb and 10.49 mb, respectively, for second-chance neutron transmission

coefficients computed using the Black Nucleus Model.

Since the TRANSM image was included in the input file, the values of the reflection factors, $\eta_{j\ell}$, and the transmission coefficients, $T_{j\ell}$, Eq. 37, are printed in the columns headed ETA and T and the l and j values for the various partial waves are given in the columns headed L and J. In this (jl) representation the expression for the total absorption cross section becomes

$$\sigma_{abs} = \frac{1}{2}\pi\lambda\!\!\!^{-2} \sum_{j,\ell} (2j + 1)\{1 - |\overline{\eta_{j\ell}}|^2\}$$

$$= \frac{1}{2}\pi\lambda\!\!\!^{-2} \sum_{j,\ell} (2j + 1)\, T_{j\ell}, \qquad (52)$$

where the factor $\frac{1}{2}$ arises from the average over the intrinsic spin states of the incident neutron. By substituting the values of $T_{j\ell}$ given in the output, one easily verifies the printed absorption cross section. Modifications identical to those made in obtaining Eq. 52 from Eq. 18 must be made in Eqs. 15 and 16 to obtain the total and shape-elastic cross sections in the $(j\ell)$ representation. As in Section 3.1, NU(+) and NU(-) are calculated using Eq. 84 and will be discussed in Section 5.2.

The user is cautioned that the capture option refers to CN capture which is significant only at relatively low energies (below a few MeV incident energy). Attempts to pursue the calculations to higher energies may lead to abortive and/or erroneous results depending upon the values of the input parameters used. It is suggested that the user limit the CAPTURE option to energies of less than ≈ 3 MeV.

5. EXCITED TARGET STATES

Thus far little information has been given about the target nucleus except that it contains A nucleons. However, when the incident neutron energy becomes sufficiently high, it is important to know other nuclear properties since there may be an appreciable cross section for the outgoing neutron to lose energy to the target and leave it in an excited state. For example, in Sections 3.2, 3.3, and 3.4 cross sections for the scattering of 3.5 MeV neutrons from ^{58}Ni were presented. Below 3.5 MeV there are nine states in ^{58}Ni with well known spins and parities (16), which means there are several exit channels, other than the elastic one, that can be populated in the scattering process.

Information regarding the target states is communicated to ABAREX through the LEVELS image discussed in Section 7.5. If this image is omitted or NLE = 0 (see below) the program assumes only the ground state, with spin and parity 0^+, is to be taken into account. Columns (8-10) of the LEVELS image contain the number of discrete levels, NLE, of the target that are going to be considered. The LEVELS image must be followed by NLE images which give the properties of the target states in order of increasing excitation energy. The first of these describes the properties of the ground state and the remainder describe the excited states. The properties of the Ith level, needed in the calculation are its excitation energy, its spin, its parity, a group number, and its weight in fitting data (discussed in Section 7.6). The format for the input of this information is discussed in Section 7.5.

Returning to the LEVELS image itself, the target charge, Z, (Z=ZTARGET) and ECONT, the energy at which the target level continuum is to start, are read in columns (11-20) and (21-30), respectively. For $Z > 0$, the target level continuum is included when E, the incident neutron energy, is $\geq$ ECONT. The default value of ECONT is the energy of the last discrete, the NLE^{th}, level. At low excitation energies the continuum level density at energy ϵ is calculated using the formula (23)

$$\rho(\epsilon) = (1/T)\{exp((\epsilon-E_0)/T)\}, \qquad (53)$$

where T=TAU, the nuclear temperature, and E_0=E0T, the energy shift, are read in columns (41-50) and (51-60), respectively. This expression is assumed to hold for energies less than or equal to

$$E_x = U_x + P(Z) + P(N), \qquad (54)$$

where $P(Z)$ and $P(N)$ are the proton and neutron pairing energies given in Table 3 of Ref. 23 and U_x, in MeV, is

$$U_x = 2.5 + 150/A. \qquad (55)$$

For excitation energies greater than E_x the density of states with energy ϵ and angular momentum J is taken to be (23)

$$\rho(\epsilon) = (1/(24\sqrt{2}\sigma^3))(2J + 1)\ \exp[-(J + \tfrac{1}{2})^2/2\sigma^2]\ \exp[2\sqrt{aU}]/(a^{\frac{1}{4}}U^{\frac{5}{4}}) \qquad (56)$$

where σ = SG is the spin cut off parameter, which can be read in columns (61-70) of the LEVELS image,

$$U = \varepsilon - P(Z) - P(N), \qquad (57)$$

and a is the level density parameter. If one wishes to specify a, the CAPTURE image must be included in the input file and, as discussed in Section 7.8, a=SA is read in columns (61-70) of that image. The default value of a is internally computed in ABAREX using the formula

$$a = (0.00917S + 0.142)A, \qquad (58)$$

where S is the shell correction given in Table 3 of Gilbert and Cameron (23). Default values for the spin cut off parameter, σ, in Eq. 56 and for the temperature, T, and the energy shift, E_0, in Eq. 53, can also be used. The default formulae for these quantities, taken directly from Gilbert and Cameron (23), are

$$\sigma^2 = 0.0888\ (aU_x)^{\frac{1}{2}}\ A^{\frac{2}{3}}, \qquad (59)$$

$$1/T = (a/U_x)^{\frac{1}{2}} - 1.5/U_x, \qquad (60)$$

and

$$E_0 = E_x - T\ ln[T\rho_2(U_x)], \qquad (61)$$

where E_x and U_x are given by Eqs. 54 and 55, respectively, and $\rho_2(U)$ is the density of states when Eq. 56 is summed over all possible J values,

$$\rho_2(U) = [exp(2\sqrt{aU})]/(12\sqrt{2}\ \sigma\ a^{\frac{1}{4}}U^{\frac{5}{4}}). \qquad (62)$$

5.1. HAUSER-FESHBACH THEORY

The Hauser-Feshbach (27) theory, which is an extension of some earlier work of Wolfenstein (28), provides a prescription for dividing the COMPOUND cross section into the elastic channel (compound elastic) and other channels in which the nucleus is primarily left in an excited state and the neutron is emitted with reduced energy. In making this division, it is assumed that the wave functions of the compound nuclear states have random phases and hence when phase averages are made all interference terms vanish. As can be seen from Eq. 52, the probability of capturing (absorbing) a neutron with energy E, angular momentum j and parity ℓ is proportional to the transmission coefficient $T_{j\ell}(E)$. By reciprocity, the probability of emission of a neutron with E', j' and ℓ' will be proportional to $T_{j'\ell'}(E')$. Consequently the probability of emission into the channel

(j',ℓ',E') when the neutron is captured in the channel (j,ℓ,E) is proportional to the product of these two transmission coefficients, provided the total angular momentum and parity of the nucleus plus neutron are the same in the initial and final states.

In order to provide a simple example, consider the scattering of neutrons by a spin 0^+ target which has a low-lying 1^+ excited state. Denote the transmission coefficients for the ground state by $T_{j\ell}(E)$, those for the 1^+ state by $T_{j\ell}(E')$, and assume they have non-vanishing values for $\ell \leq 3$. Because the ground state of the target is 0^+, in the entrance channel the angular momentum and parity of the compound nuclear states are determined entirely by the (j,ℓ) values of the incident neutron. Thus, for example, the absorption cross section for the $j=\frac{3}{2}$ $\ell=1$ state is proportional to $T_{\frac{3}{2}1}(E)$. This compound state can decay to the ground or 1^+ state and in the latter case conservation of spin and parity limit the $(j\ell)$ values of the emitted neutron to be $\ell=1$, with $j=\frac{1}{2}$ or $\frac{3}{2}$ or $\ell=3$ with $j=\frac{5}{2}$. Thus the probability for decay to the ground-state channel (compound-elastic scattering) is $T_{\frac{3}{2}1}(E)/T$ and for decay to the 1^+ state is $\{T_{\frac{1}{2}1}(E')+T_{\frac{3}{2}1}(E')+T_{\frac{5}{2}3}(E')\}/T$, where T, the normalization factor, is $T=T_{\frac{3}{2}1}(E)+T_{\frac{1}{2}1}(E')+T_{\frac{3}{2}1}(E')+T_{\frac{5}{2}3}(E')$. Proceeding in this manner one sees that the predicted total cross section for leaving the nucleus in the excited 1^+ state is

$$\sigma_{inel}(E') =$$

$$\tfrac{1}{2}\pi\,\lambda^2\Big[2T_{\frac{1}{2}0}(E)\{T_{\frac{1}{2}0}(E')+T_{\frac{3}{2}2}(E')\}/[T_{\frac{1}{2}0}(E)+T_{\frac{1}{2}0}(E')+T_{\frac{3}{2}2}(E')] +$$

$$2T_{\frac{1}{2}1}(E)\{T_{\frac{1}{2}1}(E')+T_{\frac{3}{2}1}(E')\}/[T_{\frac{1}{2}1}(E)+T_{\frac{1}{2}1}(E')+T_{\frac{3}{2}1}(E')] +$$

$$4T_{\frac{3}{2}1}(E)\{T_{\frac{1}{2}1}(E')+T_{\frac{3}{2}1}(E')+T_{\frac{5}{2}3}(E')\}/[T_{\frac{3}{2}1}(E)+T_{\frac{1}{2}1}(E')+T_{\frac{3}{2}1}(E')+T_{\frac{5}{2}3}(E')]$$

$$+4T_{\frac{3}{2}2}(E)\{T_{\frac{1}{2}0}(E')+T_{\frac{3}{2}2}(E')+T_{\frac{5}{2}2}(E')\}/[T_{\frac{3}{2}2}(E)+T_{\frac{1}{2}0}(E')+T_{\frac{3}{2}2}(E')+$$

$$T_{\frac{5}{2}2}(E')] + 6T_{\frac{5}{2}2}(E)\{T_{\frac{3}{2}2}(E')+T_{\frac{5}{2}2}(E')\}/[T_{\frac{5}{2}2}(E)+T_{\frac{3}{2}2}(E')+T_{\frac{5}{2}2}(E')] +$$

$$6T_{\frac{5}{2}3}(E)\{T_{\frac{3}{2}1}(E')+T_{\frac{5}{2}3}(E')+T_{\frac{7}{2}3}(E')\}/[T_{\frac{5}{2}3}(E)+T_{\frac{3}{2}1}(E')+T_{\frac{5}{2}3}(E')+T_{\frac{7}{2}3}(E')]$$

$$+ 8T_{\frac{7}{2}3}(E)\{T_{\frac{5}{2}3}(E')+T_{\frac{7}{2}3}(E')\}/[T_{\frac{7}{2}3}(E)+T_{\frac{5}{2}3}(E')+T_{\frac{7}{2}3}(E')]\Big]. \quad (63)$$

The expression for the total compound elastic scattering is obtained by replacing each of the { } in the numerators of Eq. 63 by the $T_{j\ell}(E)$ which multiplies it, i.e. in the last line of

Eq. 63 $\{T_{\frac{5}{2}3}(E')+T_{\frac{7}{2}3}(E')\}$ would be replaced by $T_{\frac{7}{2}3}(E)$. Hauser and Feshbach give an expression for this inelastic 1^+ cross section in the limit that the optical-model potential has no spin-orbit part. In this limit $T_{j\ell} \rightarrow T_\ell$ and Eq. 63 becomes identical to their equation.

When both the ground and excited state have spin 0 a simple expression can be given for the scattering to the excited state,

$$\sigma_{\text{inel}}(E') = \tfrac{1}{2}\pi\,\lambda^2 \sum_{j\ell\ell'} (2j+1)\left[\frac{T_{j\ell}(E)\;T_{j\ell'}(E')}{T_{j\ell}(E)+T_{j\ell'}(E')}\right]\left[\frac{1+(-1)^{\ell+\ell'+\Delta\pi}}{2}\right], \tag{64}$$

where $\Delta\pi = 0$ if the ground and excited nuclear states have the same parity and $\Delta\pi = 1$ if their parities differ.

Eqs. 63 and 64 give the total inelastic cross sections. Expressions for the angular distributions of the inelastic and compound-elastic cross sections are given by Hauser and Feshbach (27).

In order to write a general expression for the total compound elastic or inelastic cross section, it is convenient to go to a representation in which the spin of the nuclear state, J_q, and the neutron angular momentum, j, are coupled to total spin J and parity $(-1)^\ell \pi_q$, where ℓ is the orbital angular momentum of the neutron and π_q is the parity of the nuclear state. Since J and parity must be conserved, it follows that the total Hauser-Feshbach cross section for emission of a neutron with energy, E_f, leaving the nucleus in the final state (J_f,π_f), is

$$\sigma(E_f) = \frac{\pi\,\lambda^2}{2(2J_i+1)} \sum_J (2J+1)\left[\sum_{j\ell}\{T_{j\ell}(E)\Delta^J_{jJ_i} \sum'_{j'\ell'} T_{j'\ell'}(E_f)\Delta^J_{j'J_f}/T_a\}\right], \tag{65}$$

where

$$T_a = \sum'_{j''\ell''q} T_{j''\ell''}(E_q)\Delta^J_{j''J_q}. \tag{66}$$

In these expressions E_q is the energy of the outgoing neutron in channel q (E_q=E is the energy of the incident neutron), J_i is the ground state spin, Σ' means that the sum is only over those

states with parity $(-1)^{\ell}\pi_0$, and

$$\Delta^{J}_{jJ_q} = 1 \text{ if } |J_q - j| \leq J \leq (J_q + j)$$
$$= 0 \text{ otherwise.} \qquad (67)$$

To illustrate the use of the Hauser-Feshbach theory we consider the scattering of 4.5 MeV neutrons from ^{58}Ni. The six known states(16) below 3.0 MeV excitation energy are explicitly considered and above that energy a continuum of states is assumed. For the continuum, the temperature, T, the energy shift, E_0, and the spin cut-off parameter, σ, (used in Eqs. 53, 56, and 62) were taken directly from Table 5 of Gilbert and Cameron (23), while the potential was taken from Ref. 20. In EXAMPLE 5.1 the input file is given between the ****'s and the ABAREX output for this calculation follows. Since there was no entry on the LEVELS image in columns 21-30 the default value, namely the energy of the last discrete state, was used for the start of the continuum levels. By use of Eq. 53, one can easily verify that at 2.942 Mev the level density is 4.45 levels per MeV when E_0 = -0.17 MeV and T = 1.59 MeV. For the Hauser-Feshbach calculations no numerical approximations are involved in dividing the absorption cross section into its various constituents and as a consequence the ABSORPTION and TOTAL COMPOUND cross sections are identical. In the line labeled COMPOUND EXCITATIONS the total cross sections to the various open channels are given. These total compound cross sections are: 0.20782 barns for compound elastic, 0.26426 barns when the nucleus is left in its yrast 2^+ state, and 0.05768 barns for scattering in which the residual ^{58}Ni nucleus is left with an excitation energy of 2.942 MeV. Finally, the total cross section for leaving the nucleus in a continuum state is 0.68395 barns.

The angular distributions of the various discrete levels are listed under the heading LABORATORY CROSS SECTION IN BARNS PER STERADIAN. In the second column the angular distribution for shape elastic scattering is tabulated, in the third column for compound elastic, and the fourth is the sum of these two, namely the total elastic-scattering angular distribution. In columns 5 through 9 the emitted-neutron angular distributions are given when the target nucleus is left with 1.454, 2.459, 2.776, 2.902, and 2.942 MeV of excitation energy, respectively.

The excitation energy, spin, and parity of the discrete nuclear states considered in this calculation were given on the six images immediately following the LEVELS record. As discussed in Section 7.5, a group number, KGP, can be assigned to each of these levels by making an entry in columns 16-20. Since this entry was left blank, the default values were used, and these are listed in the ABAREX output in the column labelled GROUP, i.e.

the group number goes from 1 to NLE, the number of levels. When each level has a different identification number the cross section to each individual level is printed. However, it is often impossible to experimentally distinguish outgoing neutrons which leave the residual nucleus in one or another of closely spaced states. For example, in the scattering from ^{58}Ni it would be unlikely to experimentally resolve outgoing neutrons which leave the nucleus in the 2.902 MeV state from those which leave it in the 2.942 MeV level. Thus in comparing with experiment, it would be useful if these two cross sections could be lumped together. This can be accomplished by giving the two levels the same group number. Thus, in this example, if one enters the numbers 1, 2, 3, 4, 5, and 5 in columns 20 of the images describing the properties of the levels, the cross section for the scattering to the 2.902 and 2.942 MeV levels would be added together.

5.2. WIDTH FLUCTUATIONS

In Section 5.1 it was argued that the cross section for going from an initial state a to a final state b was

$$\sigma_{ab}^{HF} \propto T_a T_b / (\sum_c T_c), \qquad (68)$$

where the transmission coefficient, T_a, is related to the probability that the incident neutron forms a compound state, μ, with angular momentum J and parity π, $T_b/\sum_c T_c$ is the relative probability that this state decays into a particular channel b, and the superscript HF means that this is the Hauser-Feshbach approximation for the cross section. Because of the uncertainty principle, the lifetime, τ_μ, of this state and its total width, Γ_μ, are related,

$$1/\tau_\mu = \Gamma_\mu/\hbar, \qquad (69)$$

where $\Gamma_\mu = \sum_c \Gamma_{\mu c}$ is the sum over all the partial decay widths and is proportional to the decay probability per unit time of the state μ. Because $\Gamma_{\mu c}$ and T_c are both proportional to the decay probability of the state μ they should be proportional to each other. However, as discussed in Section 3, when T_c is calculated using the optical model it is understood to be the average value of T_c over an energy interval ΔE. Thus, it is actually the averaged value of $\Gamma_{\mu c}$, $\langle\Gamma_{\mu c}\rangle$, which is proportional to T_c. Therefore, a more realistic approximation to the average compound-nuclear cross section for going from channel a to b, is

given by the expression

$$\bar{\sigma}_{ab}^{cn} \propto \sigma_{ab}^{HF} W_{ab}, \qquad (70)$$

where

$$W_{ab} = \left\langle \frac{\Gamma_{\mu a}\Gamma_{\mu b}}{\Gamma_{\mu}} \right\rangle \frac{< \Gamma_{\mu} >}{< \Gamma_{\mu a} > < \Gamma_{\mu b} >}$$

$$= G_{ab} C_{ab}, \qquad (71)$$

with

$$G_{ab} = \frac{< \Gamma_{\mu a}\Gamma_{\mu b}/\Gamma_{\mu} > < \Gamma_{\mu} >}{< \Gamma_{\mu a}\Gamma_{\mu b} >} \qquad (72)$$

and

$$C_{ab} = \frac{< \Gamma_{\mu a}\Gamma_{\mu b} >}{< \Gamma_{\mu a} > < \Gamma_{\mu b} >}. \qquad (73)$$

Empirically it has been found that in many cases the distribution of partial decay widths for a channel is given by the Porter-Thomas distribution (29). That is, the probability that $(\Gamma_{\mu a} / < \Gamma_{\mu a} >)$ has a value between x and $x+dx$ is

$$F_{PT}(x)\, dx = (2\pi x)^{-\frac{1}{2}} \exp(-x/2)\, dx. \qquad (74)$$

There exists a general class of normalized chi-squared distributions with ν degrees of freedom and these have the form

$$F_{\nu}(x) = \{ (\nu/2)^{(\nu/2)} x^{((\nu/2)-1)} \exp(-\nu x/2) \}/\Gamma(\nu/2), \qquad (75)$$

where $\Gamma(\nu/2)$ is the mathematical gamma function (17),

$$\Gamma(z) = \int_0^{\infty} t^{z-1} \exp(-t)\, dt, \qquad (76)$$

and

$$\Gamma(z+1) = z\, \Gamma(z). \qquad (77)$$

Clearly, $F_{PT}(x) \equiv F_1(x)$, is the chi-squared distribution with one

degree of freedom. From Eq. 77 it follows that if x is distributed according to Eq. 75

$$< x^k > = \Gamma(k+\nu/2)/\{(\nu/2)^k\ \Gamma(\nu/2)\} \qquad (78)$$

and the variance of x is

$$\{ < x^2 > - < x >^2 \}^{\frac{1}{2}} = (2/\nu)^{\frac{1}{2}}. \qquad (79)$$

G_{ab}, Eq. 72, takes into account the correlation between $\Gamma_{\mu a}\Gamma_{\mu b}$ and Γ_{μ}^{-1} which is due to the fact that they both contain $\Gamma_{\mu a}$ and $\Gamma_{\mu b}$. By noting that

$$(a+b+...+s)^{-1} = \int_0^\infty \exp(-(a+b+..\ +s)t)\ dt, \qquad (80)$$

it is easily shown that if the $\Gamma_{\mu c}$ are distributed according to a normalized chi-squared distribution with ν_c degrees of freedom

$$G_{ab} = \int_0^\infty dt \prod_c \left[1 + \frac{2< \Gamma_{\mu c} >}{\nu_c < \Gamma_\nu >} t \right]^{-(\nu_c/2 + \delta_{ac} + \delta_{bc})}$$

$$= \int_0^\infty dt \prod_c \left[1 + \frac{2\ T_c}{\nu_c T} t \right]^{-(\nu_c/2 + \delta_{ac} + \delta_{bc})}, \qquad (81)$$

where $T = \sum_c T_c$. In ABAREX the integration over t in Eq. 81 is carried out numerically and it is the approximations made in doing this integral that cause the ABSORPTION and TOTAL COMPOUND cross sections to differ when other than the Hauser Feshbach theory is used.

The factor C_{ab}, Eq. 73, arises from correlations between the partial widths of channels a and b, and in terms of the partial widths correlation coefficient, ρ_{ab} , takes on the value

$$C_{ab} = 1 + 2\rho_{ab}/(\nu_a \nu_b)^{\frac{1}{2}}. \qquad (82)$$

In the absence of a direct reaction between channels a and b, ρ_{ab} is expected to vanish for $a \neq b$. For $a = b$, Eq. 78 can be used to evaluate C_{ab} and one finds

$$C_{ab} = 1 + 2\delta_{ab}/\nu_a. \qquad (83)$$

Thus the factor C_{ab} leads to an enhancement of the average compound-elastic cross section by a factor of three for the case of the Porter-Thomas distribution and by a factor of two for ν=2 in Eq. 75. Except for the gamma-ray channel, ν is expected to be in the range 1-2. On the other hand, for gamma decay many channels are open so that ν becomes large and the default value taken in ABAREX is ν=20. It is also possible for G_{ab} to be greater than unity and this has been discussed by Moldauer (30).

Eq. 81 is valid even when a different ν is used with each transmission coefficient. Moldauer (31) computed the fluctuation cross sections numerically from a unitary analytic K-matrix with normally distributed pole-residue amplitudes and pole spacing having a Wigner distribution. He found, empirically, that a different value of ν should be associated with each transmission coefficient. His results indicate that the ν_c to be associated with T_c and T of Eq. 81 should, in the absence of direct reactions, be calculated from the formula

$$\nu_c = 1.78 + (T_c^{1.212} - 0.78)\ exp(-0.228\ T). \qquad (84)$$

In the many channel limit, T becomes large and the second term in Eq. 84 is negligible. Thus ν_c = 1.78 for all cases and the elastic enhancement factor, C_{aa} of Eq. 83, has the value 2.12. The positive and negative parity degrees of freedom, NU(+) and NU(-) listed in the examples given in Sections 4.1 and 4.2, were calculated using Eq. 84.

