

C00-3496-10

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COMPUTER PROGRAMS FOR STATISTICAL  
NUCLEAR DECAY

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J. R. HUIZENGA

APRIL 1972

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COMPUTER PROGRAMS FOR STATISTICAL NUCLEAR DECAY\*

by

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\*Work supported in part by the United States Atomic Energy Commission.

# Computer Programs for Statistical Nuclear Decay

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## I. INTRODUCTION

Computer programs which generate energy spectra and angular distributions of protons, neutrons, deuterons and alpha particles emitted in a compound nuclear reaction are described. The programs incorporate explicitly the angular momentum. In addition, calculations are described which include isospin as an additional quantum number (program MACT3). Program EVAP generates angle integrated differential cross section with no limits imposed on the summation over the spin of the residual nucleus. Program descriptions accompany each program and describe the type of calculation that the relevant program is performing. Included in each description are the limitations imposed on the various sums involved in the computations. Calculations can be done by including the Legendre polynomials of the even order ( $L$ ) up to 10 (MAC10). However, for most of the cases of interest to us, accurate results are obtained by expanding the Legendre polynomials up to  $L=6$  (MAC3, YRAST, MACT3).

Calculations can be performed with either the Fermi gas model or the constant temperature model for the level density. Program YRAST uses the yrast form for the level density.

Z coefficients required in the calculations are computed for both integral and half-integral channel spins by the computer code ZCOEF.

## II. PROGRAM DESCRIPTIONS

### A. DESCRIPTION OF PROGRAM MAC3

The program calculates differential cross sections for particles evaporated from a compound nucleus where many overlapping levels are populated and the subsequent decay of these levels with different angular momenta populate many levels in the available residual nuclei. The program can also integrate the generated spectra over any desired energy range and in energy bins of any size.

#### 1. Formulation

The differential cross section for particles emitted in a nuclear reaction  $A(a,b)B$  leaving the residual nucleus B with an excitation energy  $U_b$  high enough that it can be described adequately by a continuous level density function is given by

$$\frac{d^2\sigma(a,b)}{d\Omega_b d\epsilon_b} = \frac{1}{4k_a^2(2I_a+1)(2i_a+1)} \sum_{L I_a I_b S_a S_b} \frac{p_L(\cos\theta)(-1)^{S_a - S_b}}{G(J)} T_a^{I_a}(\epsilon_a) T_b^{I_b}(\epsilon_b) Z(I_a J I_a J; S_a L) Z(I_b J I_b J; S_b L) \rho_b(U_b, I_b) \quad (1)$$

where  $G(J)$  is given by

$$G(J) = \int_0^{\infty} \frac{U_b' \max}{b'} dU_b' \sum_{i=0}^{I_{\max}} T_{b'}^{I_{b'}} (\epsilon_{b'}) \frac{J+i_{b'}}{|J-i_{b'}|} \frac{S_{b'}+i_{b'}}{|S_{b'}-i_{b'}|}$$

$$\rho_b(U_b, I_b) \quad (2)$$

The quantities  $I_a, i_a, J, I_b$  and  $i_b$  are the spins of the target, projectile, compound nucleus, residual nucleus and emitted particle, respectively.  $S_a$  and  $S_b$  are the channel spins in the incident and outgoing channels, respectively;  $t_a$  and  $t_b$  are the orbital angular momenta of the incident and outgoing particles, respectively;  $k_a$  is the wave number of the incident particles;  $P_L(\cos\theta)$  is the Legendre polynomial of order  $L$ ;  $T_a^L(\epsilon_a)$  and  $T_b^L(\epsilon_b)$  are the optical model transmission coefficients for the projectile and the emitted particle, respectively, with the channel energies of  $\epsilon_a$  and  $\epsilon_b$ ;  $Z(t_a J t_a; S_a L)$  and  $Z(t_b J t_b; S_b L)$  are the so-called  $Z$  coefficients and are defined as products of Racah and Clebsch-Gordan coefficients (we make the random sign approximation which implies that the angular distribution is symmetric about  $90^\circ$ );  $\rho_b(U_b, I_b)$  is the energy and spin-dependent level density of the residual nucleus formed by the emission of particle  $b$  with channel energy  $\epsilon_b$ ; and the sum over  $b'$  refers to the sum over all the different types of emitted particles.

The summation in the numerator of eq. (1) can be performed independently with respect to the quantum numbers  $t_a, t_b, J$  and  $I_b$  since the  $Z$ -coefficients vanish for combinations of the quantum numbers which violate the conservation of angular momentum. The sums over channel spins  $S_a$  and  $S_b$  have to be performed from  $|I_a - i_a|$  to  $|I_a + i_a|$  and  $|I_b - i_b|$  to  $|I_b + i_b|$ , respectively. The first sum over  $L$  in eq. (1) gives the energy distribution averaged over solid angle, since the contribution of the higher Legendre

polynomials vanishes when they are integrated over solid angle, owing to their orthogonality.

The wave number  $k_a$  is defined by

$$k_a = \frac{2\pi}{\lambda_a} = \frac{1}{\lambda_a}$$

In terms of the channel energy  $\epsilon_a$  and the reduced mass  $M_o$ ,

$$k_a = \frac{1}{\hbar} \sqrt{\frac{2M_o \epsilon_a}{\hbar}} \quad (3)$$

The reduced mass  $M_o$  is given by

$$M_o = \frac{M_a M_A}{M_a + M_A} \quad (4)$$

and

$$\epsilon_a = E_a(\text{lab}) \frac{M_A}{M_A + M_a} \quad (5)$$

Substituting eqs. (4) and (5) into (3) and squaring we get,

$$\begin{aligned} k_a^2 &= \frac{2}{\hbar^2} E_a(\text{lab}) M_a \left( \frac{M_A}{M_A + M_a} \right)^2 \\ k_a^2 &= 0.0047846 E_a(\text{lab}) M_a \left( \frac{M_A}{M_A + M_a} \right)^2 \text{ mbs}^{-1} \end{aligned} \quad (6)$$

where  $E_a(\text{lab})$  is the projectile energy in MeV in the laboratory,  $M_a$  and  $M_A$  are the masses (in a.m.u) of projectile and the target, respectively.

Define  $\text{EFF} = 4k_a^2 (2I_a+1)(2i_a+1)$

Then in terms of eq. (6) we can write EFF (which is one of the outputs of the program) as

$$EFF = 0.01914 E_a (\text{lab}) (2I_a + 1) (2I_a + 1) M_a \left( \frac{M_A}{M_a + M_A} \right)^2 \text{ mbs}^{-1} \quad (7)$$

The quantity  $U_b \text{ max}$  is the maximum excitation energy of the residual nucleus after emission of particle b and is related to the Q-value of the reaction by the relation,

$$U_b \text{ max} = \epsilon_a + Q_{ab} \quad (8)$$

where  $Q_{ab}$  is the ground state Q value for the reaction A(a,b)B.

## 2. Forms of Level Density

Two forms of the level density  $\rho_b(U_b, I_b)$  of the residual nuclei can be used in the program.

### I. Fermi-Gas

If one uses the Fermi-gas form, the level density for a particular spin and both parities is given by,

$$\rho_b(U_b, I_b) = \frac{a^{1/2} (2I_b + 1)}{24 \sqrt{2} c^{3/2} (U_b - \Delta + t)^{3/2}} \exp \left[ 2a^{1/2} (U_b - \Delta)^{1/2} - \frac{I_b(I_b + 1)}{2ct} \right] \quad (9)$$

where

a = Fermi gas level density parameter

$\Delta$  = energy shift

t = thermodynamic temperature

The relation between a,  $\Delta$ , t and U is given by the equation of state

$$U - \Delta = at^2 - t \quad (10)$$

The spin cut-off factor  $\sigma$  is given by

$$\sigma^2 = ct \quad (11)$$

where

$$c = \frac{I}{\gamma n^2} = 0.0137 A^{5/3} (\text{MeV}^{-1}) \quad (12)$$

where  $I$  is the moment of inertia given by

$$I = \frac{2}{5} M A R^2 \quad (13)$$

where

$A$  = mass number

$M$  = nucleon mass

and  $R$  is the nuclear radius given by

$$R = 1.2 \times 10^{-13} A^{1/3} \text{ cm} \quad (14)$$

## II. Constant Temperature Level Density

In the constant temperature formalism the form of the level density used is

$$\rho_b(U_b, I_b) = \rho_n(U_c - B_n) \exp \left[ \frac{U_b - (U_c - B_n) + (\Delta_n - \Delta_b)}{T} \right] \\ \frac{(2I_b + 1)}{2\sigma_b^2} \exp \left[ - \frac{I_b(I_b + 1)}{2\sigma_b^2} \right] \quad (15)$$

where the level densities  $\rho_b(U_b, I_b)$  of each residual nucleus  $B$  is calculated relative to the level density  $\rho_n(U_c - B_n)$  of the residual nucleus reached by emission of neutrons with zero energy. The quantity  $B_n$  is the neutron binding energy,  $T$  the nuclear temperature, and  $\Delta_n - \Delta_b$  is the difference in the energy shift for the fictive ground state energies in the residual nuclei reached by the emission of a neutron  $n$ , and a particle  $b$ .

### 3. Program Description

The program consists of the main program called MAC3, two subroutines TLREAD and DENOMR and two functions DEN and SIG

I) MAC3 performs the five fold summation  $\sum_{I_a I_b S_a J S_b}$  in eq. (1) using values of  $\rho_b(U_b, I_b)$  and DENOM(J) as calculated by the subroutines DEN, SIG and DENOMR described later. Optical model transmission coefficients are provided by the input cards and the Z-coefficients by an input tape. Two Z-coefficient tapes are necessary, one corresponding to the integer channel spins and the other corresponding to the half integer channel spins. The method of calling those tapes is described in detail later in the input data card formats. The summations are performed up to  $I_a \text{ max} = I_b \text{ max} * J_{\text{max}} * 17$  and  $S_b \text{ max} = 14$ .

#### II) Subroutines

i) TLREAD: This subroutine reads the optical model transmission coefficients supplied by the input cards and checks the right order of input cards (see the data card format of the cards for the transmission coefficients).

#### ii) DENOMR

This subroutine calculates the quantity DENOM(J) as defined in eq. (2) for J=0 to 17. The summations are performed up to  $I_{\text{max}} = 17$ ,  $S_b \text{ max} = 14$  and  $I_b \text{ max} = 13$ . The index b' refers to all the possible modes of decay. (In the present form of the program DENOM(J) is calculated for alpha particles, protons, neutrons and deuterons only). The integral in eq. (2) is approximated by sums according to Simpson's rule with 0.5 MeV steps.

iii) Functions DEN(E,NU) and SIG(E,NU,I)

The main program assumes that the level density  $\rho_b(U_b, I_b)$  is given by the product of  $DEN(E,NU)$  and  $SIG(E,NU,I)$ . Two forms are provided for these functions. These are Fermi-gas level density and the constant temperature level density described earlier. The dimension of the product  $DEN(E,NU) \cdot SIG(E,NU,I)$  is  $\text{MeV}^{-1}$ .

INPUT

a) General Remarks

i) Constants (transmission coefficients, level density constants) referring to emission of different kinds of particles and the different residual nuclei reached by the emission of these particles are labelled by an index NU with the following meaning:

NU	particle
1	compound nucleus
2	$\alpha$ -particle
3	proton
4	neutron
5	deuteron

ii) The energy scale for the excitation energy of the residual nuclei reached after the emission of the different particles is in MeV and the basic energy unit is 0.5 MeV. The integrands in eq. (2) are calculated by the program for residual excitation energies at intervals of 0.5 MeV starting at zero excitation energy and going up to the maximum excitation energy of the residual nucleus given by eq. (8). Thus the program needs the values of the transmission coefficients  $T_\ell(\epsilon)$  starting with the

highest possible channel energy  $\epsilon_{\max}$  (corresponding to residual excitation energy of zero) and followed by  $T_1(\epsilon_{\max}^{-0.5})$ ,  $T_2(\epsilon_{\max}^{-1.0})$  etc. until the lowest possible value of the channel energy is reached as decided by the Coulomb cut off in the case of charged particles or zero channel energy in the case of neutrons.

b) Data Card Formats

Card 1: col 2 1

col 3-80 A descriptive title

Card 2: col 1-8 SIMIN = smallest possible value of entrance  
(F8.1) channel spin

=|Target spin-projectile spin|

col 9-16 SIMAX = largest possible value of entrance  
(F8.1) channel spin

=target spin + projectile spin

col 17-24 N refers to the type of Z-coefficient-tapes  
(I8) required in the calculations

=5 for integer channel spin

=9 for half integer channel spin

col 25-32 JEL = an integer corresponding to the lowest  
(I8) excitation energy for which a differential  
cross section is desired.  $JEL \geq 1$ ;  $JEL=1$   
corresponds to the residual excitation energy  
= 0 MeV.

col 33-40 JEH = an integer equal to  $(2U+1)$  where U is  
(I8) the highest excitation energy.

col 41-48 JEI = energy interval between points for which  
(I8)

calculation of differential cross section is  
desired.

=1 for 0.5 MeV increment between two points

=2 for 1 MeV increment between two points

(JEL, JEH and JEI are measured in units of 0.5 MeV)

Card 3

col 1-8 JEM(1) = dummy value not used in calculation  
(I8)

col 9-16 JEM(2) = number of energies for which trans-  
(I8)  
mission coefficients for emission of  $\alpha$ -particles  
are given in the input

col 17-24 JEM(3), same for protons  
(I8)

col 25-32 JEM(4), same for neutrons  
(I8)

col 33-40 JEM(5), same for deuterons  
(I8)

For calculation of the integrals in eq. (2), (performed by  
subroutine denomR) the program needs transmission coefficients  
for the listed kinds of particles in energy intervals of 0.5 MeV  
starting with the maximum possible particle channel energy  
(corresponding to zero residual excitation energy) and going  
downward in the particle channel energy in steps of 0.5 MeV  
until either a particle channel energy of less than 0.5 MeV is  
reached or the transmission coefficients become negligible due  
to the Coulomb barrier.

Card 4

col 1-8 Estarm (1) = dummy value not used in calculation  
(F8.5)

col 9-16 Estarm (2) = maximum excitation energy of residual nucleus reached by emission of  $\alpha$ -particles  
(F8.5)

col 17-24 Estarm (3) = same for protons emission  
(F8.5)

col 25-32 Estarm (4) = same neutron emission  
(F8.5)

col 33-40 Estarm (5) = same for deuteron emission  
(F8.5)

Estarm is calculated from projectile energy and Q values for the various reactions; for example

$^{59}\text{Co} + 11 \text{ Mev proton (in Lab. system)}$ ,  
Q value for  $^{59}\text{Co}(p,\alpha)^{56}\text{Fe}$  is 3.23 MeV; then  
Estarm (2) =  $11 \times \frac{59}{60} + 3.23 = 14.05 \text{ MeV}$

Cards 5-8 give the level density parameters of the different residual nuclei reached by alpha, proton, neutron and deuteron emission; the meaning of these parameters depend on the functional form of the level density. Different forms of the level density forms are selected by means of the control parameters IC and IP in card 9.

Constant Temperature form of level density (IP=IC=2)

Card 5 (col 1-60) (SE12-5): A(NU) = T NU = 1 to 5

Card 6 (col 1-60) (SE12-5): B(NU) =  $(U_c - B_n) - (\Delta_n - \Delta_v)$

Card 7 (col 1-60) (SE12-5): C(NU) =  $\rho(U_c - B_n)$

Card 8 (col 1-60) (SE12-5): D(NU) =  $\sigma^2(NU)$

Note that  $\sigma^2(\text{NU}) = \frac{9}{\hbar^2} T(\text{NU}) = .0137 A^{5/3}(\text{NU}) + T(\text{NU})$

The values with index (1) are not used in the calculation and the indices 2,3,4, and 5 refer to the residual nuclei reached by  $\alpha$ -particle, proton, neutron and deuteron emission, respectively.

$$\text{DEN}(E,\text{NU}) = C(\text{NU}) \exp \left[ \frac{E-B(\text{NU})}{A(\text{NU})} \right] \quad (16)$$

$$\text{SIG}(E,\text{NU},I) = \frac{(2I+1)}{2D(\text{NU})} \exp \left[ -\frac{I(I+1)}{2D(\text{NU})} \right] \quad (17)$$

$\text{DEN}(E)$  and  $\text{SIG}(E,\text{NU},I)$  are the energy and the spin dependent forms of level density.  $\text{DEN}(E,\text{NU})$  has the dimension levels/ MeV and  $\text{SIG}$  is a dimensionless fraction.

#### Fermi gas model (IP=1, IC=1)

Meaning of symbols for cards 5-8 for Fermi gas

$$E = A(\text{NU}) t^2 - t \quad (18)$$

$$\text{DEN}(E,\text{NU}) = \frac{(A(\text{NU}))^{1/2} \exp \left\{ 2[A(\text{NU}) \cdot (E-B(\text{NU}))]^{1/2} \right\}}{C(\text{NU}) [E+t-B(\text{NU})]^2} \quad (19)$$

$$\text{SIG}(E,\text{NU},I) = \frac{2I+1}{[D(\text{NU})]^{1.5}} \exp \left\{ -\frac{I(I+1)}{2D(\text{NU}) \cdot t} \right\} \quad (20)$$

where  $D(\text{NU}) = \frac{9}{\hbar^2} = 0.0137 A^{5/3} \text{ MeV}^{-1}$

$$B(\text{NU}) = \Delta$$

$$C(\text{NU}) = 24\sqrt{2} = 33.941$$

$$A(\text{NU}) = a$$

Fermi gas model (IP=3, IC=1)

Function DEN is the same as above. Only function SIG is altered to

$$\text{SIG}(E, \text{NU}, I) = \frac{(2I+1)}{[\text{D}(\text{NU})]^{1.5}} \cdot \exp \left\{ \frac{-(I+\frac{1}{2})^2}{2\text{D}(\text{NU})} \right\} \quad (21)$$

D(NU) now equals to  $\sigma^2$ , i.e. the spin cut off factor  $\sigma$  is kept fixed over the available energy range.

Card 9

col 4(I4):IP      = 2 if constant temperature calculation of level density is desired  
                      =1 if Fermi gas level density is desired  
                      =3 if Fermi gas form is desired with  $\sigma^2$  = constant.  
  
col 8(I4):IC      =2 if constant temperature level density is desired  
                      =1 if Fermi gas level density is desired  
  
col 9-20(E12.5)    at present not used in the calculation  
FO  
  
col 24:(I4)        =2 if differential cross section for NUOUT  
                       $\alpha$ -emission is desired  
                      =3 if differential cross section for p- emission is desired  
                      =4 if differential cross section for neutrons emission is required  
                      =5 if differential cross section for deuterons emission is desired

col 25-28(I4)    =Mass number of compound nucleus. This  
MT  
is used only to check the transmission  
coefficients.

col 29-30(I4)    =0 read all transmission coefficients,  
ITLR  
i.e. incoming as well as those for outgoing  
particles

\*1 use previous transmission coefficients  
=2 read only the incoming transmission  
coefficients and use all the previous  
outgoing transmission coefficients

col 33-36(I4)    =0 calculate DENOMR  
IDENOM  
=1 use DENOMR calculated in the previous  
case. (This has to have the same set of  
level density parameters as the previous  
case)

col 37-40(I4)    =integration option  
ITOP  
=0 no integration  
=1 do integration in specified increments  
(see last card 18<sup>1</sup>)  
=2 do one integration only (see last  
card 18<sup>2</sup>)  
=3 do integration (as specified by ITOP=1)  
and sum between any specified energy  
interval (insert both cards 18<sup>1</sup> and 18<sup>2</sup>  
in that order)

Card 10

Col 1-8(F8.1)    =Projectile spin  
SIP

col 9-16(F8.1) =Target spin  
SIT

col 17-24(F8.3) =Projectile energy in MeV(Lab.)  
EB

col 25-32(F8.3) =exact value of projectile mass in a.m.u.  
AM

col 33-40(F8.3) =exact value of target mas in a.m.u.  
TM

col 41-48(I8) =1 if target parity (-)  
IPAR  
=2 if target parity (+)

Card 11 Format (8F10.5)

col 1-10: AM(1) =mass of projectile

col 11-20: AM(2) =mass of target

col 21-30: AM(3) =mass of outgoing light particle

col 31-40: AM(4) =mass of residual nucleus

col 41-50: AQ =Q value of the ground state

All masses are in a.m.u.

Card 12

col 1-5(I5) =number of angles at which angular dis-  
NANGLE  
tribution is desired for each particle.

Card 13 Format (8F10.5)

col 1-10: ANG(1) =angle 1 in degrees lab

col 11-20: ANG(2) =angle 2 in degrees lab

col 21-30: ANG(3) =angle 3 in degrees lab

etc.

Cards 14-16 - Transmission coefficients for bombarding particle  
channel energy

col 1-72(6E12.6)	col 73-74	col 78	col 79-80
T(L), L=0,5	0	1	MT(as on card 9)
T(L), L=6,11	6	1	MT(" " " ")
T(L), L=12,17	12	1	MT(" " " ")

Card 17

Transmission coefficients of outgoing  $\alpha$ -particles from L=0 to L=17, 6 coefficients per card (6E12.5) starting with the highest possible  $\alpha$ -energy  $\epsilon_{\max}$  (corresponding to residual excitation energy zero). Then for  $\epsilon_{\max} = 0.5$  MeV,  $\epsilon_{\max} = 1.0$  MeV,  $\epsilon_{\max} = 1.5$  MeV, etc. till the lowest possible value of outgoing particle channel energy is reached as determined by the Coulomb cut off.

Each 0.5 MeV energy interval has 18 sets of transmission coefficients. For JEM(2) for instance, they are entered in the following manner:

col 1-72 (6E12.5)	col 73-74	col 78	col 79-90
T( $\epsilon_{\max}$ ,L) L=0,5	0	2	MT( as on card 9)
T( $\epsilon_{\max}$ ,L) L=6,11	6	2	MT( " " )
T( $\epsilon_{\max}$ ,L) L=12,17	12	2	MT( " " )
T(( $\epsilon_{\max}$ -0.5),L),L=0,5	0	2	MT( " " )
T(( $\epsilon_{\max}$ -0.5),L)L=6,11	6	2	MT( " " )
T(( $\epsilon_{\max}$ -0.5),L)L=12,17	12	2	MT( " " )
+			
T(( $\epsilon_{\rm lowest}$ ,L)L=0,5	0	2	MT( " " )
T(( $\epsilon_{\rm lowest}$ ,L)L=6,11	6	2	MT( " " )
T(( $\epsilon_{\rm lowest}$ ,L)L=12,17	12	2	MT( " " )

Then follow the JEM (3) cards containing the proton transmission coefficients, the JEM (4) cards containing the neutron transmission coefficients and finally the JEM (5) cards containing deuteron transmission coefficients.

The last card or cards are inserted only when the integration option ITOP is specified either as 1, 2, or 3 as described below

For ITOP = 1, add card 18<sup>1</sup>

Card 18<sup>1</sup>

col 1-10: (F10.5) =lower energy limit of integration (in E<sub>3</sub>(c.m))  
EMINB

col 11-20:(F10.5) =higher limit of integration (in E<sub>3</sub>(c.m))  
EMAXB

col 21-30:(F10.5) =energy interval between consecutive points  
DELEB

col 31-35:(I5)      =number of integrations between the lower  
NOINT                and the higher energy limits. It must be  
                      an integer

For ITOP = 2, add only card 18<sup>2</sup>

Card 18<sup>2</sup>

col 1-10:(F10.5) =lower integration limit (>JEL)  
ETMIN

col 11-20:(F10.5) =upper integration limit (<JEH)  
ETMAX

For ITOP = 3, add both cards 18<sup>1</sup> and 18<sup>2</sup> in this order.

A magnetic tape containing the Z coefficients has to be provided. Two such tapes have been generated on the IBM 360 computer. Tape 222998 contains the coefficients for integer channel spins and the data set reference number is 13. Tape 22299 contains the coefficients

for half-integer channel spins and the data set reference number is 17.

#### B. DESCRIPTION OF PROGRAM MAC10

This program does the calculations like MAC3, but the Legendre function (see eq. 6) can be extended to either L=8 or L=10 with an option LBIG which appears on card 9 of program MAC3 in columns 41-44.

For details of the formalism of the problem, program description and general remarks see program MAC3.

Data card formats for all cards of MAC10 are identical to those of MAC3 with only one additional option LBIG appearing in columns 41-44 of card 9.

Card 9: All input on this card is identical to that of card 9 of program MAC3 except for the following additional option.

col 41-44 LBIG = L value of Legendre functions  
(I4)  
=8, L = 0, 2, 4, 6, 8  
=10, L = 0, 2, 4, 6, 8, 10

All other input cards are the same as those of program MAC3.

#### C. DESCRIPTION OF PROGRAM MACT3

This program incorporates isobaric spin conservation into the statistical model of compound nuclear decay (eq. 11). This is accomplished in the following manner.

With alpha particles as projectiles only one isobaric spin  $T_c$  is formed in the composite system. With protons as

projectiles, two isobaric spins  $T_<$  and  $T_>$  are formed in the composite system. We assume that the two isobaric spins  $T_<$  and  $T_>$  are formed with good isobaric spin purity. Hence, we treat the decay of each of these isobaric spin states separately. Conventional transmission coefficients are used in the entrance and the exit channels weighted with the appropriate Clebsch-Gordan coefficients (see fig. 1). For instance, emission of protons from the  $T_<$  state of the composite system  $^{63}\text{Cu}$  to the  $T=3$  states of  $^{62}\text{Ni}$  is characterized by a weighting factor of  $1/7$ , whereas emission of neutrons to the  $T=2$  and  $T=3$  states of  $^{62}\text{Cu}$  have associated weighting factors of  $0$  and  $6/7$ , respectively. In the calculation of the level density of the residual nuclei, account is taken of the isobaric spin as well as the excitation energy and angular momentum. Thus, the statistical calculation of the particle evaporation from the  $T_>$  states of the composite system is accomplished by using the energy shifts of the isobaric analogue nucleus at the corresponding excitation energies.

#### 1. Description of Program

For general remarks, see Program MAC3. The program MACT3 performs the same type of calculations as MAC3 but also includes the conservation of isobaric spin. In addition, it can handle another exit particle. Since the decays of  $T_<$  and  $T_>$  states of the composite are treated separately, Two different sets of data cards are required; one for transitions from  $T_<$  states and the other for the decay of  $T_>$  states.

