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**Program POD-S ; A Computer Code to Calculate Cross
Sections for Neutron-Induced Nuclear Reactions
by the Statistical Model**

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Program POD-S ; A Computer Code to Calculate Cross Sections for
Neutron-Induced Nuclear Reactions by the Statistical Model

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A computer code, POD-S, was developed for nuclear data evaluations. Energy spectra of the reactions (n, γ) , (n, n') , (n, p) , (n, α) , (n, d) , (n, t) , $(n, {}^3\text{He})$, angular distributions of the neutron elastic- and inelastic-scattering, and their integrated cross sections are calculated within the statistical model. The computational methods and input parameters are explained in this report, with sample inputs and outputs.

Keywords: Nuclear Data, Neutron, Computer Code, Cross Section, Energy Spectrum, Angular Distribution, Statistical Model.

プログラム POD-S ; 統計模型に基づく中性子誘起核反応断面積の 計算コード

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核データ評価のための計算コード POD-S を開発した。このコードは統計模型を用いて (n, γ) , (n, n') , (n, p) , (n, α) , (n, d) , (n, t) , $(n, {}^3\text{He})$ 反応に対するエネルギースペクトルと、中性子の弾性・非弾性散乱に対する角度分布、及びそれらの積分断面積を計算できる。本レポートでは計算方法及び入力データの説明を行い、いくつかの出力例を示す。

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1 Introduction

The nuclear data center is engaged in the development of the 4-th version of the Japanese Evaluated Nuclear Data Library (JENDL-4). Minor actinide (MA) and fission product (FP) data will be newly evaluated or re-evaluated for the innovative reactor design in JENDL-4, which will be completed by the end of the fiscal year 2009.

In the development of previous versions of JENDL, the programs ELIESE-3 [1] and CASTHY [2] were extensively used to evaluate data theoretically. These programs were produced in the nuclear data center of former Japan Atomic Energy Research Institute (JAERI) on the basis of the optical and statistical models. Especially, ELIESE-3 is helpful to obtain transmission coefficients for neutrons and light charged particles. CASTHY is also useful to calculate cross sections for neutron elastic- and inelastic-scattering, capture cross sections, and angular distributions of emitted neutrons.

We developed a computer code POD-S in order to estimate the data in the FP mass region where experimental data are scarce. The γ -ray emission (capture process) is not considered in ELIESE-3, and the charged particle emission is not treated in CASTHY. The competition processes among the γ -ray, n , p , α , d , t , and ^3He emissions from the compound nucleus are considered in this code. The optical model potentials (OMPs) developed by Koning and Delaroche in 2003 [3] are built in the code to compute transmission coefficients for neutrons and protons. The level density parameters in which the nuclear shell effects are considered [4] are built in for the statistical model calculation.

In the next section, formulas to calculate energy spectra and angular distributions with the statistical model are presented. The structure and subroutines of the code are described in Sec.3. Input parameters are explained in Sec.4, and the output examples are given in Sec.5. Summary of the code is presented in Sec.6. Units employed for energy, length, and cross section are MeV, fm (femto-meter), and mb (milli-barn), respectively.

2 Computational Method

2.1 Energy Spectrum

In the statistical model [1, 2, 5, 6], a compound nucleus is formed by the collision of an incident particle with the target nucleus, and light particles (including the γ -ray) are emitted from the compound. In the reaction, the energy, angular momentum, and parity must be

conserved,

$$E_a + B_a = E_{a'} + E' + B_{a'} = E, \quad (1)$$

$$\vec{s} + \vec{I} + \vec{l} = \vec{s}' + \vec{I}' + \vec{l}' = \vec{J}, \quad (2)$$

$$p \cdot P \cdot (-1)^l = p' \cdot P' \cdot (-1)^{l'} = \Pi_0, \quad (3)$$

where the symbols E , \vec{J} and Π_0 stand for the excitation energy, spin and parity of the compound nucleus; E_a and $E_{a'}$ are the relative energies of incoming- and outgoing-particles a and a' ; B_a and $B_{a'}$ denote the binding energies of particles relative to the compound system; E' is the excitation energy of the residual nucleus; \vec{s} , p (\vec{s}' , p') are the spin and parity of the incoming (outgoing) particle, while \vec{I} , P (\vec{I}' , P') stand for those of the target (the residual nucleus); \vec{l} and \vec{l}' indicate the orbital angular momentum for the incoming- and outgoing-channels, respectively.