When the incident neutron energy is greater than ECONT, the excitation energy at which the continuum of excited nuclear states becomes important or is taken into account, no width fluctuation corrections are included and the Hauser-Feshbach theory is used. However, if E < ECONT or if the continuum is disregarded, width fluctuations can be taken into account and several options are available in ABAREX for calculating them. As discussed in Section 7.5, the value of ECONT can be read in columns (21-30) of the LEVELS image. If this entry is left blank the program will assume that ECONT is the energy of the last discrete level included in the calculation. If $E \geq$ ECONT, but the target charge, ZTARGET, entered in columns (11-20) of the LEVELS image, is left blank the continuum will be disregarded. In either case the value of ν to be used in the calculation is communicated to ABAREX in columns (41-50) of the COMPUTE image, discussed in Section 7.10. The following options are available:

i) If columns (41-50) are blank, a different value of ν, computed by use of Eq. 84, will be used with each transmission coefficient.

ii) Any positive value of ν, corresponding to the desired normalized chi-squared distribution, Eq. 75, can be read in columns (41-50).

iii) If a negative number is read in columns (41-50), no width fluctuations will be considered and the Hauser-Feshbach theory will be used. Note that $\nu \rightarrow \infty$, in Eq. 75, also corresponds to this case.

To illustrate the above concepts we consider the scattering of 2.9 MeV neutrons from ^{58}Ni. The potential parameters were taken from Ref. 20, and we shall use the ABAREX default option for the calculation of width fluctuation corrections, namely a blank in columns (41-50) of the COMPUTE image. This implies that a different value of ν, calculated using Eq. 84, will be used with each transmission coefficient. The input file for this calculation is given between the ***----'s in EXAMPLE 5.2 and the ABAREX output immediately follows.

Because the 2.902 and 2.942 MeV excited discrete states were included in the input file, the continuum would have started at 2.942 MeV. Since the incident neutron energy is only 2.9 MeV the continuum levels are unimportant and width fluctuations were taken into account. This causes the message NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM ARE COMPUTED INTERNALLY to be printed. The total compound-elastic scattering is 0.78312 barns and the total inelastic cross sections for leaving the ^{58}Ni nucleus in its yrast 2^+, 4^+, or second 2^+ states are 0.66985, 0.09043, and 0.12087 barns, respectively. If a "-1" had been inserted in columns (41-50) of the COMPUTE image, the Hauser-Feshbach calculation would have been carried out. In this case the total compound elastic cross section becomes 0.51131 barns and those to the three low-lying excited states are 0.90045, 0.10529 and 0.14724 barns, respectively. Thus, in this case, width fluctuations increase the compound-elastic cross section by about 53% and decrease those to the excited states. Aside from the small error, 0.00002 barns, made in the numerical integration of Eq. 81 when width fluctuations are considered, the sum of the compound excitations for the two calculations is identical

6. FITTING DATA

Using the SEARCH image, discussed in Section 7.6, one can vary the optical-model parameters so as to get a best fit to experimental data at one or more energies With ABAREX it is possible to fit the angular distribution of both the elastic-scattering cross section, the inelastic scattering which leaves the target nucleus in an excited state, the total cross section and low-energy S_0, S_1 and R' values. If we denote by

$\sigma_{expt}(i,j)$ the experimental differential scattering cross section in which the neutron comes out at an angle θ_i with respect to the incident beam and the target nucleus is left in state j, a best fit to the data is defined as those values of the optical model parameters which minimize the function

$$\chi^2 = \sum_{i,j} [\{\sigma_{expt}(i,j) - \sigma_{th}(i,j)\}/\Delta\sigma(i,j)]^2, \qquad (85)$$

where $\sigma_{th}(i,j)$ and $\Delta\sigma(i,j)$ are the theoretical value and the uncertainty, respectively, of the $(i,j)^{th}$ cross section. Two possibilities exist for $\Delta\sigma(i,j)$ in ABAREX:- i) using statistical errors or ii) using an actual estimate of the experimental error. Eq. 85 is also used for any measured ($expt$) and calculated (th) quantities, e.g., total cross sections, strength functions, etc. However, the user should be cautioned that it is very difficult to specify experimental weights in the fitting procedures when experimental data of different types (e.g. differential scattering and total cross sections) are concurrently used. For example, a total cross section with one percent accuracy will be swamped by forty or more differential elastic-scattering cross sections with five to ten percent accuracies.

The default option is to use statistical errors. Since this error is proportional to $1/\sqrt{N}$, where N is the number of counts, and since the cross section is often proportional to N, it follows that if the counting time for each measured $\sigma(i,j)$ is the same, then

$$\Delta\sigma(i,j) \propto \sqrt{\sigma_{expt}(i,j)}. \qquad (86)$$

Alternatively, if one has a reliable estimate for the experimental error from some other source, then

$$\Delta\sigma(i,j) = \sigma_{expt}(i,j)\ ERR(i,j)/100, \qquad (87)$$

where $ERR(i,j)$ is the percentage error for the $(i,j)^{th}$ cross section. In order to have ABAREX minimize χ^2 using this weighting a "5" must be inserted in column 80 of the SEARCH image, as discussed in Section 7.6.

6.1. STATISTICAL ERRORS

To illustrate fitting when the weighting in Eq. 85 is $\sqrt{\sigma_{expt}(i,j)}$ we consider the scattering of 4.5 MeV neutrons by

^{58}Ni. Although the spins and parities of the excited states of this nucleus are well known (16) up to 3.6 MeV, we shall only take into account discrete levels up to 3.0 MeV in order to minimize the computer output. Above 3 MeV we assume a continuum of levels described by the parameters given on the LEVELS image which were taken directly from Gilbert and Cameron (23) Immediately following the LEVELS image are six lines describing the properties of the discrete levels below 3.0 MeV. On the REAL, IMAG, and SO images the starting values of the parameters describing the real, imaginary, and spin-orbit potentials are given. In order to initiate a fit to data the SEARCH image, with format (A7,I3,5F10.4,20I1), must be included. In columns (8-10) of this image the number of angles, NOA, at which differential data are available is given (a negative NOA value pertains to strength-function searches as discussed in Section 7.6), and in columns (11-20) the incident neutron energy, at which the data were taken, is listed. In columns (21-30) and (31-40) the total cross section and its weight in the fitting are given. The default option, a blank for both these entries, indicates the total cross section is not to be fitted. In columns (41-50) the desired print option is communicated to ABAREX. A blank for this entry means that only the final optical-model parameters will be shown, whereas "-1.0" or "+1.0" means that all parameters generated in the search will be printed, step by step. In columns (51-60) the tolerance parameter, TOL, which determines when a satisfactory fit has been attained, is communicated to the program. Termination occurs when the fitting algorithm estimates that either the relative error in χ^2 ($\Delta\chi^2/\chi^2$) is at most TOL or that the relative error between all parameters and their solution is at most TOL. In general the default value, TOL = 0.005, should be used in differential and total cross-section searches. Columns (61-76) contain either a "1" or "0" depending on whether or not the Ith parameter is to be varied in the fit. The order of the sixteen parameters that can be varied are VRE, VRE1, VRE2, R1, A1, VIM, VIM1, VIM2, R2, A2, VIVOL, VOLRAT, VSR, VSI, RR1, and AA1, and their meanings are discussed in Sections 7.1, 7.2, and 7.3. When a search involving statistical errors is to be made column 80 of the SEARCH image is left blank. Immediately following the SEARCH image, NOA images, which describe the differential data to be fitted, must be included, and their format is (8F10.4). In columns (1-10) and (11-20) the angle and differential elastic cross section at that angle are entered, whereas in columns (21-30), ..., and (71-80) differential cross sections for leaving the nucleus in one of its excited states can be entered. When no entries are made for these excited state cross sections, ABAREX fits only the differential elastic scattering data. Note that both the angle and the differential scattering cross sections are in the laboratory coordinate system. The final image in the file is the COMPUTE record discussed in Section 7.10. It should be noted that the neutron energy entered on the SEARCH image in columns (11-20) overrides the energy entered on the COMPUTE image. The EXAMPLE 6.1 gives the input file, between the ***'s, and the ABAREX output when

statistical errors are assumed.

Since the 37 images directly following the SEARCH record have entries only in columns (1-10) and (11-20), it is clear that only the differential elastic-scattering cross section at 37 different angles is being fitted. Further, there is a "1" in columns 61 and 66 so that only VRE = V_o and VIM = W_o are to be varied in making this fit. The remaining optical model parameters retain the values assigned them on the REAL, IMAG, and SO images of the input file. The differential elastic scattering is the sum of the shape-elastic and compound-elastic cross sections and despite the fact that the latter is less than 6.7% of the sum it is important to consider both in the fit since near the minima of the distribution these two cross sections become nearly equal. (For example, at 70° the value of the shape and compound elastic cross sections, predicted with the final optical model parameters, is 7.14 and 11.81 mb/sr, respectively.) Since the incident neutron energy is greater than ECONT, width fluctuations are neglected and the compound-elastic cross section is calculated using the Hauser-Feshbach theory.

Because "-1.0" was included in columns (41-50) all optical model parameters generated in the fit are printed at each step in the fitting. In addition the value of χ^2, Eq. 85, is listed for each set of parameters under the heading STATISTIC. When a best fit to the data has been obtained ABAREX prints the message SEARCH TERMINATED AFTER ___ CALLS UPON CONVERGENCE (INFO=___), where the number of iterations is inserted in the first blank. For INFO = 1 the fitting algorithm estimates that the relative error in χ^2 is at most TOL. When INFO = 2, the algorithm estimates that the relative error between the parameters and their final values is at most TOL and when INFO = 3 the conditions for INFO = 1 and INFO = 2 both hold. If a value other than 1, 2, or 3 appears with INFO an error has occurred in the fitting and/or the input. Next the final optical model parameters are printed under the heading FINAL OPTICAL MODEL PARAMETERS and with these parameters the various angle-integrated cross sections are computed, including those which leave ^{58}Ni in one of the five discrete excited states included in the calculation. In addition the differential cross sections to these various states are given at the angles for which experimental data was available.

For graphing purposes it may be useful to have the predicted cross sections at forward and backward angles and these can be obtained by using the INPUT image discussed in Sections 3.3 and 7.11. When the following two images are included immediately after the COMPUTE image,

```
12345678901234567890123456789012345678901234567890.....
**************************************************************

INPUT
 &INPUT KSCH=0,DANG=3.0,&END

**************************************************************
```

the differential cross sections from 0^0 to 180^0 in 3^0 steps will be included with the above ABAREX output. The entry KSCH=0 is necessary to turn off the search option (see Section 7.11).

6.2. EXPERIMENTAL ERRORS

In EXAMPLE 6.2 the differential elastic-scattering data for 8 MeV neutrons incident on ^{58}Ni is fitted using for $\Delta\sigma(i,j)$, in Eq. 85, the estimated experimental uncertainty in the measurements. In order to fit with this weighting a "5" must be inserted in column 80 of the SEARCH image. At 8 MeV there are so many open channels available to share the absorption cross section that the compound elastic contribution is negligible and the shape-elastic cross section alone should be fitted to the differential scattering data. This condition is communicated to ABAREX by making the group number negative on the image describing the properties of the nuclear ground state. That is, as discussed in Section 7.5, the entry in columns (16-20) of the image immediately following the LEVELS image should be "-1". As in the example discussed in Section 6.1, immediately following the SEARCH image there must be NOA cards (NOA = 35 in this example) giving the scattering angle and the data to be fitted. When an "error-fit" is to be made, these NOA images must be followed by an additional NOA images which give the percentage errors in the experimental data. As discussed in Section 7.6, the format for these images is (10X,7F10.4), with the errors in the differential elastic cross section being given in columns (11-20). The entries in the other fields give the percentage errors in the cross sections which leave the nucleus in excited states. EXAMPLE 6.2 gives the input file (between the ***'s) for a fit of the shape-elastic cross section to the experimental data, followed by the respective ABAREX output for this calculation.

Because there is a "1" in columns 66, 69, and 70 of the SEARCH image the parameters VIM=W_0, R2=r_w, and a2=a_w of the imaginary potential, Eq. 21, are varied in the fit. In this case 18 iterations were needed to complete the search and the convergence information, INFO = 1, means (as discussed in Section 6.1) that the fitting algorithm estimates that $\Delta(\chi^2)/\chi^2$ is at most 0.005. The angular distribution of the absorption cross section is given in the column headed C.E. However, because of the large number of channels that are open at 8 MeV, the "true"

compound-elastic cross section is negligible and it is the entries listed under S.E. which should be compared to the experimental data. The remainder of the output is much the same as that discussed in Section 6.1.

One can also parameter search using experimental total cross sections as illustrated in EXAMPLE 6.2A. In this illustration the search is on the real, V_o, and imaginary, W_o, potentials using 21 total-cross-section values distributed between 1.0 and 5.0 MeV. Each is assigned a 1% weight. The resulting V_o = 49.53 and W_o = 10.39 MeV are very close to the 49.5 and 10.5 values used to generate the total cross sections used as "pseudo-experimental" data. One can combine total cross sections with differential elastic-scattering cross sections in the fitting procedure, as illustrated in EXAMPLE 6.2B. However, there is an ambiguity in such procedures. The total cross sections are generally far better known than the differential values, while the latter are usually far more numerous. How one should weight the relative value of these two types of information is not always clear, and furthermore the normalization of the two types of experimental data may be quite different. Another factor of concern is the experimental uncertainty. It generally consists of random and systematic errors which may be correlated. Uncertainty assessment is a very complicated matter in a complex non-linear environment. The final search EXAMPLE 6.2C illustrates a search on the real and imaginary potential strengths based upon two differential cross section groups and the total cross section. The search is quite fast. It is unlikely that reasonable experimental data will be available for several scattered-neutron groups at identical experimental angles. This will lead to zero cross-section values for some groups at some measurement angles. ABAREX will ignore zero differential cross sections in the search procedure.

This version of ABAREX contains a strength-function search procedure. In that mode the first SEARCH image must be the special strength-function SEARCH image having the FORMAT(A7,I3,6F10.4). In that image NOA = -1, followed by the energy (default = 1 eV), S_o, percent uncertainty in S_o, $\bar{R}'$, the percent uncertainty in $\bar{R}'$, S_1, and the percent uncertainty in S_1. All three of these values with their corresponding uncertainties must be present. Strength functions are given in units of 10^{-4}, and $\bar{R}'$ in fms. The default uncertainties are one percent. This special SEARCH image must then be followed with a second image in the FORMAT(16I1,F12.6), specifying which of the 16 parameters are involved in the search and the magnitude of the convergence criteria, TOL. This pair of images gives three experimental values, two of which ($\bar{R}'$ and S_1) are generally not well known. These two images can be followed by more SEARCH images specifying experimental total and/or differential cross sections at various

energies in any order. However, all the experimental uncertainties must be specified as per Eq. 87. The strength-function search can be useful for determining the low-energy behavior of the potential but care must be taken in the assignment of the various percentage weighting values as quite different observables are involved with very different magnitudes, and some of them are often poorly known. An illustration of a strength-function search using S_0, R', and S_1 values together with total and differential elastic-scattering data is shown in EXAMPLE 6.2D.

7. DOCUMENTATION

Input to the spherical optical model code ABAREX is through a set of keyword records each having one keyword, one integer, and usually up to seven floating point numbers. With the exception of the SEARCH image all keyword records have the Format(A7,I3,7F10.4). Keyword records may be included in any order and any that are not needed in a specific calculation may be omitted. All keywords must be capitalized. The program sorts them using only the first two symbols, thus COMPUTE is equivalent to COMP, or even CO, but not to Compute or compute. The input of every calculation must terminate with the COMPUTE record which tells the program to begin the computation. Any number of cases can be stacked. All input is on the file 'input' (not to be confused with the keyword 'INPUT' as cited above) and all output on the file 'output'.

In ABAREX: all energies are in the laboratory coordinate system and in MeV; all lengths are in fermis; all cross sections are in the laboratory coordinate system and are in barns (b) or barns/steradian (b/sr); and all angles are in the laboratory coordinate system and are in degrees.

The following is a description of the various input records. They are also outlined by the comment cards at the beginning of the source listing as shown in Appendix B. Where relevant, the entries 1234567890 .... 1234567890 indicate the columns 1 through 80 of the input images. The full 80 columns require two lines in the following text.

7.1. REAL POTENTIAL

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
REAL    KRE    VRE        VRE1        VRE2       R1        A1
                                                12345678901234567890
                                                   VSR
```

The keyword, REAL, tells the program that the parameters of the real optical-model potential are to follow. The entry KRE in

columns (8-10) indicates the shape of this potential. However, in ABAREX the real potential can only have the Woods-Saxon form, Eq. 19, so KRE can be left blank and the default value "1" will always be printed in the output. The strength of this potential is given by Eq. 31, where V_0, V_1, and V_2 are VRE, VRE1, and VRE2, respectively, which are entered in columns (11-20), (21-30), and (31-40) of this image. The value of E appearing in Eq. 31 is the energy of the incident neutron in the center-of-mass coordinate system. In practice, the laboratory and center-of-mass energies are nearly equal. In columns (41-50) and (51-60), the geometrical parameters of the well, Eqs. 19 and 20, are assigned, R1 = r_v and A1 = a_v. If the spin-orbit interaction is real, has the Thomas form, Eq. 24, and has geometry identical to that of the real potential, i.e. $r_{so} = r_v$ and $a_{so} = a_v$, its strength V_{so} = VSR can be entered in columns (61-70) of the REAL image and the SO image, discussed below, omitted.

If the REAL record is omitted, the default parameters for the spherical optical-model potential are used. For the real potential, described by Eqs. 19 and 20, these are

$$\begin{aligned} \text{VRE} &= V_0 = 46.0 \text{ MeV} \\ \text{R1} &= r_v = 1.317 \text{ fm} \\ \text{A1} &= a_v = 0.62 \text{ fm.} \end{aligned} \qquad (88)$$

For the imaginary potential, discussed in Section 7.2, the derivative Woods-Saxon well, Eqs 21 and 23, is used with input parameters

$$\begin{aligned} \text{VIM} &= W_0 = 14.0 \text{ MeV} \\ \text{R2} &= r_w = 1.447 \text{ fm} \\ \text{A2} &= a_w = 0.25 \text{ fm.} \end{aligned} \qquad (89)$$

Finally, for the spin-orbit interaction, the Thomas term, Eqs. 24 and 25, is used with

$$\begin{aligned} \text{VSR} &= V_{so} = 7.0 \text{ MeV} \\ \text{VSI} &= 0 \\ \text{RR1} &= r_{so} = 1.317 \text{ fm} \\ \text{AA1} &= a_{so} = 0.62 \text{ fm,} \end{aligned} \qquad (90)$$

where VSI is the strength of the imaginary spin-orbit potential. If any of the potentials are omitted at input the default values will be used.

7.2. IMAGINARY POTENTIAL

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
IMAG    KIM    VIM       VIM1       VIM2       R2         A2
                                             12345678901234567890
                                               VIVOL      VOLRAT
```

The keyword, IMAG, tells the program that the parameters of the imaginary optical-model potential are to follow. The entry in columns (8-10), KIM, is important since several variants of the imaginary potential are possible. When KIM =1, the imaginary potential is a volume absorption with a Woods-Saxon form factor, Eqs. 19 and 20. On the other hand, when KIM = 2 it is the surface peaked Gaussian interaction of Eqs. 22 and 23 and when KIM = 4 it is the surface-peaked derivative Woods-Saxon form of Eqs. 21 and 23.

The strength of the potential is given by an expression analogous to Eq. 31, where $W_r \equiv$ VIM, W_1 = VIM1, and W_2 = VIM2 and, as before, E in this equation is the incident neutron energy in the center-of-mass coordinate system. The geometry of the interaction is read in columns (41-50) and (51-60), respectively R2 = r_w and A2 = a_w.

It is also possible to have an imaginary potential which is the sum of a surface and a volume part, subject to the restriction that r_w and a_w are the same for the two components. In this case KIM = 3 (or 5) and there are two ways of communicating the surface and volume strengths to the program:

i) the strength, VIM, of the surface imaginary component is read in columns (11-20) and the strength, VIVOL, of the volume absorption is read in columns (61-70). If VIM ≡ 0 the above default values will be used.

ii) the sum of the desired surface plus volume strengths, VIM + VIVOL, is read in columns (11-20) and the fraction of this total strength, which is the volume absorption, is read in columns (71-80), i.e. VOLRAT = VIVOL/(VIM+VIVOL). In this case, VIVOL in columns (61-70) is left blank.

When KIM = 3 the surface absorption has the Gaussian form, Eq. 22, and its strength, together with that of the Woods-Saxon volume absorption, Eq. 19, is communicated to ABAREX by either method (i) or (ii). For KIM = 5 the only change is that the surface absorption has the derivative Woods-Saxon shape, Eq. 21. However, if VIVOL is positive and KIM = 4 the same result will be obtained as with KIM = 5, similarly for KIM = 2 and 3. When R2 and A2 are left blank, the program assumes R2 = R1 and A2 = A1, i.e. that $r_w = r_v$ and $a_w = a_v$. If both real and imaginary records are omitted, the default parameters, discussed in Section

7.1, are used.

7.3. SPIN-ORBIT POTENTIAL

```
12345678901234567890123456789012345678901234567890.....
SO      KSO   VSR         VSI         RR1         AA1
```

The keyword, SO, tells the program that the parameters for the spin-orbit optical model potential are to follow. KSO, which is read in columns (8-10), gives the form that is being used for this interaction. When KSO = 1 the Thomas form, Eqs. 24 and 25, is used and the real and imaginary strengths, VSR and VSI, are read in columns (11-20) and (21-30), respectively. The potential strength, V_{so} of Eq. 24 is

$$V_{so} = \text{VSR} + i\ \text{VSI}. \qquad (91)$$

The reduced radius, RR1 = r_{so}, and the diffuseness, AA1 = a_{so}, are read in columns (31-40) and (41-50), respectively. There is no provision in ABAREX for an energy dependence of this potential.

Another option for the spin-orbit potential is available and when KSO = 2 the volume Woods-Saxon shape is used,

$$V_{so} = -2\underline{L}\cdot\underline{S}\ (\text{VSR} + i\ \text{VSI})\ \{1 / [1 + exp((r-R_{so})/a_{so})]\}. \qquad (92)$$

In this equation, $\underline{L}$ and $\underline{S}$ are the orbital and spin angular momentum operators, respectively, and the parameters of the interaction are communicated in the same manner as when KSO = 1. In optical model calculations, this form for the spin-orbit interaction is seldom used.

As discussed in Section 7.1, if the spin orbit potential is real, $r_{so} = r_v$ (RR1 = R1), and $a_{so} = a_v$ (AA1 = A1), VSR = V_{so} can be entered in columns (61-70) of the REAL image and the SO image omitted. In this case, in the output KSO will equal "1". If the spin-orbit image is omitted or the imaginary strength ≡ 0 and there is no VSO quantity on the REAL image, the default spin-orbit potential will be used. If the user wishes to make a calculation with the spin-obit strength ≡ 0 he should use a very small VSR; e.g. 1.0E-6 MeV.

7.4. SURFACE REAL POTENTIAL

```
12345678901234567890123456789012345678901234567890.....
DISP          SURF0      SURF1      SURF2
```

The keyword DISP tells the program that a real surface-peaked potential, proportional to the imaginary interaction, is to be added to the real Woods-Saxon well, Eq. 19. The magnitude of this added potential is

$$V_{ADD}(r) = V_{add}\, W(r), \qquad (93)$$

where $W(r)$ is given by either Eq. 21 or Eq. 22, and

$$V_{add} = \text{SURF0} + \text{SURF1}\ E + \text{SURF2}\ E^2. \qquad (94)$$

In this equation, as in Eq. 31, the energy E is the incident neutron energy in the center-of-mass coordinate system. The default values of SURF0, SURF1, and SURF2 are all zero.