025/2429

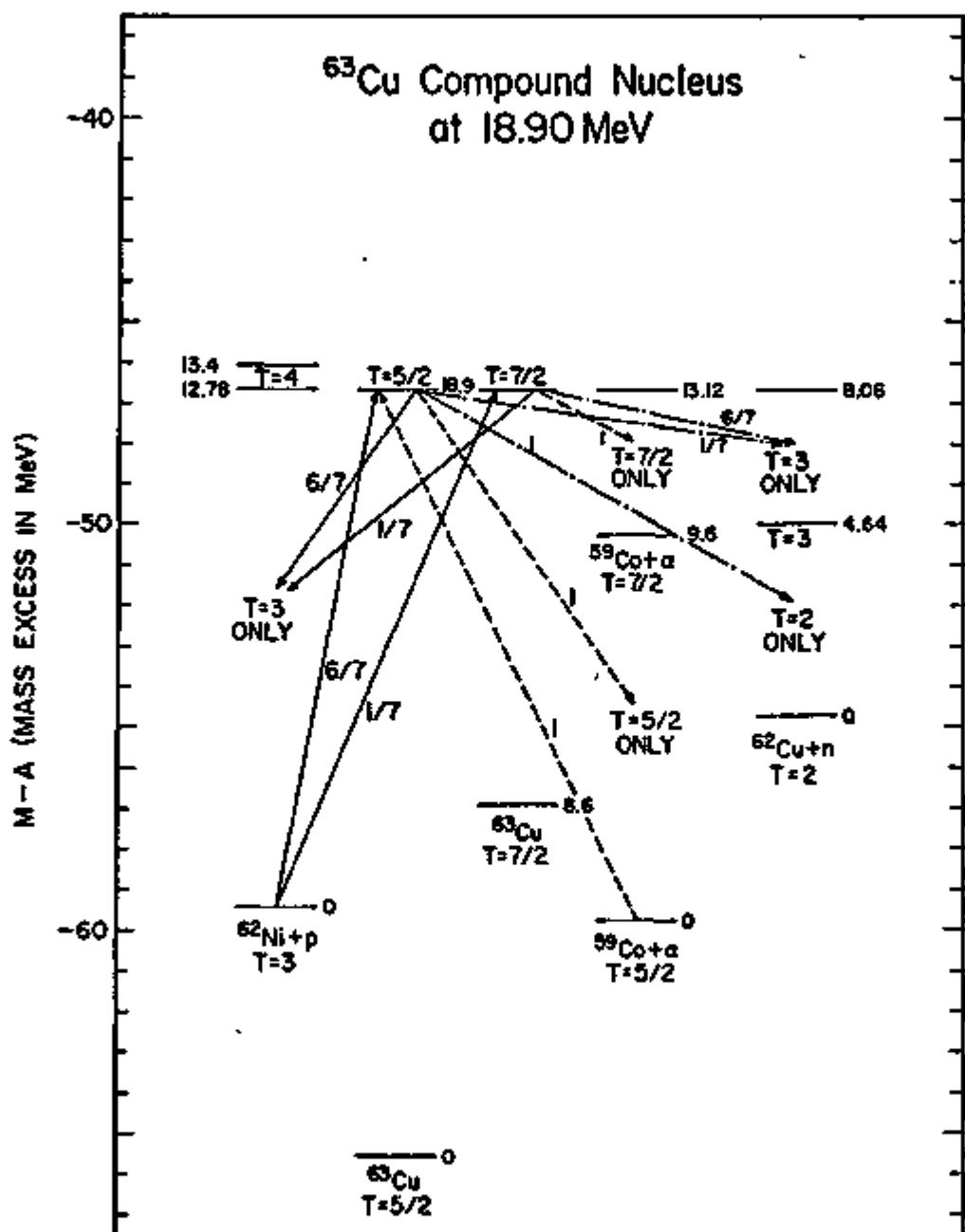


Figure 1

2. Input Cards

Card 1: col 2 1  
col 3-80 A descriptive title

Card 2: col 2 1  
col 3-80 Descriptive title indicating whether  
the decay of  $T_{<}$  or  $T_{>}$  is desired.

Card 3: (6F10.5) CG = square of Clebsch-Gordan coefficient  
col 1-10 CG(1) = CG for incoming channel  
col 10-20 CG(2) = CG for outgoing alpha particles  
col 20-30 CG(3) = CG for outgoing protons  
col 30-40 CG(4) = CG for outgoing neutrons  
col 40-50 CG(5) = CG for outgoing deuterons  
col 50-60 CG(6) = CG for the last exit particle

Card 4: col 1-5 = SPIN (6)  
(F5.2)  
= spin of the last exit particle  
col 5-10 = IEOS  
(I5)  
= integer indicating spin of the last  
exit particle  
= 1 if SPIN(6) is half integer  
= 2 if SPIN(6) is zero or integer

The rest of the input cards for the MACT3 program are the same as the input cards from MAC3, from number 2 to the last card of the program.

An additional set of transmission coefficients has to be fed in for the last exit particle.

D. DESCRIPTION OF PROGRAM YRAST

This program is modified from MAC3 to calculate the yrast level density instead of the usual level density form

(eq. (9) or (15)).

The lowest energy for a given angular momentum is called the yrast energy. The fact that there are no levels of a given angular momentum below the yrast energy is important in the de-excitation of compound nuclei.

The lowest energy for a particular spin I is given by the rotational formula  $E_I$ ,

$$E_I = I(I+1)/2\sigma \quad (22)$$

where  $E_I$  is the yrast energy for spin I and  $\sigma$  is a moment of inertia.

It can be easily shown by expanding  $2a^{1/2}(U-E_I-\Delta)^{1/2}$  in the binomial series that

$$\begin{aligned} 2a^{1/2}(U-E_I-\Delta)^{1/2} &= 2a^{1/2}(U-\Delta)^{1/2} - \frac{E_I}{\epsilon} \\ &= 2a^{1/2}(U-\Delta)^{1/2} - \frac{I(I+1)}{2\sigma^2} \end{aligned} \quad (23)$$

Using the expansion given by (23), we can write the yrast level density corresponding to eq. (9) as

$$\rho_{Yrast} = \frac{a^{1/2}(2I+1)}{24\sqrt{2} c^{3/2} (U-E_I-\Delta+\epsilon)^2} \exp [2(a(U-E_I-\Delta))^{1/2}] \quad (24)$$

The thermodynamic temperature  $t$  is given by

$$(U-E_I-\Delta) = A(NU)t^2 - t \quad (25)$$

In the constant temperature formalism, the yrast level density corresponding to eq. (15) can be easily written down as

$$\rho_b(U_b, I_b) = \rho_n(U_c - B_n) \exp\left[\frac{U_b - (U_c - B_n) - E_I + \Delta_n - \Delta_b}{T}\right] \cdot \frac{(2I_b + 1)}{2\sigma_b^2} \quad (26)$$

The program YRAST does the same type of calculations as the program MAC3 using the yrast level density forms given by equations (24) or (26). All input data is therefore identical to that of program MAC3.

#### E. DESCRIPTION OF PROGRAM EVAP

This program calculates the spectrum of evaporated particles integrated over all angles. If one performs such an integration on eq. (1) the term that gives a non-vanishing result is that with  $L=0$ . In this case, the Clebsch-Gordan and Racah coefficients become

$$(1100|00) = (-)^k / \sqrt{2k+1} \quad (27)$$

$$W(1J\ell J; S0) = (-)^{S-k-J} / \sqrt{(2k+1)(2J+1)} \quad (28)$$

Using these values and noting that integration of eq. (1) over all angles gives  $4\pi$ , we get

$$\frac{d\sigma}{d\epsilon_b} = \frac{\pi}{k_a^2 (2I_A + 1) (2i_a + 1)} \sum_{S_a=|I_A - i_a|}^{I_A + i_a} \sum_{k_a=0}^{\infty} T_U^{k_a}(\epsilon_a) \sum_{J=|I_a - S_a|}^{I_a + S_a} \frac{(2J+1)}{G(J)} \left[ \sum_{\ell_b=0}^{\infty} T_{\ell_b}^b(\epsilon_b) \sum_{S_b=|J - \ell_b|}^{J + \ell_b} \sum_{I_b=|S_b - i_b|}^{S_b + i_b} \rho(U_b, I_b) \right] \quad (29)$$

where  $G(J)$  is given by eq. (2).

The order of summation inside the square bracket of eq. (29) can be reversed to give

$$\sum_{i_b=0}^{\infty} \rho(U_b, I_b) \sum_{S_b=|I_b-i_b|}^{I_b+i_b} \sum_{i_b'=|S_b-J|}^{S_b+J} T_{i_b'}^b(\epsilon_b) \quad (30)$$

The program uses eq. (29) to calculate the spectrum of evaporated particles integrated over all angles. This program does not contain the integration option (ITOP) of program MAC3.

#### INPUT DATA FORMAT

All data cards from 1-8 are identical to data cards of program MAC3. In card 9 of program EVAP, the spin density option IP can be made to have several values which will be described below. All other options of this card, however, are the same as those in MAC3. There is no integration option.

#### Card 9 of program EVAP

col 4      IP = integer describing the form of the spin dependent level density

IP = 1, Fermi gas level density with spin cutoff factor varying with temperature

$$t = \frac{1 + \sqrt{1 + 4a(U - \Delta)}}{2a}$$

$$SIG = \frac{(2I+1)}{c^{3/2}} \exp[-(I+1/2)^2/2ct]$$

IP = 3, Fermi gas level density without the variation of spin cutoff factor with temperature

$$SIG = \frac{(2I+1)}{c^{3/2}} \exp[-(I+1/2)^2/2\sigma^2]$$

IP = 2, Constant temperature form of level density without the variation of spin cutoff factor with temperature

$$\text{SIG} = \frac{(2I+1)}{2c} \exp[-(I+1/2)^2/2\sigma^2]$$

IP = 4,  $(2I+1)$  form of level density

$$\text{SIG} = (2I+1)/c^{3/2}$$

All the other cards of this program are identical to those used in MAC3 program. EVAP program does not compute angular distribution, hence, no "angle cards" must be given. It does not require the Z coefficients.

#### DESCRIPTION OF OUTPUT OF PROGRAMS

MAC3, MAC10, MACT3, YRAST, EVAP

- 1) Common to all 5 programs
  - a) All input parameters except those of cards 11, 12, 13 and the transmission coefficient cards.
  - b) EFF given by eq. (7)
  - c)  $(\text{DENOM}(J))^{**.5}$  for  $J=0-17$ . where DENOM(J) is given by eq. (2)
- 2) Ratio of Legendre coefficients for cross section for emission of a certain type of particles at selected residual excitation energies as specified by the quantities NUOUT, JEL, JEH, and JEI in input.

The various columns of the output list of the Legendre coefficients have the following meaning:

- a) First column: residual excitation energy in MeV
- b) Second column:  $A_0/A_0 = 1$  always (no meaning)
- c) Third column:  $A_2/A_0$

- d) Fourth column:  $A_4/A_0$   
e) Fifth column:  $A_6/A_0$   
f) Sixth column:  $A_8/A_0$   
g) Seventh column:  $A_{10}/A_0$
- } For MAC10 program only depending  
on option LBIG (see card 9 of  
MAC10 program)
- Last column:  $A(L=0)$ : average differential cross  
section in mb/sr/MeV.

Columns a) - e) and the last column are common to all the programs. In addition, all programs give the total average cross sections in  $(\text{mbs sr}^{-1}(\text{bin size in MeV})^{-1})$  and in mbs.

3) Macdonald angular distributions (common to MAC3, MAC10, MACT3, and YRAST programs).

The output of this section consists of theoretical energy spectra for desired angles.

Spectra integrated over a desired energy range or integrated over specified energy bin size (0.5 MeV or 1.0 MeV) are also given if desired.

- col 1      E(RES) = residual excitation energy in  
col 2      E3(c.m.)= energy of the light outgoing  
                particle in (MeV)<sub>c.m.</sub>  
col 3      c.m. angle = scattering angle (deg.) of  
                light particle in center of mass  
col 4      Diff. cross section = differential cross  
                section (mb/sr/MeV) of light particle  
                at various energies

In addition if integration at each angle is desired, the integrated cross section (mb/sr) in each energy bin will be printed. Also the total integrated cross section (mbs/sr) within the specified limits will be printed.

#### F. DESCRIPTION OF PROGRAM ZCOEF

This program consists of main program, ZCOEF, and two subroutine functions, CLEBSCH and RACAH. It computes and writes the Z-coefficients,  $Z(iJ\&J;SL)$ , on two magnetic tapes on data set reference no. 13 and 17 for integral and half integer values of J, respectively for values of  $i \leq 17$ ,  $J \leq 17$ ,  $S \leq 14$  and even values of  $L \leq 12$ . These tapes are used as input tapes for the programs MAC3, MAC10, MACT3 and YRAST. Printed output of the Z-coefficients is also generated.

The Z-coefficients are defined as

$$Z(iJ\&J;SL) = (2i+1)(2J+1)(i\&00|L0)W(iJ\&J;SL) \quad (31)$$

The Clebsch-Gordan coefficient,  $(i\&00|L0)$  is given by<sup>2)</sup> (31)

$$(j_1 j_2 m_1 m_2 | jm) = (-1)^{j+m} (2j+1) V(j_1 j_2 j; m_1 m_2) \quad (32)$$

The V-coefficients are given by

$$V(abc; \alpha\beta\gamma) = V(abc; \alpha\beta\gamma) \cdot \\ [(a+b-c)! (a+c-b)! (b+c-a)! / (a+b+c+1)!]^{1/2} \quad (33)$$

and

$$V(abc; \alpha\beta\gamma) = \delta(\alpha+\beta, \gamma) \sum_z (-1)^{c+\gamma+z} \cdot \\ \frac{[(a+\alpha)! (a-\alpha)! (b+\beta)! (b-\beta)! (c+\gamma)! (c-\gamma)!]^{1/2}}{z! (a+b-c-z)! (a-\alpha-z)! (b+\beta-z)! (c-b+\alpha+z)! (c-a-\beta+z)!} \quad (34)$$

The functions  $V$  and  $v$  are defined for integral and half-integral values of the arguments, with the limitation that the numbers,

$$a+\alpha, a-\alpha, b+\beta, b-\beta, c+\gamma, c-\gamma, a+b-c, a+c-b, b+c-a \quad (35)$$

must be integers. The function  $V$  vanishes if one of the numbers (34) is negative, and the summation (33) reduces to one term if one of these numbers vanishes.

The Racah coefficient  $W$  is given by<sup>2)</sup>

$$w(abcd;ef) = w(abcd;ef) .$$

$$\left[ \frac{(a+b-e)! (a+e-b)! (b+e-a)! (c+d-e)! (c+e-d)! (d+e-c)!}{(a+b+e+1)! (c+d+e+1)! (a+c+f+1)! (b+d+f+1)!} \right]^{1/2} (a+c-f)! (a+f-c)! (c+f-a)! (b+d-f)! (b+f-d)! (d+f-b)! \quad (36)$$

where

$$w(abcd;ef) = \sum_z (-1)^z \frac{(a+b+c+d+1-z)!}{z! (a+b-e-z)! (c+d-e-z)! (a+c-f-z)!} \frac{1}{(b+d-f-z)! (e+f-a-d+z)! (e+f-b-c+z)!} \quad (37)$$

The functions  $w$  and  $W$  are also defined for integral and half-integral values of the arguments, with the limitation that each of the triads

$$(a,b,c), (c,d,e), (a,c,f), (b,d,f) \quad (38)$$

has an integral sum. The function  $w$  vanishes unless the elements of each triad (38) satisfy the triangular inequalities; if one of these triads reduces to a segment, the summation in (37) reduces to one term.

In (34) and (37),  $z$  takes only such integral values for which the argument of every factorial is not negative.

#### ACKNOWLEDGEMENT

The authors acknowledge the contributions of Dr. H. Bowsher, Dr. M. Halbert and Dr. H. K. Vonach in the development of earlier versions of some of these programs.

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### III. PROGRAM LISTINGS, SAMPLE INPUTS AND OUTPUTS

-29-

#### A. MAC3 Program Listing

```

C      PROGRAM MAC3
C      MODIFIED FROM PROGRAM MAC1. TREAT C.M. ANGLE EXACTLY AND
C      INTEGRATE DIFF. CROSS SECTION FOR DIFFERENT ENERGY BIN. 11/1/70
COMMON      TL,JEM,MT,DENOM,N,A,B,C,D,
1IP,IC,ESTARM,SPIN,FO,ITLR
DIMENSION      TL(5,18,45), JEM(5), DENOM(18),
1   A(5), B(5), C(5), D(5), ESTARM(5), SPIN(5),
2   O(18),Z(18,18,15),PA(4,45),PB(4),ANG(24)
3,EINT1(30),EINT2(30),NX1(30),NX2(30),DC(30),DIFF(30),E3CM(30)
710 READ(5,700,END=800) NTITLE
700 FORMAT(1X,11,78H
1
1      WRITE(6,701)
701 FORMAT(1H1,30X,'MACDONALD ANGULAR DISTRIBUTION'//)
      WRITE(6,700) NTITLE
      GC TO 10
800 CALL EXIT
10 READ(5,13) S1MIN,S1MAX,N,JEL,JEH,JE1,
11(JEM(I),I=1,5), (ESTARM(I),I=1,5), (A(I),I=1,5),
21(B(I),I=1,5), (C(I),I=1,5), (D(I),I=1,5), (P,IC, FO, NUOUT,MT,ITLR
3, IDENCM,ITDP
13 FORMAT (2F8.1,18,3I8/5I8/5F8.5/5E12.5/
15E12.5 / 5E12.5 / 5E12.5 /
2I4, 14, E12.5,5I4)
      READ(5,195) SIP,SIT,EB,AM,TM
195 FORMAT(2F8.1,3F8.3)
      WRITE(6,14) S1MIN,S1MAX,N,
1JEL,JEH,JE1,(JEM(I),I=1,5),(ESTARM(I),I=1,5),
2(A(I),I=1,5),(B(I),I=1,5),(C(I),I=1,5),
3(D(I),I=1,5),IP,IC,FO,NUOUT
14 FORMAT(1H0,28HMIN ENTRANCE CHANNEL SPIN = ,F4.1/
21H ,28HMAX ENTRANCE CHANNEL SPIN = ,F4.1/
31H ,10HTAPE NU.= ,I1/1H ,11HJE(LOWEST)=,12,5X,12+JE(HIGHEST)=,
4I2,5X,8HJE( INC)=,12/1H ,14X,3HI=1,9X,3HI=2,9X,3HI=3,
59X,3HI=4,9X,3HI=5/1H ,7HJEM(I)=,4X,5I12/
61H ,10HESTARM(I)=,1X,5E12.5/1H ,5HAI(I)=,6X,
75E12.5/1H ,5HB(I)=,6X,5E12.5/1H ,5HC(I)=,6X,5E12.5/1H ,5HD(I)=,
86X,5E12.5/1H ,26HANG MOM DENSITY OPTION IS ,12/
91H ,25HENERGY DENSITY OPTION IS ,12/1H ,3HF0=,E12.5,1H ,3HNU=,I2)
EFF=0.01914*FB*(2.0*SIP+1.0)*(2.0*SIT+1.0)*AM*(TM/LAM+TM)**2
      WRITE(6,920) SIP,SIT,AM,TM,EFF,EB
920 FFORMAT(1H0,16HPROJECTILE SPIN=F8.3/
11H0,12HTARGET SPIN=F8.3/
21H0,16HPROJECTILE MASS=F8.3/
31H0,12HTARGET MASS=F12.5/1X,4HEFF=F12.5/
41H0,18HPROJECTILE ENERGY=F12.3,3HMEV)
      IF (ICENOM.NE.1) GO TO 720
      WRITE(6,721)
721 FORMAT('0 PREVIOUS DENOM(J) VALUES ARE USED'//)
720 CONTINUE
      READ(5,750) AM1,AM2,AM3,AM4,AQ
750 FORMAT(8F10.5)
      READ(5,751) NANGLE
751 FORMAT(1S1
      READ(5,750) (ANG(I),I=1,NANGLE)
      IF (ITLR-1) 400,401,400
400 CALLTREAD
401 CONTINUE
      SPIN(1)=1.