The angle-integrated cross section of the reaction (a, a') for formation of the final state (E', I', P') from the incoming channel (E_a, I, P) is given as

$$\sigma_{a,a'}(E_a, I, P; E', I', P') = \sum_{J,\Pi} \sigma(E_a, I, P; E, J, \Pi) \frac{\Gamma_{a'}(E, J, \Pi; E', I', P')}{\Gamma(E, J, \Pi)}, \quad (4)$$

where (E, J, Π) are the quantum numbers of the compound state; $\sigma(E_a, I, P; E, J, \Pi)$ is the reaction cross section for formation of the compound nucleus with quantum numbers (E, J, Π) ; and $\Gamma_{a'}(E, J, \Pi; E', I', P')$ is the decay width of the compound nucleus into the state (E', I', P') of the residual nucleus by emission of the particle a' . $\Gamma(E, J, \Pi)$ is the total decay width for the compound state (E, J, Π) , and it is obtained by

$$\Gamma(E, J, \Pi) = \sum_{a''} \sum_{E'', I'', P''} \Gamma_{a''}(E, J, \Pi; E'', I'', P''), \quad (5)$$

where the summation over a'' includes all particles and γ -rays whose emissions are allowed from the compound state (E, J, Π) , and the summation over (E'', I'', P'') includes all possible residual states which satisfy the conservation laws described in Eqs. (1)-(3). If the decays into the continuum states of the residuals are possible, Eq. (5) is expressed with the level density ρ of the residual nuclei as

$$\begin{aligned} \Gamma(E, J, \Pi) &= \sum_{a''} \sum_{E'', I'', P''} \Gamma_{a''}(E, J, \Pi; E'', I'', P'') \\ &+ \sum_{a''} \sum_{I'', P''} \int_{E_{X''}}^{E-B_{a''}} dE'' \Gamma_{a''}(E, J, \Pi; E'', I'', P'') \rho(E'', I'', P''), \end{aligned} \quad (6)$$

where $E_{X''}$ is the maximum value of discrete-level energy of the residual nucleus.

The cross section for formation of the compound nucleus can be expressed with the transmission coefficients $T_l^j(E_a)$ as

$$\sigma(E_a, I, P; E, J, \Pi) = \frac{\pi}{k^2} \frac{(2J+1)}{(2I+1)(2s+1)} \sum_{j=|J-I|}^{J+I} \sum_{l=|j-s|}^{j+s} \omega_\Pi(p, P, l) T_l^j(E_a) \times 10, \quad (7)$$

where the symbol k is the wave number of the relative motion in the entrance channel; j stands for the total angular momentum quantum number of the incoming particle; and $\omega_\Pi(p, P, l)$ is set to be unity if the parity is conserved and zero otherwise.

The branching ratio $\Gamma_{a'}(E, J, \Pi; E', I', P')/\Gamma(E, J, \Pi)$ for decays into residual discrete states is given by

$$\frac{\Gamma_{a'}(E, J, \Pi; E', I', P')}{\Gamma(E, J, \Pi)} = \frac{1}{N(E, J, \Pi)} \sum_{j'=|J-I'|}^{J+I'} \sum_{l'=|j'-s'|}^{j'+s'} \omega_\Pi(p', P', l') T_{l'}^{j'}(E - E' - B_{a'}) \rho(E', I', P'), \quad (8)$$

where the primed quantities indicate the outgoing channels, and

$$\begin{aligned} N(E, J, \Pi) &= \sum_{a'} \sum_{E', I', P'} \sum_{j'=|J-I'|}^{J+I'} \sum_{l'=|j'-s'|}^{j'+s'} \omega_\Pi(p', P', l') T_{l'}^{j'}(E - E' - B_{a'}) \\ &+ \sum_{a'} \sum_{I', P'} \sum_{j'=|J-I'|}^{J+I'} \sum_{l'=|j'-s'|}^{j'+s'} \int_{E_{X'}}^{E' - B_{a'}} dE' \omega_\Pi(p', P', l') T_{l'}^{j'}(E - E' - B_{a'}) \rho(E', I', P'). \end{aligned} \quad (9)$$