7.5. TARGET LEVEL INFORMATION

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
LEVELS NLE  ZTARGET   ECONT      ESTEP      TAU        EOT
                                                     1234567890
                                                       SG
```

The keyword, LEVELS, indicates that information on the target levels is about to be provided. If the levels record is omitted only the target ground state is considered and its spin and parity are taken to be 0^+. In columns (8-10), NLE, the number of discrete target levels that are to be included in the calculation, is given with NLE $\leq$ 50. If NLE = 0 only the ground-state properties are used, with the default J^π values of 0^+. The remainder of the entries on the LEVELS image have to do with the target continuum and their meanings are as follows:

ZTARGET is the target charge. Unless this is included no target continuum will be considered (see the discussion in Section 5).

ECONT is the excitation energy at which the target continuum starts. The default value is ECONT = EX(NLE), i.e. the energy of the last discrete level. ECONT should not be less than EX(NLE). When ZTARGET > 0, width fluctuations, discussed in Section 5.2, will be omitted when the energy of the incident neutron is > ECONT. This is a good approximation as many channels will generally be open. On the other hand, when $E \leq$ ECONT width

fluctuations will be taken into account unless a negative number is read in columns (41-50) of the COMPUTE record, as discussed in Section 7.10.

ESTEP is the energy interval for target level continuum calculations. Generally, the default value of 0.2 MeV is satisfactory.

TAU and EOT are the temperature (TAU = T) and the energy shift parameter (EOT = E_0) in the level density formula, Eq. 53, which is used for the density of states at low excitation energies.

SG is the spin cut-off parameter, σ of Eq. 56. As discussed in Section 5, Eq. 56 is used for the density of states at higher excitation energies.

On the LEVELS image there is no place to specify the level density parameter, a, used in the expression for the level density at higher excitation energy, Eqs. 56 and 62. If one wishes to put in a specific value for this parameter, the CAPTURE image, which will be discussed in Section 7.8, must be included in the input file and the value of a = SA is read in columns (61-70). Otherwise, the default value, calculated by use of Eq. 58 will be used. The default values for the spin cut-off parameter, SG = σ, the temperature, TAU = T, and the energy shift parameter, EOT = E_0, are calculated by use of Eqs. 59, 60, and 61, respectively.

Unless NLE, the number of discrete target states to be explicitly taken into account in the calculation, is zero, the LEVELS image must be followed by NLE records. The first record describes the target ground state and the remainder characterize the excited nuclear levels. The format for these records is (F9.4,F4.1,I2,I5,F5.4) and the meaning of the various entries is as follows:-

```
123456789012345678901234567890.....
   EX(I)  FI IP  KGP GW
```

EX(I) is the excitation energy, in MeV, of the Ith state. The excitation energy of the ground state is, of course, 0.

FI is the spin of the Ith target state.

IP is the parity, +1 or -1, of the Ith target state. The default value is +1.

KGP is the group number for the Ith state. The default value of KGP(I) is I. Cross sections to consecutive levels with the same group number are added together and are considered to be a

single state as far as searching and print out are concerned. If KGP(1) is negative, only the shape elastic cross section is computed and/or fitted. These level-property lines must be in order of increasing excitation energy, starting with the ground state.

GW is the weight of the Ith level in fitting. The default value is 1.0. In some cases the experimental values may warrant various weighting factors.

7.6. FITTING EXPERIMENTAL DATA

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SEARCH NOA    E          SGTOT      GWTOT      PRINT      TOL
                                                1234567890123456789
                                                KQ(1).........KQ(20)
```

The keyword, SEARCH, indicates that some of the optical-model parameters are going to be fitted to experimental data. The format for this record is generally (A7,I3,5F10.4,20I1), and the meaning of the entries will now be discussed.

NOA is the number of input angles for which scattering data are provided.

E is the laboratory energy at which the data were taken. Note this energy overrides that given on the COMPUTE image, which will be discussed in Section 7.10.

SGTOT is the experimental total cross section. When this is left blank the total cross section is not fitted.

GWTOT is the weight of the total cross section in the fitting. The default value is GWTOT = 1.0. Other percentage errors are generally used when the fitting combines total and differential cross sections.

PRINT dictates what is printed during the fit. When PRINT = -1.0 or +1.0, the optical-model parameters generated at each step in the search are printed. When this entry is left blank only the final values are given.

TOL is the relative change in χ^2, Eq. 85, which terminates the search. The default value, TOL = 0.005, is recommended for scattering and total-cross-section searches (see Section 6.1 for further discussion).

KQ(I), for I = 1-16, is either "1" or "0" depending on whether or not the Ith optical-model parameter is to be varied. The order of the sixteen that can be varied are VRE, VRE1, VRE2, R1, A1, VIM, VIM1, VIM2, R2, A2, VIVOL, VOLRAT, VSR, VSI, RR1,

and AA1 (see Sections 7.1, 7.2, and 7.3 for a discussion of the meaning of these quantities). The first 16 KQ values must be either '0' or '1', blanks in the string are not acceptable (e.g. '1001110011' is acceptable, but '1 111 11' is not). The entry in column 80, KQ(20), is either "0" or "5" depending on whether statistical or experimental errors are used in the fitting. In the former, the error $\Delta\sigma(i,j)$ in Eq. 85 is given by Eq. 86, whereas in the latter it is given by Eq. 87.

The SEARCH record must be followed by NOA differential scattering cross sections. The format for these images is (8F10.4).

```
12345678901234567890123456789012345678901234567890.....1234567890
  A(I)    XIN(I,1)  XIN(I,2)  XIN(I,3) ..... XIN(I,7)
```

where

A(I) is the Ith laboratory angle

XIN(I,J) is the differential cross section in the laboratory coordinate system for scattering to the Jth level group at angle A(I), i.e XIN(I,J) = $\sigma_{expt}(i,j)$ of Eqs. 85-87. Up to seven level groups can be fitted and only positive non-zero entries are considered.

If a "5" is inserted in column 80 of the SEARCH record, the NOA angle and differential cross-section records, discussed above, must be followed by NOA images giving the corresponding percentage errors in the various differential cross sections. The format for these images is (10X,7F10.4).

```
12345678901234567890123456789012345678901234567890.....1234567890
           ERR(I,1)  ERR(I,2)  ..... ERR(I,7)
```

where ERR(I,J) is the percentage error for scattering to the Jth level at the angle A(I), i.e. ERR(I,J) = $ERR(i,j)$ of Eq. 87.

Data taken at several different neutron energies can be fitted simultaneously, and total and differential cross sections can be mixed, as illustrated by the examples of Section 6.2. A separate SEARCH record, and set of data, must be provided for each energy. PRINT, TOL, and KQ(I), however, need only be specified once.

This version of ABAREX contains a strength-function fitting option. In that mode the <u>first</u> search image must be:-

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SEARCH  -1   E        S_o        ERR(S_o)    R'        ERR(R')
                                                  12345678901234567890
                                                    S_1        ERR(S_1),
```

directly followed by

```
12345678901234567890123456789012345678901234567890.......
    KP(1-16)          TOL
```

where E is the energy, which should be 1 eV (the default value), S_o is the $l = 0$ strength function in units of 10^{-4}, ERR(S_o) the percent error in S_o, R' is the $l=0$ hard-sphere scattering radius, ERR(R') the corresponding percent error in R', S_1 and ERR(S_1) the corresponding $l=1$ strength-function and error. On the second line are the 16 KP parameter values (=0 for no search, =1 for search), and TOL is the convergence criteria (default=0.005). This pair of first strength-function-search images can be followed by any combination of total and differential cross-section search images, as described above. The strength-function-search procedure can be useful in fixing the lower-energy behavior of a potential. However, R' and S_1 are frequently very poorly known, and there remains the dichotomy between the various observables involved in such a search with the accompanying questions as to the relative uncertainties to employ. The user is cautioned to use the strength-function search option with care.

The present form of ABAREX does not offer the option of searching with the capture cross section.

There must be at least as many experimental values as parameters to be varied, preferably several times as many.

7.7. CALCULATIONS AT SEVERAL ENERGIES

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SCAN        E1        E2        E3        E4        E5
                                                  12345678901234567890
                                                    E6        E7
```

The keyword, SCAN, indicates the optical-model calculation is to be carried out for several different incident neutron energies, E1, E2, .. E7. SCAN images with up to fifty laboratory energies may be included, but 'SCAN' must start each line. E(I) on the SCAN record overrides the energy, E, on the COMPUTE image, discussed in Section 7.10. All energies in the

SCAN images must be non zero until the list is complete.

If a "1" is inserted in column 10 of the SCAN record, ABAREX interprets E1 as the first energy for which calculations are to be made, E2 = dE as the energy step-size, and E3 as the final energy. The program computes the cross sections for energies E1, E1+dE, E1+2dE,...., E1+NdE $\leq$ E3, with N $\leq$ (E3 - E1)/dE or 50, whichever is smaller.

7.8. RADIATIVE CAPTURE

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CAPTURE NZ    TGO       BN          FNUG       EGD       GGD
                                                1234567890123456789
                                                  SA        SG
```

The keyword, CAPTURE, causes the total gamma-ray production and radiative capture cross sections, discussed in Section 4.2, to be computed. The meaning of the input parameters on the CAPTURE image are as follows:

NZ is the compound-nucleus charge. If NZ is left blank all further entries on this record are ignored and the gamma-ray transmission coefficients must be read into the program, as outlined below.

TGO is the average radiative width-to-level-spacing ratio for s-wave neutrons near the neutron binding energy. An experimental value for this quantity can often be found in Ref. 18. When TGO > 0 the transmission coefficients for second-chance neutrons (those emitted after gamma decay) are calculated using the Black Nucleus Model, whereas if TGO < 0, these transmission coefficients are calculated using the optical model. If TGO is left blank the giant dipole gamma-ray strength normalization is computed internally. That result should be used with caution.

BN is the neutron binding energy. Values for this quantity can be obtained from Ref. 14. The default value is 8 MeV.

FNUG is the width fluctuation degrees of freedom, Eq. 75, for the gamma-ray channel. The default value, 20, is usually used.

EGD is the $E1$ giant dipole energy. Experimental values for this quantity can often be obtained from Ref. 22. When this entry is left blank, EGD is calculated using Eq. 51.

GGD is the giant dipole width and this, too, can often be obtained from Ref. 22. The default value is 5 MeV.

SA = a is the level density parameter used in Eqs. 56 and 62. Experimental values for this quantity can often be found in Tables 4 and 5 of Ref. 23. When this entry is left blank SA = a

is calculated by use of Eq. 58.

SG is the level-density spin cut-off parameter, SG = σ in Eqs. 56 and 62. Experimental values for this quantity can sometimes be found in Tables 4 and 5 of Ref. 23. When this entry is left blank, SG = σ is calculated using Eq. 59.

If the keyword CAPTURE on this record is changed to N-GAMMA, only the (n,γ) cross section will be calculated and the capture cross section will be omitted.

When NZ, columns (8-10) of the CAPTURE or N-GAMMA record, is left blank the record must be followed by an image with the format (16F5.3),

```
1234567890123456789012345678901234567890.....
TG(1)TG(2)TG(3).....
```

where TG(K) is the the gamma ray transmission coefficient for the Kth total angular momentum and either parity. Ancillary considerations must be used to provide these coefficients. The user is cautioned that, while ABAREX treats the TG(I) correctly, the physical results will depend on how those coefficients are generated.

7.9. PRINTING

```
1234567890123456789012345678901234567890.....
TRANSM KET
```

The keyword, TRANSM, must be included if one wishes to print the reflection factors, $\eta_{j\ell}$, the transmission coefficients, $T_{j\ell}$, (the (j,ℓ) analog of Eq. 37), the s- and p-wave strength functions, or the potential scattering length, R', discussed in Section 4. The entry in columns (8-10), KET, tells the program that these quantities are to be printed for the first KET target states. If this entry is left blank, KET = NLE where NLE is the number of discrete levels included in the calculation (see Section 7.5). If this image is omitted none of the above quantities will appear in the ABAREX output.

7.10. STARTING THE CALCULATION

```
1234567890123456789012345678901234567890123456789012345678901234567890
COMPUTE LM    E          ANO        ANU        FNU        DANG
                                                1234567890123456789O
                                                  C1         PTS
```

The keyword COMPUTE signals the end of the input data for a given case and causes the calculation to start. The meanings of the quantities read on this image are:-

LM specifies the maximum neutron orbital angular momentum. The default value, zero or a blank, should ordinarily be used and in this case LM is determined internally for each level with a maximum value of LM = 20.

E is the laboratory energy of incident neutron in MeV. The default value is E = 0.8 MeV.

ANO = A is the mass number of the target. The default value is 55.9349 a.m.u.

ANU is the projectile mass number. The default value is the neutron mass, 1.008665 a.m.u. ABAREX does not treat incident charged particles.

FNU is the neutron width fluctuation degrees of freedom, Eq. 75. When a zero or blank is inserted here the program computes FNU internally using the Moldauer formalism (30), Eq. 84, when $E \leq$ ECONT, where ECONT is the excitation energy at which the continuum starts (see Section 7.5). For $E >$ ECONT no width fluctuation corrections are considered and the Hauser-Feshbach theory is used (27) as many channels are open and the corrections are not generally significant. When this entry is negative the Hauser Feshbach theory, which is the $\nu \to \infty$ limit of Eq. 75, is used. When the entry is positive ν will be calculated using the distribution of Eq. 75 (see Section 5.2).

DANG is the angular interval in the printout of the scattering cross section. The default value is 15°.

C1 is the asymptotic matching radius. The default value, 15 fm, is generally satisfactory.

PTS is the number of radial integration points. The default value is 301.0. However, if the potential is a rapidly varying function of r, a better value is 601.0. PTS should be an odd number.

7.11. CHANGING PARAMETERS

```
12345678901234567890 .................
INPUT
```

The keyword INPUT indicates that changes in some of the input parameters are to be made. This instruction uses the IBM NAMELIST procedure (see IBM System/360 and System/370 FORTRAN IV

Language Document, page 50). The quantities that can be changed are:

```
NLEVEL, FNU, DANG, LMAX, Z, ANO, EX, FI, IPI, KGP, VRE, VRE1,
VRE2,R1, A1, KIM, VIM, VIM1, VIM2, R2, A2, VIVOL, C2, KETA, KSO,
VSR, VSI,RR1, AA1, TGO, BN, FNUG, EGD, GGD, SG, NZ, TGG, TFF,
FNF, SURF0, SURF1, SURF2, KSCH,
```

where C2 = VOLRAT (see Section 7.2); NLEVEL = NLE, IPI = IP (see Section 7.5); TGG = TG (see Section 7.8); KETA = KET (see Section 7.9); LMAX = LM (see Section 7.10). The register Z(1) contains the incident neutron energy (see Section 3.3) and KSCH is a keyword which is set internally in the program, KSCH = 1 or 0 depending on whether or not a search is made (see Section 6.1). The meanings of the other quantities have been discussed in the preceding sub-sections where the input on the keyword records has been described. When using the 'INPUT' option the prior input deck is only modified, thus the input is not repeated in the output listing.

Examples of the use of the INPUT record have been given in Sections 3.3 and 6.1. The parameters to be changed are followed by ",&END" in VAX/VMS and Lahey FORTRAN. In Microsoft FORTRAN this may be replaced by "/".

7.12. FISSION

```
12345678901234567890123456789O.................
FISSION NF
```

The FISSION image calculates the CN fission cross section, where NF is the number of total angular momenta in the fission transmission coefficients. This image must be directly followed by lines in the (16F5.3) format as follows:

```
     5     10     15     20     25     30     35     40........
TF+(1) FN+(1) TF-(1) FN-(1) TF+(2) FN+(2) TF-(2) FN-(2)........
.......................................... NF*20
..................TF+(NF) FN+(NF) TF-(NF) FN-(NF),
```

where TF+(I) and TF-(I) are the positive and negative parity total fission transmission coefficients for the Ith total angular momentum, respectively, and the FN+(I) and FN-(I) are the corresponding width fluctuation degrees of freedom. These fission properties must be obtained from ancillary considerations beyond ABAREX. Given reasonable input values the code provides rational fission cross sections. However,the user is cautioned that the the results will be no better than the input parameters.

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APPENDIX A

This appendix contains the input and output for all the examples referred to in the above text. In some cases the listings are truncated so as to reduce their size.

The explicit examples are:-

Example 3.1
Example 3.2
Example 3.3
Example 3.4
Example 4.1
Example 4.2
Example 5.1
Example 5.2
Example 6.1
Example 6.2
Example 6.2A
Example 6.2B
Example 6.2C
Example 6.2D

EXAMPLE 3.1

```
1234567890123456789O.....
********************************************************************************

COMPUTE

********************************************************************************

                                    ABAREX
                                    ======

 INPUT DECK :

       COMPUTE  0    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000


MASS NUMBERS(TARGET/PROJECTILE) = 55.934900/ 1.008665
============

OPTICAL MODEL PARAMETERS :          ASYMPTOPIA= 15.0000 FM           301 POINTS
=========================

 TYPE       DEPTH      (E)      (E*E)      RADIUS     DIFF.   VIVOL       C2     VOLINT

REAL    1   46.0000    0.0000    0.0000    1.3170    0.6200                      505.9803
IMAG    4   14.0000    0.0000    0.0000    1.4470    0.2500    0.0000    0.0000   96.9636
S.O.    1    7.0000    0.0000              1.3170    0.6200
DISP         0.0000    0.0000    0.0000
NO. 1 ENERGY(LABORATORY/C.M.)  =  0.800000/ 0.785829 MEV         LAMBDA-BAR =  0.51815 SQRT-BARN
============
NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
                                                    ARE COMPUTED INTERNALLY.

             TARGET LEVELS
             =============

LEVEL  GROUP   ENERGY   SPIN   PARITY   WEIGHT

   1     1    0.0000    0.0     1        1.00
 MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) =  5, (  0.5,  5.5)

  .INTEGRATED CROSS SECTIONS IN BARNS
   ================================

            TOTAL =  3.60563
       ABSORPTION =  1.67961
    SHAPE ELASTIC =  1.92602
    TOTAL ELASTIC =  3.60483
COMPOUND EXCITATIONS =  1.67881
    TOTAL COMPOUND =  1.67881

LABORATORY CROSS SECTION IN BARNS PER STERADIAN
===============================================

    ANGLE     S.E.      C.E.   LEVEL GROUP CROSS SECTIONS

    0.00   0.47453   0.24810   0.72263
   15.00   0.44341   0.22925   0.67265
```

30.00	0.36232	0.18533	0.54765
45.00	0.26096	0.14224	0.40320
60.00	0.17027	0.11699	0.28726
75.00	0.10908	0.10853	0.21761
90.00	0.08072	0.10676	0.18748
105.00	0.07836	0.10690	0.18526
120.00	0.09220	0.11462	0.20682
135.00	0.11363	0.13840	0.25203
150.00	0.13557	0.17709	0.31266
165.00	0.15189	0.21494	0.36683
180.00	0.15794	0.23083	0.38877

EXAMPLE 3.2

```
 12345678901234567890123456789012345678901234567890123456789012345678901234567890
********************************************************************************

REAL     1  45.10000                        1.29750   0.6380
IMAG     4  11.30000                        1.30200   0.3344
SO       1   5.50000             1.00500    0.65000
DISP         0.30000
COMPUTE  0  3.50       58.0                          10.00                601.0

********************************************************************************
```

ABAREX

INPUT DECK :

REAL	1	45.1000	0.0000	0.0000	1.2975	0.6380	0.0000	0.0000
IMAG	4	11.3000	0.0000	0.0000	1.3020	0.3344	0.0000	0.0000
SO	1	5.5000	0.0000	1.0050	0.6500	0.0000	0.0000	0.0000
DISP	0	0.3000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
COMPUTE	0	3.5000	58.0000	0.0000	0.0000	10.0000	0.0000	601.0000

MASS NUMBERS(TARGET/PROJECTILE) = 58.000000/ 1.008665

OPTICAL MODEL PARAMETERS : ASYMPTOPIA= 15.0000 FM 601 POINTS

TYPE		DEPTH	(E)	(E*E)	RADIUS	DIFF.	VIVOL	C2	VOLINT
REAL	1	45.1000	0.0000	0.0000	1.2975	0.6380			478.3765
IMAG	4	11.3000	0.0000	0.0000	1.3020	0.3344	0.0000	0.0000	84.3841
S.O.	1	5.5000	0.0000		1.0050	0.6500			
DISP		0.3000	0.0000	0.0000					

NO. 1 ENERGY(LABORATORY/C.M.) = 3.500000/ 3.440173 MEV LAMBDA-BAR = 0.24757 SQRT-BARN

NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 8, (0.5, 7.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	3.44697
ABSORPTION =	1.45213
SHAPE ELASTIC =	1.99484
TOTAL ELASTIC =	3.44641
COMPOUND EXCITATIONS =	1.45156
TOTAL COMPOUND =	1.45156

LABORATORY CROSS SECTION IN BARNS PER STERADIAN

ANGLE	S.E.	C.E.	LEVEL GROUP CROSS SECTIONS
0.00	1.49647	0.30869	1.80516
10.00	1.38791	0.28752	1.67532
20.00	1.10231	0.23564	1.33795
30.00	0.73861	0.17789	0.91650
40.00	0.40233	0.13346	0.53579
50.00	0.16226	0.10700	0.26926
60.00	0.03620	0.09311	0.12931
70.00	0.00326	0.08500	0.08825
80.00	0.02536	0.07969	0.10505
90.00	0.06449	0.07766	0.14215
100.00	0.09249	0.07945	0.17194
110.00	0.09544	0.08415	0.17959
120.00	0.07443	0.09160	0.16603
130.00	0.04235	0.10512	0.14747
140.00	0.01617	0.13082	0.14699
150.00	0.00746	0.17241	0.17988
160.00	0.01589	0.22439	0.24029
170.00	0.03031	0.26973	0.30004
180.00	0.03713	0.28795	0.32507

EXAMPLE 3.3

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
*****************************************************************************

REAL     1  46.15000  -0.30000   0.00000   1.29750   0.6380
IMAG     4   9.90000   0.40000   0.00000   1.30200   0.3344
SO       1   5.50000   0.00000   1.00500   0.6500
SCAN     1   3.50000   1.00000   4.50000
COMPUTE      1.00000   58.0000                       10.0000            601.0

*****************************************************************************

1                                    ABAREX
                                    ======

  INPUT DECK :

        REAL     1   46.1500   -0.3000    0.0000    1.2975    0.6380    0.0000    0.0000
        IMAG     4    9.9000    0.4000    0.0000    1.3020    0.3344    0.0000    0.0000
        SO       1    5.5000    0.0000    1.0050    0.6500    0.0000    0.0000    0.0000
        SCAN     1    3.5000    1.0000    4.5000    0.0000    0.0000    0.0000    0.0000
        COMPUTE  0    1.0000   58.0000    0.0000    0.0000   10.0000    0.0000  601.0000


MASS NUMBERS(TARGET/PROJECTILE) = 58.000000/ 1.008665
============

OPTICAL MODEL PARAMETERS :          ASYMPTOPIA= 15.0000 FM           601 POINTS
=======================

 TYPE       DEPTH      (E)      (E*E)      RADIUS     DIFF.   VIVOL       C2    VOLINT

REAL     1   46.1500   -0.3000    0.0000    1.2975    0.6380                     489.5139
IMAG     4    9.9000    0.4000    0.0000    1.3020    0.3344    0.0000    0.0000   73.9294
S.O.     1    5.5000    0.0000              1.0050    0.6500
DISP          0.0000    0.0000    0.0000

NO. 1 ENERGY(LABORATORY/C.M.)  =  3.500000/ 3.440173 MEV          LAMBDA-BAR =  0.24757 SQRT-BARN
============
NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
                                                    ARE COMPUTED INTERNALLY.

             TARGET LEVELS
             =============

LEVEL  GROUP   ENERGY   SPIN   PARITY   WEIGHT

    1     1    0.0000    0.0     1        1.00
 MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) =  8, (  0.5,  7.5)

   INTEGRATED CROSS SECTIONS IN BARNS
   ==================================

              TOTAL =  3.58108
         ABSORPTION =  1.51183
      SHAPE ELASTIC =  2.06925
      TOTAL ELASTIC =  3.58053
COMPOUND EXCITATIONS =  1.51127
```