```

```
SPIN(2)=0.
SPIN(3)=.5
SPIN(4)=.5
SPIN(5)=1.
IF(N=6)1,1,2
1 IS1MIN=S1MIN+1.
IS1MAX=S1MAX+1.
GOTO3
2 IS1MIN=S1MIN+.5
IS1MAX=S1MAX+.5
3 CONTINUE
IF (IDENOM.EQ.1) GO TO 620
CALL DENOMR
620 CONTINUE
WRITE(6,630) (DENOM(J),J=1,18)
630 FORMAT(1H0,*(DENOM(J))**0.5, J=0,17'/1H ,6E14.5/1X,6E14.5/1X,6E14.
15)
NT=N+8
DO130L=1,4
F=2*(L-1)
DO119II=1,18
DC119JJ=1,18
READ(NT) LT,IT,JT,(Z(II,JJ,KK), KK=1,15)
IFILT-L)217,301,217
301 IF(IT-II)217,302,217
302 IF(JT-JJ)217,119,217
217 WRITE(6,218) L,II,JJ,LT,IT,JT
218 FORMAT(10H BAD ZCODE READIN, L*,I2,5H I=,I2,5H J=,I2,
13X3HLT=15,3X3HIT=15,3X3HJT=15)
GO TO 800
119 CONTINUE
DO190 IO=1,18
DC190 JO=1,18
DO190 KO=1,15
190 Z(10,JO,KO)=Z(10,JO,KO)/DENOM(JO)
DO130 JE=JEL,JEH,JE1
E*JE-1
34 JD = 1
PROD=0.
DO125 S1=IS1MIN,IS1MAX
S1=IS1
IF(N=6)4,4,5
4 ES=S1-1.
GOT06
5 ES=S1-.5
6 DO 125 I = 1, 14
IF(N=6)201,201,202
201 GOTO( 203,203,204,204,203 ),NUOUT
203 FI=I-1
GOT0220
204 FI=I
FI=FI-.5
GOT0220
202 GOTO( 204,204,203,203,204 ),NUOUT
220 DENS = SIG(FI, FO, E, NCUT)
S2MIN=ABS (FI-SPIN(NUOUT))
S2MAX=FI+SPIN(NUOUT)
IF(N=6)227,227,228
227 IS2MIN=S2MIN+1.
```

```
IS2MAX=S2MAX*1.  
GOTO229  
228 IS2MIN=S2MIN+.5  
IS2MAX=S2MAX+.5  
229 DO125 IS2= IS2MIN,IS2MAX  
IF(N-61230,230,231  
230 S2=IS2-1  
GOT0232  
231 S2=IS2  
S2=S2-.5  
232 KS=S2-ES  
FAC=(-1.)**(KS))*DENS  
DO 127 L1 = 1, 18  
FL1=L1-1  
JMIN=ABS(FL1-ES)+1.  
JMAX=MINI(FL1+ES,17.0)+1  
FACA = FAC * TL(1, L1, 1 )  
DO 124 L2 = 1, 18  
FACB=FACA*TL(NUOUT,L2,JE)  
G=ABS(FACB)  
IF 1G-.0000001 ) 127, 127, 120  
120 DC123 J=JMIN,JMAX  
123 PROD = PROD + FACB * Z( L1, J, JS1 ) *Z(L2, J, IS2 )  
124 CONTINUE  
127 CONTINUE  
125 CONTINUE  
PROD=PROD/EFF  
130 PA(1,JE)=PROD*DENS,NUCUT)  
WRITE(6,41)  
41 FORMAT(1H0,1AX,'RATIO OF LEGENDRE COEFFICIENTS (A(L)/A(0)) AND A  
1[L=0]*  
2/1H0,2X,'E(RES.)',4X,' A(L=0)/A(L=0) A(L=2)/A(L=0) A(L=4)/A(L=0) A  
3(L=6)/A(L=0) A(L=0)*/4X,'MEV',65X,'MB/SR/MEV')  
DO128 JE=JEL,JEH,JE1  
E=JE-1  
E=0.5*E  
IF 1PA(1,JE).GT..000001) GO TO 501  
PB(1)=0.  
PB(2)=0.  
PB(3)=0.  
PB(4)=0.  
GO TO 502  
501 DC 500 L=1,4  
PB(L)=PA(L,JE)/PA(1,JE)  
500 CONTINUE  
502 WRITE(6,47) E, (PB(LL),LL=1,4),PA(1,JE)  
47 FORMAT(1H0,2X,F5.1,7X,5(E12.5,2X))  
128 CONTINUE  
PASUM=0.  
DO 510 J=JEL,JEH,JE1  
510 PASUM=PASUM+PA(1,J)  
PASUM=PASUM-(PA(1,JEL)+PA(1,JEH))/2.  
SJEI=JEI  
DELE=SJEI/2.  
CSECT=4.*3.14159*DELE*PASUM  
WRITE(6,511) PASUM,CSECT  
511 FORMAT(1H0,41X,'TOTAL A(L=0) IN MB/SR/MEV ',E12.5//42X,' TOTAL CROS  
1S SECTION (N MBS',E12.5)  
WRITE(6,701)
```

```
      WRITE(6,700) NTITLE
      IF (ITOP.EQ.0) GO TO 759
      IF ITOP.EQ.21 GO TO 758
      READ(5,801) EMINB,EMAXB,DELEB,NOINT
801  FORMAT(3F10.5,15)
      IF (ITOP.EQ.11) GO TO 759
758  READ(5,801) ETMIN,ETMAX
759  CONTINUE
      DO 761 JI=1,NANGLE
      XANGLE=ANG(JI)*17.453292/1000.
      WRITE(6,762) ANG(JI)
762  FORMAT(1HO,'ANGLE=',F8.3,' DEGREE(LAB.)',//'* E(RES.)   E3(C.M.)
1 C.M. ANGLE  DIFF. CROSS SECTION'//4X,4HMEV.,8X,4HMEV.,8X,*DEG.',28X,'MB/SR/MEV')
      DO 760 JJ=JEL,JEH,JEI
      E=JJ-1
      E=0.5*E
      E3CM(JJ)=EB*AM2*AM4/((AM1+AM2)**2)+(AQ-E)*AM4/(AM3+AM4)
      Z1=AM1*AM3*EB
      Z2=COS(XANGLE)
      Y1=Z1*Z2*(AM3+AM4)*(AM4*(AQ-E)+EB*(AM4-AM1))
      Y1=SQRT(Y1)
      Y2=Z2*SQRT(Z1)
      E3LAB1=(Y1+Y2)/(AM3+AM4)
      E3CM1=SQRT(E3CM(JJ))
      X1=E3LAB1*SIN(XANGLE)
      XCMANG=ARSIN(X1/E3CM1)
      V1=SQRT(2.*EB/(AM1*931.441))
      VCM=V1*AM1/(AM1+AM2)
      V3LAB=E3LAB1/SQRT(AM3*931.441/2.)
      V3X=V3LAB*Z2
      IF (VCM.GT.V3X) XCMANG=3.14159-XCMANG
      CMANG=XCMANG*100./1.74533
      CANG1=COS(XCMANG)
      CANG2=CANG1*CANG1
      CANG4=CANG2*CANG2
      CANG6=CANG4*CANG2
      CROSS1=PA(1,JJE)-PA(2,JJE)/2.+PA(3,JJE)*3./8.-PA(4,JJE)*5./16.
      CROSS2=IP(A(2,JJE)*24.-PA(3,JJE)*60.+PA(4,JJE)*105.)*CANG2+
      1|PA(3,JJE)*70.-PA(4,JJE)*315.)*CANG4+PA(4,JJE)*231.*CANG6
      DIFF(JJ)=CROSS1+CROSS2/16.
      WRITE(6,763) E,E3CM(JJ),CMANG,DIFF(JJ)
763  FORMAT(3X,F5.1,5X,F8.2,5X,F6.2,7X,E12.5)
760  CONTINUE
      IF (ITOP.EQ.0) GO TO 890
      IF (ITOP.EQ.21 GO TO 830
      EINT1(1)=EMAXB
      EINT2(1)=EMAXB-DELEB
      DO 802 NX=2,NOINT
      EINT1(NX)=EINT2(NX-1)
802  EINT2(NX)=EINT1(NX)-DELEB
      DO 803 KE=JEL,JEH,JEI
      IF (E3CM(KE).LE.EMAXB) GO TO 804
803  CONTINUE
804  NX1(1)=KE
      DO 805 LE=KE,JEH,JEI
      IF (E3CM(LE).LE.EINT2(1)) GO TO 806
805  CONTINUE
806  NX2(1)=LE-1
```

```
DC 808 NE=2,NOINT
NX1(NE)=NX2(NE-1)+1
KX1=NX1(NE)
DO 807 KX=KX1,JEH,JEI
IF (E3CM(KX).LE.EINT2(NE)) GO TO 808
807 CONTINUE
808 NX2(NE)=KX-1
DO 820 LX=1,NOINT
K1=NX1(LX)
K2=NX2(LX)
DC12=(DIFF(K1)-DIFF(K1-1))*(E3CM(K1-1)-EINT1(LX))/(E3CM(K1-1)-
E3CM(K1))+DIFF(K1-1)
DC1=(DC12+DIFF(K1))*((EINT1(LX)-E3CM(K1))/2.
DC22=(DIFF(K2+1)-DIFF(K2))*(E3CM(K2)-EINT2(LX))/(E3CM(K2)-
E3CM(K2+1))+DIFF(K2)
DC2=(DC22+DIFF(K2))*(E3CM(K2)-EINT2(LX))/2.
DC3=0.
IF (NX1(LX).EQ.NX2(LX)) GO TO 811
K22=K2-1
DO 810 LY=K1,K22
810 DC3=DC3+(E3CM(LY)-E3CM(LY+1))*(DIFF(LY)+DIFF(LY+1))/2.
811 DC(LX)=DC1+DC2+DC3
820 CONTINUE
WRITE(6,821)
821 FORMAT(1H0,6X,'INTEGRATION LIMIT DIFFERENTIAL CROSS SECTION'/
14X,'MEV',19X,'MB/SR')
WRITE(6,822) (EINT1(NZ),EINT2(NZ),DC(NZ),NZ=1,NGINT)
822 FORMAT(8X,F6.2,' - ',F6.2,11X,E12.5)
IF ((TOP.EQ.11) GO TO 890
830 DO 831 IF=JFL,JEH,JEI
IF (E3CM(IF).LE.ETMAX) GO TO 832
831 CONTINUE
832 DC 840 IE1=IE,JEH,JEI
IF (E3CM(IE1).LE.ETMIN) GO TO 841
840 CONTINUE
841 JK=IE1-1
U12=(DIFF(IF)-DIFF(IF-1))*(E3CM(IF-1)-ETMAX)/(E3CM(IF-1)-E3CM(IF))
+DIFF(IF-1)
U1=((U12+DIFF(IF))/2.)*(ETMAX-E3CM(IF))
U22=(DIFF(JK+1)-DIFF(JK))*(E3CM(JK)-ETMIN)/(E3CM(JK)-E3CM(JK+1))
+DIFF(JK)
U2=((U22+DIFF(JK))/2.)*(E3CM(JK)-ETMIN)
U3=0.
IF (IE.EQ.JK) GO TO 851
IT4=JK-1
DO 850 IT=IE,IT4
850 U3=U3+(E3CM(IT)-E3CM(IT+1))*(DIFF(IT)+DIFF(IT+1))/2.
851 DCTOT=U1+U2+U3
WRITE(6,860) ETMIN,ETMAX,DCTOT
860 FORMAT(1H0,6X,'INTEGRATION LIMIT ',F6.2,' - ',F6.2,' MEV'/
17X,'TOTAL DIFF. XSECTION=',E12.5,' MB/SR')
890 CONTINUE
761 CONTINUE
PEWIND NT
GO TO 710
END
SUBROUTINE TLREAD
C ROUTINE TO READ IN TL CARDS PRODUCED BY OPT MOD.
C REVISED BY C. C. LU
```

```
COMMON      TL,JEM,MT,DENOM,N,A,B,C,D,
1IP,IC,ESTARM,SPIN,FO,ITLR
DIMENSION      TL(5,18,45), JEM(5), DENOM(18),
1 A(5), B(5), C(5), D(5), ESTARM(5), SPIN(5)
C FIRST READ NU=1, JE=1 CARDS.
DO 52 LINODEX=1,13,6
LINMAX=LINDEX+5
L=LINDEX-1
READ 103,          (TL(1,LIND,1),LIND=LINDEX,LINMAX),
1LCARD,NUCARD,MTCARD
C CHECK CARDS FOR PROPER INDICES AND ORDER.
IF(1-NUCARD) 53,54,53
54 IF(L-LCARD)53,56,53
56 IF(MT-MTCARD) 53,52,53
52 CONTINUE
IF (ITLR-2) 200,203,203
203 CONTINUE
RETURN
C NOW READ IN FOR THE REST OF THE CHANNELS, AND CHECK ORDER.
200 NU1=2
NU2=5
57 DO 2 NU=NU1,NU2
70 JEMAX=JEM(NU)
90 CONTINUE
DO 2 JE=1,JEMAX
DO 2 LINDEX=1,13,6
LINMAX=LINDEX+5
L=LINDEX-1
READ 103,          (TL(NU,LIND,JE),LIND=LINDEX,
1LINMAX),LCARD,NUCARD,MTCARD
IF(NU-NUCARD) 3,4,3
4 IF(L-LCARD)3,6,3
6 IF(MT-MTCARD) 3,2,3
2 CONTINUE
RETURN
53 NL=1
JE=1
3 PRINT 104,NU,JE,L,MT
103 FORMAT(6F12.6,I2,2X,Z12)
104 FORMAT(23H0THE TSUBL-CARD FOR NU=I2,5H, JE=I2,7H, L =I2,9H, AND
1MT=I2,3SH IS OUT OF PLACE IN THE INPUT DECK.)
CALL EXIT
END
SUBROUTINE DENOMR
COMMON      TL,JEM,MT,DENOM,N,A,B,C,D,
1IP,IC,ESTARM,SPIN,FO
DIMENSION      TL(5,18,45), JEM(5), DENOM(18),
1 A(5), B(5), C(5), D(5), ESTARM(5), SPIN(5),SUM(5,45),DN(18,5)
10 DO 500J=1,18
DENOM(J)=0.
RJ=J-1
IF(N-6)20,20,15
20 RJ=RJ+0.5
20 DO 501 NU=2,5
IF (JEM(NU)-2) 11,11,12
11 DN(J,NU) = 0.
60 TO 431
12 DO 25 NZERO=1,45
25 SUMINU,NZERO)=0.
```

```
C      IF N=5(J-INT) J=J-1    IF N=9(J-1/2INT) J=J-.5
      JEMAX=JEM(NU)
 30 DO 301 JE=1,JEMAX
      E=JE-.1
C      U=E/2
      DENT=DEN(E,NU)
 40 DO 302 L=1,18
      RL=L-1
      TLFAC=TL(NU,L,JE)
      IF TL FAC<1.0E-10 301,41,41
 41 DENS=DENT*TLFAC
 42 NSMIN=ABS(RJ-RL)+1.
      NSMAX=J+L-1
      IF IN NSMIN-15)43,43,302
 43 IF IN NSMAX-15)46,46,44
 44 NSMAX=15
 46 DO 303 NS=NSMIN,NSMAX
      S=NS-1
C      IF N=5 S=S, IF N=9 S=S+.5          SMAX=14
      IF IN-6)60,60,50
 50 S=S+.5
 60 IMIN=ABS(S-SPIN(NU))+1.
      IMAX=S+SPIN(NU)+1.
      DC 303 I=IMIN,IMAX
      RI=I-1
      IF IN-6)70,70,72
 70 GO TO (80,80,85,85,80),NU
 72 GO TO (80,85,80,80,85),NU
 85 RI=RI+.5
 80 SIM(NU,JE)=SUM(NU,JE)+DENS*SIG(RI,FO,E,NU)
 303 CONTINUE
 302 CONTINUE
 301 CONTINUE
      DN(J,NU)=0.
      TES=JEM(NU)
      TEST=ESTARM(NU)*2.-TES
      NEST=TEST
      IF IN TEST 410,400,410
 400 NT2=JEM(NU)/2
      NT2=NT2*2
      IF 1JEM(NU)-NT2)401,401,402
 401 DN(J,NU)=(SUM(NU,JEMAX)+SUM(NU,JEMAX-1))/2.
 402 DN(J,NU)=DN(J,NU)+SUM(NU,JEMAX)*(ESTARM(NU)*2.-JEM(NU)+1)/2.
      JEMS=(JEM(NU)+1)/2
      JEMS=JEMS*2-3
      GC TO 420
 410 JEMS=JEM(NU)/2
      JEMS=JEMS*2-1
 420 DO 430 JE=1,JEMS,2
 430 DN(J,NU)=DN(J,NU)+(SUM(NU,JE+1)+.0*SUM(NU,JE+1)+SUM(NU,JE+2))/3.
      DN(J,NU)=DN(J,NU)*.5
 431 CONTINUE
 501 DENOM(J)=DENOM(J)+DN(J,NU)
 500 DENOM(J)= SQRT(DENOM(J))
      RETURN
      END
      FUNCTION DEN(E,NU)
      COMMON      TL,JEM,MT,DENOM,N,A,B,C,D,
      LTP,IC,ESTARM,SPIN,FO
```

```
DIMENSION TL(5,18,45), JEM(5), DENOM(18),
1 A(5), B(5), C(5), D(5)
U=E/2.
1 GO TO (5,9),IC
5 CHEK=A(NU)*C(NU)*(U-B(NU))*D(NU)
IF(CHEK)6,6,7
6 DEN=0.
RETURN
7 T=(1.+SQRT(1.+4.*{U-B(NU)}*A(NU)))/(2.*A(NU))
DEN=A(NU)**.5*EXP(2.*SQRT(A(NU)*(U-B(NU))))/((U+T-B(NU))**2
1*C(NU))
RETURN
9 IF(A(NU))6,6,10
10 DEN=C(NU)*EXP({U-B(NU)}/A(NU))
RETURN
END
FUNCTION SIG(FI,FD,E,NU)
COMMON TL,JB4,MT,DENOM,N,A,B,C,D,
1IP,IC
DIMENSION TL(5,18,45), JEM(5), DENOM(18),
1 A(5), B(5), C(5), D(5)
U=E/2.
2 GO TO (1,19, 1,19),IP
1 IF(A(NU)*D(NU)*(U-B(NU)))5,5,15
5 SIG=0.
RETURN
15 IF (IP.EQ.3) GO TO 16
T=(1.+SQRT(1.+4.*{U-B(NU)}*A(NU)))/(2.*A(NU))
SIG=(2.*FI+1.)*EXP((FI+.5)**2/(-2.*D(NU)*T))/(D(NU)**1.5)
RETURN
16 SIG=(2.*FI+1.)*EXP((FI+.5)**2/(-2.*D(NU)))/(D(NU)**1.5)
RETURN
19 IF(D(NU))5,5,20
20 SIG=(2.*FI+1.)*EXP(-FI*(FI+1.)/(2.*D(NU)))/(2.*D(NU))
RETURN
END
```

## B. MAC3 Program Sample Input

I 56FE(ALPHA,ALPHA)56FE 17 MEV FERMI GAS CALC.

0.0	0.0	5	1	23	1				
1	23	23	22	1					
1.0	16.02	12.78	10.93	0.0					
1.0	5.7	6.2	6.4	6.5					
1.0	0.7	-.8	-.5	-2.					
1.0	33.941	33.941	33.941	33.941					
1.0	11.23	12.25	12.25	11.91					
1	1	2	60	0	0	3			
0.0	0.0	17.	4.0026	55.9349					
4.0026	55.9349	4.0026	55.9349	0.0					
8									
43.	63.	83.	87.	112.	142.	167.	175.		
.9981	.9988	.9978	.9972	.9968	.9900	0	160		
.9890	.9549	.9006	.7150	.3819	.1350	6	160		
.0341	.0100	.0033	.0012	.0004	.0001	12	160		
.9981	.9988	.9978	.9972	.9968	.9900	0	260		
.9890	.9549	.9006	.7150	.3819	.1350	6	260		
.0341	.0100	.0033	.0012	.0004	.0001	12	260		
.9975	.9987	.9970	.9967	.9952	.9874	0	260		
.9833	.9372	.8626	.6203	.2924	.0918	6	260		
.0232	.0070	.0023	.0008	.0003	.0001	12	260		
.9968	.9984	.9960	.9961	.9928	.9838	0	260		
.9745	.9127	.8090	.5134	.2134	.0610	6	260		
.0157	.0048	.0016	.0005	.0002	.0	12	260		
.9959	.9979	.9945	.9950	.9873	.9787	0	260		
.9611	.8790	.7354	.4026	.1488	.0357	6	260		
.0105	.0032	.0011	.0004	.0001	.0	12	260		
.9946	.9971	.9926	.9932	.9843	.9712	0	260		
.9408	.8324	.6396	.2984	.0996	.0254	6	260		
.0069	.0022	.0007	.0002	.0001	.0	12	260		
.9929	.9957	.9898	.9904	.0771	.5602	0	260		
.9105	.7687	.5248	.2092	.0642	.0161	6	260		
.0045	.0014	.0005	.0001	.0	.0	12	260		
.9905	.9935	.9861	.9860	.9668	.5433	0	260		
.8656	.6840	.4016	.1394	.0400	.0100	6	260		
.0028	.0009	.0003	.0001	.0	.0	12	260		
.9873	.9901	.9909	.9792	.9517	.9171	0	260		
.2006	.5779	.2852	.0886	.0242	.0061	6	260		
.0018	.0005	.0002	.0	.0	.0	12	260		
.9827	.9847	.9734	.9681	.9291	.8760	0	260		
.7109	.4562	.1880	.0539	.0142	.0036	6	260		
.0011	.0003	.0001	.0	.0	.0	12	260		
.9759	.9762	.9620	.9501	.8948	.8131	0	260		
.5961	.3317	.1157	.0315	.0081	.0021	6	260		
.0006	.0002	.0	.0	.0	.0	12	260		
.9650	.9624	.9440	.9208	.8429	.7211	0	260		
.4632	.2200	.0670	.0177	.0045	.0012	6	260		
.0003	.0001	.0	.0	.0	.0	12	260		
.9476	.9400	.9156	.8737	.7662	.5966	0	260		
.3276	.1330	.0363	.0096	.0024	.0006	6	260		
.0002	.0	.0	.0	.0	.0	12	260		
.9192	.9037	.8700	.8001	.6575	.4474	0	260		
.2086	.0738	.0192	.0050	.0013	.0003	6	260		
.0001	.0	.0	.0	.0	.0	12	260		
.8724	.8452	.7973	.6900	.5161	.2568	0	260		
.1196	.0379	.0096	.0024	.0006	.0001	6	260		
.0	.0	.0	.0	.0	.0	12	260		
.7949	.7523	.6850	.5409	.3578	.1726	0	260		



.9415	.4960	.6486	.1429	.0378	.0035	0	360
.0002	.0	.0	.0	.0	.0	6	360
.0	.0	.0	.0	.0	.0	12	360
.9286	.4425	.5792	.0988	.0248	.0020	0	360
.0001	.0	.0	.0	.0	.0	6	360
.0	.0	.0	.0	.0	.0	12	360
.9051	.3817	.4929	.0646	.0153	.0011	0	360
.0	.0	.0	.0	.0	.0	6	360
.0	.0	.0	.0	.0	.0	12	360
.8651	.3144	.3922	.0396	.0086	.0005	0	360
.0	.0	.0	.0	.0	.0	6	360
.0	.0	.0	.0	.0	.0	12	360
.7984	.2431	.2851	.0226	.0047	.0002	0	360
.0	.0	.0	.0	.0	.0	6	360
.0	.0	.0	.0	.0	.0	12	360
.6930	.1729	.1844	.0118	.0023	.0	0	360
.0	.0	.0	.0	.0	.0	6	360
.0	.0	.0	.0	.0	.0	12	360
.5404	.1099	.1031	.0055	.0009	.0	0	360
.0	.0	.0	.0	.0	.0	6	360
.0	.0	.0	.0	.0	.0	12	360
.3528	.0602	.0482	.0022	.0003	.0	0	360
.0	.0	.0	.0	.0	.0	6	360
.0	.0	.0	.0	.0	.0	12	360
.1765	.0269	.0181	.0007	.0001	.0	0	360
.0	.0	.0	.0	.0	.0	6	360
.0	.0	.0	.0	.0	.0	12	360
.0619	.0091	.0051	.0001	.0	.0	0	360
.0	.0	.0	.0	.0	.0	6	360
.0	.0	.0	.0	.0	.0	12	360
.0136	.0020	.0009	.0	.0	.0	0	360
.0	.0	.0	.0	.0	.0	6	360
.0	.0	.0	.0	.0	.0	12	360
.0015	.0002	.0	.0	.0	.0	0	360
.0	.0	.0	.0	.0	.0	6	360
.0	.0	.0	.0	.0	.0	12	360
.8346	.6619	.8023	.8385	.4715	.5024	0	460
.0386	.0022	.0001	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.8395	.6528	.8077	.8225	.4554	.4355	0	460
.0290	.0016	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.8438	.6430	.8128	.8029	.4374	.3672	0	460
.0214	.0011	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.8476	.6326	.8172	.7794	.4174	.3006	0	460
.0154	.0007	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.8500	.6211	.8203	.7517	.3945	.2387	0	460
.0109	.0005	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.8512	.6077	.8223	.7181	.3687	.1834	0	460
.0075	.0003	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.8518	.5943	.8230	.6812	.3396	.1364	0	460
.0051	.0002	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.8511	.5791	.8222	.6378	.3076	.0979	00	460
.0033	.0001	.0	.0	.0	.0	6	460

.0	.0	.0	.0	.0	.0	12	460
.8489	.5632	.8186	.5901	.2721	.0679	0	460
.0021	.0	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.8456	.5463	.8124	.5369	.2343	.0453	0	460
.0012	.0	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.8397	.5277	.8021	.4773	.1948	.0290	0	460
.0007	.0	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.8297	.5063	.7849	.4130	.1544	.0177	0	460
.0004	.0	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.8102	.4800	.7535	.3453	.1142	.0103	0	460
.0002	.0	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.7650	.4507	.6844	.2854	.0731	.0056	0	460
.0001	.0	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.7317	.4466	.6150	.2351	.0426	.0030	0	460
.0	.0	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.7430	.4203	.6080	.1499	.0283	.0013	0	460
.0	.0	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.7546	.3884	.5925	.0856	.0167	.0005	0	460
.0	.0	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.7660	.3488	.5611	.0424	.0083	.0001	0	460
.0	.0	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.7757	.2982	.4991	.0172	.0032	.0	0	460
.0	.0	.0	.0	.0	.0	6	460
.0	.0	.0	.0	.0	.0	12	460
.7763	.2130	.3348	.0048			0	460
						6	460
						12	460
.7529	.1237	.1124	.0006			0	460
						6	460
						12	460
.5209	.0139					0	460
						6	460
						12	460
.0	.0	.0	.0	.0	.0	0	560
.0	.0	.0	.0	.0	.0	6	560
.0	.0	.0	.0	.0	.0	12	560

C. MAC3 Program Sample Output

MACDONALD ANGULAR DISTRIBUTION

56FE1ALPHA, ALPHA156FE 17 MEV FERMI GAS CALC.

MIN ENTRANCE CHANNEL SPIN = 0.0

MAX ENTRANCE CHANNEL SPIN = 0.0

TAPE NO.= 5

JE(LOWEST)= 1 JE(HIGHEST)=23 JE(INC)= 1

I=1 I=2 I=3 I=4 I=5

JEM(I)= 1 23 23 22 1

ESTARM(I)= 0.10000E 01 0.16020E 02 0.12780E 02 0.10930E 02 0.0

A(I)= 0.10000E 01 0.57000E 01 0.62000E 01 0.64000E 01 0.65000E 01

B(I)= 0.10000E 01 0.70000E 00-0.80000E 00-0.50000E 00-0.20000E 01

C(I)= 0.10000F 01 0.33941E 02 0.33941E 02 0.33941E 02 0.33941E 02

D(I)= 0.10000E 01 0.11230F 02 0.12250E 02 0.12250E 02 0.11910E 02

ANG MOM DENSITY OPTION IS 1

ENERGY DENSITY OPTION IS 1

FO= 0.0 NU= 2

PROJECTILE SPIN= 0.0

TARGET SPIN= 0.0

PROJECTILE MASS= 4.003

TARGET MASS= 55.93439

EFF= 1.13423

PROJECTILE ENERGY= 17.000MEV

(DENOMIJ)\*\*0.5, J=0,17

0.56299E 02	0.94690E 02	0.11527E 03	0.12490E 03	0.12595E 03	0.12027E 03
0.10969E 03	0.9016F 02	0.80919E 02	0.65770E 02	0.51678E 02	0.39257E 02
0.28857E 02	0.20435E 02	0.13826E 02	0.79741E 01	0.44027E 01	0.17917E 01

RATE(J OF LEGENDRE COEFFICIENTS (A(L)/A(0)) AND A(L=0)

E(RES.)	A(L=0)/A(L=0)	A(L=2)/A(L=0)	A(L=4)/A(L=0)	A(L=6)/A(L=0)	A(L=0)	M <sub>B</sub> /SR/MEV
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.0	0.0	0.0	0.0	0.0	0.0
1.0	0.10000E 01	0.92916E 00	0.58763E 00	0.31363E 00	0.18588E-01	
1.5	0.10000E 01	0.62450E 00	0.41077E 00	0.17947E 00	0.37392E-01	
2.0	0.10000E 01	0.74876E 00	0.33785E 00	0.11716E 00	0.68546E-01	
2.5	0.10000E 01	0.70327E 00	0.29033E 00	0.88415E-01	0.10486E 00	
3.0	0.10000E 01	0.62758E 00	0.22013E 00	0.56401E-01	0.18866E 00	
3.5	0.10000E 01	0.57422E 00	0.17885E 00	0.39901E-01	0.29014E 00	
4.0	0.10000E 01	0.52349E 00	0.14475E 00	0.28208E-01	0.42757E 00	
4.5	0.10000E 01	0.47461E 00	0.11624E 00	0.19807E-01	0.60523E 00	
5.0	0.10000E 01	0.42710E 00	0.92296E-01	0.13745E-01	0.92267E 00	
5.5	0.10000E 01	0.38078E 00	0.72230E-01	0.93923E-02	0.10711E 01	
6.0	0.10000E 01	0.33579E 00	0.55588E-01	0.63021E-02	0.13284E 01	
6.5	0.10000E 01	0.29256E 00	0.41980E-01	0.41397E-02	0.15535E 01	
7.0	0.10000E 01	0.25208E 00	0.31282E-01	0.27056E-02	0.16868E 01	
7.5	0.10000E 01	0.21575E 00	0.23202E-01	0.17732E-02	0.16607E 01	
8.0	0.10000E 01	0.18497E 00	0.17302E-01	0.11500E-02	0.14382E 01	
8.5	0.10000E 01	0.16074E 00	0.13274E-01	0.77658E-03	0.10600E 01	
9.0	0.10000E 01	0.14331E 00	0.10719E-01	0.59333E-03	0.64922E 00	
9.5	0.10000E 01	0.13014E 00	0.87372E-02	0.38654E-03	0.32605E 00	
10.0	0.10000E 01	0.11950E 00	0.72437E-02	0.31431E-03	0.13367E 00	
10.5	0.10000E 01	0.10599E 00	0.55676E-02	0.10869E-03	0.42440E-01	
11.0	0.10000E 01	0.69896E-01	0.17371E-02	-0.14236E-04	0.77442E-02	

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TOTAL A(L=0) IN MB/SR/REV 0.13518E 02

TOTAL CROSS SECTION IN MBS 0.84934E 02

MACDONALD ANGULAR DISTRIBUTION

I 56Fe(ALPHA,ALPHA)56Fe 17 MEV FERMI GAS CALC.

ANGLE= 43.000 DEGREE(LAB.)

E(RES.) MEV.	E3(C.M.) MEV.	C.M. ANGLE DEG.	DIFF. CROSS SECTION MB/SR/MEV
0.0	14.81	45.80	0.0
0.5	14.34	45.84	0.0
1.0	13.87	45.89	0.17317E-01
1.5	13.41	45.94	0.36911E-01
2.0	12.94	45.99	0.69547E-01
2.5	12.47	46.05	0.10762E 00
3.0	12.01	46.11	0.19643E 00
3.5	11.54	46.17	0.30388E 00
4.0	11.07	46.23	0.44926E 00
4.5	10.61	46.31	0.63666E 00
5.0	10.14	46.38	0.86498E 00
5.5	9.67	46.46	0.11242E 01
6.0	9.21	46.55	0.13501E 01
6.5	8.74	46.64	0.16197E 01
7.0	8.27	46.74	0.17511E 01
7.5	7.81	46.85	0.17164E 01
8.0	7.34	46.97	0.14804E 01
8.5	6.87	47.11	0.10872E 01
9.0	6.41	47.25	0.66403E 00
9.5	5.94	47.42	0.33276E 00
10.0	5.47	47.60	0.13616E 00
10.5	5.01	47.81	0.43133E-01
11.0	4.54	48.06	0.78306E-02

INTEGRATION LIMIT MEV	DIFFERENTIAL CROSS SECTION MB/SR
14.00 - 13.00	0.35279E-01
13.00 - 12.00	0.11750E 00
12.00 - 11.00	0.32491E 00
11.00 - 10.00	0.65589E 00
10.00 - 9.00	0.12217E 01
9.00 - 8.00	0.16667E 01
8.00 - 7.00	0.15340E 01
7.00 - 6.00	0.16473E 00

INTEGRATION LIMIT 6.00 - 14.00 MEV  
TOTAL DIFF. XSECTION= 0.63607E 01 MB/SR

ANGLE= 63.000 DEGREE(LAB.)