With Eqs. (7) to (9), the angle-integrated cross section of Eq. (4) can be written as

$$\begin{aligned} \sigma_{a,a'}(E_a, I, P; E', I', P') &= \frac{\pi}{k^2} \frac{1}{(2I+1)(2s+1)} \sum_{J, \Pi} \frac{(2J+1)}{N(E, J, \Pi)} \left[\sum_{j=|J-I|}^{J+I} \sum_{l=|j-s|}^{j+s} \omega_\Pi(p, P, l) T_l^j(E_a) \right. \\ &\times \left. \sum_{j'=|J-I'|}^{J+I'} \sum_{l'=|j'-s'|}^{j'+s'} \omega_\Pi(p', P', l') T_{l'}^{j'}(E - E' - B_{a'}) W_{ajla'j'l'}^J \right] \times 10, \end{aligned} \quad (10)$$

where $W_{ajla'j'l'}^J$ is the width fluctuation factor[7] which is set equal to unity for original statistical model calculations.

In the code, the cross section of Eq. (4) is calculated by using Eqs. (7) to (9). The energy spectrum (energy-differential cross section) is obtained by dividing $\sigma_{a,a'}$ by the width of energy bin (dE'). The cross section $\sigma_{a,a'}$ for residual continuum states is obtained by multiplying transmission coefficients $T_l^{j'}$ in Eqs. (8) and (9) by the factor $\rho(E', I', P')dE'$.

2.2 Angular Distribution

The angle-differential cross section is calculated for the elastic scattering within the framework of the statistical model. The cross sections are also computed for the inelastic scattering over the low-lying discrete states of the target.

The angle-differential cross section is given by the Legendre expansion form [1] as

$$\frac{d\sigma_{a,a'}(E_a, I, P; E', I', P')}{d\Omega} = \sum_L B_L(E_a, I, P; E', I', P') P_L(\cos \theta), \quad (11)$$

with

$$\begin{aligned} & B_L(E_a, I, P; E', I', P') \\ &= \frac{1}{4k^2} \frac{(-1)^{I'-I+s-s'}}{(2I+1)(2s+1)} \sum_{J,\Pi} \frac{(2J+1)^2}{N(E, J, \Pi)} \sum_{j=|J-I|}^{J+I} \sum_{l=|j-s|}^{j+s} \omega_{\Pi}(p, P, l) \tau_l^j(E_a s I L J) \\ &\times \sum_{j'=|J-I'|}^{J+I'} \sum_{l'=|j'-s'|}^{j'+s'} \omega_{\Pi}(p', P', l') \tau_{l'}^{j'}(E - E' - B_{a'} s' I' L J) W_{ajla'j'l'}^J \times 10, \end{aligned} \quad (12)$$

and

$$\tau_l^j(E s I L J) = Z(l j l j s I L J) T_l^j(E), \quad (13)$$

$$\begin{aligned} Z(l_1 j_1 l_2 j_2 s I L J) &= \sqrt{(2l_1 + 1)(2j_1 + 1)(2l_2 + 1)(2j_2 + 1)} \\ &\times \langle l_1, l_2, 0, 0 | L, 0 \rangle W(l_1 j_1 l_2 j_2; sL) W(j_1 J j_2 J; IL), \end{aligned} \quad (14)$$

where the symbol P_L stands for the Legendre function; $\langle l_1, l_2, m_1, m_2, |l, m\rangle$ is the Clebsch-Gordan coefficient; and $W(l_1 j_1 l_2 j_2; sL)$ denotes the W coefficient of Racah[8].

2.3 Width Fluctuation Correction

The width fluctuation factor (WFF) is calculated to correct the elastic scattering cross section which may be underestimated in the statistical model calculation. WFF is evaluated in the code if the incident neutron energy is smaller than the highest discrete energy of target. The increase of elastic scattering cross section by the width fluctuation correction is compensated by the decrease of the inelastic scattering cross section. WFF for the (n, γ) reaction is also calculated in the code when WFF is calculated for the (n, n') reaction.