TOTAL COMPOUND = 1.51127

LABORATORY CROSS SECTION IN BARNS PER STERADIAN

ANGLE	S.E.	C.E.	LEVEL GROUP CROSS SECTIONS
0.00	1.57194	0.31690	1.88884
10.00	1.46005	0.29596	1.75601
20.00	1.16554	0.24433	1.40987
30.00	0.78883	0.18606	0.97489
40.00	0.43798	0.14013	0.57811
50.00	0.18405	0.11178	0.29583
60.00	0.04635	0.09650	0.14285
70.00	0.00445	0.08804	0.09249
80.00	0.02006	0.08312	0.10318
90.00	0.05495	0.08130	0.13624
100.00	0.08104	0.08274	0.16378
110.00	0.08475	0.08711	0.17186
120.00	0.06705	0.09503	0.16208
130.00	0.03961	0.10995	0.14956
140.00	0.01738	0.13736	0.15474
150.00	0.01017	0.18019	0.19037
160.00	0.01744	0.23253	0.24998
170.00	0.02965	0.27760	0.30725
180.00	0.03539	0.29560	0.33100

NO. 2 ENERGY(LABORATORY/C.M.) = 4.500000/ 4.423079 MEV LAMBDA-BAR = 0.21833 SQRT-BARN

NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 8, (0.5, 7.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL = 3.67255
ABSORPTION = 1.47065
SHAPE ELASTIC = 2.20191
TOTAL ELASTIC = 3.67201
COMPOUND EXCITATIONS = 1.47011
TOTAL COMPOUND = 1.47011

LABORATORY CROSS SECTION IN BARNS PER STERADIAN

ANGLE	S.E.	C.E.	LEVEL GROUP CROSS SECTIONS
0.00	1.96197	0.33966	2.30163
10.00	1.79817	0.31253	2.11070
20.00	1.37931	0.24791	1.62723
30.00	0.87397	0.17983	1.05380
40.00	0.44319	0.13155	0.57474

50.00	0.16665	0.10564	0.27229
60.00	0.03854	0.09317	0.13172
70.00	0.00905	0.08556	0.09461
80.00	0.02573	0.07989	0.10563
90.00	0.05226	0.07762	0.12989
100.00	0.06899	0.07974	0.14873
110.00	0.06832	0.08469	0.15302
120.00	0.05192	0.09146	0.14339
130.00	0.02989	0.10361	0.13250
140.00	0.01172	0.12917	0.14089
150.00	0.00945	0.17493	0.18438
160.00	0.02154	0.23670	0.25824
170.00	0.03767	0.29343	0.33110
180.00	0.04498	0.31683	0.36181

EXAMPLE 3.4

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
********************************************************************************

REAL     1  45.10000                      1.29750   0.6380
IMAG     3  11.30000                      1.30200   0.3344   2.825
SO       1   5.50000            1.00500   0.6500
COMPUTE      3.50000   58.0000

********************************************************************************
                                    ABAREX
                                    ======

  INPUT DECK :

        REAL     1   45.1000    0.0000    0.0000    1.2975    0.6380    0.0000    0.0000
        IMAG     3   11.3000    0.0000    0.0000    1.3020    0.3344    2.8250    0.0000
        SO       1    5.5000    0.0000    1.0050    0.6500    0.0000    0.0000    0.0000
        COMPUTE  0    3.5000   58.0000    0.0000    0.0000    0.0000    0.0000    0.0000


MASS NUMBERS(TARGET/PROJECTILE) = 58.000000/ 1.008665
============

OPTICAL MODEL PARAMETERS :          ASYMPTOPIA= 15.0000 FM           301 POINTS
========================

 TYPE       DEPTH      (E)      (E*E)      RADIUS     DIFF.   VIVOL       C2     VOLINT

REAL     1   45.1000    0.0000   0.0000    1.2975    0.6380                     478.3765
IMAG     3   11.3000    0.0000   0.0000    1.3020    0.3344    2.8250   0.0000    0.0000
S.O.     1    5.5000    0.0000             1.0050    0.6500
DISP          0.0000    0.0000   0.0000
NO. 1 ENERGY(LABORATORY/C.M.)  =  3.500000/ 3.440173 MEV         LAMBDA-BAR =  0.24757 SQRT-BARN
============
NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
                                                  ARE COMPUTED INTERNALLY.

             TARGET LEVELS
             =============

LEVEL  GROUP   ENERGY   SPIN   PARITY   WEIGHT

   1     1    0.0000    0.0     1        1.00
 MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) =  8, (  0.5,  7.5)

   INTEGRATED CROSS SECTIONS IN BARNS
   ==================================

            TOTAL =  3.63896
       ABSORPTION =  1.62764
    SHAPE ELASTIC =  2.01131
    TOTAL ELASTIC =  3.63839
COMPOUND EXCITATIONS =  1.62708
     TOTAL COMPOUND =  1.62708

LABORATORY CROSS SECTION IN BARNS PER STERADIAN
===============================================
```

ANGLE	S.E.	C.E.	LEVEL GROUP CROSS SECTIONS
0.00	1.56015	0.33570	1.89586
15.00	1.31631	0.29029	1.60661
30.00	0.77451	0.20062	0.97513
45.00	0.29880	0.13437	0.42317
60.00	0.04613	0.10395	0.15007
75.00	0.00831	0.09169	0.10000
90.00	0.05086	0.08776	0.13862
105.00	0.07685	0.09096	0.16782
120.00	0.05689	0.10245	0.15934
135.00	0.02158	0.13207	0.15364
150.00	0.01440	0.19414	0.20854
165.00	0.03813	0.27395	0.31208
180.00	0.05423	0.31314	0.36738

EXAMPLE 4.1

```
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
********************************************************************************

REAL      1  47.3530                        1.30500   0.6461
IMAG      4  17.3930                        1.50000   0.2600
SO        1   5.5000              1.00500   0.6500
TRANSM
COMPUTE   0   0.0001    58.0000

********************************************************************************
```

ABAREX
======

INPUT DECK :

REAL	1	47.3530	0.0000	0.0000	1.3050	0.6461	0.0000	0.0000
IMAG	4	17.3930	0.0000	0.0000	1.5000	0.2600	0.0000	0.0000
SO	1	5.5000	0.0000	1.0050	0.6500	0.0000	0.0000	0.0000
TRANSM	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
COMPUTE	0	0.0001	58.0000	0.0000	0.0000	0.0000	0.0000	0.0000

MASS NUMBERS(TARGET/PROJECTILE) = 58.000000/ 1.008665
============

OPTICAL MODEL PARAMETERS : ASYMPTOPIA= 15.0000 FM 301 POINTS
========================

TYPE		DEPTH	(E)	(E*E)	RADIUS	DIFF.	VIVOL	C2	VOLINT
REAL	1	47.3530	0.0000	0.0000	1.3050	0.6461			512.0033
IMAG	4	17.3930	0.0000	0.0000	1.5000	0.2600	0.0000	0.0000	132.9948
S.O.	1	5.5000	0.0000		1.0050	0.6500			
DISP		0.0000	0.0000	0.0000					

NO. 1 ENERGY(LABORATORY/C.M.) = 0.000100/ 0.000098 MEV LAMBDA-BAR = 46.31569 SQRT-BARN
============

0.100E-03/ 0.983E-04
NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS
=============

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00

O. M. OUTPUT FOR LEVEL 1 CHANNEL ENERGY= 0.0001 MEV WAVE NUMBER= 0.002159

L	J	ETA		T	GAMMASQ/D	R-INFINITY	STR.FN.	R-PRIME
0	1/2	0.992355	-0.028061	0.014444	0.1062	-0.2960	0.2336E-03	0.6547E+01
1	1/2	1.000000	-0.000001	0.000000	0.0263	-0.1666	0.1926E-04	0.2037E-06
1	3/2	1.000000	-0.000001	0.000001				

0.0402 -0.0919 0.5894E-04 0.1581E-06

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 1, (0.5, 1.5)

TRANSMISSION COEFFS. T AND WIDTH FLUCTUATION DEGREES OF FREEDOM NU FOR TOTAL ANG. MOM. J AND PARITIES (+) AND (-)

2*J	LEVEL	CHANNEL	T(+)	NU(+)	T(-)	NU(-)
1	1	1	0.014444	1.008428	0.000000	1.000000

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL	=103.04707
ABSORPTION	= 97.34643
SHAPE ELASTIC	= 5.70063
TOTAL ELASTIC	=102.96506
COMPOUND EXCITATIONS	= 97.26443
TOTAL COMPOUND	= 97.26443

LABORATORY CROSS SECTION IN BARNS PER STERADIAN

ANGLE	S.E.	C.E.	LEVEL GROUP CROSS SECTIONS
0.00	0.46963	8.01161	8.48124
15.00	0.46908	8.00220	8.47128
30.00	0.46746	7.97467	8.44212
45.00	0.46489	7.93101	8.39589
60.00	0.46155	7.87437	8.33592
75.00	0.45769	7.80880	8.26649
90.00	0.45357	7.73889	8.19246
105.00	0.44948	7.66945	8.11893
120.00	0.44570	7.60516	8.05086
135.00	0.44247	7.55028	7.99275
150.00	0.44000	7.50838	7.94838
165.00	0.43846	7.48213	7.92058
180.00	0.43793	7.47319	7.91112

EXAMPLE 4.2

```
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

CAPTURE 26  .00005     7.65                17.4       4.4
TRANSM
COMPUTE

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

ABAREX
======

INPUT DECK :

CAPTURE	26	0.0001	7.6500	0.0000	17.4000	4.4000	0.0000	0.0000
TRANSM	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
COMPUTE	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

MASS NUMBERS(TARGET/PROJECTILE) = 55.934900/ 1.008665
============

OPTICAL MODEL PARAMETERS : ASYMPTOPIA= 15.0000 FM 301 POINTS
========================

TYPE		DEPTH	(E)	(E*E)	RADIUS	DIFF.	VIVOL	C2	VOLINT
REAL	1	46.0000	0.0000	0.0000	1.3170	0.6200			505.9803
IMAG	4	14.0000	0.0000	0.0000	1.4470	0.2500	0.0000	0.0000	96.9636
S.O.	1	7.0000	0.0000		1.3170	0.6200			
DISP		0.0000	0.0000	0.0000					

RADIATIVE CAPTURE INTO COMPOUND NUCLEUS
=======================================

A= 57 Z= 26 N= 31 7.650 MEV NEUTRON BINDING 20.00 RADIATIVE D. OF F. SIGMA= 2.800
NORMALIZED TO SLOW S-WAVE NEUTRON GAMMA WIDTHS/SPACINGS = 0.5000E-04
E1 GIANT RESONANCE AT 17.40 MEV WIDTH= 4.40 MEV EXCHANGE FRACTION=0.50
BLACK NUCLEUS SECOND CHANCE NEUTRON CHANNELS
NO. 1 ENERGY(LABORATORY/C.M.) = 0.800000/ 0.785829 MEV LAMBDA-BAR = 0.51815 SQRT-BARN
============
NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS
=============

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00

O. M. OUTPUT FOR LEVEL 1 CHANNEL ENERGY= 0.7858 MEV WAVE NUMBER= 0.192994

L	J	ETA		T	GAMMASQ/D	R-INFINITY	STR.FN.	R-PRIME
0	1/2	-0.325299	-0.174555	0.863711	0.1665	-0.2898	0.3578E-03	0.6863E+01

1	1/2	0.869255	-0.410147	0.076175				
					0.0176	-0.2901	0.9760E-05	0.2827E-06
1	3/2	0.889130	-0.339705	0.094048				
					0.0200	-0.1884	0.2433E-04	0.2340E-06
2	3/2	0.907925	-0.020066	0.175270				
2	5/2	0.910914	-0.069022	0.165472				
3	5/2	0.999368	0.000478	0.001264				
3	7/2	0.998537	0.002183	0.002918				
4	7/2	0.999925	0.000045	0.000150				
4	9/2	0.999967	-0.000018	0.000066				
5	9/2	1.000000	0.000001	0.000001				
5	11/2	0.999999	0.000002	0.000002				

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 5, (0.5, 5.5)

TRANSMISSION COEFFS. T AND WIDTH FLUCTUATION DEGREES OF FREEDOM NU FOR TOTAL ANG. MOM. J AND PARITIES (+) AND (-)

2*J	LEVEL	CHANNEL	T(+)	NU(+)	T(-)	NU(-)
1	1	1	0.363711	1.827046	0.076175	1.056916
3	1	1	0.175270	1.147139	0.094048	1.072502
5	1	1	0.165472	1.137888	0.001264	1.000762
7	1	1	0.000150	1.000254	0.002918	1.001568
9	1	1	0.000066	1.000170	0.000001	1.000151

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	3.60563
ABSORPTION =	1.67961
SHAPE ELASTIC =	1.92602
TOTAL ELASTIC =	3.59399
COMPOUND EXCITATIONS =	1.66798
N-GAMMA =	0.01106
RADIATIVE CAPTURE =	0.01106
TOTAL COMPOUND =	1.67903

LABORATORY CROSS SECTION IN BARNS PER STERADIAN

ANGLE	S.E.	C.E.	LEVEL GROUP CROSS SECTIONS
0.00	0.47453	0.24565	0.72018
15.00	0.44341	0.22716	0.67057
30.00	0.36232	0.18396	0.54628
45.00	0.26096	0.14137	0.40233
60.00	0.17027	0.11632	0.28659
75.00	0.10908	0.10794	0.21701
90.00	0.08072	0.10619	0.18692
105.00	0.07836	0.10631	0.18467
120.00	0.09220	0.11396	0.20616
135.00	0.11363	0.13754	0.25118
150.00	0.13557	0.17576	0.31133
165.00	0.15189	0.21297	0.36487
180.00	0.15794	0.22855	0.38649

EXAMPLE 5.1

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
*****************************************************************************

LEVELS   6   28.                    0.2     1.5900    -.17      2.950
 .0       0.0+1    1
1.454     2.0+1    2
2.459     4.0+1    3
2.776     2.0+1    4
2.902     1.0+1    5
2.942     0.0+1    6
REAL     1  47.46900   0.00000   0.00000   1.27800   0.6461
IMAG     4  17.75000   0.00000   0.00000   1.18500   0.3500
SO       1   5.50000             1.00500   0.6500
COMPUTE  0    4.5000   58.0000

*****************************************************************************
```

ABAREX
======

INPUT DECK :

```
LEVELS   6   28.0000    0.0000    0.2000    1.5900   -0.1700    2.9500    0.0000
   0.0000 0.0 1    1 1.00
   1.4540 2.0 1    2 1.00
   2.4590 4.0 1    3 1.00
   2.7760 2.0 1    4 1.00
   2.9020 1.0 1    5 1.00
   2.9420 0.0 1    6 1.00
REAL     1   47.4690    0.0000    0.0000    1.2780    0.6461    0.0000    0.0000
IMAG     4   17.7500    0.0000    0.0000    1.1850    0.3500    0.0000    0.0000
SO       1    5.5000    0.0000    1.0050    0.6500    0.0000    0.0000    0.0000
COMPUTE  0    4.5000   58.0000    0.0000    0.0000    0.0000    0.0000    0.0000
```

MASS NUMBERS(TARGET/PROJECTILE) = 58.000000/ 1.008665
==========

OPTICAL MODEL PARAMETERS : ASYMPTOPIA= 15.0000 FM 301 POINTS
==========

TYPE		DEPTH	(E)	(E*E)	RADIUS	DIFF.	VIVOL	C2	VOLINT
REAL	1	47.4690	0.0000	0.0000	1.2780	0.6461			484.9162
IMAG	4	17.7500	0.0000	0.0000	1.1850	0.3500	0.0000	0.0000	115.4495
S.O.	1	5.5000	0.0000		1.0050	0.6500			
DISP		0.0000	0.0000	0.0000					

NO. 1 ENERGY(LABORATORY/C.M.) = 4.500000/ 4.423079 MEV LAMBDA-BAR = 0.21833 SQRT-BARN
==========

NO WIDTH FLUCTUATION CORRECTION

TARGET LEVELS
==========

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00

2	2	1.4540	2.0	1	1.00
3	3	2.4590	4.0	1	1.00
4	4	2.7760	2.0	1	1.00
5	5	2.9020	1.0	1	1.00
6	6	2.9420	0.0	1	1.00

TARGET LEVEL CONTINUUM STARTS AT 2.94 MEV

LEVEL DENSITY PARAMETERS: TEMP. = 1.590 MEV EO = -0.170 MEV SIGMA = 2.950

AT 2.94 MEV, COMPUTED TOTAL LEVEL DENSITY = 4.45/MEV

OPTICAL MODEL CONTINUUM CHANNELS

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 8, (0.5, 8.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	3.42263					
ABSORPTION =	1.69389					
SHAPE ELASTIC =	1.72875					
TOTAL ELASTIC =	1.93656					
COMPOUND EXCITATIONS =	0.20782	0.26426	0.14078	0.19640	0.14300	0.05768
CONTINUUM LEVELS =	0.68395					
TOTAL COMPOUND =	1.69389					

LABORATORY CROSS SECTION IN BARNS PER STERADIAN

ANGLE	S.E.	C.E.	LEVEL GROUP CROSS SECTIONS					
0.00	1.65114	0.04134	1.69248	0.02228	0.01000	0.01659	0.01602	0.00904
15.00	1.33495	0.03576	1.37071	0.02256	0.01019	0.01669	0.01555	0.00834
30.00	0.68916	0.02474	0.71391	0.02289	0.01065	0.01681	0.01430	0.00671
45.00	0.20442	0.01698	0.22140	0.02253	0.01122	0.01663	0.01265	0.00507
60.00	0.02530	0.01376	0.03905	0.02148	0.01175	0.01610	0.01109	0.00402
75.00	0.01696	0.01215	0.02912	0.02039	0.01207	0.01550	0.01001	0.00355
90.00	0.04412	0.01145	0.05557	0.01986	0.01206	0.01513	0.00960	0.00342
105.00	0.05109	0.01209	0.06317	0.02005	0.01168	0.01512	0.00985	0.00350
120.00	0.03181	0.01350	0.04531	0.02072	0.01105	0.01528	0.01068	0.00392
135.00	0.00906	0.01662	0.02568	0.02128	0.01033	0.01537	0.01186	0.00486
150.00	0.00940	0.02394	0.03334	0.02125	0.00967	0.01521	0.01304	0.00622
165.00	0.03105	0.03374	0.06479	0.02076	0.00919	0.01494	0.01391	0.00749
180.00	0.04436	0.03856	0.08292	0.02047	0.00901	0.01481	0.01423	0.00802

EXAMPLE 5.2

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
*****************************************************************************

LEVELS   6   28.                    0.2      1.5900    -.17      2.950
 .0       0.0+1    1
1.454     2.0+1    2
2.459     4.0+1    3
2.776     2.0+1    4
2.902     1.0+1    5
2.942     0.0+1    6
REAL     1  47.43800   0.00000   0.00000   1.28760   0.6461
IMAG     4  17.29000   0.00000   0.00000   1.29700   0.3180
SO       1   5.50000             1.00500   0.6500
COMPUTE  0    2.9000   58.0000

*****************************************************************************
```

ABAREX
======

INPUT DECK :

```
LEVELS   6   28.0000    0.0000    0.2000    1.5900   -0.1700    2.9500    0.0000
   0.0000 0.0 1    1 1.00
   1.4540 2.0 1    2 1.00
   2.4590 4.0 1    3 1.00
   2.7760 2.0 1    4 1.00
   2.9020 1.0 1    5 1.00
   2.9420 0.0 1    6 1.00
REAL     1   47.4380    0.0000    0.0000    1.2876    0.6461    0.0000    0.0000
IMAG     4   17.2900    0.0000    0.0000    1.2970    0.3180    0.0000    0.0000
SO       1    5.5000    0.0000    1.0050    0.6500    0.0000    0.0000    0.0000
COMPUTE  0    2.9000   58.0000    0.0000    0.0000    0.0000    0.0000    0.0000
```

MASS NUMBERS(TARGET/PROJECTILE) = 58.000000/ 1.008665
==========

OPTICAL MODEL PARAMETERS : ASYMPTOPIA= 15.0000 FM 301 POINTS
==========

TYPE		DEPTH	(E)	(E*E)	RADIUS	DIFF.	VIVOL	C2	VOLINT
REAL	1	47.4380	0.0000	0.0000	1.2876	0.6461			494.5414
IMAG	4	17.2900	0.0000	0.0000	1.2970	0.3180	0.0000	0.0000	121.6874
S.O.	1	5.5000	0.0000		1.0050	0.6500			
DISP		0.0000	0.0000	0.0000					

NO. 1 ENERGY(LABORATORY/C.M.) = 2.900000/ 2.850429 MEV LAMBDA-BAR = 0.27198 SQRT-BARN
==========

NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS
==========

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT

1	1	0.0000	0.0	1	1.00
2	2	1.4540	2.0	1	1.00
3	3	2.4590	4.0	1	1.00
4	4	2.7760	2.0	1	1.00

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 7, (0.5, 7.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	3.17784			
ABSORPTION =	1.66429			
SHAPE ELASTIC =	1.51355			
TOTAL ELASTIC =	2.29667			
COMPOUND EXCITATIONS =	0.78312	0.66985	0.09043	0.12087
TOTAL COMPOUND =	1.66427			

LABORATORY CROSS SECTION IN BARNS PER STERADIAN

ANGLE	S.E.	C.E.	LEVEL GROUP CROSS SECTIONS			
0.00	1.06351	0.14036	1.20388	0.05370	0.00680	0.01186
15.00	0.91265	0.12475	1.03740	0.05434	0.00691	0.01177
30.00	0.56509	0.09218	0.65727	0.05552	0.00718	0.01151
45.00	0.23036	0.06600	0.29636	0.05595	0.00749	0.01112
60.00	0.04319	0.05276	0.09595	0.05513	0.00772	0.01063
75.00	0.00314	0.04655	0.04969	0.05373	0.00778	0.01008
90.00	0.03396	0.04431	0.07828	0.05273	0.00765	0.00954
105.00	0.06148	0.04623	0.10771	0.05249	0.00735	0.00902
120.00	0.05570	0.05191	0.10762	0.05255	0.00693	0.00857
135.00	0.03082	0.06454	0.09536	0.05210	0.00647	0.00820
150.00	0.01416	0.08877	0.10293	0.05082	0.00604	0.00792
165.00	0.01396	0.11752	0.13147	0.04930	0.00575	0.00775
180.00	0.01709	0.13093	0.14802	0.04862	0.00564	0.00770

EXAMPLE 6.1

```
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
********************************************************************************

LEVELS   6   28.        0.0       0.2       1.5900   -0.17     2.95
 .0       0.0+1    1
1.454     2.0+1    2
2.459     4.0+1    3
2.776     2.0+1    4
2.902     1.0+1    5
2.942     0.0+1    6
REAL     1  44.30000  0.00000   0.00000   1.27800   0.6461
IMAG     4  11.70000  0.00000   0.00000   1.18500   0.3500
SO       1   5.50000            1.00500   0.6500
SEARCH  37    4.5000                      -1.0000          1000010000
     16.4    1.5000
     19.4    1.4100
     25.4    1.0300
     30.0     .8260
     35.4     .5780
     39.9     .4110
     42.1     .3390
     45.1     .2660
     50.1     .1560
     55.8     .0756
     60.6     .0427
     65.6     .0243
     70.0     .0218
     73.0     .0208
     76.0     .0224
     78.8     .0258
     81.0     .0272
     84.0     .0323
     88.5     .0394
     92.0     .0415
     96.5     .0480
    100.0     .0484
    104.0     .0514
    107.0     .0496
    110.0     .0448
    112.0     .0485
    117.0     .0450
    122.0     .0358
    125.0     .0323
    130.0     .0270
    135.0     .0209
    138.0     .0196
    141.0     .0185
    145.0     .0186
    148.0     .0204
    151.0     .0216
    156.0     .0287
COMPUTE  0    4.5000   58.0000

********************************************************************************
```