E(RES.) MEV.	E3(C.M.) MEV.	C.M. ANGLE DEG.	DIFF. CROSS SECTION MB/SR/MEV
0.0	14.81	66.66	0.0
0.5	14.34	66.71	0.0
1.0	13.87	66.78	0.14531E-01
1.5	13.41	66.84	0.29425E-01
2.0	12.94	66.91	0.54726E-01
2.5	12.47	66.98	0.84592E-01
3.0	12.01	67.06	0.15554E 00
3.5	11.54	67.14	0.24305E 00
4.0	11.07	67.23	0.36381E 00
4.5	10.61	67.32	0.52293E 00
5.0	10.14	67.42	0.72151E 00
5.5	9.67	67.52	0.95318E 00

D. MAC10 Program Listing

```
C      PROGRAM MAC10
C      MODIFIED FROM PROGRAM MAC3 TO EXTEND LEGENDRE FUNCTION TO L=10.
COMMON      TL,JEM,MT,DENOM,N,A,B,C,D,
1IP,IC,ESTARM,SPIN,FO,ITLR
      DIMENSION      TL(5,18,45), JEM(15), DENOM(18),
1  A(5), B(5), C(5), D(5), ESTARM(5), SPIN(5),
2  Q(18),Z(18,18,15),PA(6,45),PB(5),ANG(24)
3,EINT1(30),EINT2(30),NX1(30),NX2(30),DC(30),DIFF(30),E3CM(30)
710 READ(5,700,END=800) NTITLE
700 FORMAT(1X,F1,78H
1
1      WRITE(6,701)
701 FORMAT(1H1,30X,'MACDONALD ANGULAR DISTRIBUTION//')
      WRITE(6,700) NTITLE
      GC TO 10
800 CALL EXIT
10 READ(5,131) S1MIN,S1MAX,N,JEL,JEH,JEI,
1(JEM(I)),I=1,5), (ESTARM(I),I=1,5), (A(I),I=1,5),
2(B(I),I=1,5), (C(I),I=1,5), (D(I),I=1,5), IP,IC, FO, NUOUT,MT,ITLR
3, IDENCM, ITDP, LBIG
13 FORMAT (2F8.1,18,3I8/5I8/5F8.5/5E12.5/
15E12.5 / 5E12.5 / 5E12.5 /
214, I4, E12.5,6I4)
      READ(5,195) SIP,SIT,E8,AM,TM
195 FORMAT(2F8.1,3F8.3)
      WRITE(6,141) S1MIN,S1MAX,N,
1JEL,JEH,JEI,(JEM(I),I=1,5),(ESTARM(I),I=1,5),
2(A(I),I=1,5),(B(I),I=1,5),(C(I),I=1,5),
3(D(I),I=1,5),IP,IC,FO,NUOUT
14 FORMAT(1H0,28HMIN ENTRANCE CHANNEL SPIN = ,F4.1/
21H ,28HMAX ENTRANCE CHANNEL SPIN = ,F4.1/
31H ,10HTAPE NO.= ,I1/IH ,11HJE (LOWEST)= ,I2,5X+12HJE (HIGHEST)= ,
4I2,5X,8HJE INC)= ,I2/IH ,14X,3HI=1,9X,3HI=2,9X,3HI=3,
59X,3HI=4,9X,3HI=5/1H ,7HJEM(I)=,4X,5I12/
61H ,10HESTARM(I)=,IX,5E12.5/1H ,5HA(I)=,6X,
75E12.5/1H ,5HB(I)=,6X,5E12.5/1H ,5HC(I)=,6X,5E12.5/1H ,5HD(I)=,
86X,5E12.5/1H ,26HANG MOM DENSITY OPTION IS ,I2/
91F ,25HENERGY DENSITY OPTION IS ,I2/IH ,3HFO=,E12.5,IH ,3HNU=,12)
EFF=0.01914*FB*(2.0*SIP+1.0)*(2.0*SIT+1.0)*AM*(TM/(AM+TM))**2
      WRITE(6,920) SIP,SIT,AM,TM,EFF,E8
920 FORMAT(1H0,16HPROJECTILE SPIN=F8.3/
11H0,12HTARGET SPIN=F8.3/
21H0,16HPROJECTILE MASS=F8.3/
31H0,12HTARGET MASS=F12.5/1X,4HEFF=F12.5/
4I0,18HPROJECTILE ENERGY=F12.3,3HMEV)
      IF ((DENOM.NE.1)) GO TO 720
      WRITE(6,721)
721 FORMAT('0 PREVIOUS DENOM(I) VALUES ARE USED//')
720 CCNTINUE
      READ(5,750) AM1,AM2,AM3,AM4,AQ
750 FORMAT(8F10.5)
      READ(5,751) NANGLE
751 FORMAT(1S)
      READ(5,750) IANG(I),I=1,NANGLE)
      IF ((ITLR-1) 400,401,400
400 CALLTLREAD
401 CCNTINUE
      SPIN(1)=1.
      SPIN(2)=0.
```

```
SPIN(3)=.5
SPIN(4)=.5
SPIN(5)=1.
IF(N=6)1,1,2
1 IS1MIN=SIMIN+1.
IS1MAX=SIMAX+1.
GOTO3
2 IS1MIN=SIMIN+.5
IS1MAX=SIMAX+.5
3 CONTINUE
IF(IIDENOM.EQ.1) GO TO 620
CALL DENOMR
620 CONTINUE
WRITE(6,630) (DENCM(J),J=1,18)
630 FORMAT(1H0, '(DENOM(J))**0.5, J=1,18' / 1H ,6E13.5/LX,6E13.5/
11X,6E13.5)
NT=N+8
LXX=4
IF(LBIG.EQ.0) LBIG=6
IF(LBTG.EQ.8) LXX=5
IF(LBIG.EQ.10) LXX=6
DC130L*1,LXX
F=2*(L-1)
DC119II=1,18
DC119JJ=1,18
READ(NT) LT,IT,JT,(Z(II,JJ,KK), KK=1,15)
IF(LT=L)217,301,217
301 IF((T-(I))217,302,217
302 IF(JT-JJ)217,119,217
119 WRITE(6,218) L,II,JJ,LT,IT,JT
218 FORMAT(120H BAD ZCODE READIN, L=,12,5H I=,12,5H J=,12,
13X3HLT=15,3X3HIT=15,3X3HJT=15)
GO TO 800
119 CONTINUE
DC190JO=1,18
DC190JO=1,18
DC190KO=1,15
190 Z(IU,JO,KO)=Z(IC,JO,KC)/DENOM(JO)
DC130JE*JEL,JEH,JEI
E=JE-1
34 JO = 1
PROD=C,
DC125(SI=ISIMIN,ISIMAX
SI=ISI
IF(N=6)4,4,5
4 FS=SI-1.
GOTO6
5 ES=SI-.5
6 DO 125 I = 1, 14
IF(N=6)201,201,202
201 GOTO(203,203,204,204,203),NUOUT
203 FI=I-1
GOTO220
204 FI=I
FI=FI-.5
GOTO220
202 GOTO(204,204,203,203,204),NUOUT
220 DENS = SIG(FI, FO, E, NUOUT)
S2MIN=ABS (FI-SPIN(NUOUT))
```

```
S2MAX=F1+SP IN(NUOUT)
IF(N=6)227,227,228
227 IS2MIN=S2MIN+1.
IS2MAX=S2MAX+1.
GOTO229
228 IS2MIN=S2MIN+.5
IS2MAX=S2MAX+.5
229 00125IS2=IS2MIN,IS2MAX
IF(N=6)230,230,231
230 S2=IS2-1
GOTO232
231 S2=IS2
S2=S2-.5
232 KS=S2-ES
FAC=(-1.)**(KS))*DENS
DO 127 L1 = 1, 18
FL1=L1-1
JMIN=ABS(FL1-ES)+1.
JMAX=MIN1(FL1+ES,17.0)+1
FACA = FAC * TL(1, L1, 1 )
DO 124 L2 = 1, 18
FACB=FACA*TL(NUOUT,L2,JE)
G=ABS(FACB)
IF (G-.0000001) 127, 127, 120
120 00123J=JM[N,JMAX
123 PROD = PROD + FACB * Z( L1, J, IS1 ) * Z(L2, J, IS2 )
124 CONTINUE
127 CONTINUE
125 CONTINUE
PROD=PROD/EFF
130 PA(L,JE)=PROD*DENS(E,NUOUT)
WRITE(6,41)
41 FORMAT(1H0,18X,'RATIO OF LEGENDRE COEFFICIENTS (A(L)/A(0)) AND A
1(L=0)'
2/1H0,2X,*E(RES.),4X,' A(L=2)/A(L=0) A(L=4)/A(L=0) A(L=6)/A(L=0) A
3(L=8)/A(L=0) A(L=10)/A(L=0) A(L=0)'/4X,'MEV',80X,'MB/SR/MEV')
DO128 JE=JEL,JEH,JEI
E=JE-1
E=0.5*F
IF (PA(1,JE).GT..000001) GO TO 501
PB(1)=0.
PB(2)=0.
PB(3)=0.
PB(4)=0.
PB(5)=0.
GO TO 502
501 CONTINUE
LXX2=3
IF (LBIG.EQ.8) LXX2=4
IF (LBIG.EQ.10) LXX2=5
DO 500 L=1,LXX2
LK=L+1
PB(L)=PA(LK,JE)/PA(1,JE)
500 CONTINUE
IF (LBIG.EQ.8) GO TO 550
IF (LBIG.EQ.10) GO TO 560
502 WRITE(6,47) E, (PB(LL),LL=1,3),PA(1,JE)
47 FORMAT(1H ,2X,F5.1,7X,3(E12.5,2X),28X,E12.5)
GO TO 128
```

```
550 WRITE(6,551) E,(PB(LL),LL=1,4),PA(1,JE)
551 FORMAT(1H ,2X,F5.1,7X,4(E12.5,2X),14X,E12.5)
      GO TO 128
560 WRITE(6,561) E,(PB(LL),LL=1,5),PA(1,JE)
561 FORMAT(1H ,2X,F5.1,7X,6(E12.5,2X))
128 CONTINUE
      PASUM=0.
      DO 510 J=JEL,JEH,JEI
510  PASUM=PASUM+PA(1,J)
      PASUM=PASUM-(PA(1,JEL)+PA(1,JEH))/2.
      SJEI=JEI
      DELE=SJEI/2.
      CSECT=4.*3.14159*DELE*PASUM
      WRITE(6,511) PASUM,CSECT
511  FORMAT(1H0,41X,*TOTAL A(L=0) IN MB/SR/MEV *,E12.5//42X,*TOTAL CROS
1S SECTION IN MBS*,E12.5)
      WRITE(6,701)
      WRITE(6,700) NTITLE
      IF (ITOP.EQ.0) GO TO 759
      IF (ITOP.EQ.2) GO TO 758
      READ(5,801) EMINB,EMAXB,DELEB,NOINT
801  FORMAT(3F10.5,15)
      IF (ITOP.EQ.1) GO TO 759
758  READ(5,801) ETMIN,ETMAX
759  CCNTINUE
      DO 761 JI=1,NANGLE
      XANGLE=ANG(JI)*17.453292/1000.
      WRITE(6,762) ANG(JI)
762  FORMAT(1H0,*ANGLE=' ,F8.3,' DEGREE(LAB.)*//* E(RES.) E3(C.M.)
1 C.M. ANGLE DIFF. CROSS SECTION'/4X,4HMEV.,8X,4HMEV.,8X,*DEG.*,
2BX,*MB/SR/MEV *)
      DO 760 JJE=JEL,JEH,JEI
      E=JJE-1
      E=0.5*E
      E3CM(JJE)=E8*AM2*AM4/(AM1+AM2)**2)+(AQ-E)*AM4/(AM3+AM4)
      Z1=AM1*AM3*E8
      Z2=COS(XANGLE)
      Y1=Z1*Z2*(Z1+AM3+AM4)*(AM4*(AQ-E)+E8*(AM4-AM1))
      Y1=SQRT(Y1)
      Y2=Z2*SQRT(Z1)
      E3LAB1=(Y1+Y2)/(AM3+AM4)
      E3CM1=SQRT(E3CM(JJE))
      X1=E3LAB1*SIN(XANGLE)
      XCMANG=ARSIN(X1/E3CM1)
      V1=SQRT(2.*E8/(AM1*931.441))
      VCM=V1*AM1/(AM1+AM2)
      V3LAB=E3LAB1/SQRT(AM3*931.441/2.)
      V3X=V3LAB*22
      IF (VCM.GT.V3X) XCMANG=3.14159-XCMANG
      CMANG=XCMANG*100./1.74533
      CANG1=COS(XCMANG)
      CANG2=CANG1*CANG1
      CANG4=CANG2*CANG2
      CANG6=CANG4*CANG2
      CANG8=CANG6*CANG2
      CANG10=CANG8*CANG2
      CROSS1=PA(1,JJE)-PA(2,JJE)/2.+PA(3,JJE)*3./8.-PA(4,JJE)*5./16.
      CROSS2=(PA(2,JJE)*24.-PA(3,JJE)*60.+PA(4,JJE)*105.)*CANG2+
1 PA(3,JJE)*70.-PA(4,JJE)*315.)*CANG4+PA(4,JJE)*231.*CANG6
```

```
IF (LBIG.EQ.8) GO TO 770
IF (LBIG.EQ.10) GO TO 770
DIFF(JJE)=CROSS1+CROSS2/16.
GO TO 780
770 P8=(6435.*CANG8-12012.*CANG6+6930.*CANG4-1260.*CANG2+35.)/128.
CROSS53=PA(5,JJE)*P8
IF (LBIG.EQ.10) GO TO 771
DIFF(JJE)=CROSS1+CROSS2/16.+CROSS3
GO TO 780
771 P10=(46189.*CANG10-109395.*CANG8+90090.*CANG6-30030.*CANG4+
1 3465.*CANG2-63.)/256.
CROSS4=PA(6,JJE)*P10
DTFF(JJE)=CROSS1+CROSS2/16.+CROSS3+CROSS4
780 CONTINUE
WRITE(6,763) E,E3CM(JJE),CMANG,DIFF(JJE)
763 FORMAT(3X,F5.1,5X,F8.2,5X,F6.2,7X,E12.5)
760 CONTINUE
IF (ITOP.EQ.0) GO TO 890
IF (ITOP.EQ.2) GO TO 830
EINT1(1)=EMAXB
EINT2(1)=EMAXB-DELEB
DO 802 NX=2,NCINT
EINT1(NX)=EINT2(NX-1)
802 EINT2(NX)=EINT1(NX)-DELEB
DO 803 KE=JEL,JEH,JET
IF (E3CM(KE).LE.EMAXB) GO TO 804
803 CONTINUE
804 NX1(1)=KE
DC 805 LE=KE,JEH,JEI
IF (E3CM(LE).LE.EINT2(1)) GO TO 806
805 CONTINUE
806 NX2(1)=LE-1
DO 808 NE=2,NOINT
NX1(NE)=NX2(NE-1)+1
KX1=NX1(NE)
DO 807 KX=KX1,JEH,JEI
IF (E3CM(KX).LE.EINT2(NE)) GO TO 808
807 CONTINUE
808 NX2(NE)=KX-1
DO 820 LX=1,NOINT
K1=NX1(LX)
K2=NX2(LX)
DC12=(DIFF(K1)-DIFF(K1-1))*(E3CM(K1-1)-EINT1(LX))/(E3CM(K1-1)-
1E3CM(K1))+DIFF(K1-1)
DC1=(DC12+DIFF(K1))*((EINT1(LX)-E3CM(K1))/2.
DC22=(DIFF(K2+1)-DIFF(K2))*(E3CM(K2)-EINT2(LX))/(E3CM(K2)-
1E3CM(K2+1))+DIFF(K2)
DC2=(DC22+DIFF(K2))*((E3CM(K2)-EINT2(LX))/2.
DC3=0.
IF (NX1(LX).EQ.NX2(LX)) GO TO 811
K22=K2-1
DO 810 LY=K1,K22
810 DC3=DC3+(E3CM(LY)-E3CM(LY+1))*(DIFF(LY)+DIFF(LY+1))/2.
811 DC(LX)=DC1+DC2+DC3
820 CONTINUE
WRITE(6,821)
821 FORMAT(1H0,6X,*INTEGRATION LIMIT DIFFERENTIAL CROSS SECTION*/
114X,'MEV',19X,'MB/SR')
WRITE(6,822) (EINT1(NZ),EINT2(NZ),DC(NZ),NZ=1,NOINT)
```

```
822 FORMAT(8X,F6.2,* - *,F6.2,11X,E12.5)
  IF (ITOP.EQ.1) GO TO 890
  830 DO 831 IE=JEL,JEM,JE1
    IF (E3CM(IE).LE.ETMAX) GO TO 832
  831 CONTINUE
  832 DO 840 IE1=IE,JEH,JE1
    IF (E3CM(IE1).LE.ETMIN) GO TO 841
  840 CONTINUE
  841 JK=IE1-1
    U12=(DIFF(IE)-DIFF(IE-1))*(E3CM(IE-1)-ETMAX)/(E3CM(IE-1)-E3CM(IE))
    I+DIFF(IE-1)
    U1=((U12+DIFF(IE))/2.)*(ETMAX-E3CM(IE))
    U22=(DIFF(JK+1)-DIFF(JK))*(E3CM(JK)-ETMIN)/(E3CM(JK)-E3CM(JK+1))
    I+DIFF(JK)
    U2=((U22+DIFF(JK))/2.)*(E3CM(JK)-ETMIN)
    U3=0.
    IF (IE.EQ.JK) GO TO 851
    IT4=JK-1
    DO 850 IT=IE,IT4
  850 U3=U3+(E3CM(IT)-E3CM(IT+1))*(DIFF(IT)+DIFF(IT+1))/2.
  851 OCTOT=U1+U2+U3
    WRITE(6,860) ETMIN,ETMAX,OCTOT
  860 FORMAT(1H0,6X,'INTEGRATION LIMIT ',F6.2,* - *,F6.2,' MEV'/
    17X,'TOTAL DIFF. XSECTION=',E12.5,' MB/SR')
  890 CCNTINUE
  761 CONTINUE
  REWIND NT
  GO TO 710
  END
  SUBROUTINE TLREAD
C ROUTINE TO READ IN TL CARDS PRODUCED BY OPT MDO.
C REVISED BY C. C. LU
C COMMON      TL,JEM,MT,DENOM,N,A,B,C,D,
  1 IP,IC,ESTARM,SPIN,FD,ITLR
  DIMENSION      TL(5,18,45), JEM(5), DENOM(18),
  1 A(5), B(5), C(5), D(5), ESTARM(5), SPIN(5)
C FIRST READ NU=1, JE=1 CARDS.
  DO 52 L INDEX=1,13,6
  LINMAX=L INDEX+5
  L=L INDEX-1
  READ 103,          (TL(1,L IND,1),LIND=L INDEX,LINMAX),
  1 LCARD,NUCARD,MTCARD
C CHECK CARDS FOR PROPER INDICES AND ORDER.
  IF(L-NUCARD) 53,54,53
  54 IF(L-LCARD) 53,56,53
  56 IF(MT-MTCARD) 53,52,53
  52 CCNTINUE
  IF (ITLR-2) 200,203,203
  203 CCNTINUE
  RETURN
C NOW READ IN FOR THE REST OF THE CHANNELS, AND CHECK ORDER.
  200 NU1=2
  NU2=5
  57 DO 2 NU=NU1,NU2
  70 JEMAX=JEM(NU)
  90 CCNTINUE
  DO 2 JE=1,JEMAX
  DO 2 L INDEX=1,13,6
  LINMAX=L INDEX+5
```

```
L=LINDEX-1
READ 103,          (TL(NU,LIND,JE),LIND=LINDEX,
1LINMAXI,LCARD,NUCARD,MTCARD
IF(NU=NUCARD) 3,4,3
4 IF(L=LCARD)3,6,3
6 IF(MT=MTCARD) 3,2,3
2 CONTINUE
RETURN
53 NU=1
JE=1
3 PRINT 104,NU,JE,L,MT
103 FORMAT(6F12.6,I2,2X,2I2)
104 FORMAT(23H0 THE TSUBL-CARD FOR NU=I2,5H, JE=I2,7H, L =I2,9H, AND
1MT=I2,35H IS OUT OF PLACE IN THE INPUT DECK.)
CALL EXIT
END
SUBROUTINE DENOMR
COMMON      TL,JEM,MT,DENOM,N,A,B,C,D,
1IP,IC,ESTARM,SPIN,FO
DIMENSION    TL(5,18,45), JEM(5), DENOM(18),
1 A(5), B(5), C(5), D(5), ESTARM(5), SPIN(5),SUM(5,45),DN(18,5)
10 DC 500J=1,18
DENOM(J)=0.
RJ=J-1
IF(N=6)20,20,15
15 RJ=RJ+0.5
20 DO 501 NU=2,5
IF (JFM(NU)=2) 11,11,12
11 DN(J,NU) = 0.
GO TO 431
12 DO 25 NZERO=1,45
25 SUM(NU,NZERO)=0.
C     IF N=5(J-INT) J=J-1    IF N=9(J-1/2INT) J=J-.5
JEMAX=JEM(NU)
30 DO 301 JE=1,JEMAX
E=JE-1
C     U=E/2
DENT=DEN(E,NU)
40 DO 302 L=1,18
RL=L-1
TLFAC=TL(NU,L,JE)
IF(TLFAC-1.OE-10)301,41,41
41 DENS=DENT*TLFAC
42 NSMIN=ABS(RJ-RL)+1.
NSMAX=J+L-1
IF(NSMIN-15)43,43,302
43 IF(NSMAX-15)46,46,44
44 NSMAX=15
46 DO 303 NS=NSMIN,NSMAX
S=NS-1
C     IF N=5 S=S, IF N=9 S=S+.5           SMAX=14
IF(N=6)60,60,50
50 S=S+.5
60 IMIN=ABS(S-SPIN(NU))+1.
IPAX=S+SPIN(NU)+1.
DO 303 I=IMIN,IMAX
RI=I-1
IF(N=6)70,70,72
70 GO TO 180,80,85,85,801,NU
```

```
72 GO TO (80,85,80,80,85),NU
85 RI=RI+.5
80 SUM(NU,JE)=SUM(NU,JE)+DENS*SIG(RI,FO,E,NU)
303 CONTINUE
302 CONTINUE
301 CONTINUE
DN(J,NU)=0.
TES=JEM(NU)
TEST=ESTARM(NU)*2.-TES
NEST=TEST
IF(NEST)410,400,410
400 NT2=JEM(NU)/2
NT2=NT2*2
TF(JEM(NU))-NT2)401,401,402
401 DN(J,NU)=(SUM(NU,JEMAX)+SUM(NU,JEMAX-1))/2.
402 DN(J,NU)=DN(J,NU)+SUM(NU,JEMAX)*(ESTARM(NU)*2.-JEM(NU)+1)/2.
JEMS=1JEM(NU)+1)/2
JEMS=JEMS*2-3
GO TO 420
410 JEMS=JEM(NU)/2
JEMS=JEMS*2-1
420 DO 430 JE=1,JEMS+2
430 DN(J,NU)=DN(J,NU)+(SUM(NU,JE)+4.0*SUM(NU,JE+1)+SUM(NU,JE+2))/3.
DN(J,NU)=DN(J,NU)*.5
431 CONTINUE
501 DENOM(J)=DENOM(J)+DN(J,NU)
500 DENOM(J)=SQRT(DENOM(J))
RETURN
END
FUNCTION DFN(F,NU)
COMMON      TL,JEM,MT,DENOM,N,A,B,C,D,
1 IP,IC,ESTARM,SPIN,FO
DIMENSION      TL(5,18,45), JEM(5), DENOM(18),
1 A(5), B(5), C(5), D(5)
U=F/2.
1 GO TO (5,9),1C
5 CHEK=A(NU)*C(NU)*(U-B(NU))*D(NU)
1F(CHEK)6,7
6 DEN=0.
RETURN
7 T=(1.+SQRT(1.+4.*U-B(NU))*A(NU))/((2.*A(NU))
DEN=A(NU)**.5*EXP(2.*SQRT(A(NU)*(U-B(NU))))/(U+T-B(NU))**2
1*C(NU))
RETURN
9 IF(A(NU))6,6,10
10 DFN=C(NU)*EXP((U-B(NU))/A(NU))
RETURN
END
FUNCTION SIGIFI,FO,E,NU)
COMMON      TL,JEM,MT,DENOM,N,A,B,C,D,
1 IP,IC
DIMENSION      TL(5,18,45), JEM(5), DENOM(18),
1 A(5), B(5), C(5), D(5)
U=E/2.
2 GO TO (1,19, 1,19),IP
1 IF(A(NU)*D(NU)*(U-B(NU)))5,5,15
5 SIG=0.
RETURN
15 IF (IP.EQ.3) GO TO 16
```

```
T=(1.+SQRT(1.+4.*I0-B(NU)))*A(NU))/({2.*A(NU)})
SIG={2.*FI+1.)*EXP({FI+.5)**2/(-2.*D(NU)*T)}/{0(NU)**1.5}
RETURN
16 SIG={2.*FI+1.)*EXP({FI+.5)**2/(-2.*D(NU))}/{0(NU)**1.5}
RETURN
19 IF(D(NU)>5,5,20
20 SIG={2.*FI+1.)*EXP(-FI*(FI+1.)/({2.*D(NU)})){2.*D(NU)}
RETURN
END
```