According to [7], WFF for the neutron elastic- and inelastic-scattering is calculated by the following formula.

$$\begin{aligned} W_{ajla'j'l'}^J &= \left(1 + \frac{2\delta_{ajl,a'j'l'}}{\nu_{ajl}} \right) \\ &\times \int_0^\infty \exp \left(-\frac{T_\gamma^{TOT}}{T} t \right) \prod_{c \neq c_\gamma} \left(1 + \frac{2T_c}{\nu_c T} t \right)^{-(\delta_{ajl,c} + \delta_{a'j'l',c} + \nu_c/2)} dt, \end{aligned} \quad (15)$$

where the symbol T corresponds to the sum of transmission coefficients for possible neutron and γ -ray decay channels as given in Eq. (9) for $a' = n, \gamma$; T_γ^{TOT} is the sum of γ -ray transmission coefficients for possible γ -ray decay channels; j (j') and l (l') stand for the total

and orbital angular momentum quantum numbers for incoming (outgoing) neutrons; and the product \prod over c includes all possible neutron channels except γ -ray channels. The factor ν_c is obtained by[9]

$$\nu_c = 1.78 + (T_c^{1.212} - 0.78) \exp(-0.228 T). \quad (16)$$

The factor WFF for the (n, γ) reaction is calculated by setting $\delta_{a'j'\nu',c} \equiv 0$ in Eq. (15). The energy- and angle-differential cross sections with the width fluctuation correction are obtained by inserting WFF values derived from Eqs. (15) and (16) into Eqs. (10) and(12).

2.4 Level Density

The level density $\rho(E, J, \Pi)$ in Eqs. (6) and (9) which describes the nuclear continuum state is defined as[6]

$$\rho(E, J, \Pi) = F_\pi(\Pi) F_J(E, J) \rho(E), \quad (17)$$

where $F_\pi(\Pi)$ and $F_J(E, J)$ correspond with the parity and spin components, respectively. They are given by

$$F_\pi(\Pi) = \frac{1}{2}, \quad (18)$$

$$F_J(E, J) = \frac{(2J+1)}{2\sigma(E-\Delta)^2} \exp[-J(J+1)/2\sigma(E-\Delta)^2], \quad (19)$$

with the spin cutoff function σ and the pairing correction energy Δ .

The energy-dependent level density $\rho(E)$ in Eq. (17) consists of a constant temperature form for lower excitation energy region, and a Fermi-gas form for higher excitation energy region [10]. The constant temperature form is given by

$$\rho_T(E) = \frac{1}{T} \exp[(E-E_0)/T], \quad (20)$$

where the symbol T stands for the nuclear temperature, and E_0 is the normalization factor. The Fermi-gas form is given by

$$\rho_F(E) = \frac{\exp(2\sqrt{aU})}{12\sqrt{2}\sigma(U)U(aU)^{1/4}}, \quad (21)$$

where the symbol a denotes the level density parameter, and the quantity U is defined by the excitation energy E and the pairing energy Δ as

$$U = E - \Delta. \quad (22)$$

In the Gilbert-Cameron formulation[10], the spin cutoff function σ is given by

$$\sigma(U)^2 = C_{sc} A^{2/3} \sqrt{aU}, \quad (23)$$

where the constant C_{sc} is taken to be 0.146, and A is the mass number defined with the sum of charge number Z and neutron number N in the nucleus. The pairing energies Δ are tabulated in Ref.[10].

The level density parameter a in Eqs. (21) and (23) in the Gilbert-Cameron formulation[10] is given as

$$\frac{a}{A} = 0.00917[S(Z) + S(N)] + C, \quad (24)$$

where $S(Z)$ and $S(N)$ are the shell factors tabulated in Ref.[10]. The constant C is set equal to 0.142 MeV $^{-1}$ for spherical nuclei and 0.120 MeV $^{-1}$ for deformed nuclei.

In the code, the energy-dependent level density parameter a of Mengoni-Nakajima[4] is also available. It is described as [11]

$$a(U) = a^* \left[1 + \frac{E_{sh}}{U} \{1 - \exp(-\gamma U)\} \right], \quad (25)$$

where the pairing energy Δ is given by $\Delta = 24/\sqrt{A}$ for even-even nuclei, $\Delta = 12/\sqrt{A}$ for odd nuclei, and $\Delta = 0$ for odd-odd nuclei. The parameter a^* is obtained with the form

$$a^* = \alpha A(1 - \beta A^{-1/3}), \quad (26)$$

with following values.