ABAREX
======

INPUT DECK :

```
LEVELS   6   28.0000    0.0000    0.2000    1.5900   -0.1700    2.9500    0.0000
   0.0000 0.0 1    1 1.00
   1.4540 2.0 1    2 1.00
   2.4590 4.0 1    3 1.00
   2.7760 2.0 1    4 1.00
   2.9020 1.0 1    5 1.00
   2.9420 0.0 1    6 1.00
REAL     1   44.8000    0.0000    0.0000    1.2780    0.6461    0.0000    0.0000
IMAG     4   11.7000    0.0000    0.0000    1.1850    0.3500    0.0000    0.0000
SO       1    5.5000    0.0000    1.0050    0.6500    0.0000    0.0000    0.0000
SEARCH  37    4.5000    0.0000    0.0000   -1.0000    0.0000100001000000000000
   16.4000    1.5000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   19.4000    1.4100    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   25.4000    1.0300    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   30.0000    0.8260    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   35.4000    0.5730    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   39.9000    0.4110    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   42.1000    0.3390    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   45.1000    0.2660    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   50.1000    0.1560    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   55.8000    0.0756    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   60.6000    0.0427    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   65.6000    0.0243    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   70.0000    0.0218    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   73.0000    0.0208    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   76.0000    0.0224    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   78.8000    0.0258    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   81.0000    0.0272    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   84.0000    0.0323    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   88.5000    0.0394    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   92.0000    0.0415    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   96.5000    0.0480    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  100.0000    0.0484    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  104.0000    0.0514    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  107.0000    0.0496    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  110.0000    0.0448    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  112.0000    0.0485    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  117.0000    0.0450    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  122.0000    0.0358    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  125.0000    0.0323    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  130.0000    0.0270    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  135.0000    0.0209    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  138.0000    0.0176    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  141.0000    0.0185    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  145.0000    0.0186    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  148.0000    0.0204    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  151.0000    0.0216    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  156.0000    0.0287    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
COMPUTE  0    4.5000   58.0000    0.0000    0.0000    0.0000    0.0000    0.0000
```

MASS NUMBERS(TARGET/PROJECTILE) = 58.000000/ 1.008665
==========

OPTICAL MODEL PARAMETERS : ASYMPTOPIA= 15.0000 FM 301 POINTS
==========

TYPE		DEPTH	(E)	(E*E)	RADIUS	DIFF.	VIVOL	C2	VOLINT
REAL	1	44.8000	0.0000	0.0000	1.2780	0.6461			457.6513
IMAG	4	11.7000	0.0000	0.0000	1.1850	0.3500	0.0000	0.0000	76.0991
S.O.	1	3.5000	0.0000		1.0050	0.6500			
DISP		0.0000	0.0000	0.0000					

SEARCH FOR 2 PARAMETERS

CHI-SQUARE

AT LAB/CM ENERGY = 4.500000/ 4.423079 MEV

SCATTERING DATA

ANGLE	CROSS SECTION DATA FOR SUCCESSIVE LEVEL GROUPS
16.40	1.50000
19.40	1.41000
25.40	1.03000
30.00	0.82600
35.40	0.57800
39.90	0.41100
42.10	0.33900
45.10	0.26600
50.10	0.15600
55.80	0.07560
60.60	0.04270
65.60	0.02430
70.00	0.02180
73.00	0.02080
76.00	0.02240
78.80	0.02580
81.00	0.02720
84.00	0.03230
88.50	0.03940
92.00	0.04150
96.50	0.04800
100.00	0.04840
104.00	0.05140
107.00	0.04960
110.00	0.04480
112.00	0.04850
117.00	0.04500
122.00	0.03580
125.00	0.03230
130.00	0.02700
135.00	0.02090
138.00	0.01960
141.00	0.01850
145.00	0.01860
148.00	0.02040
151.00	0.02160
156.00	0.02870

GENERATED OPTICAL MODEL PARAMETERS IN SEARCH : STATISTIC

0.4480E+02 0.1170E+02 0.296514

0.4480E+02 0.1170E+02 0.296514

0.4480E+02 0.1170E+02 0.296514

0.4435E+02	0.1648E+02	0.041734
0.4435E+02	0.1648E+02	0.041734
0.4435E+02	0.1648E+02	0.041734
0.4406E+02	0.1780E+02	0.033908
0.4406E+02	0.1780E+02	0.033908
0.4406E+02	0.1780E+02	0.033908
0.4409E+02	0.1780E+02	0.033902

SEARCH TERMINATED AFTER 10 CALLS
UPON CONVERGENCE (INFO=3)

FINAL OPTICAL MODEL PARAMETERS :

TYPE		DEPTH	(E)	(E*E)	RADIUS	DIFF.	VIVOL	C2	VOLINT
REAL	1	44.0870	0.0000	0.0000	1.2780	0.6461			450.3675
IMAG	4	17.8007	0.0000	0.0000	1.1850	0.3500	0.0000	0.0000	115.7791
S.O.	1	5.5000	0.0000		1.0050	0.6500			

NO. 1 ENERGY(LABORATORY/C.M.) = 4.500000/ 4.423079 MEV LAMBDA-BAR = 0.21833 SQRT-BARN

NO WIDTH FLUCTUATION CORRECTION

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00
2	2	1.4540	2.0	1	1.00
3	3	2.4590	4.0	1	1.00
4	4	2.7760	2.0	1	1.00
5	5	2.9020	1.0	1	1.00
6	6	2.9420	0.0	1	1.00

TARGET LEVEL CONTINUUM STARTS AT 2.94 MEV

LEVEL DENSITY PARAMETERS: TEMP. = 1.590 MEV EO = -0.170 MEV SIGMA = 2.950

AT 2.94 MEV, COMPUTED TOTAL LEVEL DENSITY = 4.45/MEV
OPTICAL MODEL CONTINUUM CHANNELS
MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 8, (0.5, 8.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	3.55760
ABSORPTION =	1.67122
SHAPE ELASTIC =	1.88638
TOTAL ELASTIC =	2.08234

COMPOUND EXCITATIONS = 0.19595 0.26664 0.13783 0.20121 0.14891 0.06056
CONTINUUM LEVELS = 0.66011
TOTAL COMPOUND = 1.67122

LABORATORY CROSS SECTION IN BARNS PER STERADIAN

ANGLE	S.E.	C.E.	LEVEL GROUP CROSS SECTIONS					
16.40	1.40080	0.03159	1.43238	0.02224	0.01012	0.01684	0.01624	0.00879
19.40	1.27382	0.02988	1.30370	0.02234	0.01020	0.01689	0.01601	0.00845
25.40	1.00096	0.02624	1.02720	0.02253	0.01037	0.01699	0.01547	0.00770
30.00	0.79263	0.02348	0.81611	0.02264	0.01052	0.01705	0.01499	0.00709
35.40	0.56840	0.02052	0.58892	0.02269	0.01071	0.01708	0.01438	0.00638
39.90	0.40822	0.01840	0.42662	0.02266	0.01087	0.01707	0.01384	0.00583
42.10	0.34033	0.01749	0.35782	0.02262	0.01095	0.01705	0.01357	0.00558
45.10	0.25932	0.01639	0.27571	0.02253	0.01105	0.01700	0.01321	0.00526
50.10	0.15352	0.01490	0.16841	0.02234	0.01121	0.01689	0.01262	0.00480
55.80	0.07354	0.01363	0.08716	0.02203	0.01138	0.01672	0.01197	0.00439
60.60	0.03398	0.01284	0.04682	0.02174	0.01151	0.01654	0.01148	0.00414
65.60	0.01319	0.01222	0.02542	0.02142	0.01162	0.01634	0.01102	0.00394
70.00	0.00714	0.01181	0.01895	0.02115	0.01169	0.01616	0.01067	0.00382
73.00	0.00747	0.01159	0.01905	0.02098	0.01172	0.01605	0.01047	0.00376
76.00	0.01018	0.01140	0.02158	0.02082	0.01175	0.01594	0.01030	0.00372
78.80	0.01409	0.01126	0.02534	0.02069	0.01176	0.01585	0.01016	0.00369
81.00	0.01767	0.01117	0.02883	0.02060	0.01176	0.01579	0.01008	0.00367
84.00	0.02280	0.01107	0.03387	0.02050	0.01175	0.01571	0.00999	0.00364
88.50	0.03007	0.01100	0.04106	0.02040	0.01172	0.01563	0.00991	0.00362
92.00	0.03470	0.01099	0.04569	0.02036	0.01168	0.01558	0.00989	0.00361
96.50	0.03874	0.01105	0.04978	0.02037	0.01159	0.01556	0.00994	0.00361
100.00	0.04019	0.01114	0.05133	0.02040	0.01151	0.01555	0.01002	0.00362
104.00	0.04003	0.01131	0.05134	0.02048	0.01140	0.01557	0.01016	0.00365
107.00	0.03872	0.01148	0.05019	0.02056	0.01131	0.01559	0.01029	0.00368
110.00	0.03652	0.01168	0.04820	0.02064	0.01121	0.01562	0.01045	0.00374
112.00	0.03463	0.01184	0.04647	0.02071	0.01114	0.01564	0.01057	0.00378
117.00	0.02883	0.01234	0.04118	0.02087	0.01095	0.01568	0.01090	0.00393
122.00	0.02224	0.01303	0.03527	0.02103	0.01074	0.01572	0.01128	0.00415
125.00	0.01830	0.01355	0.03185	0.02111	0.01062	0.01573	0.01153	0.00432
130.00	0.01237	0.01465	0.02702	0.02121	0.01040	0.01573	0.01196	0.00466
135.00	0.00792	0.01610	0.02402	0.02125	0.01018	0.01570	0.01240	0.00507
138.00	0.00620	0.01715	0.02335	0.02125	0.01005	0.01566	0.01267	0.00534
141.00	0.00528	0.01834	0.02362	0.02122	0.00992	0.01561	0.01293	0.00564
145.00	0.00534	0.02013	0.02547	0.02114	0.00976	0.01554	0.01327	0.00605
148.00	0.00632	0.02161	0.02793	0.02107	0.00964	0.01547	0.01352	0.00637
151.00	0.00801	0.02317	0.03118	0.02097	0.00953	0.01539	0.01375	0.00669
156.00	0.01208	0.02588	0.03796	0.02078	0.00935	0.01526	0.01411	0.00722

EXAMPLE 6.2

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
********************************************************************************
LEVELS   1
 .0       0.0+1   -1
REAL     1  47.48900   0.00000   0.00000   1.25700   0.6461
IMAG     4  14.91120   0.00000   0.00000   1.17610   0.4206
SD       1   5.50000             1.00500   0.6500
SEARCH  35    8.0000                       -1.0000          0000010011         5
      14.5    2.3600
      19.1    1.8500
      24.3    1.2500
      28.2     .9650
      32.2     .6190
      34.2     .5680
      40.1     .2540
      44.3     .1350
      48.4     .0698
      51.1     .0347
      55.6     .0133
      59.1     .0077
      63.6     .0076
      68.7     .0141
      74.0     .0220
      78.0     .0217
      82.0     .0258
      86.5     .0229
      90.8     .0181
      94.5     .0186
      99.0     .0136
     102.0     .0121
     106.0     .0097
     110.0     .0076
     115.0     .0057
     120.0     .0040
     125.0     .0025
     128.0     .0023
     131.0     .0026
     136.0     .0028
     140.0     .0039
     144.0     .0067
     149.0     .0089
     151.0     .0134
     154.0     .0160
               4.
               4.
               4.
               4.
               4.
               5.
               5.
               5.
               6.
               6.
               6.
               8.
               3.
               6.
               6.
```

```
          6.
          6.
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          7.
          8.
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          8.
          8.
          8.
          8.
          7.
          7.
          7.
COMPUTE  0    8.0000   58.0000

#################################################################################
```

ABAREX

```
======
```

INPUT DECK :

```
      LEVELS   1    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
         0.0000 0.0 1   -1 1.00
      REAL     1   47.4890    0.0000    0.0000    1.2570    0.6461    0.0000    0.0000
      IMAG     4   14.9112    0.0000    0.0000    1.1761    0.4206    0.0000    0.0000
      SO       1    5.5000    0.0000    1.0050    0.6500    0.0000    0.0000    0.0000
      SEARCH  35    8.0000    0.0000    0.0000   -1.0000    0.00000000010011000000005
          14.5000   2.3600    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          19.1000   1.8500    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          24.3000   1.2500    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          28.2000   0.9650    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          32.2000   0.6190    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          34.2000   0.5680    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          40.1000   0.2540    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          44.3000   0.1350    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          48.4000   0.0698    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          51.1000   0.0347    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          55.6000   0.0133    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          59.1000   0.0077    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          63.6000   0.0076    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          68.7000   0.0141    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          74.0000   0.0220    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          78.0000   0.0217    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          82.0000   0.0258    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          86.5000   0.0229    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          90.8000   0.0181    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          94.5000   0.0186    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
          99.0000   0.0136    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
         102.0000   0.0121    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
         106.0000   0.0097    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
         110.0000   0.0076    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
         115.0000   0.0057    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
```

120.0000	0.0040	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
125.0000	0.0025	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
128.0000	0.0023	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
131.0000	0.0026	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
136.0000	0.0028	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
140.0000	0.0039	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
144.0000	0.0067	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
149.0000	0.0089	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
151.0000	0.0134	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
154.0000	0.0160	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	4.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	4.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	4.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	4.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	4.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	5.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	5.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	5.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	6.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	6.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	6.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	8.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	8.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	6.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	6.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	6.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	6.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	6.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	6.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	6.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	6.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	7.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	8.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	8.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	8.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	8.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	8.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	8.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	8.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	7.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	7.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	7.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
COMPUTE 0	8.0000	58.0000	0.0000	0.0000	0.0000	0.0000	0.0000

MASS NUMBERS(TARGET/PROJECTILE) = 58.000000/ 1.008665
==========

OPTICAL MODEL PARAMETERS : ASYMPTOPIA= 15.0000 FM 301 POINTS
==========

TYPE		DEPTH	(E)	(E*E)	RADIUS	DIFF.	VIVOL	CZ	VOLINT
REAL	1	47.4890	0.0000	0.0000	1.2570	0.6461			463.8380
IMAG	4	14.9112	0.0000	0.0000	1.1761	0.4206	0.0000	0.0000	115.8102
S.O.	1	5.5000	0.0000		1.0050	0.6500			

DISP 0.0000 0.0000 0.0000

SEARCH FOR 3 PARAMETERS

NORMALIZED LEAST SQUARE

AT LAB/CM ENERGY = 3.000000/ 7.363252 MEV

SCATTERING DATA

ANGLE	CROSS SECTION DATA FOR SUCCESSIVE LEVEL GROUPS
14.50	2.36000
19.10	1.85000
24.30	1.25000
28.20	0.96500
32.20	0.61900
34.20	0.56800
40.10	0.25400
44.30	0.13500
48.40	0.06980
51.10	0.03470
55.60	0.01330
59.10	0.00770
63.60	0.00760
68.70	0.01410
74.00	0.02200
78.00	0.02170
82.00	0.02580
86.50	0.02290
90.80	0.01810
94.50	0.01860
99.00	0.01360
102.00	0.01210
106.00	0.00970
110.00	0.00760
115.00	0.00570
120.00	0.00400
125.00	0.00250
129.00	0.00230
131.00	0.00260
136.00	0.00280
140.00	0.00390
144.00	0.00670
149.00	0.00890
151.00	0.01340
154.00	0.01600

GENERATED OPTICAL MODEL PARAMETERS IN SEARCH :			STATISTIC
0.1491E+02	0.1176E+01	0.4206E+00	
0.1491E+02	0.1176E+01	0.4206E+00	233.866543
0.1491E+02	0.1176E+01	0.4206E+00	233.866563
0.1491E+02	0.1176E+01	0.4206E+00	233.866551
0.1135E+02	0.1175E+01	0.4687E+00	233.866569
0.1306E+02	0.1181E+01	0.4393E+00	246.915537
0.1306E+02	0.1181E+01	0.4393E+00	170.382914

0.1306E+02	0.1181E+01	0.4393E+00
0.1306E+02	0.1181E+01	0.4393E+00
0.1202E+02	0.1178E+01	0.4653E+00
0.1202E+02	0.1178E+01	0.4653E+00
0.1202E+02	0.1178E+01	0.4653E+00
0.1202E+02	0.1178E+01	0.4653E+00
0.1235E+02	0.1182E+01	0.4583E+00
0.1235E+02	0.1182E+01	0.4583E+00
0.1235E+02	0.1182E+01	0.4583E+00
0.1235E+02	0.1182E+01	0.4583E+00
0.1227E+02	0.1181E+01	0.4605E+00

170.382808
170.382802
170.382801
162.184717
162.184713
162.184711
162.184711
160.444823
160.444823
160.444823
160.444822
160.405617

SEARCH TERMINATED AFTER 18 CALLS
UPON CONVERGENCE (INFO=1)

FINAL OPTICAL MODEL PARAMETERS :
==========

TYPE		DEPTH	(E)	(E*E)	RADIUS	DIFF.	VIVOL	C2	VOLINT
REAL	1	47.4890	0.0000	0.0000	1.2570	0.6461			463.8380
IMAG	4	12.2696	0.0000	0.0000	1.1811	0.4605	0.0000	0.0000	105.7692
S.O.	1	5.5000	0.0000		1.0050	0.6500			

NO. 1 ENERGY(LABORATORY/C.M.) = 8.000000/ 7.863252 MEV LAMBDA-BAR = 0.16375 SQRT-BARN
==========
NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS
==========

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	-1	0.0000	0.0	1	1.00

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 10, (0.5, 10.5)

INTEGRATED CROSS SECTIONS IN BARNS
==========

TOTAL =	3.42563
ABSORPTION =	1.57051
SHAPE ELASTIC =	1.85512
TOTAL ELASTIC =	3.42513
COMPOUND EXCITATIONS =	1.57001
TOTAL COMPOUND =	1.57001

EXAMPLE 6.2A

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
*****************************************************************************
LEVELS  15   42.                          0.7250    1.01      3.700
 .0       0.0+1    1
1.509     2.0+1    2
2.283     4.0+1    3
2.520     0.0+1    4
2.527     5.0-1    5
2.612     6.0+1    6
2.761     8.0+1    7
2.850     3.0-1    8
3.007     5.0-1    9
3.064     3.0-1   10
3.091     2.0+1   11
3.369     4.0+1   12
3.542     2.0+1   13
3.580     3.0-1   14
3.621     2.0+1   15
REAL     1  46.55880   0.00000   0.00000   1.20850   0.6281
IMAG     4   8.23160   0.00000   0.00000   1.26490   0.4707
SO       1   5.94090   0.00000   1.10300   0.5600
SEARCH     1.0       5.4       1.        -1.0              1000010000
SEARCH     1.2       5.0       1.        -1.0              1000010000
SEARCH     1.4       4.75      1.        -1.0              1000010000
SEARCH     1.6       4.4       1.        -1.0              1000010000
SEARCH     1.8       4.35      1.        -1.0              1000010000
SEARCH     2.0       4.2       1.        -1.0              1000010000
SEARCH     2.2       4.2       1.        -1.0              1000010000
SEARCH     2.4       4.05      1.        -1.0              1000010000
SEARCH     2.6       3.92      1.        -1.0              1000010000
SEARCH     2.8       3.87      1.        -1.0              1000010000
SEARCH     3.0       3.7       1.        -1.0              1000010000
SEARCH     3.2       3.8       1.        -1.0              1000010000
SEARCH     3.4       3.71      1.        -1.0              1000010000
SEARCH     3.6       3.6       1.        -1.0              1000010000
SEARCH     3.8       3.72      1.        -1.0              1000010000
SEARCH     4.0       3.6       1.        -1.0              1000010000
SEARCH     4.2       3.61      1.        -1.0              1000010000
SEARCH     4.4       3.65      1.        -1.0              1000010000
SEARCH     4.6       3.58      1.        -1.0              1000010000
SEARCH     4.8       3.67      1.        -1.0              1000010000
SEARCH     5.0       3.61      1.        -1.0              1000010000
COMPUTE  0    0.4060   92.0000                      6.0000             601.0

*****************************************************************************
```

ABAREX
======

INPUT DECK :

```
LEVELS  15   42.0000    0.0000    0.0000    0.7250    1.0100    3.7000    0.0000
   0.0000 0.0 1    1 1.00
   1.5090 2.0 1    2 1.00
   2.2830 4.0 1    3 1.00
   2.5200 0.0 1    4 1.00
   2.5270 5.0-1    5 1.00
   2.6120 6.0 1    6 1.00
```