E. MACT3 Program Listing

```
C      PROGRAM MACT3
      COMMON DUMMY,TL,JEM,MT,DENOM,N,A,B,C,D,
     1IP,IC,ESTARM,SPIN,FO,ITLR,CG,1EOS
      DIMENSION DUMMY(18), TL(6,18,40), JEM(6), DENOM(18),
     1 A(6), B(6), C(6), D(6), ESTARM(6), SPIN(6),CG(10),
     2 Q(18),Z(18,18,15),PA(4,40),PB(4),ANG(24)
     3,EINT1(30),EINT2(30),NX1(30),NX2(30),DC(30),DIFF(30),E3CM(30)
710 READ(5,700,END=800) NTITLE
700 FCRMAT(1X,11,78H
   1
   READ(5,852) LTITLE
852 FCRMAT(1X,11,78H
   1
   READ(5,850) (CG(I),I=1,6)
   READ(5,851) SPIN(6),IECS
850 FORMAT(6F10.5)
851 FORMAT(F5.2,$)
   WRITE(6,701)
701 FORMAT(1H1,30X,*MACDONALD ANGULAR DISTRIBUTION*//)
   WRITE(6,700) NTITLE
   WRITE(6,852) LTITLE
   GO TO 10
800 CALL EXIT
10 READ(5,13) S1MIN,S1MAX,N,JEL,JEH,JEI,
   1(JEM(I),I=1,6), (ESTARM(I),I=1,6), (A(I),I=1,6),
   2(B(I),I=1,6), (C(I),I=1,6), (D(I),I=1,6), IP,IC, FO, NUOUT,MT,ITLR
   3,1DENOM,1TOP
13 FCRMAT (2F8.1,18,318/618/6F8.5/6E12.5/
   16E12.5 / 6E12.5 / 6E12.5 /
   214, 14, E12.5,514)
   READ(5,195) SIP,SIT,EB,AM,TM
195 FORMAT(2F8.1,3F8.3)
   WRITE(6,14) S1MIN,S1MAX,N,
   1JEL,JFH,JEI,(JEM(I),I=1,6),(ESTARM(I),I=1,6),
   2(A(I),I=1,6),(B(I),I=1,6),(C(I),I=1,6),
   3(D(I),I=1,6),(CG(I),I=1,6)
14 FORMAT(1H0,28HMIN ENTRANCE CHANNEL SPIN = ,F4.1/
   21H ,28HMAX ENTRANCE CHANNEL SPIN = ,F4.1/
   31H ,10HTAPE NO.= ,11/1H ,11HJE(LOWEST)=,12,5X,12HJE(HIGHEST)=,
   4T2,5X,8HJE(INC)=,12/1H ,14X,3HI=1,9X,3HI=2,9X,3HI=3,
   59X,3HI=4,9X,3HI=5,9X,3HI=6/1H ,7HJEM(I)=,4X,6E12/
   61H ,10HESTARM(I)=,1X,6E12.5/1H ,5HA(I)=,6X,
   76E12.5/1H ,5HB(I)=,6X,6E12.5/1H ,5HC(I)=,6X,6E12.5/1H ,5HD(I)=,
   86X,6E12.5/1H ,5CG(I)=,5X,6E12.5)
   WRITE(6,15) IP,IC,FO,NUOUT
15 FORMAT(1H0,'ANG MOM DENSITY OPTION IS ',12/1H , 'ENERGY DENSITY OPT
   1ION IS ',12/1H ,3HFC=,E12.5,1X,'NUUUT=',12)
   EFF=0.01914*FB*(2.0*SIP+1.0)*12.0*SIT+1.01*AN*(TM/(AM+TM))**2
   WRITE(6,920) SIP,SIT,AM,TM,EFF,EB
920 FORMAT(1H0,16HPROJECTILE SPIN=F8.3/
   11H0,12HTARGET SPIN=F8.3/
   21H0,16HPROJECTILE MASS=F8.3/
   31H0,12HTARGET MASS=F12.5/1X,4HEFF=F12.5/
   41H0,18HPROJECTILE ENERGY=F12.3,3HMEV)
   IF (1DENOM.NE.1) GO TO 720
   WRITE(6,721)
721 FORMAT('0 PREVIOUS DENOM(I) VALUES ARE USED'//)
720 CONTINUE
   READ(5,750) AM1,AM2,AM3,AM4,AQ
```

```
750 FORMAT(8F10.5)
  READ(5,751) NANGLE
751 FORMAT(I5)
  READ(5,750) (ANG(I),I=1,NANGLE)
  IF I(ILR-1) 400,401,400
400 CALLTLREAD
401 CONTINUE
  SPIN(1)=1.
  SPIN(2)=0.
  SPIN(3)=.5
  SPIN(4)=.5
  SPIN(5)=1.
  IF(N=6)1,1,2
1  ISIMIN=SIMIN+1.
  ISIMAX=SIMAX+1.
  GOTO3
2  ISIMIN=SIMIN+.5
  ISIMAX=SIMAX+.5
3  CONTINUE
  IF (IDENOM.EQ.1) GO TO 620
  CALL DENOMR
620 CONTINUE
  WRITE(6,630) (DENOM(J),J=1,18)
630 FORMAT(1H0,'(DENOM(J))**0.5, J=0+17*IH ,6E14.5/1X,6E14.5/1X,6E14.
15)
  NT=N+8
  DC130L=1,4
  F=2*(L-1)
  DO119II=1,18
  DO119JJ=1,18
  READ(NT) LT,IT,JT,(Z(IJ,JJ,KK), KK=1,15)
  IF(LT-L)217,301,217
301 IF(IT-II)217,302,217
302 IF(JT-JJ)217,119,217
217 WRITE(6,218) L,II,JJ,LT,IT,JT
218 FORMAT(12H BAD ZCODE READIN, L=,I2.5H   I=,I2.5H   J=,I2.
13X3H LT=I5,3X3H IT=I5,3X3H JT=I5)
  GO TO 800
119 CONTINUE
  DO190 IO=1,18
  DC190 JO=1,18
  DO190 KO=1,15
190 Z(IO,JO,KO)=/(IO,JO,KO)/DENOM(JO)
  DO130 JE=JEL,JEH,JEI
  E=JE-1
34  JD = 1
  PROD=0.
  DO125 IS1=ISIMIN,ISIMAX
  SI=IS1
  IF(N=6)4,4,5
4   ES=SI-1.
  GOTO6
5   ES=SI-.5
6   DC 125 I = 1, 14
  IF(N=6)201,201,202
201 GO TO (203,203,204,204,203,198),N/OUT
198 GO TO (204,203),IEOS
203 FT=I-1
  GOT0220
```

```
204 FI=I
    FI=FI-.5
    GOTO220
202 GO TO (204,204,203,203,204,199),NUDUT
199 GO TO (203,204),IEOS
220 DENS = SIG(FI, FO, E, NUDUT)
S2MIN=ABS (FI-SPIN(NUDUT))
S2MAX=FI+SPIN(NUDUT)
IF(N=6)227,227,228
227 IS2MIN=IS2MIN+1.
IS2MAX=IS2MAX+1.
GOTO229
228 IS2MIN=IS2MIN+.5
IS2MAX=IS2MAX+.5
229 DO125 IS2=IS2MIN,IS2MAX
IF(N=6)230,230,231
230 S2=IS2
GCT0232
231 S2=IS2
S2=S2-.5
232 KS=S2-ES
FAC=1(-1.)**(KS)*DENS
DO 127 L1 = 1, 18
FL1=L1-1
JM1N=ABS(FL1-ES)+1.
JM1X=MIN1(FL1+ES,17.0)+1
FACA = FAC * TL(1, L1, 1 )
DO 124 L2 = 1, 18
FACB=FACA*TL(NUDUT,L2,JE)
G=ABS(FACB)
IF (G<.0000001 ) 127, 127, 120
120 DC123 J=JM1N,JMAX
123 PROD = PROD + FACB * Z( L1, J, IS1 ) *Z(L2, J, IS2 )
124 CONTINUE
127 CONTINUE
125 CONTINUE
PRCD=PROD/EFF
130 PA1L,JE1=PRCD*DFN(IF,NUCUT)*CG(1)*CG(NUDUT)
WRITE(6,41)
41 FFORMAT(1H0,18X,*RATIO OF LEGENDRE COEFFICIENTS (A(L)/A(0)) AND A
L(L=0)*
2/1H0,2X,'E(RES,J)*,4X,' A(L=0)/A(L=0) A(L=2)/A(L=0) A(L=4)/A(L=0) A
3LL=6)/A(L=0) A(L=0)*/4X,*MEV*,65X,*MB/SR/MEV*
D0128JE=JEL,JEH,JET
E=JE-1
E=0.5*E
IF (PA1L,JE1).GT..000001) GO TO 501
PB(1)=0.
PB(2)=0.
PB(3)=0.
PB(4)=0.
GO TO 502
501 DO 500 L=1,4
PB(L)=PA1L,JE1/P4(1,JE1)
500 CCNTINUE
502 WRITE(6,47) E, (PB(LL),LL=1,4),PA1L,JE1
47 FFORMAT(1H0,2X,F5.1,7X,S(E12.5,2X))
128 CONTINUE
PASUM=0.
```

```
DO 510 J=JEL,JEH,JEI
510 PASUM=PASUM+PA(1,J)
PASUM=PASUM-(PA(1,JEL)+PA(1,JEH))/2.
SJEI=JET
DELF=SJEI/2.
CSECT=4.*3.14159*DELE*PASUM
WRITE(6,511) PASUM,CSECT
511 FORMAT(1H0,41X,'TOTAL A(L=0) IN MB/SR/MEV ',E12.5//42X,'TOTAL CROS
IS SECTION IN NBS',E12.5)
WRITE(6,701)
WRITE(6,700) NTITLE
WRITE(6,852) LTITLE
IF (ITOP.EQ.0) GO TO 759
IF (ITOP.EQ.2) GO TO 758
READ(5,801) EMINB,EMAXB,DELEB,NOINT
801 FORMAT(3F10.5,15)
IF (ITOP.EQ.1) GO TO 759
758 READ(5,801) ETMIN,ETMAX
759 CONTINUE
DO 761 JI=1,NANGLE
XANGLE=ANG(JI)*17.453292/1000.
WRITE(6,762) ANG(JI)
762 FORMAT(1H0,'ANGLE=',F8.3,* DEGREE(LAB.)*//* E(RES.) E3(C.M.)
* C.M. ANGLE DIFF. CROSS SECTION */4X,4HMEV.,8X,4HMEV.,8X,'DEG.',*
28X,'MB/SR/MEV')
DO 760 JJE=JEL,JEH,JEI
E=JJEE-1
E=0.5*E
E3CM1(JJE)=EB*AM2*AM4/((AM1+AM2)**2)+(AQ-E)*AM4/(AM3+AM4)
Z1=AM1*AM3*EB
Z2=COS(XANGLE)
Y1=Z1*Z2*Z2+(AM3+AM4)*(AM4*(AQ-E)+EB*(AM4-AM1))
Y1=SQRT(Y1)
Y2=Z2*SQRT(Z1)
E3LAB1=(Y1+Y2)/(AM3+AM4)
E3CM1=SQRT(E3CM1(JJE))
X1=E3LAB1*SIN(XANGLE)
XCMANG=ARSIN(X1/E3CM1)
V1=SQRT(1.*EB/(AM1*931.441))
VCM=V1*AM1/(AM1+AM2)
V3LAB=F3LAB1/SQRT(AM3*931.441/2.)
V3X=V3LAB*Z2
IF (VCM.GT.V3X) XCMANG=3.14159-XCMANG
CMANG=XCMANG*100./1.74533
CANG1=COS(XCMANG)
CANG2=CANG1*CANG1
CANG4=CANG2*CANG2
CANG6=CANG4*CANG2
CROSS1=PA(1,JJE)-PA(2,JJE)/2.+PA(3,JJE)*3./8.-PA(4,JJE)*5./16.
CROSS2=(PA(2,JJE)*24.-PA(3,JJE)*60.+PA(4,JJE)*105.)*CANG2+
1*(PA(3,JJE)*70.-PA(4,JJE)*315.)*CANG4+PA(4,JJE)*231.*CANG6
DIFF(JJE)=CROSS1+CROSS2/16.
WRITE(6,763) E,E3CM1(JJE),CMANG,DIFF(JJE)
763 FORMAT(3X,F5.1,5X,F8.2,5X,F6.2,7X,E12.5)
760 CONTINUE
IF (ITOP.EQ.0) GO TO 890
IF (ITOP.EQ.2) GO TO 830
EINT1(1)=EMAXB
EINT2(1)=EMAXB-DELEB
```

```
DO 802 NX*2,NOINT
EINT1(NX)=EINT2(NX-1)
802 EINT2(NX)=EINT1(NX)-DELEB
DO 803 KE=JEL,JEH,JEI
IF (E3CM(KE).LE.EMAXB) GO TO 804
803 CONTINUE
804 NX1(1)=KE
DO 805 LE=KE,JEH,JEI
IF (E3CM(LE).LE.EINT2(1)) GO TO 806
805 CONTINUE
806 NX2(1)=LE-1
DO 808 NE*2,NOINT
NX1(NE)=NX2(NE-1)+1
KX1=NX1(NE)
DO 807 KX=KX1,JEH,JEI
IF (E3CM(KX).LE.EINT2(NE)) GO TO 808
807 CONTINUE
808 NX2(NE)=KX-1
DO 820 LX=1,NOINT
K1=NX1(LX)
K2=NX2(LX)
DC12=(DIFF(K1)-DIFF(K1-1))*(E3CM(K1-1)-EINT1(LX))/(E3CM(K1-1)-
E3CM(K1))+0.5*DIFF(K1-1)
DC1=(DC12+DIFF(K1))*((EINT1(LX)-E3CM(K1))/2.
DC22=(0.5*DIFF(K2+1)-DIFF(K2))*(E3CM(K2)-EINT2(LX))/(E3CM(K2)-
E3CM(K2+1))+DIFF(K2)
DC2=(DC22+DIFF(K2))*(E3CM(K2)-EINT2(LX))/2.
DC3=0.
IF (NX1(LX).EQ.NX2(LX)) GO TO 811
K22=K2-1
DO 810 LY=K1,K22
810 DC3=DC3+(E3CM(LY)-E3CM(LY+1))*(DIFF(LY)+DIFF(LY+1))/2.
811 DC(LX)=DC1+DC2+DC3
820 CONTINUE
WRTTE(6,821)
821 FORMAT(1HO,6X,'INTEGRATION LIMIT DIFFERENTIAL CROSS SECTION'/
114X,'MEV',15X,'MB/SR')
WRTTE(6,822) (EINT1(NZ),EINT2(NZ),DC(NZ),NZ=1,NOINT)
822 FORMAT(8X,F6.2,' - ',F6.2,11X,E12.5)
IF (ITOP.EQ.1) GO TO 890
830 DO 831 IE=JEL,JEH,JET
IF (E3CM(IE).LE.ETMAX) GO TO 832
831 CONTINUE
832 DC 840 IE1=IE,JEH,JEI
IF (E3CM(IE1).LE.ETMIN) GO TO 841
840 CONTINUE
841 JK=IE1-1
U12=(DIFF(IE)-DIFF(IE-1))*(E3CM(IE-1)-ETMAX)/(E3CM(IE-1)-E3CM(IE))
U1=(U12+DIFF(IE))/2.+0.5*(ETMAX-E3CM(IE))
U22=(DIFF(JK+1)-DIFF(JK))*(E3CM(JK)-ETMIN)/(E3CM(JK)-E3CM(JK+1))
U2=(U22+DIFF(JK))/2.+0.5*(E3CM(JK)-ETMIN)
U3=0.
IF (IE.EQ.JK) GO TO 871
IT4=JK-1
DO 870 IT=IE,IT4
870 U3=U3+(E3CM(IT)-E3CM(IT+1))*(DIFF(IT)+DIFF(IT+1))/2.
871 DCTOT=U1+U2+U3
```

```
      WRITE(6,860) ETMIN,ETMAX,OCTOT.
860 FORMAT(1HO,EX,'INTEGRATION LIMIT ',F6.2,' - ',F6.2,' MEV'
     17X,'TOTAL DIFF. XSECTION=',E12.5,' MB/SR')
890 CONTINUE
761 CONTINUE
      REWIND NT
      GO TO 710
      END
      SUBROUTINE TLREAD
      ROUTINE TO READ IN TL CARDS PRODUCED BY OPT MOD.
C      REVISED BY C. C. LU
      COMMON DUMMY,TL,JEM,MT,DENOM,N,A,B,C,D,
     1IP,IC,ESTARM,SPIN,FO,ITLR
      DIMENSION DUMMY(18), TL(6,18,40), JEM(6), DENOM(18),
     1 A(6), B(6), C(6), D(6), ESTARM(6), SPIN(6)
C      FIRST READ NU=1, JE=1 CARDS.
      DO 52 LINMAX=LINDEX+5
      L=LINDEX-1
      READ 103,          (TL(1,LIND,1),LIND=LINDEX,LINMAX),
     1LCARD,NUCARD,MTCARD
C      CHECK CARDS FOR PROPER INDICES AND ORDER.
      IF(1-NUCARD) 53,54,53
      54 IF(L-LCARD) 53,56,53
      56 IF(MT-MTCARD) 53,52,53
      52 CONTINUE
      IF (ITLR-2) 200,203,203
203 CONTINUE
      RETURN
C      NOW READ IN FOR THE REST OF THE CHANNELS, AND CHECK ORDER.
200 NU1=2
      NU2=6
      57 DO 2 NU=NU1,NU2
      70 JEMAX=JEMINU
      90 CONTINUE
      DO 2 JE=1,JEMAX
      DO 2 LINDEX=1,13,6
      LINMAX=LINDEX+5
      L=LINDEX-1
      READ 103,          (TL(NU,LIND,JE),LIND=LINDEX,
     1LINMAX),LCARD,NUCARD,MTCARD
      IF(NU-NUCARD) 3,4,3
      4 IF(L-LCARD) 3,6,3
      6 IF(MT-MTCARD) 3,2,3
      2 CONTINUE
      RETURN
      53 NU=1
      JE=1
      3 PRINT 104,NU,JE,L,MT
103 FORMAT(6F12.6,I2,2X,2I2)
104 FORMAT(23HO THE TSUBL-CARD FOR NU=I2,5H, JE=I2,7H, L =I2,9H, AND
     1MT=I2,3SH IS OUT OF PLACE IN THE INPUT DECK.)
      CALL EXIT
      END
      SUBROUTINE DENOMR
      COMMON DUMMY,TL,JEM,MT,DENOM,N,A,B,C,D,
     1IP,IC,ESTARM,SPIN,FO,ITLR,CG,IEOS
      DIMENSION DUMMY(18), TL(6,18,40), JEM(6), DENOM(18),
     1 A(6), B(6), C(6), D(6), ESTARM(6), SPIN(6),CG(10).
```

```
2 SUM(6,40),DN(18,6)
10 DO 500 J=1,18
    DENOM(J)=0.
    RJ=J-1
    IF(N=6)20,20,15
15 RJ=RJ+0.5
20 DO 501 NU=2,6
    IF (JEMINU)-2) 11,11,12
11 DN(J,NU) = 0.
    GO TO 431
12 DC 25 NZERO=1,40
25 SUM(NU,NZERO)=0.
C     IF N=5(J- INT) J=J-1   IF N=9(J-1/2INT) J=J-.5
     JEMAX=JEMINU
30 DO 301 JE=1,JEMAX
    E=JE-1
C     U=E/2
    DENT=DEN(E,NU)
40 DC 302 L=1,18
    RL=L-1
    TLFAC=TL(NU,L,JE)
    IF(TLFAC-1.OE-10)301,41,41
41 DENS=DENT*TLFAC
42 NSMIN=ABS(RJ-RL)+1.
    NSMAX=J+L-1
    IF(NSMIN-15)43,43,302
43 IF(NSMAX-15)46,46,44
44 NSMAX=15
46 DO 303 NS=NSMIN,NSMAX
    S=NS-1
C     IF N=5 S=S, IF N=9 S=S+.5          SMAX=14
    IF(N=6)60,60,50
50 S=S+.5
60 IMIN=ABS(S-SP(NU))+1.
    IMAX=S+SP(NU)+1.
    DO 303 I=IMIN,IMAX
    RI=I-1
    IF(N=6)70,70,72
70 GO TO (80,80,85,85,80,100),NU
100 IF(IEOS.EQ.1) GO TO 85
    IF(IEOS.EQ.2) GO TO 80
    72 GO TO (80,85,80,80,85,110),NU
110 IF (IEOS.EQ.1) GO TO 80
    IF (IEOS.EQ.2) GO TO 85
85 RI=RI+.5
80 SUM(NU,JE)=SUM(NU,JE)+DENS*SIG(R,I,FO,E,NU)
303 CONTINUE
302 CONTINUE
301 CONTINUE
    DN(J,NU)=0.
    TES=JEM(NU)
    TEST=ESTARM(NU)*2.-TES
    NEST=TEST
    IF(NEST)410,400,410
400 NT2=JEM(NU)/2
    NT2=NT2*2
    IF(JEM(NU)-NT2)401,401,402
401 DN(J,NU)=(SUM(NU,JEMAX)+SUM(NU,JEMAX-1))/2.
402 DN(J,NU)=DN(J,NU)+SUM(NU,JEMAX)*(ESTARM(NU)*2.-JEM(NU)+1)/2.
```

```
JEMS=(JEM(NU)+1)/2
JEMS=JEMS*2-3
GO TO 420
410 JEMS=JEM(NU)/2
JFMS=JEMS*2-1
420 DO 430 JE=1,JEMS,2
430 DNI(J,NU)=DNI(J,NU)+(SUM(NU,JE)+4.0*SUM(NU,JE+1)+SUM(NU,JE+2))/3.
DNI(J,NU)=DNI(J,NU)*.5
431 CONTINUE
501 DENOM(J)= DENOM(J)+DNI(J,NU) *CG(NU)
500 DENOM(J)= SQRT(DENOM(J))
RETURN
END
FUNCTION DENCE,NU)
COMMON DUMMY,TL,JE4,MT,DENOM,N,A,B,C,D,
IP,IC,ESTARM,SPIN,FO
DIMENSION DUMMY(18), TL(6,18,40), JEM(6), DENOM(18),
A(6), B(6), C(6), D(6)
U=E/2.
1 GO TO 15,91,IC
5 CHEK=A(NU)*C(NU)*(U-B(NU))*D(NU)
IF(CHEK)6,6,7
6 DEN=0.
RETURN
7 T=(1.+SQRT(1.+4.*U-B(NU)))*A(NU)/(2.*A(NU))
DEN=A(NU)**.5*EXP(2.*SQRT(A(NU)*(U-B(NU))))/((U+T-B(NU))**2
*C(NU))
RETURN
9 IF(A(NU))5,6,10
10 DEN=C(NU)*EXP((U-B(NU))/A(NU))
RETURN
END
FUNCTION SIG(FI,FO,E,NU)
COMMON DUMMY,TL,JE4,MT,DENOM,N,A,B,C,D,
IP,IC
DIMENSION DUMMY(18), TL(6,18,40), JEM(6), DENOM(18),
A(6), B(6), C(6), D(6)
U=F/2.
2 GO TO 1,19, 1,191,IP
1 IF(A(NU)*D(NU)*(U-B(NU)))115,5,15
5 SIG=0.
RETURN
15 IF (IP.EQ.3) GO TO 16
T=(1.+SQRT(1.+4.*U-B(NU))*A(NU))/(2.*A(NU))
SIG=(2.*FI+1.)*EXP((FI+.5)**2/(-2.*D(NU)*T))/D(NU)**1.5
RETURN
16 SIG=(2.*FI+1.)*EXP((FI+.5)**2/(-2.*D(NU)))/D(NU)**1.5
RETURN
19 IF(D(NU))5,5,20
20 SIG=(2.*FI+1.)*EXP(-FI*(FI+1.)/(2.*D(NU)))/(2.*D(NU))
RETURN
END
```

F. MACT3 Program Sample Input

1 62NIIP, P162NI 13MEV FERM1 GAS CALC.  
 1 COMPOUND NUCLEUS T-LOWER STATE TRANSITION  
 .857 1.0 .857 1.0 1.0 .143  
 0.5 1  
 0.5 0.5 9 1 22 1  
 1 17 22 16 6 7  
 1.0 13.10 12.80 8.06 4.4 3.42  
 1.0 6.2 6.4 6.9 7.2 6.4  
 1.0 -.8 .5 -2.2 -.5 .5  
 1.0 33.941 33.941 33.941 33.941 33.941  
 1.0 12.25 13.31 13.31 12.95 13.31  
 1 1 3 63 0 0 0  
 0.5 0.0 13.0 1.0078 61.9283 2  
 1.0078 61.9283 1.0078 61.9283 0.0  
 3  
 90.0 130.0 165.0  
 .8991 .7836 .8110 .8475 .3370 .1703 0 163  
 .0163 .0015 .0001 0 0 0 6 163  
 0 0 0 0 0 0 12 163  
 .9914 .9941 .9879 .9869 .9727 .9488 0 263  
 .8919 .7268 .4716 .1793 .0540 .0138 6 263  
 .0039 .0012 .0004 .0001 .0000 .0000 12 263  
 .9883 .9913 .9830 .9812 .9596 .9268 0 263  
 .8372 .6299 .3496 .1163 .0332 .0085 6 263  
 .0024 .0008 .0002 0 0 0 12 263  
 .9839 .9869 .9761 .9721 .9400 .8926 0 263  
 .7591 .5143 .2400 .0721 .0198 .0051 6 263  
 .0015 .0005 .0001 0 0 0 12 263  
 .9776 .9798 .9658 .9574 .9102 .8400 0 263  
 .6545 .3896 .1529 .0428 .0114 .0030 6 263  
 .0009 .0003 .0001 0 0 0 12 263  
 .9478 .9683 .9498 .9332 .8649 .7617 0 263  
 .5269 .2705 .0911 .0245 .0065 .0017 6 263  
 .0005 .0001 0 0 0 0 12 263  
 .9523 .9494 .9247 .8939 .7976 .6518 0 263  
 .3885 .1712 .0511 .0135 .0035 .0009 6 263  
 .0003 .0001 0 0 0 0 12 263  
 .9275 .9186 .8852 .8315 .7008 .5121 0 263  
 .2587 .0991 .0273 .0071 .0019 .0005 6 263  
 .0001 0 0 0 0 0 12 263  
 .8871 .8686 .8225 .7360 .5707 .3591 0 263  
 .1550 .0529 .0139 .0036 .0009 .0002 6 263  
 0 0 0 0 0 0 12 263  
 .8210 .7884 .7249 .6004 .4164 .2211 0 263  
 .0840 .0262 .0067 .0017 .0004 .0001 6 263  
 0 0 0 0 0 0 12 263  
 .7150 .6660 .5841 .4340 .2645 .1195 0 263  
 .0414 .0121 .0030 .0008 .0002 0 6 263  
 0 0 0 0 0 0 12 263  
 .5608 .5008 .4104 .2686 .1441 .0571 0 263  
 .0186 .0052 .0013 .0003 .0001 0 6 263  
 0 0 0 0 0 0 12 263  
 .3746 .3191 .2408 .1399 .0674 .0243 0 263  
 .0076 .0020 .0005 .0001 0 0 6 263  
 0 0 0 0 0 0 12 263  
 .2029 .1658 .1154 .0612 .0272 .0092 0 263  
 .0028 .0007 .0002 0 0 0 6 263  
 0 0 0 0 0 0 12 263  
 .0873 .0695 .0452 .0227 .0095 .0031 0 263





0	0	0	0	0	0	0	12	463
.6883	.2099	.2244	.0028	.0002		0	0	463
0	0	0	0	0		0	6	463
0	0	0	0	0		0	12	463
.6098	.0920	.0564	.0001	0		0	0	463
0	0	0	0	0		0	6	463
0	0	0	0	0		0	12	463
.6297	.5176	.3536	.1398	.0367	.0057	0	563	
.0007						6	563	
						12	563	
.4350	.3210	.1829	.0572	.0127	.0017	0	563	
.0002						6	563	
						12	563	
.2222	.1448	.0684	.0178	.0034	.0004	0	563	
						6	563	
						12	563	
.0723	.0428	.0173	.0039	.0006		0	0	563
						6	563	
						12	563	
.0131	.0073	.0026	.0005			0	0	563
						6	563	
						12	563	
.0010	.0005	.0001				0	0	563
						6	563	
						12	563	
.6939	.4818	.5393	.2645	.0280	.0028	0	663	
						6	663	
						12	663	
.7014	.4507	.5216	.1601	.0174	.0011	0	663	
						6	663	
						12	663	
.7075	.4119	.4923	.0848	.0095	.0003	0	663	
						6	663	
						12	663	
.7109	.3625	.4430	.0378	.0042	.0001	0	663	
						6	663	
						12	663	
.7079	.2976	.3598	.0131	.0013		0	0	663
						6	663	
						12	663	
.6883	.2099	.2244	.0028	.0002		0	0	663
						6	663	
						12	663	
.6098	.0920	.0564	.0001	0		0	0	663
						6	663	
						12	663	

1 62Ni(P,P)62Ni 13MEV FERMI GAS CALC.