Z-N	$\alpha(\text{MeV}^{-1})$	β
even-even	0.067946	-4.1277
even-odd	0.053061	-7.1862
odd-even	0.066920	-3.8767
odd-odd	0.065291	-4.4505

In Eq. (25), the factor γ is obtained by

$$\gamma = \frac{0.40}{A^{1/3}}. \quad (27)$$

The shell correction energy E_{sh} is defined by the difference between the experimental nuclear mass E_{exp} and the calculated mass M_w with the liquid-drop model [12] :

$$E_{sh} = M_{exp} - M_w, \quad (28)$$

where

$$M_w = A + M_n N + M_H Z - c_1 A + c_2 A^{2/3} + c_3 \frac{Z^2}{A^{1/3}} - c_4 \frac{Z^2}{A} + p, \quad (29)$$

with

$$c_i = a_i \left[1 - \kappa \left(\frac{N-Z}{A} \right)^2 \right], \quad i = 1, 2 \quad (30)$$

$$\begin{aligned}
a_1 &= 15.677 \text{ MeV} \\
a_2 &= 18.56 \text{ MeV} \\
\kappa &= 1.79 \\
c_3 &= 0.717 \text{ MeV} \\
c_4 &= 1.21129 \text{ MeV} \\
M_n &= 8.07144 \text{ MeV} \\
M_H &= 7.28899 \text{ MeV}.
\end{aligned}$$

In Eq. (29), 1 amu is set equal to 931.44 MeV, and the quantity $p = -11/\sqrt{A}$ for even-even nuclei, $p = +11/\sqrt{A}$ for odd-odd nuclei, and $p = 0$ for odd mass nuclei. If the level density parameter a of Mengoni-Nakajima[4] is applied in the calculation, following spin cutoff function is used,

$$\sigma^2 = 0.01389 A^{5/3} T. \quad (31)$$

The quantity T corresponds to the nuclear temperature.

The constant temperature density ρ_T in Eq. (20) is used for lower excitation energy range while the Fermi-gas density ρ_F in Eq. (21) is utilized for higher energy range. According to the GNASH code[6], the constant temperature density is determined to reproduce the cumulative number of known discrete levels (N_{exp}) in the excitation energy interval E_L to E_U as

$$N_{exp}(E_U) = N_{exp}(E_L) + \int_{E_L}^{E_U} dE \rho_T(E), \quad (32)$$

which provides

$$N_{exp}(E_U) = N_{exp}(E_L) + \left[\exp\left(\frac{E_U}{T}\right) - \exp\left(\frac{E_L}{T}\right) \right] \exp\left(\frac{-E_0}{T}\right). \quad (33)$$

The constant temperature and Fermi-gas densities are matched continuously at an energy E_M :

$$\rho_T(E_M) = \rho_F(E_M), \quad (34)$$

$$\frac{d\rho_T(E_M)}{dE} = \frac{d\rho_F(E_M)}{dE}. \quad (35)$$

From Eq. (35), the nuclear temperature of the Gilbert-Cameron form is obtained by

$$\frac{1}{T} = \sqrt{\frac{a}{U_M}} - \frac{3}{2U_M}, \quad (36)$$

with $U_M = E_M - \Delta$. The nuclear temperature of Mengoni-Nakajima[4] is obtained by

$$\frac{1}{T} = \sqrt{\frac{a(U_M)}{U_M}} - \frac{5}{4U_M}. \quad (37)$$

Three quantities T , E_0 , and E_M can be determined from Eqs. (33) to (37).

2.5 γ -ray Strength Function

The γ -ray transmission coefficients are evaluated on the basis of the detailed balance for the inverse photoabsorption process and the Brink-Axel hypothesis[6], where the cross section for photoabsorption by an excited state is equated with that of the ground state. The standard Lorentzian form is used for the γ -ray strength functions for the E1 and M1 radiations.

The transmission coefficients for γ -ray emission are obtained by[6]

$$T^{Xl}(\epsilon_\gamma) = 2\pi f_{Xl}(\epsilon_\gamma) \epsilon_\gamma^{2l+1}, \quad (38)$$

where the symbol ϵ_γ denotes the γ -ray energy; Xl the multipolarity of the γ -ray; and $f_{Xl}(\epsilon_\gamma)$ is the γ -ray strength function. The γ -ray strength function $f_{Xl}(\epsilon_\gamma)$ is given by

$$f_{E1}(\epsilon_\gamma) = K_{E1} \frac{\epsilon_\gamma \Gamma_{E1}^2}{(\epsilon_\gamma^2 - E_{E1}^2)^2 + \epsilon_\gamma^2 \Gamma_{E1}^2}, \quad (39)$$

$$f_{M1}(\epsilon_\gamma) = K_{M1} \frac{\epsilon_\gamma \Gamma_{M1}^2}{(\epsilon_\gamma^2 - E_{M1}^2)^2 + \epsilon_\gamma^2 \Gamma_{M1}^2}, \quad (40)$$

where the default parameters are set to $E_{E1} = 40A^{-0.2}$ MeV and $\Gamma_{E1} = 6$ MeV [13] for the E1 strength function. The parameters E_{M1} , Γ_{M1} , and the relative contribution of M1 (the $M1/E1$ ratio) must be given in the input data, if the M1 strength function is considered.