LABORATORY CROSS SECTION IN BARNS PER STERADIAN

ANGLE	S.E.	C.E.	LEVEL GROUP CROSS SECTIONS
14.50	2.12863	0.34248	
19.10	1.70133	0.28993	
24.30	1.21695	0.23422	
28.20	0.88970	0.19906	
32.20	0.60677	0.17024	
34.20	0.48825	0.15853	
40.10	0.22829	0.13282	
44.30	0.11616	0.12068	
48.40	0.05201	0.11208	
51.10	0.02794	0.10765	
55.60	0.00934	0.10177	
59.10	0.00633	0.09814	
63.60	0.00930	0.09427	
68.70	0.01509	0.09057	
74.00	0.01961	0.08721	
78.00	0.02122	0.08501	
82.00	0.02142	0.08326	
86.50	0.02040	0.08203	
90.80	0.01863	0.08174	
94.50	0.01676	0.08220	
99.00	0.01428	0.08350	
102.00	0.01259	0.08470	
106.00	0.01040	0.08659	
110.00	0.00836	0.08872	
115.00	0.00614	0.09175	
120.00	0.00440	0.09546	
125.00	0.00322	0.10030	
128.00	0.00282	0.10402	
131.00	0.00267	0.10858	
136.00	0.00308	0.11885	
140.00	0.00411	0.13053	
144.00	0.00590	0.14655	
149.00	0.00934	0.17448	
151.00	0.01110	0.18843	
154.00	0.01414	0.21234	

```
          2.7610 8.0 1    7 1.00
          2.8500 3.0-1    8 1.00
          3.0070 5.0-1    9 1.00
          3.0640 3.0-1   10 1.00
          3.0910 2.0 1   11 1.00
          3.3690 4.0 1   12 1.00
          3.5420 2.0 1   13 1.00
          3.5800 3.0-1   14 1.00
          3.6210 2.0 1   15 1.00
     REAL     1   46.5588    0.0000    0.0000    1.2085    0.6281    0.0000    0.0000
     IMAG     4    8.2316    0.0000    0.0000    1.2649    0.4707    0.0000    0.0000
     SO       1    5.9409    0.0000    1.1030    0.5600    0.0000    0.0000    0.0000
     SEARCH   0    1.0000    5.4000    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    1.2000    5.0000    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    1.4000    4.7500    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    1.6000    4.4000    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    1.8000    4.3500    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    2.0000    4.2000    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    2.2000    4.2000    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    2.4000    4.0500    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    2.6000    3.9200    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    2.8000    3.8700    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    3.0000    3.7000    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    3.2000    3.8000    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    3.4000    3.7100    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    3.6000    3.6000    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    3.8000    3.7200    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    4.0000    3.6000    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    4.2000    3.6100    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    4.4000    3.6500    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    4.6000    3.5800    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    4.8000    3.6700    1.0000   -1.0000    0.00001000010000000000000
     SEARCH   0    5.0000    3.6100    1.0000   -1.0000    0.00001000010000000000000
     COMPUTE  0    0.4060   92.0000    0.0000    0.0000    6.0000    0.0000  601.0000


MASS NUMBERS(TARGET/PROJECTILE) = 92.000000/ 1.008665
============

OPTICAL MODEL PARAMETERS :          ASYMPTOPIA= 15.0000 FM          601 POINTS
=========================

 TYPE       DEPTH      (E)      (E*E)      RADIUS     DIFF.   VIVOL       C2     VOLINT

REAL    1   46.5588    0.0000    0.0000    1.2085    0.6281                      389.2469
IMAG    4    8.2316    0.0000    0.0000    1.2649    0.4707    0.0000    0.0000   70.5673
S.O.    1    5.9409    0.0000              1.1030    0.5600
DISP         0.0000    0.0000    0.0000


                        SEARCH FOR  2 PARAMETERS
              CHI-SQUARE
    AT LAB/CM ENERGY =  1.000000/ 0.989155 MEV
    TOTAL CROSS SECTION DATA    5.400000     WEIGHT=    1.0000
    AT LAB/CM ENERGY =  1.200000/ 1.186986 MEV
    TOTAL CROSS SECTION DATA    5.000000     WEIGHT=    1.0000
    AT LAB/CM ENERGY =  1.400000/ 1.384817 MEV
    TOTAL CROSS SECTION DATA    4.750000     WEIGHT=    1.0000
    AT LAB/CM ENERGY =  1.600000/ 1.582648 MEV
    TOTAL CROSS SECTION DATA    4.400000     WEIGHT=    1.0000
```

```
     AT LAB/CM ENERGY =  1.300000/ 1.780479 MEV
     TOTAL CROSS SECTION DATA    4.350000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  2.000000/ 1.978310 MEV
     TOTAL CROSS SECTION DATA    4.200000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  2.200000/ 2.176141 MEV
     TOTAL CROSS SECTION DATA    4.200000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  2.400000/ 2.373972 MEV
     TOTAL CROSS SECTION DATA    4.050000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  2.600000/ 2.571803 MEV
     TOTAL CROSS SECTION DATA    3.920000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  2.800000/ 2.769634 MEV
     TOTAL CROSS SECTION DATA    3.870000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  3.000000/ 2.967465 MEV
     TOTAL CROSS SECTION DATA    3.700000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  3.200000/ 3.165296 MEV
     TOTAL CROSS SECTION DATA    3.800000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  3.400000/ 3.363128 MEV
     TOTAL CROSS SECTION DATA    3.710000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  3.600000/ 3.560959 MEV
     TOTAL CROSS SECTION DATA    3.600000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  3.800000/ 3.758790 MEV
     TOTAL CROSS SECTION DATA    3.720000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  4.000000/ 3.956621 MEV
     TOTAL CROSS SECTION DATA    3.600000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  4.200000/ 4.154452 MEV
     TOTAL CROSS SECTION DATA    3.610000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  4.400000/ 4.352283 MEV
     TOTAL CROSS SECTION DATA    3.650000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  4.600000/ 4.550114 MEV
     TOTAL CROSS SECTION DATA    3.580000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  4.800000/ 4.747945 MEV
     TOTAL CROSS SECTION DATA    3.670000     WEIGHT=    1.0000
     AT LAB/CM ENERGY =  5.000000/ 4.945776 MEV
     TOTAL CROSS SECTION DATA    3.610000     WEIGHT=    1.0000
GENERATED OPTICAL MODEL PARAMETERS IN SEARCH :                          STATISTIC

 0.4656E+02  0.8232E+01
                                                                        0.735948
 0.4656E+02  0.8232E+01
                                                                        0.735947
 0.4656E+02  0.8232E+01
                                                                        0.735948
 0.4869E+02  0.1127E+02
                                                                        0.042577
 0.4869E+02  0.1127E+02
                                                                        0.042577
 0.4869E+02  0.1127E+02
                                                                        0.042577
 0.4960E+02  0.1054E+02
                                                                        0.015931
 0.4960E+02  0.1054E+02
                                                                        0.015931
 0.4960E+02  0.1054E+02
                                                                        0.015931
 0.4953E+02  0.1037E+02
                                                                        0.015622
 SEARCH TERMINATED AFTER   10 CALLS
                                  UPON CONVERGENCE (INFO=2)
FINAL OPTICAL MODEL PARAMETERS :
```

==========

TYPE		DEPTH	(E)	(EIE)	RADIUS	DIFF.	VIVOL	C2	VOLINT
REAL	1	49.5279	0.0000	0.0000	1.2085	0.6281			414.0698
IMAG	4	10.3868	0.0000	0.0000	1.2649	0.4707	0.0000	0.0000	89.0434
S.O.	1	5.9409	0.0000		1.1030	0.5600			

NO. 1 ENERGY(LABORATORY/C.M.) = 1.000000/ 0.989155 MEV LAMBDA-BAR = 0.46023 SQRT-BARN

NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 6, (0.5, 6.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	5.34718
ABSORPTION =	2.42530
SHAPE ELASTIC =	2.92188
TOTAL ELASTIC =	5.34629
COMPOUND EXCITATIONS =	2.42441
TOTAL COMPOUND =	2.42441

NO. 2 ENERGY(LABORATORY/C.M.) = 1.200000/ 1.186986 MEV LAMBDA-BAR = 0.42013 SQRT-BARN

NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 6, (0.5, 6.5)

Continued To:-

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	5.00911
ABSORPTION =	2.32325
SHAPE ELASTIC =	2.68586
TOTAL ELASTIC =	5.00823
COMPOUND EXCITATIONS =	2.32237
TOTAL COMPOUND =	2.32237

NO.19 ENERGY(LABORATORY/C.M.) = 4.600000/ 4.550114 MEV LAMBDA-BAR = 0.21458 SQRT-BARN

NO WIDTH FLUCTUATION CORRECTION

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00
2	2	1.5090	2.0	1	1.00
3	3	2.2830	4.0	1	1.00
4	4	2.5200	0.0	1	1.00
5	5	2.5270	5.0	-1	1.00
6	6	2.6120	6.0	1	1.00
7	7	2.7610	8.0	1	1.00
8	8	2.8500	3.0	-1	1.00
9	9	3.0070	5.0	-1	1.00
10	10	3.0640	3.0	-1	1.00
11	11	3.0910	2.0	1	1.00
12	12	3.3690	4.0	1	1.00
13	13	3.5420	2.0	1	1.00
14	14	3.5800	3.0	-1	1.00
15	15	3.6210	2.0	1	1.00

TARGET LEVEL CONTINUUM STARTS AT 3.62 MEV

LEVEL DENSITY PARAMETERS: TEMP. = 0.725 MEV E0 = 1.010 MEV SIGMA = 3.700

AT 3.62 MEV, COMPUTED TOTAL LEVEL DENSITY = 50.55/MEV

OPTICAL MODEL CONTINUUM CHANNELS

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 9, (0.5, 9.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	3.60550									
ABSORPTION =	1.93565									
SHAPE ELASTIC =	1.66985									
TOTAL ELASTIC =	1.75785									
COMPOUND EXCITATIONS =	0.08800	0.12091	0.07012	0.02912	0.03046	0.01378	0.00066	0.06056	0.02278	0.05442
	0.07381	0.04034	0.05900	0.03967	0.05616					
CONTINUUM LEVELS =	1.17585									
TOTAL COMPOUND =	1.93565									

NO.20 ENERGY(LABORATORY/C.M.) = 4.800000/ 4.747945 MEV LAMBDA-BAR = 0.21007 SQRT-BARN

NO WIDTH FLUCTUATION CORRECTION

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00
2	2	1.5090	2.0	1	1.00
3	3	2.2830	4.0	1	1.00

4	4	2.3200	0.0	1	1.00
5	5	2.5270	5.0	-1	1.00
6	6	2.6120	6.0	1	1.00
7	7	2.7610	8.0	1	1.00
8	8	2.8500	3.0	-1	1.00
9	9	3.0070	5.0	-1	1.00
10	10	3.0640	3.0	-1	1.00
11	11	3.0910	2.0	1	1.00
12	12	3.3690	4.0	1	1.00
13	13	3.5420	2.0	1	1.00
14	14	3.5800	3.0	-1	1.00
15	15	3.6210	2.0	1	1.00

TARGET LEVEL CONTINUUM STARTS AT 3.62 MEV

LEVEL DENSITY PARAMETERS: TEMP. = 0.725 MEV EO = 1.010 MEV SIGMA = 3.700

AT 3.62 MEV, COMPUTED TOTAL LEVEL DENSITY = 50.55/MEV

OPTICAL MODEL CONTINUUM CHANNELS

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 9, (0.5, 9.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	3.60614								
ABSORPTION =	1.91900								
SHAPE ELASTIC =	1.68714								
TOTAL ELASTIC =	1.74953								
COMPOUND EXCITATIONS =	0.06239	0.08824	0.05422	0.02150	0.02520	0.01209	0.00069	0.04730	0.01947	0.04292
	0.05627	0.03260	0.04610	0.03246	0.04427					
CONTINUUM LEVELS =	1.33326									
TOTAL COMPOUND =	1.91900									

NO.21 ENERGY(LABORATORY/C.M.) = 5.000000/ 4.945776 MEV LAMBDA-BAR = 0.20582 SQRT-BARN

NO WIDTH FLUCTUATION CORRECTION

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00
2	2	1.5090	2.0	1	1.00
3	3	2.2930	4.0	1	1.00
4	4	2.5200	0.0	1	1.00
5	5	2.5270	5.0	-1	1.00
6	6	2.6120	6.0	1	1.00
7	7	2.7610	8.0	1	1.00
8	8	2.8500	3.0	-1	1.00
9	9	3.0070	5.0	-1	1.00
10	10	3.0640	3.0	-1	1.00
11	11	3.0910	2.0	1	1.00
12	12	3.3690	4.0	1	1.00
13	13	3.5420	2.0	1	1.00
14	14	3.5800	3.0	-1	1.00
15	15	3.6210	2.0	1	1.00

TARGET LEVEL CONTINUUM STARTS AT 3.62 MEV

LEVEL DENSITY PARAMETERS: TEMP. = 0.725 MEV E0 = 1.010 MEV SIGMA = 3.700

AT 3.62 MEV, COMPUTED TOTAL LEVEL DENSITY = 50.55/MEV
OPTICAL MODEL CONTINUUM CHANNELS
MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 9, (0.5, 9.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	3.61117									
ABSORPTION =	1.90486									
SHAPE ELASTIC =	1.70631									
TOTAL ELASTIC =	1.75110									
COMPOUND EXCITATIONS =	0.04479	0.06483	0.04197	0.01601	0.02078	0.01042	0.00070	0.03710	0.01653	0.03396
	0.04311	0.02637	0.03588	0.02639	0.03461					
CONTINUUM LEVELS =	1.45140									
TOTAL COMPOUND =	1.90486									

```
EXAMPLE 6.2B

12345678901234567890123456789012345678901234567890123456789012345678901234567890
********************************************************************************

LEVELS  15   42.                          0.7250    1.01      3.700
 .0       0.0+1    1
1.509     2.0+1    2
2.283     4.0+1    3
2.520     0.0+1    4
2.527     5.0-1    5
2.612     6.0+1    6
2.761     8.0+1    7
2.850     3.0-1    8
3.007     5.0-1    9
3.064     3.0-1   10
3.091     2.0+1   11
3.369     4.0+1   12
3.542     2.0+1   13
3.580     3.0-1   14
3.621     2.0+1   15
REAL      1  46.55880   0.00000   0.00000   1.20850   0.6281
IMAG      4   8.23160   0.00000   0.00000   1.26490   0.4707
SO        1   5.94090   0.00000   1.10300   0.5600
SEARCH    8    0.4060   7.6       1.0       -1.0000          1000010000         5
     28.20    1.1950
     38.00    1.0750
     53.50    0.8635
     68.80    0.6629
     84.00    0.5220
    113.80    0.4180
    129.50    0.4217
    154.00    0.4177
             10.0000
             10.0000
             10.0000
             10.0000
             10.0000
             10.0000
             10.0000
             10.0000
SEARCH     1.0       5.4       1.        -1.0              1000010000
SEARCH     1.2       5.0       1.        -1.0              1000010000
SEARCH     1.4       4.75      1.        -1.0              1000010000
SEARCH     1.6       4.4       1.        -1.0              1000010000
SEARCH     1.8       4.35      1.        -1.0              1000010000
SEARCH     2.0       4.2       1.        -1.0              1000010000
SEARCH     2.2       4.2       1.        -1.0              1000010000
SEARCH     2.4       4.05      1.        -1.0              1000010000
SEARCH     2.6       3.92      1.        -1.0              1000010000
COMPUTE  0    0.4060   92.0000                        6.0000              601.0

********************************************************************************

1                                    ABAREX
                                     ======

  INPUT DECK :

        REAL      1   46.5588    0.0000    0.0000    1.2085    0.6281    0.0000    0.0000
```

```
IMAG     4    8.2316    0.0000    0.0000    1.2649    0.4707    0.0000    0.0000
3D       1    5.9409    0.0000    1.1030    0.5600    0.0000    0.0000    0.0000
SEARCH   8    0.4060    7.6000    1.0000   -1.0000    0.00001000010000000000005
   28.2000    1.1950    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   38.0000    1.0750    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   53.5000    0.8635    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   68.8000    0.6629    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   84.0000    0.5220    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  113.8000    0.4180    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  129.5000    0.4217    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  154.0000    0.4177    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
SEARCH   0    1.0000    5.4000    1.0000   -1.0000    0.00001000010000000000000
SEARCH   0    1.2000    5.0000    1.0000   -1.0000    0.00001000010000000000000
SEARCH   0    1.4000    4.7500    1.0000   -1.0000    0.00001000010000000000000
SEARCH   0    1.6000    4.4000    1.0000   -1.0000    0.00001000010000000000000
SEARCH   0    1.8000    4.3500    1.0000   -1.0000    0.00001000010000000000000
SEARCH   0    2.0000    4.2000    1.0000   -1.0000    0.00001000010000000000000
SEARCH   0    2.2000    4.2000    1.0000   -1.0000    0.00001000010000000000000
SEARCH   0    2.4000    4.0500    1.0000   -1.0000    0.00001000010000000000000
SEARCH   0    2.6000    3.9200    1.0000   -1.0000    0.00001000010000000000000
COMPUTE  0    0.4060   92.0000    0.0000    0.0000    6.0000    0.0000  601.0000


MASS NUMBERS(TARGET/PROJECTILE) = 92.000000/ 1.008665
============

OPTICAL MODEL PARAMETERS :          ASYMPTOPIA= 15.0000 FM           601 POINTS
========================

 TYPE        DEPTH      (E)      (E*E)      RADIUS     DIFF.   VIVOL       C2     VOLINT

REAL    1   46.5588    0.0000    0.0000    1.2085    0.6281                      389.2469
IMAG    4    8.2316    0.0000    0.0000    1.2649    0.4707    0.0000    0.0000   70.5673
S.O.    1    5.9409    0.0000              1.1030    0.5600
DISP         0.0000    0.0000    0.0000


                    SEARCH FOR  2 PARAMETERS
              CHI-SQUARE
    AT LAB/CM ENERGY =  0.406000/ 0.401597 MEV
    TOTAL CROSS SECTION DATA    7.600000     WEIGHT=    1.0000
    SCATTERING DATA

   ANGLE     CROSS SECTION DATA FOR SUCCESSIVE LEVEL GROUPS

   28.20   1.19500
   38.00   1.07500
   53.50   0.86350
   68.80   0.66290
   84.00   0.52200
  113.80   0.41800
  129.50   0.42170
```

```
  154.00   0.41770
    AT LAB/CM ENERGY =  1.000000/ 0.989155 MEV
    TOTAL CROSS SECTION DATA    5.400000     WEIGHT=    1.0000
    AT LAB/CM ENERGY =  1.200000/ 1.186986 MEV
    TOTAL CROSS SECTION DATA    5.000000     WEIGHT=    1.0000
    AT LAB/CM ENERGY =  1.400000/ 1.384817 MEV
    TOTAL CROSS SECTION DATA    4.750000     WEIGHT=    1.0000
    AT LAB/CM ENERGY =  1.600000/ 1.582648 MEV
    TOTAL CROSS SECTION DATA    4.400000     WEIGHT=    1.0000
    AT LAB/CM ENERGY =  1.800000/ 1.780479 MEV
    TOTAL CROSS SECTION DATA    4.350000     WEIGHT=    1.0000
    AT LAB/CM ENERGY =  2.000000/ 1.978310 MEV
    TOTAL CROSS SECTION DATA    4.200000     WEIGHT=    1.0000
    AT LAB/CM ENERGY =  2.200000/ 2.176141 MEV
    TOTAL CROSS SECTION DATA    4.200000     WEIGHT=    1.0000
    AT LAB/CM ENERGY =  2.400000/ 2.373972 MEV
    TOTAL CROSS SECTION DATA    4.050000     WEIGHT=    1.0000
    AT LAB/CM ENERGY =  2.600000/ 2.571803 MEV
    TOTAL CROSS SECTION DATA    3.920000     WEIGHT=    1.0000
GENERATED OPTICAL MODEL PARAMETERS IN SEARCH :                                  STATISTIC

 0.4656E+02  0.8232E+01
                                                                                1.276486
 0.4656E+02  0.8232E+01
                                                                                1.276486
 0.4656E+02  0.8232E+01
                                                                                1.276486
 0.5275E+02  0.6071E+01
                                                                                1.328856
 0.4961E+02  0.1011E+02
                                                                                0.177069
 0.4961E+02  0.1011E+02
                                                                                0.177069
 0.4961E+02  0.1011E+02
                                                                                0.177069
 0.5041E+02  0.4893E+01
                                                                                0.168145
 0.5041E+02  0.4893E+01
                                                                                0.168145
 0.5041E+02  0.4893E+01
                                                                                0.168145
 0.5027E+02  0.7907E+01
                                                                                0.100759
 0.5027E+02  0.7907E+01
                                                                                0.100759
 0.5027E+02  0.7907E+01
                                                                                0.100759
 0.5009E+02  0.6307E+01
                                                                                0.100668
 0.5009E+02  0.6307E+01
                                                                                0.100668
 0.5009E+02  0.6307E+01
                                                                                0.100668
 0.5017E+02  0.7844E+01
                                                                                0.099971
 0.5017E+02  0.7844E+01
                                                                                0.099971
 0.5017E+02  0.7844E+01
                                                                                0.099971
```

0.5012E+02 0.6337E+01

0.099823

SEARCH TERMINATED AFTER 20 CALLS
UPON CONVERGENCE (INFO=2)

FINAL OPTICAL MODEL PARAMETERS :

TYPE		DEPTH	(E)	(E*E)	RADIUS	DIFF.	VIVOL	C2	VOLINT
REAL	1	50.1223	0.0000	0.0000	1.2085	0.6281			419.0392
IMAG	4	6.3370	0.0000	0.0000	1.2649	0.4707	0.0000	0.0000	54.3256
S.O.	1	5.9409	0.0000		1.1030	0.5600			

NO. 1 ENERGY(LABORATORY/C.M.) = 0.406000/ 0.401597 MEV LAMBDA-BAR = 0.72229 SQRT-BARN

NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 4, (0.5, 4.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	7.31438
ABSORPTION =	3.13388
SHAPE ELASTIC =	4.18050
TOTAL ELASTIC =	7.31312
COMPOUND EXCITATIONS =	3.13263
TOTAL COMPOUND =	3.13263

LABORATORY CROSS SECTION IN BARNS PER STERADIAN

ANGLE	S.E.	C.E.	LEVEL GROUP CROSS SECTIONS
28.20	0.69297	0.36276	1.05573
38.00	0.63278	0.32112	0.95390
53.50	0.52149	0.25359	0.77508
68.30	0.40897	0.20019	0.60916
84.00	0.30956	0.17257	0.48213
113.80	0.17872	0.20748	0.38620
129.50	0.14475	0.26270	0.40745
154.00	0.12460	0.35891	0.48351

Continued To:-

NO. 7 ENERGY(LABORATORY/C.M.) = 2.000000/ 1.978310 MEV LAMBDA-BAR = 0.32543 SQRT-BARN

NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 7, (0.5, 7.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	4.23925
ABSORPTION =	2.18004
SHAPE ELASTIC =	2.05922
TOTAL ELASTIC =	4.23843
COMPOUND EXCITATIONS =	2.17921
TOTAL COMPOUND =	2.17921

NO. 8 ENERGY(LABORATORY/C.M.) = 2.200000/ 2.176141 MEV LAMBDA-BAR = 0.31029 SQRT-BARN

NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 7, (0.5, 7.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	4.11281
ABSORPTION =	2.17797
SHAPE ELASTIC =	1.93484
TOTAL ELASTIC =	4.11201
COMPOUND EXCITATIONS =	2.17717
TOTAL COMPOUND =	2.17717

NO. 9 ENERGY(LABORATORY/C.M.) = 2.400000/ 2.373972 MEV LAMBDA-BAR = 0.29708 SQRT-BARN

NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT

```
    1     1    0.0000    0.0     1        1.00
 MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) =  7, (  0.5,  7.5)

   INTEGRATED CROSS SECTIONS IN BARNS
   ==================================

              TOTAL =  4.00831
         ABSORPTION =  2.16927
      SHAPE ELASTIC =  1.83903
      TOTAL ELASTIC =  4.00753
COMPOUND EXCITATIONS =  2.16850
      TOTAL COMPOUND =  2.16850



NO.10 ENERGY(LABORATORY/C.M.)  =  2.600000/ 2.571803 MEV         LAMBDA-BAR =  0.28542 SQRT-BARN
============
NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
                                                  ARE COMPUTED INTERNALLY.

             TARGET LEVELS
             =============

LEVEL  GROUP   ENERGY   SPIN   PARITY   WEIGHT

    1     1    0.0000    0.0     1        1.00
 MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) =  7, (  0.5,  7.5)

   INTEGRATED CROSS SECTIONS IN BARNS
   ==================================

              TOTAL =  3.91952
         ABSORPTION =  2.15138
      SHAPE ELASTIC =  1.76814
      TOTAL ELASTIC =  3.91877
COMPOUND EXCITATIONS =  2.15064
      TOTAL COMPOUND =  2.15064
```

EXAMPLE 6.2C

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
*****************************************************************************

LEVELS  15   42.                          0.7250    1.01      3.700
 .0       0.0+1    1
1.509     2.0+1    2
2.283     4.0+1    3
2.520     0.0+1    4
2.527     5.0-1    5
2.612     6.0+1    6
2.761     8.0+1    7
2.850     3.0-1    8
3.007     5.0-1    9
3.064     3.0-1   10
3.091     2.0+1   11
3.369     4.0+1   12
3.542     2.0+1   13
3.580     3.0-1   14
3.621     2.0+1   15
REAL     1  49.23830   0.00000   0.00000   1.20850   0.6281
IMAG     4   9.36310   0.00000   0.00000   1.25020   0.5025
SO       1   5.94090   0.00000   1.10300   0.5600
SEARCH  20    2.4000   4.37      1.0      -1.0000          1000010000        5
     20.29    0.9536
     26.21    0.8699
     30.18    0.6797
     36.14    0.5832
     46.10    0.3031
     52.08    0.2690
     62.06    0.2075
     68.04    0.2019
     78.02    0.1703
     84.01    0.1613
     93.99    0.1389
     99.98    0.1325
    110.00    0.0905
    115.90    0.0783
    125.90    0.0801
    131.90    0.0914
    141.90    0.1520
    146.80    0.1750
    151.80    0.2572
    156.80    0.2805
             13.0000
             13.0000
             13.0000
             13.0000
             13.0000
             13.0000
             20.0000
             20.0000
             13.0000
             13.0000
             13.0000
             13.0000
             13.0000
             13.0000
             13.0000
```