1 COMPOUND NUCLEUS T-UPPER TRANSITION

.143 1.0 .143 .857 1.0 .778

0.5 1

0.5	0.5	9	1	22	1
1	1	22	7	1	1
1.0	3.52	12.80	3.42	1.0	1.0

1.0 6.2 6.4 6.4 7.2 7.6

1.0 -.8 .5 .5 -.5 -1.3

1.0 33.941 33.941 33.941 33.941 33.941

1.0 13.31 13.31 13.31 12.95 13.31

1 1 3 63 0

0.5 0.0 13.0 1.0078 61.9283

2

1.0078	61.9283	1.0078	61.9283	0.0				
3								
90.0	130.0	165.0						
.8991	.7836	.8110	.8475	.3370	.1703	0	163	
.0163	.0015	.0001	0	0	0	6	163	
0	0	0	0	0	0	12	163	
					0	263		
					6	263		
					12	263		
.8991	.7836	.8110	.8475	.3370	.1703	0	363	
.0163	.0015	.0001	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.9018	.7739	.8060	.8102	.3027	.1350	0	363	
.0121	.0011	.0001	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.9042	.7625	.7994	.7650	.2678	.1047	0	363	
.0089	.0008	0	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.9063	.7490	.7911	.7112	.2330	.0793	0	363	
.0064	.0005	0	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.9081	.7328	.7806	.6489	.1988	.0587	0	363	
.0045	.0003	0	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.9094	.7136	.7673	.5786	.1658	.0424	0	363	
.0031	.0002	0	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.9101	.6909	.7502	.5019	.1349	.0297	0	363	
.0021	.0001	0	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.9098	.6640	.7283	.4214	.1067	.0204	0	363	
.0013	.0001	0	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.9078	.6317	.7001	.3409	.0818	.0135	0	363	
.0008	0	0	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.9036	.5931	.6639	.2648	.0605	.0087	0	363	
.0005	0	0	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.8959	.5469	.6179	.1965	.0429	.0053	0	363	
.0003	0	0	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.8833	.4927	.5602	.1388	.0291	.0031	0	363	
.0001	0	0	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.8630	.4302	.4891	.0928	.0187	.0017	0	363	
0	0	0	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.8306	.3600	.4049	.0584	.0113	.0009	0	363	
0	0	0	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.7794	.2844	.3117	.0343	.0063	.0004	0	363	
0	0	0	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.7000	.2081	.2178	.0186	.0033	.0002	0	363	
0	0	0	0	0	0	6	363	
0	0	0	0	0	0	12	363	
.5831	.1378	.1343	.0091	.0015	0	0	363	
0	0	0	0	0	0	6	363	

0	0	0	0	0	0	12	363
.4269	.0800	.0708	.0039	.0006	0	0	363
0	0	0	0	0	0	6	363
0	0	0	0	0	0	12	363
.2540	.0391	.0308	.0014	.0002	0	0	363
0	0	0	0	0	0	6	363
0	0	0	0	0	0	12	363
.1108	.0152	.0104	.0004	0	0	0	363
0	0	0	0	0	0	6	363
0	0	0	0	0	0	12	363
.0331	.0042	.0025	0	0	0	0	363
0	0	0	0	0	0	6	363
0	0	0	0	0	0	12	363
.0056	.0007	.0003	0	0	0	0	363
0	0	0	0	0	0	6	363
0	0	0	0	0	0	12	363
.6939	.4818	.5393	.2645	.0280	.0028	0	463
0	0	0	0	0	0	6	463
0	0	0	0	0	0	12	463
.7014	.4507	.5216	.1601	.0174	.0011	0	463
0	0	0	0	0	0	6	463
0	0	0	0	0	0	12	463
.7075	.4119	.4923	.0648	.0095	.0003	0	463
0	0	0	0	0	0	6	463
0	0	0	0	0	0	12	463
.7109	.3625	.4430	.0378	.0042	.0001	0	463
0	0	0	0	0	0	6	463
0	0	0	0	0	0	12	463
.7079	.2976	.3598	.0131	.0013	0	0	463
0	0	0	0	0	0	6	463
0	0	0	0	0	0	12	463
.6883	.2099	.2244	.0028	.0002	0	0	463
0	0	0	0	0	0	6	463
0	0	0	0	0	0	12	463
.6098	.0920	.0564	.0001	0	0	0	463
0	0	0	0	0	0	6	463
0	0	0	0	0	0	12	463
					0	563	
					6	563	
					12	563	
					0	663	
					6	663	
					12	663	

G. MACT3 Program Sample Output

MACDONALD ANGULAR DISTRIBUTION

62Ni(P,P)62Ni 13MEV FERMI GAS CALC.  
1 COMPOUND NUCLEUS T-LOWER STATE TRANSITION

MIN ENTRANCE CHANNEL SPIN = 0.5

MAX ENTRANCE CHANNEL SPIN = 0.5

TAPE NO.= 9

JE(LOWEST)= 1 JE(HIGHEST)=22 JE(INC)= 1

I=1 I=2 I=3 I=4 I=5 I=6

JEM(I)= 1 17 22 16 6 7

ESTARM(I)= 0.10000E 01 0.13100E 02 0.12800E 02 0.80600E 01 0.44000E 01 0.34200E 01

A(I)= 0.10000E 01 0.62000E 01 0.64000E 01 0.69000E 01 0.72000E 01 0.64000E 01

B(I)= 0.10000E 01 -0.80000E 00 0.50000E 00 -0.22000E 01 -0.50000E 00 0.50000E 00

C(I)= 0.10000E 01 0.33941E 02 0.33941E 02 0.33941E 02 0.33941E 02 0.33941E 02

D(I)= 0.10000E 01 0.12250E 02 0.13310E 02 0.13310E 02 0.12950E 02 0.13310E 02

CG(I)= 0.85700E 00 0.10000E 01 0.85700E 00 0.10000E 01 0.10000E 01 0.14300E 00

ANG MOM DENSITY OPTION IS 1

ENERGY DENSITY OPTION IS 1

FO= 0.0 NUOUT= 3

PROJECTILE SPIN= 0.500

TARGET SPIN= 0.0

PROJECTILE MASS= 1.008

TARGET MASS= 61.92830

EFF= 0.48559

PROJECTILE ENERGY= 13.000MEV

(DENOM(J))\*\*0.5, J=0,17

0.63319E 02 0.85663F 02 0.97444F 02 0.10147E 03 0.99340E 02 0.92532E 02  
0.82529E 02 0.70751F 02 0.58445E 02 0.46600E 02 0.35907F 02 0.26762F 02  
0.19303E 02 0.13421E 02 0.89048E 01 0.50713E 01 0.26920E 01 0.10107E 01

RATIO OF LEGENDRE COEFFICIENTS A(L)/A(L=0) AND A(L=0)

E(RFS,I)	A(L=0)/A(L=0)	A(L=2)/A(L=0)	A(L=4)/A(L=0)	A(L=6)/A(L=0)	A(L=8)/A(L=0)
MEV					MB/SR/MEV
0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.0	0.0	0.0	0.0	0.0
1.0	0.10000E 01	0.18563E 00	0.15749E-01	0.78807E-03	0.18708E-01
1.5	0.10000E 01	0.13155E 00	0.75507E-02	0.24861E-03	0.34914E-01
2.0	0.10000E 01	0.1019PE 00	0.44122E-02	0.10736E-03	0.61120E-01
2.5	0.10000E 01	0.82419E-01	0.28288E-02	0.53587E-04	0.10122E 00
3.0	0.10000E 01	0.68157E-01	0.19089E-02	0.28919E-04	0.15997E 00
3.5	0.10000E 01	0.57131E-01	0.13290E-02	0.16450E-04	0.24283E 00
4.0	0.10000E 01	0.48265E-01	0.94017E-03	0.98849F-05	0.35557F 00
4.5	0.10000E 01	0.40978E-01	0.67250E-03	0.58344E-05	0.50390E 00
5.0	0.10000E 01	0.34885E-01	0.48219E-03	0.34768E-05	0.69170E 00
5.5	0.10000E 01	0.29782E-01	0.34620E-03	0.19442E-05	0.91949E 00
6.0	0.10000E 01	0.25485E-01	0.24964E-03	0.11113E-05	0.11778E 01
6.5	0.10000E 01	0.21835E-01	0.18145E-03	0.67201E-06	0.14424E 01
7.0	0.10000E 01	0.18617E-01	0.13153E-03	0.42390E-06	0.16687E 01
7.5	0.10000E 01	0.15728E-01	0.96646E-04	-0.83765E-08	0.17962E 01
8.0	0.10000E 01	0.12978E-01	0.68510E-04	0.23111F-06	0.17607F 01
8.5	0.10000E 01	0.10520E-01	0.49681E-04	0.87678E-07	0.15229E 01
9.0	0.10000E 01	0.84831E-02	0.35415E-04	0.48571E-07	0.11013E 01

0.10000E 01	0.68897E-02	0.24288E-04	0.83288E-08	0.60906E 00	-68-
0.10000E 01	0.55319E-02	0.15292E-04	0.0	0.23411E 00	
0.10000E 01	0.44240E-02	0.10719E-04	0.0	0.51188E-01	

TOTAL ALT=0) IN MB/SR/MEV 0.14428E 02

TOTAL CROSS SECTION IN MBS 0.90655E 02

## MACDONALD ANGULAR DISTRIBUTION

1 62NI(P,P)62NI 13MEV FERMI GAS CALC.  
 1 COMPOUND NUCLEUS T-LOWER STATE TRANSITION

ANGLE= 90.000 DEGREE(LAB.)

E(RES.) MEV.	E3(C.M.) MEV.	C.M. ANGLE DEG.	DIFF. CROSS SECTION MB/SR/MEV
0.0	12.59	90.93	0.0
0.5	12.09	90.95	0.0
1.0	11.60	90.97	0.17079E-01
1.5	11.11	90.99	0.32716E-01
2.0	10.62	91.02	0.58105E-01
2.5	10.13	91.04	0.97160E-01
3.0	9.64	91.07	0.15464E 00
3.5	9.14	91.09	0.23602E 00
4.0	8.65	91.13	0.34712E 00
4.5	8.16	91.16	0.49372E 00
5.0	7.67	91.20	0.67985E 00
5.5	7.18	91.24	0.90593E 00
6.0	6.68	91.28	0.11629E 01
6.5	6.19	91.33	0.14268E 01
7.0	5.70	91.39	0.16532E 01
7.5	5.21	91.45	0.17822E 01
8.0	4.72	91.52	0.17493E 01
8.5	4.22	91.61	0.15150E 01
9.0	3.73	91.71	0.10966E 01
9.5	3.24	91.84	0.60698E 00
10.0	2.75	92.00	0.23346E 00
10.5	2.26	92.20	0.51075E-01

ANGLE= 130.000 DEGREE(LAB.)

E(RES.) MEV.	E3(C.M.) MEV.	C.M. ANGLE DEG.	DIFF. CROSS SECTION MB/SR/MEV
0.0	12.59	130.71	0.0
0.5	12.09	130.73	0.0
1.0	11.60	130.74	0.19065E-01
1.5	11.11	130.76	0.35442E-01
2.0	10.62	130.78	0.61876E-01
2.5	10.13	130.80	0.10227E 00
3.0	9.64	130.82	0.16138E 00
3.5	9.14	130.84	0.24465E 00
4.0	8.65	130.86	0.35786E 00
4.5	8.16	130.89	0.50671E 00
5.0	7.67	130.91	0.69509E 00
5.5	7.18	130.95	0.92330E 00
6.0	6.68	130.98	0.11820E 01
6.5	6.19	131.02	0.14469E 01
7.0	5.70	131.06	0.16731E 01
7.5	5.21	131.11	0.18004E 01
8.0	4.72	131.17	0.17641E 01
8.5	4.22	131.23	0.15253E 01
9.0	3.73	131.31	0.11027E 01
9.5	3.24	131.41	0.60971E 00
10.0	2.75	131.53	0.23431E 00
10.5	2.26	131.69	0.51225E-01

ANGLE= 165.000 DEGREE(LAB.)

E(RES.) MEV.	E3(C.M.) MEV.	C.M. ANGLE DEG.	DIFF. CROSS SECTION MB/SR/MEV
0.0	12.59	165.00	0.0

MACDONALD ANGULAR DISTRIBUTION

1 62Ni(p,pi)62Ni 13MeV FERMI GAS CALC.

1 COMPOUND NUCLEUS T-UPPER TRANSITION

MIN ENTRANCE CHANNEL SPIN = 0.5

MAX ENTRANCE CHANNEL SPIN = 0.5

TAPE NO.= 9

JE(LOWEST)= 1 JE(HIGHEST)=22 JE(INC)= 1

I=1 I=2 I=3 I=4 I=5 I=6

JEM(I)= 1 1 22 7 1 1

ESTARM(I)= 0.10000E 01 0.35200E 01 0.12800E 02 0.34200E 01 0.10000E 01 0.10000E 01

A(I)= 0.10000E 01 0.62000E 01 0.64000E 01 0.64000E 01 0.72000E 01 0.76000E 01

B(I)= 0.10000E 01-0.80000E 00 0.50000E 00 0.50000E 00-0.50000E 00-0.13000E 01

C(I)= 0.10000E 01 0.33941E 02 0.33941E 02 0.33941E 02 0.33941E 02 0.33941E 02

D(I)= 0.10000E 01 0.13310F 02 0.13310E 02 0.13310E 02 0.12950E 02 0.13310E 02

CG(I)= 0.14300E 00 0.10000E 01 0.14300E 00 0.85700E 00 0.10000E 01 0.77800E 00

ANG MOM DENSITY OPTION IS 1

ENERGY DENSITY OPTION IS 1

FO= 0.0 MUQUT= 3

PROJECTILE SPIN= 0.500

TARGET SPIN= 0.0

PROJECTILE MASS= 1.008

TARGET MASS= 61.92830

EFF= 0.48559

PROJECTILE ENERGY= 13.000MEV

(DENOM(J))\*\*0.5, J=0,17

0.89104E 01	0.12005E 02	0.13566E 02	0.14003E 02	0.13565E 02	0.12486E 02
0.10993E 02	0.92958E 01	0.75710E 01	0.59501E 01	0.45185E 01	0.33192E 01
0.23600E 01	0.16188E 01	0.10603E 01	0.56567E 00	0.28891E 00	0.94976E-01

RATIO OF LEGENDRE COEFFICIENTS (A(L)/A(0)) AND A(L=0)

E(RES.)	A(L=0)/A(L=0)	A(L=2)/A(L=0)	A(L=4)/A(L=0)	A(L=6)/A(L=0)	A(L=8)	MB/SR/MEV
0.0	C.0	0.0	0.0	0.0		0.0
0.5	0.0	0.0	0.0	0.0		0.0
1.0	0.10000E 01	0.18855E 00	0.16220E-01	0.82334E-03	0.27007E-01	
1.5	0.10000E 01	0.13371E 00	0.77855E-02	0.26008E-03	0.50480E-01	
2.0	0.10000E 01	0.10371E 00	0.45527E-02	0.11241E-03	0.88444E-01	
2.5	0.10000E 01	0.83856E-01	0.29199E-02	0.56136E-04	0.14655E 00	
3.0	0.10000E 01	0.69366E-01	0.19710E-02	0.3C293E-04	0.23172E 00	
3.5	0.10000E 01	0.58162E-01	0.13724E-02	0.17263E-04	0.35187E 00	
4.0	0.13000E 01	0.49133E-01	0.97131E-03	0.10404E-04	0.51538E 00	
4.5	0.10000E 01	0.41721E-01	0.69514E-03	0.61408E-05	0.73056E 00	
5.0	0.10000E 01	0.35525E-01	0.49856E-03	0.36594E-05	0.10031E 01	
5.5	0.10000E 01	0.30331E-01	0.35811E-03	0.20478E-05	0.13334E 01	
6.0	0.10000E 01	0.25957E-01	0.25828E-03	0.11469E-05	0.17083E 01	
6.5	0.10000E 01	0.22240E-01	0.18779E-03	0.70888E-06	0.20925E 01	
7.0	0.10000E 01	0.18965E-01	0.13611E-03	0.44730E-06	0.24210F 01	
7.5	0.10000E 01	0.16025E-01	0.10000E-03	-0.17103E-07	0.26065E 01	
8.0	0.10000E 01	0.13223F-01	0.70779E-04	0.25099E-06	0.25557E 01	
8.5	0.10000E 01	0.10718E-01	0.51380E-04	0.93517E-07	0.22109E 01	
9.0	0.10000E 01	0.86427E-02	0.36624E-04	0.56444E-07	0.15990E 01	

9.5	0.10000E 01	0.70207E-02	0.25109E-04	0.87975E-06	0.88431E 00	-71-
10.0	0.10000E 01	0.56365E-02	0.15777E-04	0.0	0.33497E 00	
10.5	0.10000E 01	0.45076E-02	0.11072E-04	0.0	0.74336E-01	

TOTAL ALT=C) IN MB/SR/MEV 0.20934E 02

TOTAL CROSS SECTION IN MBS 0.13153E 03

MACDONALD ANGULAR DISTRIBUTION

I 62NJIIP,P162NI 13MEV FERMI GAS CALC.  
I COMPOUND NUCLEUS T-UPPER TRANSITION

ANGLE= 90.000 DEGREE(LAB.)

E(RES.) MEV.	E3(C.M.) MEV.	C.M. ANGLE DEG.	DIFF. CROSS SECTION MB/SR/MEV
0.0	12.59	90.93	0.0
0.5	12.09	90.95	0.0
1.0	11.60	90.97	0.24620E-01
1.5	11.11	90.99	0.47251E-01
2.0	10.62	91.02	0.84009E-01
2.5	10.13	91.04	0.14057E 00
3.0	9.64	91.07	0.22386E 00
3.5	9.14	91.09	0.34183E 00
4.0	8.65	91.13	0.50292E 00
4.5	8.16	91.16	0.71553E 00
5.0	7.67	91.20	0.98546E 00
5.5	7.18	91.24	0.13134E 01
6.0	6.68	91.28	0.16863E 01
6.5	6.19	91.33	0.20694E 01
7.0	5.70	91.39	0.23982E 01
7.5	5.21	91.45	0.25858E 01
8.0	4.72	91.52	0.25389E 01
8.5	4.22	91.61	0.21991E 01
9.0	3.73	91.71	0.15921E 01
9.5	3.24	91.84	0.88123E 00
10.0	2.75	92.00	0.33901E 00
10.5	2.26	92.20	0.74170E-01

ANGLE= 130.000 DEGREE(LAB.)

E(RES.) MEV.	E3(C.M.) MEV.	C.M. ANGLE DEG.	DIFF. CROSS SECTION MB/SR/MEV
0.0	12.59	130.71	0.0
0.5	12.09	130.73	0.0
1.0	11.60	130.74	0.27528E-01
1.5	11.11	130.76	0.51253E-01
2.0	10.62	130.78	0.89554E-01
2.5	10.13	130.80	0.14810E 00
3.0	9.64	130.82	0.23379E 00
3.5	9.14	130.84	0.35456E 00
4.0	8.65	130.86	0.51876E 00
4.5	8.16	130.89	0.73469E 00
5.0	7.67	130.91	0.10080E 01
5.5	7.18	130.95	0.13390E 01
6.0	6.68	130.98	0.17145E 01
6.5	6.19	131.02	0.20991E 01
7.0	5.70	131.06	0.24276E 01
7.5	5.21	131.11	0.26126E 01
8.0	4.72	131.17	0.25607E 01
8.5	4.22	131.23	0.22144E 01
9.0	3.73	131.31	0.16011E 01
9.5	3.24	131.41	0.88527E 00
10.0	2.75	131.53	0.34027E 00
10.5	2.26	131.69	0.74390E-01

ANGLE= 165.000 DEGREE(LAB.)