The normalization factor K_{Xl} is determined so as to reproduce the experimental strength function $2\pi <\Gamma_{\gamma 0}> / < D_0 >$ [14] for s-wave resonances as the same manner with the GNASH code[6] as

$$2\pi \frac{<\Gamma_{\gamma 0}>}{< D_0 >} = \sum_{J\Pi} \sum_{Xl} \sum_{j'=|J-l|}^{J+l} \left[\int_0^{S_n - E_{c'}} d\epsilon_\gamma T^{Xl}(\epsilon_\gamma) \omega(l, J, j') \rho(S_n - \epsilon_\gamma, j', \Pi) \right. \\ \left. + \sum_{E_k} T^{Xl}(\epsilon_\gamma = S_n - E_k) \omega(l, J, j') \right], \quad (41)$$

where the summation over $J\Pi$ includes the possible compound states that can be formed with the s-wave neutrons, and the summation over j' includes spins of the possible final states. The factor $\omega(l, J, j')$ is unity if the multipole radiation selection rule is satisfied, and zero otherwise. The symbol S_n stands for the neutron separation energy of the compound, and $E_{c'}$ is the highest discrete energy of the compound. The summation over E_k includes all discrete energies up to $E_{c'}$, and integration over ϵ_γ is taken for the continuum state. The factors K_{E1} and K_{M1} are evaluated from Eqs. (38) to (41) with the relative strength of M1 (the $M1/E1$ ratio) which is given in the input data.

If the experimental strength function $2\pi <\Gamma_{\gamma 0}> / < D_0 >$ [14] is unavailable, the s-wave average level-spacing $< D_0 >$ is estimated by

$$< D_0 > = \frac{1}{\rho(S_n, J = 1/2, \Pi)}, \quad (42)$$

for target nuclei with spin $I = 0$. If the target spin is not zero ($I \neq 0$), following relation is used.

$$< D_0 > = \frac{1}{\rho(S_n, J = I + 1/2, \Pi) + \rho(S_n, J = I - 1/2, \Pi)}. \quad (43)$$

The average radiative width $<\Gamma_{\gamma 0}>$ for s-wave resonances is estimated by using the Mughabghab formula[14] as

$$<\Gamma_{\gamma 0}> = \frac{7.32}{(22A)^{1/3}} \left(\frac{U}{a} \right)^{3/2}, \quad (44)$$

where the symbol A denotes the mass number of compound nucleus and $U = S_n - \Delta$.

3 Explanation of the Computer Code

3.1 Structure of the Code

The flow chart of the code is presented in Fig.1, where subroutines are enclosed by solid rectangles, and functions are enclosed by dotted ones. In the subprogram block L001, physical constants, nuclear masses, and other basic quantities are determined. The input parameters are also read and stored here. The shape-elastic scattering cross sections and analyzing powers are calculated in the block L101. These subprograms L001 and L101 are taken from the program POD[15].

The statistical model computation is performed in the block L401. Reaction chains are defined in the subroutine STACHN, and nuclear discrete level data are read in STAL. Particle transmission coefficients are calculated in PREREA, and coefficients for the cubic spline interpolation are stored in STATR2. The structure of PREREA is similar to L101. The shell factors and pairing energies for the Gilbert-Cameron level densities are stored in SHELIN and PAIRIN. The level density parameters for the Gilbert-Cameron form are stored in STAGC, where the pairing energies for the Mengoni-Nakajima level densities are also calculated. The nuclear temperatures and the other parameters which determine continuum level densities are calculated in STAMT1 and STAMT2. The maximum value of nuclear spin (J_{max}) is determined in STALMX, and level densities used in the statistical model calculation are stored here. The γ -ray strength functions are defined in STAGAM, and they are normalized in STANOR. The particle transmission coefficients used in the subroutine STATIS are interpolated and stored in STATRS. The statistical model calculation is performed in STATIS. Energy spectra are calculated and the output file is produced in STASPE and STASP2. Angular distributions for elastic- and inelastic-scattering are calculated in STAANG. The width fluctuation correction is carried out in the subroutine STAWIG for the (n, γ) reaction and in STAANG for (n, n') , where the width fluctuation factor is calculated in the function SFACTR.