```
            13.0000
            13.0000
            13.0000
            20.0000
            20.0000
SEARCH  14    2.5200   4.27      1.0       -1.0000          1000010000         5
     30.00    0.7669
     40.00    0.4653
     50.00    0.2848
     60.00    0.2126
     70.00    0.1925
     80.01    0.1903
     90.01    0.1696
     99.99    0.1139
    110.00    0.0828
    120.00    0.0683
    130.00    0.0755
    140.00    0.1131
    150.00    0.1977
    154.00    0.2320
            2.0140
            1.7280
            1.6590
            1.8640
            1.7640
            1.7770
            1.8690
            2.5550
            4.1610
            5.9120
            5.3790
            2.9910
            1.5290
            1.4710
COMPUTE  0    2.5200   92.0000                      6.0000             601.0
```

****

ABAREX

INPUT DECK :

```
      LEVELS  15   42.0000    0.0000    0.0000    0.7250    1.0100    3.7000    0.0000
         0.0000 0.0 1    1 1.00
         1.5090 2.0 1    2 1.00
         2.2830 4.0 1    3 1.00
         2.5200 0.0 1    4 1.00
         2.5270 5.0-1    5 1.00
         2.6120 6.0 1    6 1.00
         2.7610 8.0 1    7 1.00
         2.8500 3.0-1    8 1.00
         3.0070 5.0-1    9 1.00
         3.0640 3.0-1   10 1.00
         3.0910 2.0 1   11 1.00
         3.3690 4.0 1   12 1.00
         3.5420 2.0 1   13 1.00
         3.5800 3.0-1   14 1.00
         3.6210 2.0 1   15 1.00
      REAL     1   49.2383    0.0000    0.0000    1.2085    0.6281    0.0000    0.0000
```

```
IMAG     4    9.3631   0.0000   0.0000   1.2502   0.5025   0.0000   0.0000
SO       1    5.9409   0.0000   1.1030   0.5600   0.0000   0.0000   0.0000
SEARCH  20    2.4000   4.3700   1.0000  -1.0000   0.000010000100000000000005
   20.2900   0.9536   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   26.2100   0.8699   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   30.1300   0.6797   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   36.1400   0.5832   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   46.1000   0.3031   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   52.0800   0.2690   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   62.0600   0.2075   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   68.0400   0.2019   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   78.0200   0.1703   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   84.0100   0.1613   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   93.9900   0.1389   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   99.9800   0.1325   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  110.0000   0.0905   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  115.9000   0.0783   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  125.9000   0.0801   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  131.9000   0.0914   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  141.9000   0.1520   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  146.8000   0.1750   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  151.8000   0.2572   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  156.8000   0.2805   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  20.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  20.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  13.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  20.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000  20.0000   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
SEARCH  14    2.5200   4.2700   1.0000  -1.0000   0.000010000100000000000005
   30.0000   0.7669   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   40.0000   0.4653   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   50.0000   0.2848   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   60.0000   0.2126   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   70.0000   0.1925   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   80.0100   0.1903   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   90.0100   0.1696   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
   99.9900   0.1139   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  110.0000   0.0828   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  120.0000   0.0683   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  130.0000   0.0755   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  140.0000   0.1131   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  150.0000   0.1977   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
  154.0000   0.2320   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000   2.0140   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
    0.0000   1.7280   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
```

0.0000	1.6590	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	1.3640	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	1.7640	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	1.7770	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	1.8690	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	2.5550	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	4.1610	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	5.9120	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	5.3790	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	2.9910	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	1.5290	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	1.4710	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
COMPUTE 0	2.5200	92.0000	0.0000	0.0000	6.0000	0.0000	601.0000

MASS NUMBERS(TARGET/PROJECTILE) = 92.000000/ 1.008665
==========

OPTICAL MODEL PARAMETERS : ASYMPTOPIA= 15.0000 FM 601 POINTS
==========

TYPE		DEPTH	(E)	(E*E)	RADIUS	DIFF.	VIVOL	C2	VOLINT
REAL	1	49.2383	0.0000	0.0000	1.2085	0.6281			411.6484
IMAG	4	9.3631	0.0000	0.0000	1.2502	0.5025	0.0000	0.0000	84.0150
S.O.	1	5.9409	0.0000		1.1030	0.5600			
DISP		0.0000	0.0000	0.0000					

SEARCH FOR 2 PARAMETERS

NORMALIZED LEAST SQUARE

AT LAB/CM ENERGY = 2.400000/ 2.373972 MEV

TOTAL CROSS SECTION DATA 4.370000 WEIGHT= 1.0000

SCATTERING DATA

ANGLE	CROSS SECTION DATA FOR SUCCESSIVE LEVEL GROUPS
20.29	0.95360
26.21	0.86990
30.18	0.67970
36.14	0.58320
46.10	0.30310
52.08	0.26900
62.06	0.20750
68.04	0.20190
78.02	0.17030
84.01	0.16130
93.99	0.13890
99.98	0.13250
110.00	0.09050
115.90	0.07830
125.90	0.08010
131.90	0.09140
141.90	0.15200
146.80	0.17500
151.80	0.25720
156.80	0.28050

AT LAB/CM ENERGY = 2.520000/ 2.492671 MEV

TOTAL CROSS SECTION DATA 4.270000 WEIGHT= 1.0000

SCATTERING DATA

ANGLE	CROSS SECTION DATA FOR SUCCESSIVE LEVEL GROUPS
30.00	0.76690
40.00	0.46530
50.00	0.28480
60.00	0.21260
70.00	0.19250
80.01	0.19030
90.01	0.16960
99.99	0.11390
110.00	0.08280
120.00	0.06830
130.00	0.07550
140.00	0.11310
150.00	0.19770
154.00	0.23200

GENERATED OPTICAL MODEL PARAMETERS IN SEARCH : STATISTIC

0.4924E+02 0.9363E+01	1758.135947
0.4924E+02 0.9363E+01	1758.135689
0.4924E+02 0.9363E+01	1758.135946
0.5552E+02 0.1402E+01	10326.020292
0.5022E+02 0.9077E+01	1323.076450
0.5022E+02 0.9077E+01	1323.076262
0.5022E+02 0.9077E+01	1323.076458
0.5163E+02 0.6811E+01	626.016989
0.5163E+02 0.6811E+01	626.016922
0.5163E+02 0.6811E+01	626.017003
0.5230E+02 0.2808E+01	916.616447
0.5197E+02 0.4432E+01	244.162773
0.5197E+02 0.4432E+01	244.162774
0.5197E+02 0.4432E+01	244.162774
0.5196E+02 0.4307E+01	242.619317

SEARCH TERMINATED AFTER 15 CALLS

UPON CONVERGENCE (INFO=2)

FINAL OPTICAL MODEL PARAMETERS :

TYPE		DEPTH	(E)	(E*E)	RADIUS	DIFF.	VIVOL	C2	VOLINT
REAL	1	51.9581	0.0000	0.0000	1.2085	0.6281			434.3869
IMAG	4	4.3072	0.0000	0.0000	1.2502	0.5025	0.0000	0.0000	38.6481
S.O.	1	5.9409	0.0000		1.1030	0.5600			

NO. 1 ENERGY(LABORATORY/C.M.) = 2.400000/ 2.373972 MEV LAMBDA-BAR = 0.29708 SQRT-BARN

NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00
2	2	1.5090	2.0	1	1.00
3	3	2.2830	4.0	1	1.00

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 7, (0.5, 7.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL	4.39986
ABSORPTION	2.07428
SHAPE ELASTIC	2.32558
TOTAL ELASTIC	3.35921
COMPOUND EXCITATIONS	1.03362 0.93550 0.10513
TOTAL COMPOUND	2.07426

LABORATORY CROSS SECTION IN BARNS PER STERADIAN

ANGLE	S.E.	C.E.	LEVEL GROUP CROSS SECTIONS		
20.29	1.03329	0.16044	1.19373	0.08085	0.00807
26.21	0.83137	0.13713	0.96850	0.08054	0.00821
30.18	0.69755	0.12230	0.81985	0.08022	0.00832
36.14	0.51491	0.10300	0.61791	0.07955	0.00850
46.10	0.29004	0.08102	0.37106	0.07796	0.00879
52.08	0.20829	0.07340	0.28169	0.07682	0.00894
62.06	0.14104	0.06614	0.20717	0.07486	0.00913
68.04	0.12538	0.06324	0.18862	0.07379	0.00919
78.02	0.11112	0.05937	0.17049	0.07237	0.00919
84.01	0.10107	0.05785	0.15892	0.07179	0.00913
93.99	0.07716	0.05752	0.13468	0.07134	0.00893
99.98	0.06000	0.05865	0.11866	0.07137	0.00875
110.00	0.03198	0.06193	0.09391	0.07189	0.00839
115.90	0.01877	0.06438	0.08315	0.07241	0.00815
125.90	0.00849	0.07056	0.07904	0.07348	0.00771
131.90	0.01332	0.07708	0.09040	0.07413	0.00745
141.90	0.04542	0.09628	0.14170	0.07500	0.00705
146.80	0.07228	0.11010	0.18238	0.07528	0.00687
151.80	0.10565	0.12676	0.23241	0.07546	0.00670
156.80	0.14247	0.14492	0.28739	0.07553	0.00656

NO. 2 ENERGY(LABORATORY/C.M.) = 2.520000/ 2.492671 MEV LAMBDA-BAR = 0.28992 SQRT-BARN

NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00
2	2	1.5090	2.0	1	1.00
3	3	2.2830	4.0	1	1.00

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 7, (0.5, 7.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	4.29871		
ABSORPTION =	2.05013		
SHAPE ELASTIC =	2.24859		
TOTAL ELASTIC =	3.20096		
COMPOUND EXCITATIONS =	0.95237	0.88334	0.21440
TOTAL COMPOUND =	2.05011		

LABORATORY CROSS SECTION IN BARNS PER STERADIAN

ANGLE	S.E.	C.E.	LEVEL GROUP CROSS SECTIONS		
30.00	0.67445	0.11362	0.78807	0.07512	0.01666
40.00	0.38217	0.08626	0.46843	0.07432	0.01719
50.00	0.20787	0.06992	0.27778	0.07292	0.01770
60.00	0.13721	0.06176	0.19896	0.07122	0.01812
70.00	0.11906	0.05730	0.17636	0.06963	0.01837
80.01	0.10851	0.05438	0.16289	0.06844	0.01842
90.01	0.08745	0.05323	0.14068	0.06779	0.01824
99.99	0.05874	0.05422	0.11297	0.06773	0.01785
110.00	0.03115	0.05685	0.08800	0.06818	0.01729
120.00	0.01263	0.06102	0.07365	0.06900	0.01660
130.00	0.01167	0.06906	0.08073	0.06990	0.01586
140.00	0.03784	0.08512	0.12296	0.07054	0.01514
150.00	0.09447	0.11132	0.20579	0.07074	0.01450
154.00	0.12353	0.12393	0.24746	0.07069	0.01428

EXAMPLE 6.2D

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
********************************************************************************
LEVELS   6   42.                          0.7250    1.01      3.700
 .0        0.0+1    1
1.509      2.0+1    2
2.283      4.0+1    3
2.520      9.0+1    4
2.527      5.0-1    5
2.612      6.0+1    6
REAL       1  46.97440   0.00000   0.00000   1.20850   0.6281
IMAG       4   7.87660   0.00000   0.00000   1.23860   0.5280
SC         1   5.94090   0.00000   1.10300   0.5600
SEARCH    -1    0.0000   1.106     5.0       6.79      60.0      3.541     15.0
1000010000000000 .00001
SEARCH     0    0.4060   6.8       20.       -1.0000             1000010000          5
SEARCH     0    0.4160   6.7       20.       -1.0000             1000010000          5
SEARCH     0    0.4260   6.6       20.       -1.0000             1000010000          5
SEARCH     8    0.4060   6.85      20.       -1.0000             1000010000          5
     28.20      1.1950
     38.00      1.0750
     53.50      0.8635
     68.80      0.6629
     84.00      0.5220
    113.80      0.4180
    129.50      0.4217
    154.00      0.4177
               10.0000
               10.0000
               10.0000
               10.0000
               10.0000
               10.0000
               10.0000
               10.0000
SEARCH     8    0.4160                         -1.0000             1000010000          5
     28.20      1.1950
     38.00      1.0750
     53.50      0.8635
     68.80      0.6629
     84.00      0.5220
    113.80      0.4180
    129.50      0.4217
    154.00      0.4177
               10.0000
               10.0000
               10.0000
               10.0000
               10.0000
               10.0000
               10.0000
               10.0000
COMPUTE 0      0.4060   92.0000                          6.0000                601.0

********************************************************************************
```

ABAREX
======

INPUT DECK :

```
 LEVELS   6   42.0000    0.0000    0.0000    0.7250    1.0100    3.7000    0.0000
    0.0000 0.0 1    1 1.00
    1.5090 2.0 1    2 1.00
    2.2830 4.0 1    3 1.00
    2.5200 0.0 1    4 1.00
    2.5270 5.0-1    5 1.00
    2.6120 6.0 1    6 1.00
 REAL     1   46.9744    0.0000    0.0000    1.2085    0.6281    0.0000    0.0000
 IMAG     4    7.8766    0.0000    0.0000    1.2386    0.5280    0.0000    0.0000
 SO       1    5.9409    0.0000    1.1030    0.5600    0.0000    0.0000    0.0000
 SEARCH  -1    0.0000    1.1060    5.0000    6.7900   60.0000    3.5410   15.0000
 SEARCH   0    0.4060    6.8000   20.0000   -1.0000    0.000010000100000000000005
 SEARCH   0    0.4160    6.7000   20.0000   -1.0000    0.000010000100000000000005
 SEARCH   0    0.4260    6.6000   20.0000   -1.0000    0.000010000100000000000005
 SEARCH   8    0.4060    6.8500   20.0000   -1.0000    0.000010000100000000000005
   28.2000    1.1950    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   38.0000    1.0750    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   53.5000    0.8635    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   68.8000    0.6629    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   84.0000    0.5220    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  113.8000    0.4180    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  129.5000    0.4217    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  154.0000    0.4177    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
 SEARCH   8    0.4160    0.0000    0.0000   -1.0000    0.000010000100000000000005
   28.2000    1.1950    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   38.0000    1.0750    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   53.5000    0.8635    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   68.8000    0.6629    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
   84.0000    0.5220    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  113.8000    0.4180    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  129.5000    0.4217    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
  154.0000    0.4177    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
    0.0000   10.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
 COMPUTE  0    0.4060   92.0000    0.0000    0.0000    6.0000    0.0000  601.0000
```

MASS NUMBERS(TARGET/PROJECTILE) = 92.000000/ 1.008665
==========

OPTICAL MODEL PARAMETERS : ASYMPTOPIA= 15.0000 FM 601 POINTS
==========

TYPE		DEPTH	(E)	(E*E)	RADIUS	DIFF.	VIVOL	C2	VOLINT
REAL	1	46.9744	0.0000	0.0000	1.2085	0.6281			392.7214
IMAG	4	7.8766	0.0000	0.0000	1.2386	0.5280	0.0000	0.0000	73.1228
S.O.	1	5.9409	0.0000		1.1030	0.5600			
DISP		0.0000	0.0000	0.0000					

SEARCH FOR 2 PARAMETERS

NORMALIZED LEAST SQUARE

AT LAB ENERGY = 0.00000100

S-WAVE STRENGTH FN. = 1.1060D-4 WEIGHT = 5.0000

R - PRIME = 6.7900 FM WEIGHT = 60.0000

P-WAVE STRENGTH FN. = 3.5410D-4 WEIGHT = 15.0000

AT LAB/CM ENERGY = 0.406000/ 0.401597 MEV

TOTAL CROSS SECTION DATA 6.800000 WEIGHT= 20.0000

AT LAB/CM ENERGY = 0.416000/ 0.411489 MEV

TOTAL CROSS SECTION DATA 6.700000 WEIGHT= 20.0000

AT LAB/CM ENERGY = 0.426000/ 0.421380 MEV

TOTAL CROSS SECTION DATA 6.600000 WEIGHT= 20.0000

AT LAB/CM ENERGY = 0.406000/ 0.401597 MEV

TOTAL CROSS SECTION DATA 6.850000 WEIGHT= 20.0000

SCATTERING DATA

ANGLE CROSS SECTION DATA FOR SUCCESSIVE LEVEL GROUPS

28.20	1.19500
38.00	1.07500
53.50	0.86350
68.80	0.66290
84.00	0.52200
113.80	0.41800
129.50	0.42170
154.00	0.41770

AT LAB/CM ENERGY = 0.416000/ 0.411489 MEV

SCATTERING DATA

ANGLE CROSS SECTION DATA FOR SUCCESSIVE LEVEL GROUPS

28.20	1.19500
38.00	1.07500
53.50	0.86350
68.80	0.66290
84.00	0.52200
113.80	0.41800
129.50	0.42170
154.00	0.41770

GENERATED OPTICAL MODEL PARAMETERS IN SEARCH : STATISTIC

0.4697E+02 0.7877E+01 61614.566330

0.4697E+02 0.7877E+01 61614.536232

0.4697E+02 0.7877E+01 61614.565531

0.4910E+02 0.6891E+01 10242.469166

0.4910E+02 0.6891E+01 10242.489242

0.4910E+02 0.6891E+01

0.4867E+02	0.7342E+01	10242.469129
0.4867E+02	0.7342E+01	1802.478619
0.4867E+02	0.7342E+01	1802.479995
0.4862E+02	0.7772E+01	1802.478619
0.4862E+02	0.7772E+01	1747.796329
0.4862E+02	0.7772E+01	1747.796154
0.4862E+02	0.7640E+01	1747.796330
0.4862E+02	0.7640E+01	1747.039386
0.4862E+02	0.7640E+01	1747.039364
0.4863E+02	0.7913E+01	1747.039386
0.4863E+02	0.7737E+01	1747.374414
0.4863E+02	0.7737E+01	1746.828911
0.4863E+02	0.7737E+01	1746.828895
0.4863E+02	0.7843E+01	1746.828911
0.4863E+02	0.7801E+01	1746.866820
0.4863E+02	0.7801E+01	1746.813356
0.4863E+02	0.7801E+01	1746.813351
0.4863E+02	0.7736E+01	1746.813356
0.4863E+02	0.7769E+01	1746.822025
0.4863E+02	0.7769E+01	1746.804372
0.4863E+02	0.7769E+01	1746.804373
0.4863E+02	0.7785E+01	1746.804372
0.4863E+02	0.7777E+01	1746.805286
		1746.804043

SEARCH TERMINATED AFTER 29 CALLS

UPON CONVERGENCE (INFO=3)

FINAL OPTICAL MODEL PARAMETERS :

TYPE		DEPTH	(E)	(E*E)	RADIUS	DIFF.	VIVOL	C2	VOLINT
REAL	1	48.6268	0.0000	0.0000	1.2085	0.6281			406.5359
IMAG	4	7.7767	0.0000	0.0000	1.2386	0.5280	0.0000	0.0000	72.1951
S.O.	1	5.9409	0.0000		1.1030	0.5600			

AT 0.1000E-05 MEV	L	J	GAMMASQ/D	R-INFINITY	STR.FN.	R-PRIME

0	1/2				
		0.0443	-0.2626	0.1057E-03	0.6888E+01
1	1/2				
		0.1123	0.1078	0.8922E-04	0.4562E-07
1	3/2				
		0.1475	0.1454	0.2344E-03	0.1646E-07

NO. 1 ENERGY(LABORATORY/C.M.) = 0.406000/ 0.401597 MEV LAMBDA-BAR = 0.72229 SQRT-BARN

NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 4, (0.5, 4.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	6.75992
ABSORPTION =	2.84437
SHAPE ELASTIC =	3.91554
TOTAL ELASTIC =	6.75863
COMPOUND EXCITATIONS =	2.84308
TOTAL COMPOUND =	2.84308

NO. 2 ENERGY(LABORATORY/C.M.) = 0.416000/ 0.411489 MEV LAMBDA-BAR = 0.71356 SQRT-BARN

NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 4, (0.5, 4.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	6.72698
ABSORPTION =	2.83763
SHAPE ELASTIC =	3.88935
TOTAL ELASTIC =	6.72570
COMPOUND EXCITATIONS =	2.83635
TOTAL COMPOUND =	2.83635

NO. 3 ENERGY(LABORATORY/C.M.) = 0.426000/ 0.421380 MEV LAMBDA-BAR = 0.70513 SQRT-BARN

```
============
NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
                                                    ARE COMPUTED INTERNALLY.

              TARGET LEVELS
              =============

 LEVEL  GROUP   ENERGY   SPIN   PARITY   WEIGHT

    1     1    0.0000    0.0     1        1.00
 MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) =  4, (  0.5,  4.5)

   INTEGRATED CROSS SECTIONS IN BARNS
   ==================================

             TOTAL =  6.69422
        ABSORPTION =  2.83067
      SHAPE ELASTIC =  3.86356
      TOTAL ELASTIC =  6.69296
COMPOUND EXCITATIONS =  2.82941
     TOTAL COMPOUND =  2.82941



NO. 4 ENERGY(LABORATORY/C.M.) =  0.406000/ 0.401597 MEV         LAMBDA-BAR =  0.72229 SQRT-BARN
============
NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
                                                    ARE COMPUTED INTERNALLY.

              TARGET LEVELS
              =============

LEVEL  GROUP   ENERGY   SPIN   PARITY   WEIGHT

    1     1    0.0000    0.0     1        1.00
 MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) =  4, (  0.5,  4.5)

   INTEGRATED CROSS SECTIONS IN BARNS
   ==================================

             TOTAL =  6.75992
        ABSORPTION =  2.84437
      SHAPE ELASTIC =  3.91554
      TOTAL ELASTIC =  6.75863
COMPOUND EXCITATIONS =  2.84308
     TOTAL COMPOUND =  2.84308

LABORATORY CROSS SECTION IN BARNS PER STERADIAN
===============================================

    ANGLE     S.E.      C.E.   LEVEL GROUP CROSS SECTIONS

   28.20   0.63607   0.32268   0.95875
   38.00   0.58225   0.28646   0.86871
   53.50   0.48331   0.22899   0.71230
   68.80   0.38382   0.18482   0.56864
   84.00   0.29571   0.16239   0.45810
  113.80   0.17488   0.19041   0.36528
  129.50   0.13871   0.23622   0.37492
  154.00   0.10992   0.31913   0.42905
```

NO. 5 ENERGY(LABORATORY/C.M.) = 0.416000/ 0.411489 MEV LAMBDA-BAR = 0.71356 SQRT-BARN

NEUTRON CHANNEL WIDTH FLUCTUATION DEGREES OF FREEDOM
ARE COMPUTED INTERNALLY.