E(RES.) MEV.	E3(C.M.) MEV.	C.M. ANGLE DEG.	DIFF. CROSS SECTION MB/SR/MEV
0.0	12.59	165.00	0.0

## H. YRAST Program Listing

```
C      PROGRAM YRAST
C      MODIFIED FROM MAC3
COMMON      TL,JEM,MT,DENOM,N,A,B,C,D,
1IP,IC,ESTARM,SPIN,FO,ITLR
      DIMENSION      TL(5,18,45), JEM(5), DENOM(18),
1   A(5), B(5), C(5), D(5), ESTARM(5), SPIN(5),
2   Q(18),Z(18,18,15),PA(4,45),PB(4),ANG(24)
3,EINT1(30),EINT2(30),NX1(30),NX2(30),DC(30),DIFF(30),E3CM(30)
710 READ(5,700,END=800) NTITLE
700 FORMAT(1X,I1,78H
1
1      WRITE(6,701)
701 FORMAT(1H1,30X,'MACDONALD ANGULAR DISTRIBUTION//')
1      WRITE(6,700) NTITLE
1      GO TO 10
800 CALL EXIT
10 READ(5,13) S1MIN,S1MAX,N,JEL,JEH,JEI,
1(JEM(I),I=1,5), (ESTARM(I),I=1,5), (A(I),I=1,5),
2(B(I),I=1,5), (C(I),I=1,5), (D(I),I=1,5), IP,IC, FO, NUOUT,MT,ITLR
3, IDENCM,ITOP
13 FORMAT (2F8.1,18,3I8/5I8/5F8.5/5E12.5/
15E12.5 / 5E12.5 / 5E12.5 /
214, 14, E12.5,SI4)
1      READ(5,195) SIP,SIT,EB,AM,TM
195 FORMAT(2F8.1,3F8.3)
1      WRITE(6,14) S1MIN,S1MAX,N,
1JEL,JEH,JEI,(JEM(I),I=1,5),(ESTARM(I),I=1,5),
2(A(I),I=1,5),(B(I),I=1,5),(C(I),I=1,5),
3(D(I),I=1,5),IP,IC,FC, NUOUT
14 FORMAT(1H0,28HMIN ENTRANCE CHANNEL SPIN = ,F4.1/
21H ,20HMAX ENTRANCE CHANNEL SPIN = ,F4.1/
31H ,10HTAPE NO.= ,11/1H ,11HJE(LOWEST)=,12,5X,12HJE(HIGHEST)=,
4I2,5X,8HJE INC)=,12/ 1H ,14X,3HI=1,9X,3HI=2,9X,3HI=3,
59X,3HI=4,9X,3HI=5/1H ,7HJEM(I)=,4X,5I12/
61H ,10HESTARM(I)=,1X,5E12.5/1H ,5HA(I)=,6X,
75E12.5/1H ,5HB(I)=,6X,5E12.5/1H ,5HC(I)=,6X,5E12.5/1H ,5HD(I)=,
86X,5F12.5/1H ,26HANG MOM DENSITY OPTION IS , I2/
91H ,25HENERGY DENSITY OPTION IS ,I2/1H ,3HFO=,E12.5,1H ,3HNU=,I21
EFF=0.01914*EB*(2.0*SIP+1.0)*I2.0*SIT+1.0)*AM*(TM/(AM+TM))**2
1      WRITE(6,920) SIP,SIT,AM,TM,EFF,EB
920 FORMAT(1H0,16HPROJECTILE SPIN=F8.3/
11H0,12HTARGET SPIN=F8.3/
21H0,16HPROJECTILE MASS=F8.3/
31H0,12HTARGET MASS=F12.5/1X,4HEFF=F12.5/
41H0,18HPROJECTILE ENERGY=F12.3,3HMEV)
1      IF (ICENOM.NE.1) GO TO 720
1      WRITE(6,721)
721 FORMAT('0 PREVIOUS DENOM(J) VALUES ARE USED')
720 CONTINUE
1      READ(5,750) AM1,AM2,AM3,AM4,AQ
750 FORMAT(8F10.5)
1      READ(5,751) NANGLE
751 FORMAT(I5)
1      READ(5,750) LANG(I),I=1,NANGLE)
1      IF (ITLR-1) 400,401,400
400 CALLTLREAD
401 CONTINUE
1      SPIN(1)=1.
1      SPIN(2)=0.
```

```
SPIN(3)=.5
SPIN(4)=.5
SPIN(5)=1.
IF(N=6)1,1,2
1 IS1MIN=S1MIN+1.
IS1MAX=S1MAX+1.
GOTO3
2 IS1MIN=S1MIN+.5
IS1MAX=S1MAX+.5
3 CONTINUE
IF (IDENOM.EQ.1) GO TO 620
CALL DENOMR
620 CONTINUE
WRITE(6,6301) (DENOM(J),J=1,18)
630 FORMAT(1H0,*(DENOM(J))**0.5, J=1,18*1H ,6E13.5/1X,6E13.5/
1LX,6E13.5)
NT=N+8
DO130L=1,4
F=2*(L-1)
DO119II=L,LE
DO119JJ=L,18
READ(NT) LT,IT,JT,(Z(II,JJ,KK), KK=1,15)
IF(LT=L)217,301,217
301 IF(IT=I)217,302,217
302 IF(JT=J)217,119,217
119 WRITE(6,218) L,II,JJ,LT,IT,JT
218 FORMAT (20H BAD ZCODE READIN, L*,I2,5H I=,I2,5H J=,I2,
13X3HLT=I5,3X3HIT=I5,3X3HJT=I5)
GO TO 800
119 CONTINUE
DO190IO=1,18
DO190JO=1,18
DO190KO=1,15
190 Z(I0,JO,KO)=Z(I0,JO,KO)/DENOM(JO)
DO130JE=JEL,JEH,JEI
E=JE-1
34 JO = 1
PROD=0.
DO1251S1=IS1MIN,IS1MAX
S1=IS1
IF(N=6)4,4,5
4 FS=S1-.5
GOTO6
5 FS=S1+.5
6 DO 125 I = 1, 14
IF(N=6)201,201,202
201 GOTO(203,203,204,204,203),NUOUT
203 FI=I-1
GCT0220
204 FI=I
FI=F$-.5
GCT0220
202 GOTO1204,204,203,203,204),NUOUT
220 EROTA=FI*(IFI+1.)/(0(NUOUT))
FMROTA=E-EROTA
DENS=DEN(EMROTA,NUOUT)*SIG(FI,F0,E,NUOUT)
S2MIN=ABS (FI-SPIN(NUOUT))
S2MAX=FI+SPIN(NUOUT)
IF(N=6)227,227,228
```

```
227 IS2MIN=S2MIN+1.  
IS2MAX=S2MAX+1.  
GOTO229  
228 IS2MTN=S2MIN+.5  
IS2MAX=S2MAX+.5  
229 DO125IS2=IS2MIN,IS2MAX  
IF(N=6)230,230,231  
230 S2=IS2-1  
GOTO232  
231 S2=IS2  
S2=S2-.5  
232 KS=S2-ES  
FAC=(1-1.)**(KS))*DENS  
DO 127 L1 = 1, 18  
FL1=L1-1  
JMIN=ABS(IFL1-ES)+1.  
JMAX=MIN1(FL1+ES,17.0)+1  
FACA = FAC * TL(1, L1, 1 )  
DO 124 L2 = 1, 18  
FACB=FACA*TL(NUDUT,L2,JE)  
G=ABS(FACB)  
IF (G-.0000001) 127, 127, 120  
120 DD123J=JMIN,JMAX  
123 PROD = PROD + FACB * Z( L1, J, IS1 ) * Z(L2, J, IS2 )  
124 CONTINUE  
127 CONTINUE  
125 CCNTINUE  
PROD=PROD/EFF  
130 PA(L,JE)=PROD  
WRITE(6,41)  
41 FORMAT(1H0,18X,'RATIO OF LEGENDRE COEFFICIENTS (A(L)/A(0)) AND A  
1(L=0)'  
2/1H0,2X,'E(IRES.)',4X,' A(L=0)/A(L=0) A(L=2)/A(L=0) A(L=4)/A(L=0) A  
3(L=6)/A(L=0) A(L=0)',4X,'MEV',65X,'MB/SR/MEV')  
DC128JE=JEL,JEH,JEI  
E=JE-I  
E=0.5*E  
IF (PA(I,JE)>.0000001) GO TO 501  
PB(1)=0.  
PB(2)=0.  
PB(3)=0.  
PB(4)=0.  
GO TO 502  
501 DO 500 L=1,4  
PB(L)=PA(L,JE)/PA(1,JE)  
500 CCNTINUE  
502 WRITE(6,47) E, (PB(LL),LL=1,4),PA(1,JE)  
47 FORMAT(1H0,2X,F5.1,TX,5(E12.5,2X))  
128 CENTINUE  
PASUM=0.  
DO 510 J=JEL,JEH,JEI  
510 PASUM=PASUM+PA(1,J)  
PASUM=PASUM-(PA(1,JEL)+PA(1,JEH))/2.  
SJEI=JEI  
DELE=SJEI/2.  
CSECT=4.*3.14159*DELE*PASUM  
WRITE(6,511) PASUM,CSECT  
511 FORMAT(1H0,41X,'TOTAL A(L=0) IN MB/SR/MEV ',E12.5//42X,'TOTAL CROS  
IS SECTION IN MBS',E12.5)
```

```
      WRITE(6,701)
      WRITE(6,700) NTITLE
      IF (ITOP.EQ.0) GO TO 759
      IF (ITOP.EQ.2) GO TO 758
      READ(5,801) EMINB,EMAXB,DELEB,NOINT
801 FORMAT(3F10.5,15I)
      IF (ITOP.EQ.1) GO TO 759
758 READ(5,801) ETMIN,ETMAX
759 CONTINUE
      DO 761 JI=1,NANGLE
      XANGLE=ANG(JI)*17.453292/1000.
      WRITE(6,762) ANG(JI)
762 FORMAT(1H0,'ANGLE=',F8.3,' DEGREE(LAB.)'//' E(RES.) E3(C.M.)'
     1 C.M. ANGLE DIFF. CROSS SECTION'/4X,4HMEV.,8X,4HMEV.,8X,'DEG.',28X,'MB/SR/MEV' )
      DO 760 JJE=JEL,JEH,JEI
      E=JJE-1
      E=0.5*E
      E3CM(JJE)=EB*AM2*AM4/1(AM1+AM2)**2)+(AQ-E)*AM4/(AM3+AM4)
      Z1=AM1*AM3*EB
      Z2=COS(XANGLE)
      Y1=Z1*Z2*Z2+(AM3+AM4)*(AM4*(AQ-E)+EB*(AM4-AM1))
      Y1=SQRT(Y1)
      Y2=Z2*SQRT(Z1)
      E3LAB1=Y1+Y2)/(AM3+AM4)
      E3CM1=SQRT(E3CM(JJE))
      X1=E3LAB1*SIN(XANGLE)
      XCMANG=AR SIN(X1/E3CM1)
      V1=SQRT(2.*EB/(AM1*931.441))
      VCM=V1*AM1/(AM1+AM2)
      V3LAB=E3LAB1/SQRT(AM3*931.441/2.)
      V3X=V3LAB*Z2
      IF (VCM.GT.V3X) XCMANG=3.14159-XCMANG
      CMANG=XCMANG*100./1.74533
      CANG1=COS(XCMANG)
      CANG2=CANG1*CANG1
      CANG4=CANG2*CANG2
      CANG6=CANG4*CANG2
      CROSS1=PA(1,JJE)-PA(2,JJE)/2.+PA(3,JJE)*3./8.-PA(4,JJE)*5./16.
      CROSS2=(PA(2,JJE)*24.-PA(3,JJE)*60.+PA(4,JJE)*105.)*CANG2+
     1(PA(3,JJE)*70.-PA(4,JJE)*315.)*CANG4+PA(4,JJE)*231.*CANG6
      DIFF(JJE)=CROSS1+CROSS2/16.
      WRITE(6,763) E,E3CM(JJE),CMANG,DIFF(JJE)
763 FORMAT(3X,F5.1,5X,F8+2,5X,F6.2,7X,E12.5)
760 CONTINUE
      IF (ITOP.EQ.0) GO TO 890
      IF (ITOP.EQ.2) GO TO 830
      EINT1(1)=EMAXB
      EINT2(1)=EMAXB-DELEB
      DC 802 NX=2,NOINT
      EINT1(NX)=EINT2(NX-1)
802 EINT2(NX)=EINT1(NX)-DELEB
      DC 803 KE=JEL,JEH,JEI
      IF (E3CM(KE).LE.EMAXB) GO TO 804
803 CONTINUE
804 NX1(1)=KE
      DO 805 LE=KE,JEH,JEI
      IF (E3CM(LE).LE.EINT2(1)) GO TO 806
805 CONTINUE
```

```
806 NX2(1)=LE-1
    DO 808 NE=2,NOINT
        NX1(NE)=NX2(NE-1)+1
        KX1=NX1(NE)
        DO 807 KX=KX1,JEH,JEI
            IF (E3CM(KX).LE.EINT2(NE)) GO TO 808
807 CONTINUE
808 NX2(NE)=KX-1
    DO 820 LX=1,NCINT
        K1=NX1(LX)
        K2=NX2(LX)
        DC12=(DIFF(K1)-DIFF(K1-1))*(E3CM(K1-1)-EINT1(LX))/(E3CM(K1-1)-
        E3CM(K1))+DIFF(K1-1)
        DC1=(DC12+DIFF(K1))/*(EINT1(LX)-E3CM(K1))/2.
        DC22=(DIFF(K2+1)-DIFF(K2))*(E3CM(K2)-EINT2(LX))/(E3CM(K2)-
        E3CM(K2+1))+DIFF(K2)
        DC2=(DC22+DIFF(K2))/*(E3CM(K2)-EINT2(LX))/2.
        DC3=0.
        IF (NX1(LX).EQ.NX2(LX)) GO TO 811
        K22=K2-1
        DO 810 LY=K1,K22
810 DC3=DC3+(E3CM(LY)-E3CM(LY+1))*(DIFF(LY)+DIFF(LY+1))/2.
811 DC(LX)=DC1+DC2+DC3
820 CONTINUE
    WRITE(6,821)
821 FORMAT(1HO,6X,'INTEGRATION LIMIT DIFFERENTIAL CROSS SECTION'/
114X,'MEV',19X,'MB/SR')
    WRITE(6,822) (EINT1(NZ),EINT2(NZ),DC(NZ),NZ=1,NOINT)
822 FORMAT(8X,F6.2,' - ',F6.2,11X,E12.5)
    IF (ITOP.EQ.1) GO TO 890
830 DO 831 IE=JEL,JEH,JEI
    IF (E3CM(IE).LE.ETMAX) GO TO 832
831 CCNTINUE
832 DO 840 IE1=1E,JEH,JEI
    IF (E3CM(IE1).LE.ETMIN) GO TO 841
840 CONTINUE
841 JK=IE1-1
    U12=(DIFF(IE)-DIFF(IE-1))*(E3CM(IE-1)-ETMAX)/(E3CM(IE-1)-E3CM(IE))-
    1+DIFF(IE-1)
    U1=((U12+DIFF(IE))/2.)*(ETMAX-E3CM(IE))
    U22=(DIFF(JK+1)-DIFF(JK))*(E3CM(JK)-ETMIN)/(E3CM(JK)-E3CM(JK+1))-
    1+DIFF(JK)
    U2=((U22+DIFF(JK))/2.)*(E3CM(JK)-ETMIN)
    U3=0.
    IF (IE.EQ.JK) GO TO 851
    IT4=JK-1
    DO 850 IT=(E,IT4
850 U3=U3+(E3CM(IT)-E3CM(IT+1))*(DIFF(IT)+DIFF(IT+1))/2.
851 OCTOT=U1+U2+U3
    WRITE(6,860) ETMIN,ETMAX,OCTOT
860 FORMAT(1HO,6X,'INTEGRATION LIMIT ',F6.2,' - ',F6.2,' MEV'/
17X,'TOTAL DIFF. XSECTION=',E12.5,' MB/SR')
890 CONTINUE
761 CCNTINUE
    REWIND NT
    GO TO 710
    END
    SUBROUTINE TLREAD
    ROUTINE TO READ IN TL CARDS PRODUCED BY OPT MOD.
```

C REVISED BY C. C. LU  
CCMOMON TL,JEM,MT,DENOM,N,A,B,C,D,  
IIP,IG,ESTARM,SPIN,FO,ITLR  
DIMENSTON TL(5,18,45), JEM(5), DENOM(18),  
A(5), B(5), C(5), D(5), ESTARM(5), SPIN(5)  
C FIRST READ NU=1, JE=1 CARDS.  
DO 52 L INDEX=1,13,6  
LINMAX=L INDEX+5  
L=L INDEX-1  
READ 103, (TL(1,L IND,1),L IND=L INDEX,LINMAX),  
ILCARD,NUCARD,MTCARD  
C CHECK CARDS FOR PROPER INDICES AND ORDER.  
IF(1-NUCARD) 53,54,53  
54 IF(IL-LCARD) 53,56,53  
56 IF(MT-MTCARD) 53,52,53  
52 CCNTINUE  
IF (ITLR-2) 200,203,203  
203 CCNTINUE  
RETURN  
C NOW READ IN FOR THE REST OF THE CHANNELS, AND CHECK ORDER.  
200 NU1=2  
NU2=5  
57 DO 2 NU=NU1,NU2  
70 JEMAX=JEM(NU)  
90 CONTINUE  
DO 2 JE=1,JEMAX  
DO 2 L INDEX=1,13,6  
LINMAX=L INDEX+5  
L=L INDEX-1  
READ 103, (TL(NU,L IND,JE1,L IND=L INDEX,  
IL IND),LCARD,NUCARD+MTCARD  
IF(NU-NUCARD) 3,4,3  
4 IF(IL-LCARD) 3,6,3  
6 IF(MT-MTCARD) 3,2,3  
2 CCNTINUE  
RETURN  
53 NU=1  
JE=1  
3 PRINT 104,NU,JE,L,MT  
103 FORMAT(6F12.6,12,2X,2I2)  
104 FORMAT(23H0 THE TSUBL-CARD FOR NU=I2,5H, JE=I2,7H, L =I2,9H, AND  
IMT=I2,35H IS OUT OF PLACE IN THE INPUT DECK.)  
CALL EXIT  
END  
SUBROUTINE DENOMR  
CCMOMON TL,JEM,MT,DENOM,N,A,B,C,D,  
IIP,IG,ESTARM,SPIN,FO  
DIMENSION TL(5,18,45), JEM(5), DENOM(18),  
A(5), B(5), C(5), D(5), ESTARM(5), SPIN(5),SUM(5,45),DN(18,5)  
10 DO 500J=1,18  
DENOM(J)=0.  
RJ=J-1  
IF(N-6) 20,20,15  
15 RJ=RJ+0.5  
20 DO 501 NU=2,5  
IF (JFM(NU)-2) 11,11,12  
11 DN(J,NU) = 0.  
GO TO 431  
12 DO 25 NZERO=1,45

```
      25 SUM(NU,NZERO)=0.  
C      IF N=5(J-INT) J=J-1    IF N=9(J-1/2INT) J=J-.5  
      JEMAX=JEM(NU)  
      30 DO 301 JE=1,JEMAX  
      E=JE+1  
C      U=E/2  
      40 DO 302 L=1,18  
      RL=L-1  
      TLFAC=TL(NU,L,JE)  
      IF(TLFAC-1.0E-10)301,41,41  
      41 CONTINUE  
      42 NSMIN=ABS(RJ-RL)+1.  
      NSMAX=J+L-1  
      IF(NSMIN=15)43,43,302  
      43 IF(NSMAX=15)46,46,44  
      44 NSMAX=15  
      46 DO 303 NS=NSMIN,NSMAX  
      S=NS-1  
C      IF N=5 S=S, IF N=9 S=S+.5          SMAX=14  
      IF(N=6)60,60,50  
      50 S=S+.5  
      60 IMIN=ABS(S-SP(IN(NU))+1.  
      IMAX=S+SP(IN(NU))+1.  
      DO 303 I=IMIN,IMAX  
      RI=I-1  
      IF(N=6)70,70,72  
      70 GO TO 180,80,85,85,80),NU  
      72 GO TO 180,85,80,80,85),NU  
      85 RI=RI+.5  
      80 CONTINUE  
C      U=E/2  
      EROT=RI*(RI+1.)/(D(NU))  
      EMR=E-EROT  
      DENT=DE(EMR,NU)  
      DENS=DENT*TLFAC  
      SUM(NU,JE)=SUM(NU,JE)+DENS*SIG(RI,F0,E,NU)  
303 CONTINUE  
302 CONTINUE  
301 CONTINUE  
      DM(J,NU)=0.  
      TES=JEM(NU)  
      TEST=ESTARM(NU)*2.-TES  
      NEST=TEST  
      IF(NEST)410,400,410  
400 NT2=JEM(NU)/2  
      NT2=NT2*2  
      IF(JEM(NU)-NT2)401,401,402  
401 DM(J,NU)=(SUM(NU,JEMAX)+SUM(NU,JEMAX-1))/2.  
402 DN(J,NU)=DN(J,NU)+SUM(NU,JEMAX)*ESTARM(NU)*2.-JEM(NU)+1)/2.  
      JEMS=1JEM(NU)+1)/2  
      JEMS=JEMS*2-3  
      GO TO 420  
410 JEMS=JEM(NU)/2  
      JEMS=JEMS*2-1  
420 DO 430 JE=1,JEMS,2  
430 DN(J,NU)=DN(J,NU)+(SUM(NU,JE)+4.0*SUM(NU,JE+1)+SUM(NU,JE+2))/3.  
      DN(J,NU)=DN(J,NU)*.5  
431 CONTINUE  
501 DENOM(J)=DENOM(J)+DN(J,NU)
```

```
500 DENOM(IJ)= SQRT(DENOM(IJ))
      RETURN
      END
      FUNCTION DEN(E,NU)
      COMMON      TL,JEM,MT,DENOM,N,A,B,C,D,
      IIP,IC,ESTARM,SPIN,FO
      DIMENSION      TL(5,18,45), JEM(5), DENOM(18),
      A(5), B(5), C(5), D(5)
      U=E/2.
      1 GO TO 15,IC
      5 CHEK=A(NU)*C(NU)*(U-B(NU))*D(NU)
      IF(CHEK)6,7
      6 DEN=0.
      RETURN
      7 T=(1.+SQRT(1.+4.* (U-B(NU))*A(NU)))/(2.*A(NU))
      DEN=A(NU)**.5*EXP(2.*SQRT(A(NU)*(U-B(NU)))/(U+T-B(NU))**2
      *C(NU))
      RETURN
      9 IF(A(NU))6,6,10
      10 DEN=C(NU)*EXP((U-B(NU))/A(NU))
      RETURN
      END
      FUNCTION SIG(IFI,FO,E,NU)
      COMMON      TL,JEM,MT,DENOM,N,A,B,C,D,
      IIP,IC
      DIMENSION      TL(5,18,45), JEM(5), DENOM(18),
      A(5), B(5), C(5), D(5)
      U=E/2.
      2 GO TO 11,19,1,19,IP
      1 IF(A(NU)*D(NU)*(U-B(NU)))5,5,15
      5 SIG=0.
      RETURN
      15 IF (IP.EQ.3) GO TO 16
      T=(1.+SQRT(1.+4.* (U-B(NU))*A(NU)))/(2.*A(NU))
      SIG=(2.*IFI+1.)/(D(NU)**1.5)
      RETURN
      16 SIG=(2.*IFI+1.)/(D(NU)**1.5)
      RETURN
      19 IF(D(NU))5,5,20
      20 SIG=(2.*IFI+1.)*EXP(-IFI*(IFI+1.)/(2.*D(NU)))/(2.*D(NU))
      RETURN
      END
```

## I. EVAP Program Listing

```
C      PROGRAM EVAP
      CALL ERRSET (208,256,-1,1)
      COMMON      TL,JEM,MT,DENOM,N,A,B,C,D,
      IIP,IC,ESTARM,SPIN,FO,ITLR
      DIMENSION      TL(5,18,45), JEM(5), DENOM(24),
      A(5), B(5), C(5), D(5), ESTARM(5), SPIN(5),
      2PA(45),E3CM(45)
710 READ(5,700,END=800) NTITLE
700 FORMAT(1X,11,78H
      )
      WRITE(6,701)
701 FORMAT(1HL,15X,*EVAPORATION SPECTRUM*)
      WRITE(6,700) NTITLE
      GO TO 10
800 CALL EXIT
10 READ(5,131 S1MIN,S1MAX,N,JEL,JEH,JEI,
      1(JEM(I),I=1,5), (ESTARM(I),I=1,5), (A(I),I=1,5),
      2(B(I),I=1,5), (C(I),I=1,5), (D(I),I=1,5), IP,IC, FO, NUOUT,MT, ITLR
      3,TDENOM
13 FORMAT (2F8.1,[8.3]18/518/5F8.5/5E12.5/
      15E12.5 / 5E12.5 / 5E12.5 /
      2I4, [4, E12.5,5]4)
      READ(5,195) SIP,SIT,EB,AM,TM
195 FORMAT(2F8.1,3F8.3)
      WRITE(6,141 S1MIN,S1MAX,N,
      1JFL,JEH,JEI,(JEM(I),I=1,5),(ESTARM(I),I=1,5),
      2(A(I),I=1,5),1B(I),I=1,5),(C(I),I=1,5),
      3(D(I),I=1,5),IP,IC,FO, NUOUT
14 FORMAT(1H0,28HMIN ENTRANCE CHANNEL SPIN = ,F4.1/
      21H ,28HMAX ENTRANCE CHANNEL SPIN = ,F4.1/
      31H ,10HTAPE NO.= ,11/1H ,11HJE(LOWEST)=,12.5X,12HJE(HIGHEST)=,
      412.5X,8HJE(TNC)=,12/1H ,14X,3H=1.9X,3H=2.9X,3H=3 ,
      59X,3H=4.9X,3H=5/1H ,7HJEM(I)=,4X,5I12/
      61H ,10HESTARM(I)=,1X,5E12.5/1H ,5HAI(I)=,6X,
      75E12.5/1H ,5HB(I)=,6X,5E12.5/1H ,5HC(I)=,6X,5E12.5/1H ,5HD(I)=,
      86X,5F12.5/1H ,26HANG MOM DENSITY OPTION IS ,I2/
      91H ,25HENERGY DENSITY OPTION IS ,12/1H ,3HEF=,E12.5,1H ,3HNU=,12)
      EFF=0.01914*EB*(2.0*SIP+1.0)*(2.0*SIT+1.0)*AM*(TM/(AM+TM))**2
      WRITE(6,920) SIP,SIT,AM,TM,EFF,EB
920 FORMAT(1H0,16HPROJECTILE SPTN=F8.3/
      11H0,12HTARGET SPIN=F8.3/
      21H0,16HPROJECTILE MASS=F8.3/
      31H0,12HTARGET MASS=F12.5/1X,4HEFF=F12.5/
      41H0,18HPROJECTILE ENERGY=F12.3,3HMEV)
      IF (TIDENOM.NE.1) GO TO 720
      WRITE(6,721)
721 FORMAT('0 PREVIOUS DENOM(I) VALUES ARE USED'//)
720 CONTINUE
      READ(5,750) AM1,AM2,AM3,AM4,AD
750 FORMAT(8F10.5)
      IF (ITLR-1) 400,401,400
400 CALLTREAD
401 CONTINUE
      SPIN(1)=1.
      SPIN(2)=0.
      SPIN(3)=.5
      SPIN(4)=.5
      SPIN(5)=1.
      IF(N-6)1,1,2
```

```
1 IS1MIN=S1MIN+1.  
IS1MAX=S1MAX+1.  
GOTO3  
2 IS1MIN=S1MIN+.5  
IS1MAX=S1MAX+.5  
3 CONTINUE  
IF (IDENOM,F0.1) GO TO 620  
CALL DENOMR  
620 CONTINUE  
WRITE(6,630) (DENOM(J),J=1,24)  
630 FORMAT(1H0, '(DENOM(J))**Q.5, J=0,23',//1X,6E14.5/1X,6E14.5/1X,6E14.  
15/1X,6E14.5)  
DO130 JE=JEL,JEH,JEI  
F=JE-1  
PROD=0.  
DO125 IS1=IS1MIN,IS1MAX  
S1*IS1  
IF(N=6)4,4,5  
4 ES=S1-1.  
GO TO 6  
5 FS=S1-.5  
5 DO 125 L1=1,19  
FL1=L1-1  
IF (FL1(1,L1,1).EQ.0.0) GO TO 125  
JMIN=ABS(FL1-ES)+1.  
JMAX=FL1+ES+1  
DO 125 J=JMIN,JMAX  
FJ=J-1  
IF (N=6) 50,50,51  
50 F2J=2*j-1  
GO TO 52  
51 F2J=2*j  
FJ=FJ+0.5  
52 DO 125 L2=1,18  
IF (FL1(NUOUT,L2,JE).EQ.0.0) GO TO 125  
FL2=L2-1  
S2MIN=4PSI(FL2-FJ)  
S2MAX=FL2+FJ  
IF(N=6)227,227,228  
227 IS2MIN=S2MIN+1.  
IS2MAX=S2MAX+1.  
GO TO 229  
228 IS2MIN=S2MIN+.5  
IS2MAX=S2MAX+.5  
229 CONTINUE  
DO 125 IS2=IS2MIN,IS2MAX  
IF(N=6)230,230,231  
230 S2=IS2-1  
GO TO 232  
231 S2=IS2  
S2=S2-.5  
232 F12MIN=ABS(S2-SPIN(NUOUT))  
F12MAX=S2+SPIN(NUOUT)  
IF (N=6) 233,233,234  
233 I2MIN=F12MIN+1.  
I2MAX=F12MAX+1.  
GO TO 235  
234 I2MIN=F12MIN+.5  
I2MAX=F12MAX+.5
```

```
235 DO 125 I2=12MIN,12MAX
  IF(N=6) 201,201,202
  201 GOTO( 203,203,204,204,203),NUOUT
  203 FI2=12-1
    GO TO 236
  204 FI2=I2
    FI2=FI2-.5
    GO TO 236
  202 GO TO 1204,204,203,203,204), NUOUT
  236 PROD=PROD+TL(1,L1,1)*TL(NUOUT,L2,JET+F2J*SIG(FI2,FO,E,NUOUT)/
    1(DENOM(J))
  125 CONTINUE
    PROD=PROD/EFF
  130 PA(JJE)=PROD*DEN(E,NUOUT)
    WRITE(6,762)
    DC 760 JJE=JEL,JEH,JET
    E=JJE-1
    F=.5*E
    E3CM(JJE)=EB*AM2*AM4/((AM1+AM2)**2)+(AQ-E1*AM4/(AM3+AM4))
    WRITE(6,763) E,E3CM(JJE),PA(JJE)
  760 CONTINUE
  762 FORMAT(1HO,' E(RFS.) E3(C.M.) DIFF. CROSS SECTION /'
    14X,'MEV.',8X,'MEV.',8X,'MB/SR/MEV')
  763 FORMAT(3X,F5.1,5X,F8.2,7X,E12.5)
    GO TO 710
    END
    SUBROUTINE TLREAD
C     ROUTINE TO READ IN TL CARDS PRODUCED BY OPT MOD.
C     REVISED BY C. C. LU
      COMMON      TL,JEM,MT,DENOM,N,A,B,C,D,
      TIP,TC,ESTARM,SPIN,FO,ITLR
      DIMENSION    TU(5,18,45), JEP(5), DENOM(24),
      1 A(5), B(5), C(5), D(5), ESTARM(5), SPIN(5)
C     FIRST READ NJ=1, JE=1 CARDS.
      DO 52 LININDEX=1,13,6
      LINMAX=LININDEX+5
      L=LINDEX-1
      READ 103,          (TL(I,LIND,1),LIND=LINDEX,LINMAX),
      1LCARD,NUCARD,MTCARD
C     CHECK CARDS FOR PROPER INDICES AND ORDER.
      IF(L=NUCARD) 53,54,53
      54 IF(L=LCARD) 53,56,53
      56 IF(MT=MTCARD) 53,52,53
      52 CONTINUE
      IF (ITLR-2) 200,203,203
  203 CONTINUE
      RETURN
C     NOW READ IN FOR THE REST OF THE CHANNELS, AND CHECK ORDER.
  200 NUL=2
      NU2=5
      57 DO 2 NU=NUL,NU2
      20 JEMAX=JEM(NU)
      90 CONTINUE
      DO 2 JE=1,JEMAX
      20 LINDEX=1,13,6
      LINMAX=LINDEX+5
      L=LINDEX-1
      READ 103,          (TL(NU,LIND,JE),LIND=LINDEX,
      1LINMAX),LCARD,NUCARD,MTCARD
```

```
1 IF(NU=NUCARD) 3,4,3
2 IF(L=LCARD) 3,6,3
3 IF(MT=MTCARD) 3,2,3
4 CONTINUE
5 RETURN
6 IF(JE=1) 103
7 IF(NU>12) 104
8 IF(JE>7) 104
9 IF(L>12) 104
10 IF(MT>35) 104
11 PRINT 104,NU,JE,L,MT
12 FORMAT(6F12.6,12,2X,2I2)
13 FORMAT(23H0 THE TSUBL-CARD FOR NU=I2,5H, JE=T2,7H, L =I2,9H, AND
14 IMT=T2,35H IS OUT OF PLACE IN THE INPUT DECK.)
15 CALL EXIT
16 END
17 SUBROUTINE DENOMR
18 COMMON TL,JE4,MT,DENOM,N,A,B,C,D,
19 IIP,IC,ESTARM,SPIN,FO
20 DIMENSION TL(5,18,45), JEM(5), DENOM(24),
21 A(5), B(5), C(5), D(5), ESTARM(5), SPIN(5), SUM(5,45),ON(24,5)
22 DO 500 J=1,24
23 DENOM(J)=0.
24 RJ=J-1
25 IF(N=6) 20,20,15
26 PJ=RJ+0.5
27 DO 301 NU=2,5
28 IF (JEM(NU)=2) 11,11,12
29 DM(J,NU)=C.
30 GO TO 431
31 DO 25 NZERO=1,45
32 SUM(NU,NZERO)=0.
33 IF N=5(J-INT) J=J-1 IF N=9(J-1/2INT) J=J-5
34 JEMAX=JEM(NU)
35 DO 301 JE=1,JEMAX
36 E=JE-1
37 U=F?
38 DENT=DFN(E,NU)
39 DO 302 L=1,18
40 RL=L-1
41 TLFAC=TL(NU,L,JE)
42 IF(TLFAC<1.0E-10) 301,41,41
43 DENS=DENT*TLFAC
44 NSMTN=ABS(RJ-RL)+1.
45 NSMAX=J+L-1
46 DO 303 NS=NSMIN,NSMAX
47 S=NS-1
48 IF N=5 S=S, IF N=9 S=S+.5 SMAX=14
49 IF(N=6) 60,60,50
50 S=S+.5
51 IMIN=ABS(S-SPIN(NU))+1.
52 IMAX=S+SPIN(NU)+1.
53 DO 303 I=IMIN,IMAX
54 RI=I-1
55 IF(N=6) 70,70,72
56 GO TO 180,80,85,85,801,NU
57 GO TO (80,85,80,80,85),NU
58 RI=RI+.5
59 SUMNU,JE I=SUM(NU,JE)+DENS*S(I,RI,FO,E,NU)
60 CONTINUE
61 CONTINUE
62 CONTINUE
63 CONTINUE
```

```
D(N,J,NU)=0.
TES=JEM(NU)
TEST=ESTARM(NU)*2.-TES
NTEST=TEST
IF(NTEST>410,400,410
400 NT2=JEM(NU)/2
NT2=NT2*2
1F(JEM(NU)-NT2)401,401,402
401 D(N,J,NU)=(SUM(NU,JEMAX)+SUM(NU,JEMAX-1))/2.
402 D(N,J,NU)=D(N,J,NU)+SUM(NU,JEMAX)*ESTARM(NU)*2.-JEM(NU)+1)/2.
JEMS=(JEM(NU)+1)/2
JEMS=JEMS*2-3
GO TO 420
410 JEMS=JEM(NU)/2
JEMS=JEMS*2-1
420 DO 430 JE=1,JEMS,2
430 D(N,J,NU)=D(N,J,NU)+(SUM(NU,JE)+4.0*SUM(NU,JE+1)+SUM(NU,JE+2))/3.
D(N,J,NU)=D(N,J,NU)*.5
431 CONTINUE
501 DENOM(J)=DENOM(J)+D(N,J,NU)
500 CONTINUE
RETURN
END
FUNCTION DE(N,E,NU)
COMMON TL,JE4,MT,DENOM,N,A,B,C,D,
IP,IC,ESTARM,SPTN,F0
DIMENSION TL(5,19,45), JEM(5), DENOM(24),
A(5), B(5), C(5), D(5)
U=E/2.
1 GO TO (5,9),1C
5 CHEK=A(NU)*C(NU)*(J-B(NU))*D(NU)
1F(CHEK)6,6,7
6 DEN=0.
RETURN
7 T=(1.+SQRT(1.+4.*U-B(NU)))*A(NU))/12.*A(NU))
DEN=A(NU)**.5*EXP((2.*SQRT(A(NU)*(U-B(NU))))/((U+T-B(NU))**2
1*C(NU)))
RETURN
9 1F(A(NU))6,6,10
10 DEN=C(NU)*EXP((U-B(NU))/A(NU))
RETURN
END
FUNCTION SIG(FT,FC,E,NU)
COMMON TL,JEM,MT,DENOM,N,A,B,C,D,
IP,IC
DIMENSION TL(5,19,45), JEM(5), DENOM(24),
A(5), B(5), C(5), D(5)
U=E/2.
2 GO TO (1,19,1,30),IP
1 1F(A(NU)*D(NU)*(U-B(NU)))15,5,15
5 SIG=0.
RETURN
15 1F ((P.EQ.3))-GO TO 16
T=(1.+SQRT(1.+4.*U-B(NU))*A(NU))/12.*A(NU))
SIG=(2.*FT+1.)*EXP((FT+.5)**2/(-2.*D(NU)*T))/(D(NU)**1.5)
RETURN
16 SIG=(2.*FT+1.)*EXP((FT+.5)**2/(-2.*D(NU)))/(D(NU)**1.5)
RETURN
19 1F(D(NU))5,5,20
```

```
20 SIG=(2.*FI+1.)*EXP(-FI*(FI+1.)/(2.*D(NU)))/(2.*D(NU))
  RETURN
30 IF(A(NU)*D(NU)*(U-B(NU))>5.5,31
31 SIG=(2.*FI+1.)/(D(NU)**1.5)
  RETURN
END
```

J. EVAP Program Sample Output

EVAPORATION SPECTRUM

I 56FE(ALPHA,ALPHA)56FE 17 MEV FERMI GAS CALC.