TARGET LEVELS

LEVEL	GROUP	ENERGY	SPIN	PARITY	WEIGHT
1	1	0.0000	0.0	1	1.00

MAXIMUM NEUTRON L VALUE,(RANGE OF TOTAL J VALUES) = 4, (0.5, 4.5)

INTEGRATED CROSS SECTIONS IN BARNS

TOTAL =	6.72698
ABSORPTION =	2.83763
SHAPE ELASTIC =	3.88935
TOTAL ELASTIC =	6.72570
COMPOUND EXCITATIONS =	2.83635
TOTAL COMPOUND =	2.83635

LABORATORY CROSS SECTION IN BARNS PER STERADIAN

ANGLE	S.E.	C.E.	LEVEL GROUP CROSS SECTIONS
28.20	0.63976	0.32227	0.96203
38.00	0.58462	0.28591	0.87053
53.50	0.48347	0.22836	0.71183
68.80	0.38209	0.18422	0.56631
84.00	0.29265	0.16183	0.45448
113.80	0.17069	0.18981	0.36050
129.50	0.13446	0.23561	0.37007
154.00	0.10583	0.31879	0.42462

APPENDIX B

This appendix contains an introduction to the FORTRAN source listing of the code ABAREX. This listing outlines the input requirements.

```
C ******************** ABAREX MAIN ************************************AB
C                                                                      AB
C ********************INPUT KEYWORDS AND FORMATS*************************AB
C                                                                      AB
C ALL INPUT FORMATS ARE (A2,5X,I3,7F10.4) UNLESS OTHERWISE SPECIFIED.  AB
C ALL ENERGIES ARE IN MEV(LAB).                                        AB
C ALL LENGTHS ARE IN FERMIS.                                           AB
C ALL XSECS. ARE IN BARNS OR BARNS/SR IN THE LAB. SYSTEM.              AB
C ALL ANGLES ARE IN DEGREES(LAB).                                      AB
C ANY NUMBER OF CASES CAN BE STACKED AT THE INPUT.                     AB
C KEYWORDS CAN BE IN ANY ORDER EXCEPT WHERE OTHERWISE STATED.          AB
C EACH CASE MUST END WITH A 'COMPUTE' LINE.                            AB
C                                                                      AB
C ********* START CALCULATIONS, ALWAYS LAST CARD OF GIVEN PROBLEM.     AB
C  1- 7 'COMPUTE'                                                      AB
C  8-10 LMAX, MAXIMUM ORBITAL ANGULAR MOMENTUM.                        AB
C       DEFAULT = 0, USE ORDINARILY, LMAX DETERMINED INTERNALLY FOR    AB
C       EACH LEVEL SEPARATELY. MAX VALUE = 20.                         AB
C 11-20 E, LAB ENERGY OF INCIDENT NEUTRONS IN MEV.  DEFAULT VALUE = 0.8.AB
C 21-30 ANO, TARGET MASS NUMBER, DEFAULT = 55.9349.                    AB
C 31-40 ANU, PROJECTILE MASS NUMBER, DEFAULT = 1.008665.               AB
C 41-50 FNU, WIDTH FLUCTUATION DEGREES OF FREEDOM, DEFAULT = 1 + T**0.6.AB
C       IF FNU IS NEGATIVE NO FLUCTUATION CORRECTION, I.E. H-F CAL.    AB
C       THERE IS NO FLUCTUATION CORRECTION WHEN CONTINUUM EXCITATIONS  AB
C       ARE INVOLVED IN THE CALCULATION.                               AB
C 51-60 DANG, ANGLE INTERVAL OF DIFFERENTIAL XSEC.  DEFAULT =          AB
C       15 DEG. (LAB)                                                  AB
C 61-70 C1, ASYMPTOTIC MATCHING RADIUS, DEFAULT VALUE = 15 FM.         AB
C 71-80 PTS, NO. OF RADIAL INTEGRATION POINTS, DEFAULT = 301.0.        AB
C       SHOULD BE AN ODD NUMBER.                                       AB
C                                                                      AB
C ********* PARAMETERS FOR DISPERSION CONTRIBUTION                     AB
C  1- 7 'DISP   '                                                      AB
C  8-10 BLANK.                                                         AB
C 11-20 SURF0.                                                         AB
C 21-30 SURF1.                                                         AB
C 31-40 SURF2.                                                         AB
C       WHERE A REAL SURFACE POTENTIAL --                              AB
C            V=(SURF0+SURF1*E+SURF2*E**2)*W                            AB
C       IS ADDED TO THE REAL POTENTIAL, 'W' IS THE IMAGINARY           AB
C       POTENTIAL AND 'E' THE INCIDENT ENERGY.  DEFAULT VALUES OF      AB
C       SURF0, SURF1 AND SURF2 ARE ZERO. ENERGY E IN CM SYSTEM.        AB
C                                                                      AB
C ********* INPUT CHANGE IN PARAMETERS                                 AB
C  1- 7 'INPUT  '                                                      AB
C       CHANGE INPUT PARAMETERS FROM PREVIOUS CASE USING NAMELIST/INPUT/AB
C       LINES WHICH MUST FOLLOW.  NOT PERMITTED FOR FIRST CASE.        AB
C       FOR EXAMPLE --                                                 AB
C           COMPUTE (FROM PREVIOUS CASE)                               AB
C           INPUT                                                      AB
C            &INPUT Z(1)=5.0,VRE=46.0,&END                             AB
C       IN THIS EXAMPLE THE ENERGY OF THE PREVIOUS CASE WILL BE CHANGED AB
C       TO 5.0 MEV, THE REAL POTENTIAL TO 46.0 MEV, AND THE PROBLEM    AB
C       WILL BE RUN AGAIN.  THIS IS AN IBM PROCEDURE WHICH MAY NOT     AB
C       EXIST IN ALL FORTRAN.  IT IS NOT A RECOMMENDED PROCEDURE FOR   AB
C       ABAREX UNLESS YOU ARE CAREFUL.                                 AB
C                                                                      AB
C ********* PRINT TRANS. COEF., S-MATRIX, ETC.                         AB
C  1- 7 'TRANSM '                                                      AB
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C  8-10 KETA, PRINTS TRANSMISSION COEFFICIENTS, S-MATRIX, STRN. FUNCT., AB   60
C       R-PRIME FOR FIRST KETA LEVELS. DEFAULT MEANS KETA = NLEVEL.      AB   61
C                                                                        AB   62
C ********** ENTER REAL OPTICAL POTENTIAL, SAXON-WOODS FORM              AB   63
C  1- 7 'REAL   '                                                        AB   64
C  8-10 KRE, DUMMY CAN BE ANY VALUE OR OMITTED. TYPICALLY KRE = 1.       AB   65
C       CODE USES WOODS-SAXON REAL POTENTIAL FORM IN ALL CASES.          AB   66
C 11-20 VRE, REAL POTENTIAL STRENGTH IN MEV, ASSUMED TO BE POSITIVE.     AB   67
C 21-30 VRE1, LINEAR PARAMETER OF STRENGTH.                              AB   68
C 31-40 VRE2, QUADRATIC PARAMETER OF STRENGTH.                           AB   69
C            WHERE V = VRE + VRE1*E +VRE2*E**2. E IN CM.                 AB   70
C 41-50 R1, REAL POTENTIAL REDUCED RADIUS IN FERMIS.                     AB   71
C 51-60 A1, REAL POTENTIAL DIFFUSENESS IN FERMIS.                        AB   72
C 61-70 VSR, SPIN-ORBIT STRENGTH IN MEV, ASSUMES REAL SO POTENTIAL,      AB   73
C       SAME GEOMETRY AS REAL POTENTIAL AND THE THOMAS FORM. IF          AB   74
C       IDENTICALLY = 0 SO LINE (BELOW) MUST BE INCLUDED IN THE INPUT.   AB   75
C                                                                        AB   76
C ********** ENTER IMAGINARY OPTICAL POTENTIAL                          AB   77
C  1- 7 'IMAG   '                                                        AB   78
C  8-10 KIM, SETS IMAGINARY WELL FORM AS FOLLOWS--                       AB   79
C            1 = VOLUME WELL (WOODS-SAXON).                              AB   80
C            2 = GAUSSIAN-SURFACE WELL (V*EXP(-((R-r)/A)**2).            AB   81
C            3 = GAUSSIAN-SURFACE + VOLUME WELL (SUM OF ABOVE).          AB   82
C            4 = WOODS-SAXON DERIVATIVE WELL.                            AB   83
C            5 = WOODS-SAXON DERIVATIVE + VOLUME WELL.                   AB   84
C                IF VIVOL (BELOW) IS USED, KIM = 2 AND 3 ARE             AB   85
C                EQUIVALENT,  THAT IS ALSO TRUE FOR KIM = 4 AND 5.       AB   86
C 11-20 VIM, IMAGINARY POTENTIAL STRENGTH IN MEV.                        AB   87
C 21-30 VIM1, LINEAR PARAMETER OF STRENGTH.                              AB   88
C 31-40 VIM2, QUADRATIC PARAMETER OF STRENGTH.                           AB   89
C            WHERE VI = VIM + VIM1*E + VIM2*E**2, E IN CM SYSTEM.        AB   90
C 41-50 R2, IMAGINARY POTENTIAL REDUCED RADIUS IN FERMIS.                AB   91
C 51-60 A2, IMAGINARY POTENTIAL DIFFUSENESS IN FERMIS.                   AB   92
C 61-70 VIVOL, VOLUME IMAGINARY POTENTIAL STRENGTH IN MEV.               AB   93
C 71-80 VOLRAT, RATIO OF VOLUME TO SURFACE POTENTIAL.                    AB   94
C                                                                        AB   95
C ********** ENTER SPIN-ORBIT POTENTIAL (VSR (ABOVE) MUST BE 0)         AB   96
C  1- 7 'SO     '                                                        AB   97
C  8-10 KSO, = 1 FOR THOMAS FORM. THIS FORM IS RECOMMENDED.              AB   98
C           = 2 WOODS-SAXON VOLUME FORM.                                 AB   99
C           = 3 WOODS-SAXON-DERIVATIVE FORM.                             AB  100
C 11-20 VSR, REAL SPIN-ORBIT STRENGTH IN MEV.                            AB  101
C 21-30 VSI, IMAGINARY SPIN-ORBIT STRENGTH IN MEV.                       AB  102
C 31-40 RR1, SO REDUCED RADIUS IN FERMIS.                                AB  103
C 41-50 AA1, SO DIFFUSENESS IN FERMIS.                                   AB  104
C                                                                        AB  105
C ********** INPUT TARGET LEVEL DATA                                     AB  106
C  1- 7 'LEVELS '                                                        AB  107
C  8-10 NLE, NUMBER OF DESCRETE TARGET LEVELS, MAXIMUM = 50              AB  108
C 11-20 ZTARGET, TARGET CHARGE NUMBER. DEFAULT = 0 (BLANK) IN WHICH      AB  109
C               CASE THERE IS NO TARGET LEVEL CONTINUUM.                 AB  110
C 21-30 ECONT, ENERGY FOR START OF CONTINUUM, DEFAULT ECONT=EX(NLE).     AB  111
C 31-40 ESTEP, ENERGY INTERVAL OF CONTINUUM CALCULATIONS,                AB  112
C            DEFAULT = 0.2 MEV.                                          AB  113
C 41-50 TAU, TEMPERATURE IN CONTINUUM LEVEL-DENSITY FORMULA,             AB  114
C           RHO(E) =EXP((E-EOT)/TAU).                                    AB  115
C 51-60 EOT, ENERGY SHIFT IN RHO FORMULA.                                AB  116
C 61-70 SGT, LEVEL DENSITY SPIN CUTOFF PARAMETER.                        AB  117
C           IF TAU = 0.0 TAU, EOT AND SGT AARE COMPUTED INTERNALLY. THEAB  118
C           RESULTS MAY NOT BE REALISTIC. INSPECT THEM!                  AB  119
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C       UNLESS NLE = 0, NLE CARDS MUST FOLLOW IN THE FORMAT           AB   120
C       (F9.4,F4.1,I2,I5,F5.4) DESCRIBING THE TARGET STATE FOLLOWED BY AB   121
C       EXCITED STATES IN ORDER OF INCREASING ENERGY.  THE SPECIFICATIONAB   122
C       THESE LEVEL CARDS FOLLOWS  --                                 AB   123
C                                                                     AB   124
C *********** LEVEL CARDS, FORMAT(F9.4,F4.1,I2,I5,F5.4)              AB   125
C  1- 9 EX(I), EXCITATION OF THE I-TH TARGET STATE.                   AB   126
C 10-13 FI(I), THE STATE SPIN.                                        AB   127
C 14-15 IPI(I), THE STATE PARITY, +1 OR -1, DEFAULT = +1.             AB   128
C 16-20 KGP(I), THE STATE GROUP NUMBER.  USED FOR SEARCH AND PRINTOUT. AB   129
C       XSECS. FOR CONSECUTIVE LEVELS WITH IDENTICAL GROUP NUMBERS ARE AB   130
C       ADDED TOGETHER IN PRINTOUT AND/OR SEARCH.                     AB   131
C       IF KGP(1) IS NEGATIVE ONLY THE SHAPE-ELASTIC CROSS SECTION    AB   132
C       IS CALCULATED AND FITTED.                                     AB   133
C 21-25 GW(I), WEIGHT OF I-TH LEVEL FOR FITTING, DEFAULT=1.           AB   134
C                                                                     AB   135
C *********** SCAN ENERGY RANGE IN CACULATIONS                        AB   136
C  1- 7 'SCAN   '                                                     AB   137
C  8-10 KK, = 0 FOR SIMPLE SCAN, THEN --                              AB   138
C 11-20 E1, DESIRED.                                                  AB   139
C 21-30 E2, DESIRED.                                                  AB   140
C ETC. TO                                                             AB   141
C 71-80 E7, DESIRED.                                                  AB   142
C       REPEAT LINE TO CALCULATE UP TO 50 ENERGIES.                   AB   143
C       KK = 1 FOR INCREMENTAL SCAN, THEN --                          AB   144
C 11-20 EI, THE INITIAL ENERGY IN MEV.                                AB   145
C 21-30 DE, THE ENERGY INCREMENT BETWEEN EI AND EF, MAX. OF 50 STEPS. AB   146
C 31-40 EF, THE FINAL ENERGY.                                         AB   147
C                                                                     AB   148
C *********** SEARCH FOR PARAMETERS BY FITTING DATA                   AB   149
C           CHI-SQUARE FIT TO TOTAL AND SCATTERING CROSS SECTIONS.    AB   150
C           FORMAT OF LINE IS (A7,I3,5F10.4,20I).                     AB   151
C  1- 7 'SEARCH '                                                     AB   152
C  8-10 NOA, NUMBER OF SCATTERING ANGLES WITH DIFFERENTIAL DATA.      AB   153
C 11-20 E, LAB. NEUTRON ENERGY OF THE DATA.                           AB   154
C 21-30 SGTOT, EXP. TOTAL CROSS SECTION, DEFAULT NO TOTAL CROSS SECTION AB   155
C              FIT.                                                   AB   156
C 31-40 GWTOT, WEIGHT OF TOTAL CROSS SECTION, DEFAULT = 1.0.          AB   157
C 41-50 FPRINT, -1.0 PRINTS PARAMETERS AT EACH STEP, DEFAULT NO       AB   158
C              INTERMEDIATE PRINT OUTS.                               AB   159
C 51-60 TOL, CONVERGENCE TERMINATION OF FIT, DEFAULT = 0.005.         AB   160
C 61-80 KQ(I), 1 OR 0 DEPENDING WHETHER THE PARAMETER IS TO BE        AB   161
C              FITTED OR NOT. THE ORDER OF THE PARAMETERS IS--        AB   162
C              VRE,VRE1,VRE2,R1,A1,VIM,VIM1.VM2,R2,A2,VIVOL,VOLRAT,   AB   163
C              VSR,VSR1,RR1,AA1.  THERE ARE 16 IN TOTAL.  KQ(20) MUST AB   164
C              BE 5 IF DIFFERENTIAL DATA HAS % ERROR ASSIGNED,        AB   165
C              AS BELOW.  IF WEIGHTING IS PROPORTIONAL TO XSEC.       AB   166
C              MAGNITUDE KQ(20) IS 0 OR BLANK.  BLANKS ARE NOT        AB   167
C              EQUIVALENT TO '0' IN THE KG(I) STRING AND SHOULD       AB   168
C              NOT BE USED.  EVERY SEARCH LINE MUST BE FOLLOWED BY NOA AB   169
C              DIFFERENTIAL DATA LINES AS FOLLOWS --                  AB   170
C                                                                     AB   171
C *********** DIFFERENTIAL DATA INPUT, FORMAT(8F10.4)                 AB   172
C  1-10 A(I), THE I-TH LABORATORY ANGLE.                              AB   173
C 11-20 XIN(I,1), EXPERIMENTAL LAB. XSEC. FOR SCATTERING TO THE J-TH  AB   174
C  ETC.           LEVEL AT THE I-TH ANGLE.  UP TO SEVEN LEVEL GROUPS  AB   175
C 71-80 XIN(I,7), CAN BE FITTED.  THERE WILL BE NOA SUCH LINES.  IF   AB   176
C                 KQ(20) OF THE SEARCH LINE = 5 THE CORRESPONDING     AB   177
C                 NOA % ERRORS MUST FOLLOW IN THE SAME FORMAT AS      AB   178
C                 FOLLOWS --                                          AB   179
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C  1-10 BLANK                                                        AB  180
C 10-20 ERR(I,1),                                                    AB  181
C  ETC.                                                             AB  182
C 71-80 ERR(I,7),                                                    AB  183
C                ONLY POSITIVE NON-ZERO CROSS SECTIONS ARE FITTED.   AB  184
C                                                                    AB  185
C $$$$$$$$$ SEARCH INCLUDING STRENGTH FUNCTIONS                      AB  186
C                STRENGTH-FUNCTION SEARCH LINE MUST BE FIRST SEARCH  AB  187
C                LINE AND BE FOLLOWED BY A PARAMETER LINE.  AFTER THESEAB  188
C                TWO LINES ANY COMBINATION OF SEARCH INPUTS MAY BE   AB  189
C                ADDED.  S0, R-PRIME AND S1 MUST ALL BE INTRODUCED.  AB  190
C                PERCENT ERRORS ARE USED FOR WEIGHTING.              AB  191
C                THE INPUT IS:-                                      AB  192
C  1- 7 'SEARCH '                                                    AB  193
C  8-10 NOA, MUST BE -1 FOR STRENGTH-FUNCTION INPUT.                 AB  194
C 11-20 E-LAB IN MEV, DEFAULT VALUE = 1 EV.                          AB  195
C 21-30 S0 IN UNITS OF 1E-4.                                         AB  196
C 31-40 S0 % ERROR.                                                  AB  197
C 41-50 R-PRIME IN UNITS OF FMS.                                     AB  198
C 51-60 R-PRIME % ERROR.                                             AB  199
C 61-70 S1 IN UNITS OF 1E-4.                                         AB  200
C 71-80 S1 % ERROR.                                                  AB  201
C       THIS LINE MUST BE FOLLOWED BY A LINE IN FORMAT(16I1,F12.6)   AB  202
C       GIVING:-                                                     AB  203
C  1-16 THE 16 '1' OR '0' VALUES INDICATING THE PARAMETERS           AB  204
C       TO BE SEARCHED AS PER THE GENERAL 'SEARCH' LINE, ABOVE.      AB  205
C 17-29 THE CONVERGENCE VALUE TOL, DEFAULT TOL=0.005                 AB  206
C                                                                    AB  207
C                THERE MUST BE AT LEAST AS MANY DATA VALUES IN A     AB  208
C                SEARCH AS THE NUMBER OF PARAMETERS SOUGHT.  A       AB  209
C                NUMBER OF SEARCH SETS CAN BE USED CONCURRENTLY, EACH AB  210
C                AT DIFFERENT ENERGIES.  WITH NOA EQUAL ZERO A SET OF AB  211
C                TOTAL CROSS SECTIONS CAN BE FITTED. TOTAL,          AB  212
C                DIFERENTIAL AND STRENGTH-FUNCTION SEARCHS CAN BE    AB  213
C                INTERMIXED, PROVIDING THE STRENGTH-FUNCTION SEARCH  AB  214
C                INPUT IS GIVEN FIRST.                               AB  215
C                                                                    AB  216
C $$$$$$$$$ CAPTURE INPUT, GAMMA-PRODUCTION AND RADIATIVE CAPTURE    AB  217
C  1- 7 'CAPTURE'                                                    AB  218
C  8-10 IABS(NZ), COMPOUND-NUCLEUS CHARGE NUMBER.  DEFAULT-READ      AB  219
C                IN TRANSMISSION COEFFICIENTS. ALL OTHER ENTRIES ON  AB  220
C                LINE ARE THEN IGNORED.                              AB  221
C 11-20 TGO, RATIO OF AVERAGE RADIATION WIDTH TO LEVEL SPACING FOR   AB  222
C           ALL S-WAVE NEUTRONS NEAR THE NEUTRON BINDING ENERGY.     AB  223
C           DEFAULT- GIANT DIPOLE GAMMA STRENGTH COMPUTED            AB  224
C           INTERNALLY.                                              AB  225
C 21-30 BN, NEUTRON BINDING ENERGY, DEFAULT = 8 MEV.                 AB  226
C 31-40 FNUG, GAMMA CHANNEL WIDTH FLUCTION DEGREES OF FREEDOM,       AB  227
C            DEFAULT = 20.                                           AB  228
C 41-50 GGD, E2 GIANT DIPOLE WIDTH, DEFAULT = 5.0.                   AB  229
C 51-60 EGD, E2 GIANT DIPOLE ENERGY, DEFAULT = 163.*SQRT(N*Z)/       AB  230
C           A**1.333.                                                AB  231
C 61-70 XFR, EXCHANGE FRACTION, DEFAULT = 0.5.                       AB  232
C 70-80 SG, LEVEL DENSITY SPIN COUTOFF PARAMETER, DEFAULT -          AB  233
C          INTERNALLY COMPUTED.                                      AB  234
C          IF NZ=0 THE CAPTURE LINE MUST BE FOLLOWED                 AB  235
C          BY ONE LINE IN FORMAT(16F5.3), AS FOLLOWS --              AB  236
C  1- 5 TGG(1) WHERE THE TGG(K) ARE THE SUM OF GAMMA TRANSMISSION    AB  237
C  6-10 TGG(2) COEFFICIENTS FOR THE K-TH TOTAL ANGULAR MOMENTUM      AB  238
C  ETC.        AND EITHER PARITY.                                    AB  239
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C 76-80 TGG(16)                                                        AB  240
C                                                                      AB  241
C $$$$$$$$$ N-GAMMA, INCLUDE ONLY EFFECTS OF GAMMA-RAY CHANNELS.       AB  242
C  1- 7 'N-GAMMA'                                                      AB  243
C        PARAMETERS ARE IDENTICAL TO THOSE OF 'CAPTURE' LINE.          AB  244
C        THE SAME RESULTS ARE OBTAINED WITH THE CAPTURE LINE.          AB  245
C                                                                      AB  246
C $$$$$$$$$ FISSION, CALCULATE FISSION CROSS SECTIONS.                 AB  247
C  1- 7 'FISSION'                                                      AB  248
C  8-10 NF, TOTAL ANGULAR MOMENTUM IN THE FISSION CHANNELS.            AB  249
C           MUST BE FOLLOWED BY LINES IN THE FORMAT(16F5.3) AS FOLLOWS- AB  250
C  1- 5 TF+(1), TF+(I) AND TF-(I) ARE THE TOTAL FISSION TRANSM-        AB  251
C  6-10 FN+(1), MISSION COEFFICIENTS FOR THE I-TH TOTAL ANGULAR MOM-   AB  252
C 11-15 TF-(2), ENTUM AND + AND- PARITIES, RESPECTIVELY.  THE          AB  253
C 16-20 FN-(2), FN+(I) AND FN-(I) ARE THE CORRESPONDING WIDTH          AB  254
C  ETC.         FLUCTUATION DEGREEES OF FREEDOM.  THE VALUES ARE READ  AB  255
C               IN FOR THE NF TOTAL ANGULAR MOMENTA.                   AB  256
C                                                                      AB  257
C $$$$$$$$$$$$$$$$$$$$$$$$$$$$END INPUT OUTLINE $$$$$$$$$$$$$$$$$$$$$$$$$$$$AB  258
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