IN ENTRANCE CHANNEL SPIN = 0.0

MAX ENTRANCE CHANNEL SPIN = 0.0

TAPE NO.= 5

JE(LOWEST)= 1 JE(HIGHEST)=23 JE(INC)= 1

I=1 I=2 I=3 I=4 I=5

JEM(I)= 1 23 23 22 1

ESTARM(I)= 0.10000E 01 0.16020E 02 0.12780E 02 0.10930E 02 0.0

A(I)= 0.10000E 01 0.57000E 01 0.62000E 01 0.64000E 01 0.65000E 01

B(I)= 0.10000E 01 0.70000F 00-0.80000E 00-0.50000E 00-0.20000E 01

C(I)= 0.10000F 01 0.33941E 02 0.33941E 02 0.33941E 02 0.33941E 02

D(I)= 0.10000E 01 0.11230E 02 0.12250E 02 0.12250E 02 0.11910E 02

ANG MOM DENSITY OPTION IS 1

ENERGY DENSITY OPTION IS 1

F0= 0.0 NU= 2

PROJECTILE SPIN= 0.0

TARGET SPIN= 0.0

PROJECTILE MASS= 4.003

TARGET MASS= 55.93489

EFF= 1.13423

PROJECTILE ENERGY= 17.000MEV

DENOM(J), J=0,23

0.31696E 04	0.89662E 04	0.13288E 05	0.15599F 05	0.15862E 05	0.14464E 05
0.12031E 05	0.92192E 04	0.65479E 04	0.43284E 04	0.26706E 04	0.15412E 04
0.83328E 03	0.42258E 03	0.20121E 03	0.90032E 02	0.37883E 02	0.14999E 02
0.55915E 01	0.19636E 01	0.64591E 00	0.20282E 00	0.59703E-01	0.16581E-01

E(RES.) E3(C.M.) DIFF. CROSS SECTION

MEV.	MEV.	MB/SR/MEV
0.0	14.81	0.0
0.5	14.34	0.0
1.0	13.87	0.18586E-01
1.5	13.41	0.37382E-01
2.0	12.94	0.68519E-01
2.5	12.47	0.10483E 00
3.0	12.01	0.18858E 00
3.5	11.54	0.29001E 00
4.0	11.07	0.42739E 00
4.5	10.61	0.60499E 00
5.0	10.14	0.82241E 00
5.5	9.67	0.10709E 01
6.0	9.21	0.13282E 01
6.5	8.74	0.15535E 01
7.0	8.27	0.16870E 01
7.5	7.81	0.16610E 01
8.0	7.34	0.14388E 01
8.5	6.87	0.10607E 01
9.0	6.41	0.64984E 00
9.5	5.94	0.32652E 00
10.0	5.47	0.13397E 00
10.5	5.01	0.42627E-01
11.0	4.54	0.78003E-02

K. ZCOEF Program Listing

```
C      PROGRAM ZCOEF
      DIMENSION ZCOE (18,18,15)
      DO 31 N=5,9,4
      IF(N-6)1,1,2
1  WRITE(6,3)
3  FORMAT(33H                                     J IS INTEGRAL)
      GO TO 15
2  WRITE(6,14)
14 FORMAT(38H                                     J IS HALF INTEGRAL)
15 NT=N+8
      DF 30 L=1,7
      F=2*(L-1)
11 WRITE(6,110) F
110 FORMAT(1H ,60X,2HL=,F4.1)
      DO 30 I=1,18
      A=I-1
      WRITE(6,150) A
150 FORMAT(1H ,60X,9HLORBITAL=,F4.1)
      CLEB=CLEBSH(A,A,F,0,0)
      DO 30 J=1,18
      DO 30 K=1,15
      IF (N-6) 4,4,5
4   P=J-1
      E=K-1
      GO TO 7
5   B=J
      B=B-.5
      E=K
      F=E-.5
7   ZCOE(I,J,K)=(2.*A+1.)*(2.*B+1.)*CLEB*RACAH(A,B,A,B,E,F)
      IF(K-15)30,41,41
41  WRITE(6,32) L,I,J,
     1(ZCOE(I,J,KK),KK=1,15)
32  FORMAT(1H ,3I4,7E12.4/IH 8E12.4)
      WRITE(NT) L,I,J,(ZCOE(I,J,KK),KK=1,15)
30  CONTINUE
      END FILE NT
31  CONTINUE
      END
      FUNCTION CLEBSH(A,B,C,ALPHA,BETA)
C      THIS IS A GENERAL FORMULATION OF CLEBSCH-GORDAN
C      COEFFICIENTS.
      DIMENSION FACTOL(182)
      CLEBSH=0.
      GAMMA=ALPHA+BETA
      2 IF((A+B+C)-INT (A+B+C))21,3,21
21  GOT029
      3 IF(A+B-C)21,4,4
      4 IF(A-B+C)21,5,5
      5 IF(-A+B+C)21,6,6
      6 IF(ABS (ALPHA)-A)7,7,21
      7 IF(ABS (BETA)-B)8,8,21
      8 IF(ABS (GAMMA)-C)9,9,21
      9 IF((A+ALPHA)-INT (A+ALPHA))21,10,21
10  IF((B+BETA)-INT (B+BETA))21,11,21
11  IF((C+GAMMA)-INT (C+GAMMA))21,12,21
12  N1=A+B-C+1.
      N2=C+A-B+1.
      N3=L+B-A+1.
```

```
T DE1=A+B+C+2.  
N4=A+ALPHA+1.  
N5=A-ALPHA+1.  
N6=B+BETA+1.  
N7=B-BETA+1.  
N8=C+GAMMA+1.  
N9=C-LAMMA+1.  
TCP1=.43429448*ALCG(2.*C+1.)  
IF(FACTOL(41)=47.91164507)13,14,13  
13 FACTOL(1)=0.  
FACTOL(2)=0.0  
FACTOL(3)=0.3010299957  
FACTOL(4)=0.7781512504  
FACTOL(5)=1.380211242  
FACTOL(6)=2.079181246  
FACTOL(7)=2.857332496  
FACTOL(8)=3.702430536  
FACTOL(9)=4.605520523  
FACTOL(10)=5.559763037  
FACTOL(11)=6.559763033  
FACTOL(12)=7.601155718  
FACTOL(13)=8.680336964  
FACTOL(14)=9.794280316  
FACTOL(15)=10.94040835  
FACTOL(16)=12.11649961  
FACTOL(17)=13.32061959  
FACTOL(18)=14.55106852  
FACTOL(19)=15.80634102  
FACTOL(20)=17.08509462  
FACTOL(21)=18.38612462  
FACTOL(22)=19.70834391  
FACTOL(23)=21.05076659  
FACTOL(24)=22.41249443  
FACTOL(25)=23.79270567  
FACTOL(26)=25.19064568  
FACTOL(27)=26.60561903  
FACTOL(28)=28.03698279  
FACTOL(29)=29.48414082  
FACTOL(30)=30.94653882  
FACTOL(31)=32.42366007  
FACTOL(32)=33.91502177  
FACTOL(33)=35.42017175  
FACTOL(34)=36.93868569  
FACTOL(35)=38.47016460  
FACTOL(36)=40.01423265  
FACTOL(37)=41.57053515  
FACTOL(38)=43.13873687  
FACTOL(39)=44.71852047  
FACTOL(40)=46.30958508  
FACTOL(41)=47.91164507  
FACTOL(42)=49.5244289248  
FACTOL(43)=51.1476782152  
FACTOL(44)=52.7811466708  
FACTOL(45)=54.4245993473  
FACTOL(46)=56.0778118611  
FACTOL(47)=57.7405696927  
FACTOL(48)=59.4126675507  
FACTOL(49)=61.0939087881  
FACTOL(50)=62.7841048681
```

```
FACTOL(51)=64.4830748724
FACTOL(52)=66.1906450485
FACTOL(53)=67.9066483922
FACTOL(54)=69.6309242618
FACTOL(55)=71.3633180216
FACTOL(56)=73.1036807111
FACTOL(57)=74.8518687381
FACTOL(58)=76.6077435938
FACTOL(59)=78.3711715873
FACTOL(60)=80.1420235990
FACTOL(61)=81.9201748493
FACTOL(62)=83.7055046844
FACTOL(63)=85.4978963738
FACTOL(64)=87.2972369233
FACTOL(65)=89.1034168973
FACTOL(66)=90.9163302539
FACTOL(67)=92.7358741895
FACTOL(68)=94.5615489922
FACTOL(69)=96.3944579049
FACTOL(70)=98.2333069956
FACTOL(71)=100.0784050356
FACTOL(72)=101.9296633843
FACTOL(73)=103.7869958808
FACTOL(74)=105.6503187409
FACTOL(75)=107.5195504606
FACTOL(76)=109.3946117240
FACTOL(77)=111.2754253163
FACTOL(78)=113.1619160415
FACTOL(79)=115.0540106442
FACTOL(80)=116.9516377355
FACTOL(81)=118.8547277224
FACTOL(82)=120.7632127413
14 S01=.5*(FACTOL(N1)+FACTOL(N2)+FACTOL(N3)+TCPI-FACTOL(IDE1))
S02=.5*(FACTOL(N4)+FACTOL(N5)+FACTOL(N6)+FACTOL(N7)
1+FACTOL(N8)+FACTOL(N9))
SUM=0.
SUM3=0.
16 KMAX=MIND(N1,N5,N6)
18 IF(C-B+ALPHA) 19,23,23
19 IF(C-A-BETA) 219,224,224
23 IF(C-A-BETA) 218,24,24
218 KMIN=ABS(C-A-BETA)+1.0
GOTO26
219 KMIN=MAX1(ABS(C-B+ALPHA),ABS(C-A-BETA))+1
GOTO26
224 KMIN=ABS(C-B+ALPHA)+1.0
GOTO26
24 KMIN=1
GO TO 17
26 IF(KMAX-KMIN) 27,17,17
27 KMIN=KMAX
17 DC50K=KMIN,KMAX
D=K
KD=K-1
IDE2=N1-KD
IDE3=N5-KD
IDE4=N6-KD
IDE5=C-B+ALPHA+D
IDE6=C-A-BETA+D
```

```
    IF(2*(K/2)-K)31,32,32
31 FAC=1.0
GOTO22
32 FAC=-1.0
SUM1=2.302585093*(SQ1+SQ2-(FACTOL(K)+FACTOL(1DE2)-
1FACTOL(1DE3)+FACTOL(1DE4)+FACTOL(1DE5)+FACTOL(1DE6)))
IF(SUM1-88.165,65,70
65 SUM3=SUM3+FAC*EXP(SUM1)
GOTO50
22 SUM2=2.302585093*(SQ1+SQ2-(FACTOL(K)+FACTOL(1DE2)-
1FACTOL(1DE3)+FACTOL(1DE4)+FACTOL(1DE5)+FACTOL(1DE6)))
IF(SUM2-88.160,60,70
60 SUM=SUM+FACTOL(SUM2)
50 CONTINUE
CLEBSI=SUM+SUM3
29 RETURN
70 WRITE(6,71) A,B,C,ALPHA,BETA
71 FORMAT(9H1OVERFLOW/3H0C(5(1PE15.0),1H)/1H1)
GOTO24
END
FUNCTION RACAH(A,B,C,D,E,F)
C THIS IS A GENERAL NUMERICAL FORMULATION
C OF RACAH COEFFICIENTS.
DIMENSION FACTOL(82)
RACAH=0.
1 IF((A+B+E)=INT(A+B+E))35,2,35
2 IF((C+D+E)=INT(C+D+E))35,3,35
3 IF((A+C+F)=INT(A+C+F))35,4,35
4 IF((B+D+F)=INT(B+D+F))35,5,35
5 I1=A+B+E
J1=C+D+E
K1=A+C+F
L1=B+D+F
I2=A+B-E
J2=A-B+E
K2=A-C+F
L2=B-D+F
I3=A-B-E
J3=C-D+F
K3=A-C-F
L3=B-D-F
I4=-A+B+E
J4=-A-B+E
K4=-A+C+F
L4=-B+D+F
7 IF(I2)65,8,8
8 IF(I3)65,9,9
35 WRITE(6,461) A,B,C,D,E,F
461 FORMAT(17H0SUM NCT INTEGRAL,3X,5HLORB=,F4.1,3X,2HJ=,F4.1,3X,2HS=,F
14.1,3X,2HL=,F4.1)
9 IF(I4)65,10,10
10 IF(J2)65,11,11
11 IF(J3)65,12,12
12 IF(J4)65,13,13
13 IF(K2)65,14,14
14 IF(K3)65,15,15
15 IF(K4)65,16,16
16 IF(L2)65,17,17
17 IF(L3)65,18,18
```

```
18 IF(L4)65,19,19
65 GOTO110
19 IF(FACTOL(41)=47.91164507)40,41,40
40 FACTOL(1)=0.0
FACTOL(2)=0.0
FACTOL(3)=0.3010299957
FACTOL(4)=0.7781512504
FACTOL(5)=1.380211242
FACTOL(6)=2.079181246
FACTOL(7)=2.857332496
FACTOL(8)=3.702430536
FACTOL(9)=4.605520523
FACTOL(10)=5.559763033
FACTOL(11)=6.559763033
FACTOL(12)=7.601155718
FACTOL(13)=8.681336964
FACTOL(14)=9.794280316
FACTOL(15)=10.94040835
FACTOL(16)=12.11649961
FACTOL(17)=13.32061959
FACTOL(18)=14.55106852
FACTOL(19)=15.80634102
FACTOL(20)=17.08509462
FACTOL(21)=18.38612462
FACTOL(22)=19.70834391
FACTOL(23)=21.05076659
FACTOL(24)=22.41249443
FACTOL(25)=23.79270567
FACTOL(26)=25.19064568
FACTOL(27)=26.60561903
FACTOL(28)=28.03658279
FACTOL(29)=29.48414082
FACTOL(30)=30.94653882
FACTOL(31)=32.42366007
FACTOL(32)=33.91502177
FACTOL(33)=35.42017175
FACTOL(34)=36.93868569
FACTOL(35)=38.47016460
FACTOL(36)=40.01423265
FACTOL(37)=41.57053515
FACTOL(38)=43.13873687
FACTOL(39)=44.71852047
FACTOL(40)=46.30958508
FACTOL(41)=47.91164507
FACTOL(42)=49.5244285248
FACTOL(43)=51.1476782152
FACTOL(44)=52.7811466708
FACTOL(45)=54.4245993473
FACTOL(46)=56.0778118611
FACTOL(47)=57.7405696927
FACTOL(48)=59.4126675507
FACTOL(49)=61.0939087881
FACTOL(50)=62.7841048681
FACTOL(51)=64.4830748724
FACTOL(52)=66.1906450485
FACTOL(53)=67.9066483922
FACTOL(54)=69.6309242618
FACTOL(55)=71.3633180216
FACTOL(56)=73.1036807111
```

```
FACTOL(57)=74.8518687381
FACTOL(58)=76.6077435938
FACTOL(59)=78.3711715873
FACTOL(60)=80.1420235990
FACTOL(61)=81.9201748493
FACTOL(62)=83.7055046844
FACTOL(63)=85.4978963738
FACTOL(64)=87.2972369233
FACTOL(65)=89.1034168973
FACTOL(66)=90.9163302539
FACTOL(67)=92.7358741895
FACTOL(68)=94.5619489922
FACTOL(69)=96.3944579049
FACTOL(70)=98.2333069956
FACTOL(71)=100.0784050356
FACTOL(72)=101.9296633843
FACTOL(73)=103.7869958808
FACTOL(74)=105.6503187409
FACTOL(75)=107.5195504606
FACTOL(76)=109.3946117240
FACTOL(77)=111.2754253163
FACTOL(78)=113.1619160415
FACTOL(79)=115.0540106442
FACTOL(80)=116.9516377355
FACTOL(81)=118.8547277224
FACTOL(82)=120.7632127413
41 DELABE=.5*(FACTOL(I2+1)+FACTOL(I3+1)+FACTOL(I4+1)-
1-FACTOL(I1+2))
DELCOE=.5*(FACTOL(J2+1)+FACTOL(J3+1)+FACTOL(J4+1)-
1FACTOL(J1+2))
DELACF=.5*(FACTOL(K2+1)+FACTOL(K3+1)+FACTOL(K4+1)-
1FACTOL(K1+2))
DELTAE=.5*(FACTOL(L2+1)+FACTOL(L3+1)+FACTOL(L4+1)-FACTOL(L1+1)-
1+DELACF+DELCOE+DELABE)*2.302585093
SUM1=0.
SUM3=0.
21 KMAX= MIN0 (I2,J2,K2,L2)+1
1F(E+F-A-D)230,240,240
230 1F(E+F-B-C)250,260,260
240 1F(E+F-B-C)270,25,25
270 KMIN=ABS (E+F-B-C)+1.0
GO TO 26
250 KMIN= MAX1 (ABS (E+F-A-D),ABS (E+F-B-C))+1
GO TO 26
260 KMIN=ABS (E+F-A-D)+1.0
GO TO 26
25 KMIN=1
GO TO 28
26 1F(KMAX-KMIN)27,28,28
27 KMIN=KMAX
28 DD34K=KMIN,KMAX
Z=K
N1=I2-K+2
N2=J2-K+2
N3=K2-K+2
N4=L2-K+2
M1=E+F-A-D+2
M2=E+F-B-C+Z
M3=A+B+C+D+3.-Z
```

```
IF(2*K/2)=K)31,32,32
31 FAC=1.0
GOTO29
32 FAC=-1.0
SUM4=(FACTOL(M3)-(FACTOL(N1)+FACTOL(N2)+FACTOL(N3)-
1FACTOL(N4)+FACTOL(M1)+FACTOL(M2)+FACTOL(K)))*2.302585093
IF(SUM4+DELTA-88.138,38,35C
38 SUM3=SUM3+FAC*EXP(-SUM4+DELTA)
GOTO34
29 SUM2=(FACTOL(M3)-(FACTOL(N1)+FACTOL(N2)+FACTOL(N3)-
1+FACTOL(N4)+FACTOL(M1)+FACTOL(M2)+FACTOL(K)))*2.302585093
IF(SUM2+DELTA-88.130,30,350
30 SUM1=SUM1+FAC*EXP(-SUM2+DELTA)
34 CONTINUE
RACAH=SUM1+SUM3
110 RETURN
350 WRITE(6,36) A,B,C,D,E
36 FORMAT(9H00VERFLOW/3H0W(61PE15.6),IH)
GOTO110
END
```

L. Sample Output of ZCOEFF  
Z(iJzJ; LS)

J IS INTEGRAL

$\ell_1$	$\ell_2$	$J_{12}$	$S=0$	$S=1$	$S=2$	$S=3$	$S=4$	$S=5$	$S=6$	$L=0,0$	$L$	$L=0,0-S$	$L=0,0-S$	$L=0,0-S$
1	1	1	0.1000E 01	0.0-S=1	0.0-S=2	0.0-S=3	0.0-S=4	0.0-S=5	0.0-S=6	0.0	0.0	0.0	0.0	0.0
0.0-S=7			0.0-S=8	0.0-S=9	0.0-S=10	0.0-S=11	0.0-S=12	0.0-S=13	0.0-S=14	0.0	0.0	0.0	0.0	0.0
1	1	2	0.0	0.1732E 01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	3	0.0	0.0	0.2236E C1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	4	0.0	0.0	0.0	0.2646E C1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3000E C1	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3317E 01	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.3873E C1			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.4123E C1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.4359E C1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.4583E C1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.4796E C1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.5000E 01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	1	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
											LCRBITAL = 1.0			
1	2	1	0.0	-0.1000E 01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	2	2	-0.1732E 01	0.1732E 01	-0.1732E C1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	2	3	0.0	-0.2236E 01	0.2236E C1	-0.2236E C1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	2	4	0.0	0.0	-0.2646E C1	0.2646E C1	-0.2646E C1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	2	5	0.0	0.0	0.0	-0.3000E C1	0.3000E C1	-0.3000E C1	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	2	6	0.0	0.0	0.0	0.0	0.0	-0.3317E 01	0.3317E 01	-0.3317F 01	0.0	0.0	0.0	0.0
0.0			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	2	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.3606E C1			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	2	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.3873E 01	0.0
0.3873E C1			-0.3873E C1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	2	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.4123E C1			0.4123E C1	-0.4123E 01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	2	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			-0.4359E 01	0.4359E C1	-0.4359E C1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	2	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0			0.0	-0.4583E C1	0.4583E C1	-0.4583E C1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	2	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

$L=0,2,4,\dots/2$
$\ell=0,1,2,\dots/1$
$J=0,1,2,\dots/1$
$S=0,1,2,\dots/4$

IV. DESCRIPTION OF JCL CARDS FOR PROGRAM ZCOEF  
(IBM-360/65, Computer Center, University of Rochester)

```
//ZCOEF JOB AHS18, 'LUCC'  
// *OPTIONS T=3,P=200,CLASS=B  
// *SETUP ZZZ998,HUIZENGA,RING  
// *SETUP ZZZ999,HUIZENGA,RING  
// EXEC FORTCLG,REGION.GO=60K  
//FORT.SYSIN DD *
```

---

SOURCE DECK

---

```
//GO.FT13F001 DD DSN=ZCOEFI,UNIT=TAPE9,DISP=(NEW,PASS),  
// VOL=SER=ZZZ998,DCB=(RECFM=VBS,LRECL=76,BLKSIZE=764)  
//GO.FT17F001 DD DSN=ZCOEFH,UNIT=TAPE9,DISP=(NEW,PASS),  
// VOL=SER=ZZZ999,DCB=(RECFM=VBS,LRECL=76,BLKSIZE=764)  
//GO.SYSIN DD *
```

---

DESCRIPTION OF JCL CARDS FOR PROGRAMS MAC3, MAC10, MACT3  
AND YRAST WHICH REQUIRE THE USE OF THE OUTPUT TAPES GENERATED  
BY THE PROGRAM ZCOEF

(IBM-360/65, Computer Center, University of Rochester)

Case a): Channel spin is integer.

```
//MAC3 JOB AHS18,'HUIZENGA'  
// *OPTIONS T=5,P=60,CLASS=A  
// *SETUP ZZZ998,HUIZENGA  
// EXEC FORTCLG,REGION.GO=92K  
//FORT.SYSIN DD *
```

---

SOURCE DECK

---

```
//GO.FT13F001 DD DSN=ZCOEFI,UNIT=TAPE9,DISP=(OLD,PASS)  
// VOL=SER=ZZZ998,DCB=(RECFM=VBS,LRECL=76,BLKSIZE=764)  
//GO.SYSIN DD *
```

---

DATA CARDS

//

---

Case b): Channel spin is half-integer.

```
//MAC3 JOB AHS18,'HUIZENGA'  
//OPTIONS T=5,P=60,CLASS=A  
//SETUP ZZZ999,HUIZENGA  
// EXEC FORTCLG,REGION.GO=92K  
//FORT.SYSIN DD *
```

---

SOURCE DECK

---

```
//GO.FT17F001 DD DSN=ZCOEPH,UNIT=TAPE9,DISP=(OLD,PASS)  
// VOL=SER=ZZZ999,DCB=(RECFM=VBS,LRECL=76,BLKSIZE=764)  
//GO.SYSIN DD *
```

---

DATA CARDS

---

//

---