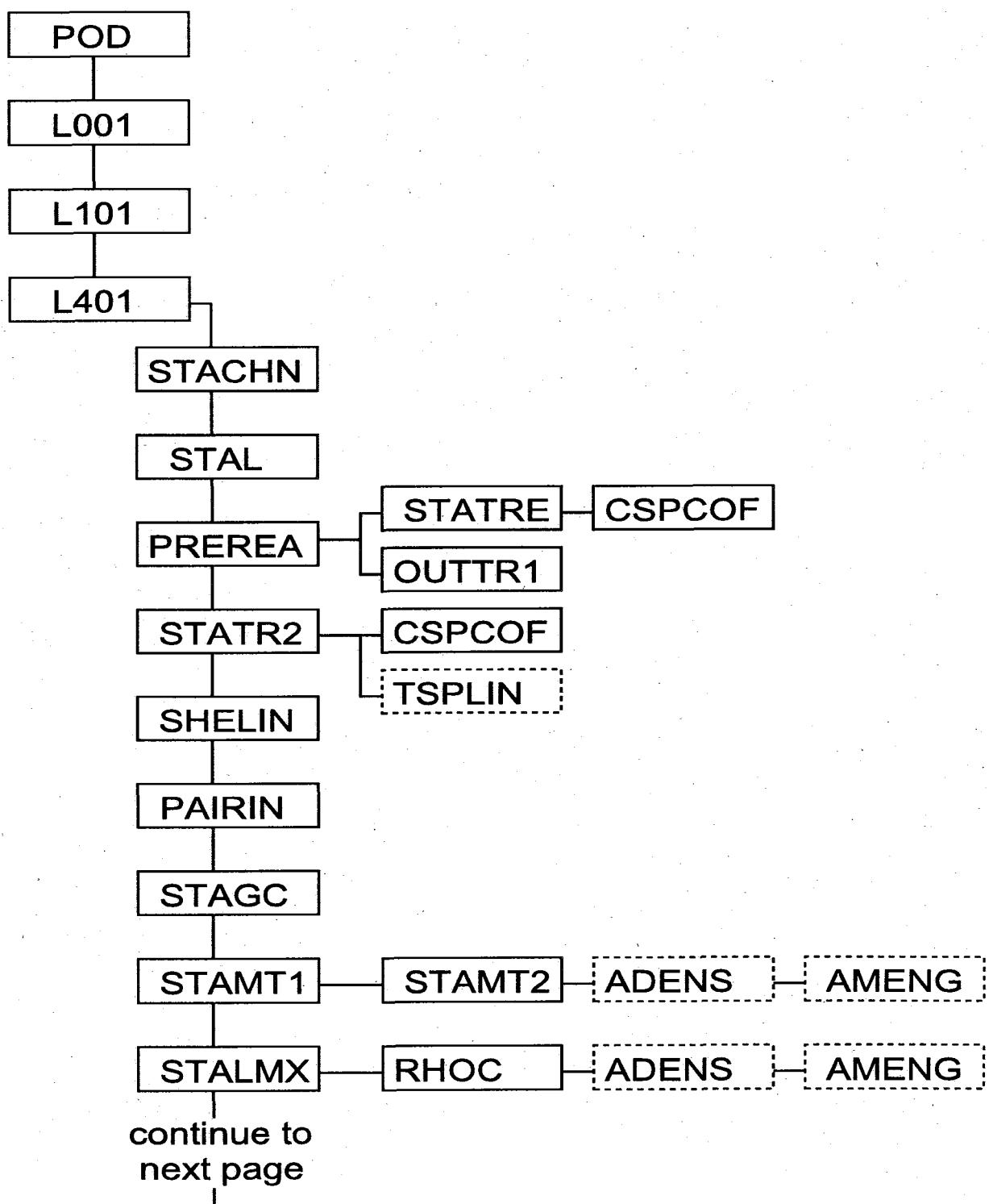


Fig. 1: Flow Chart of Code

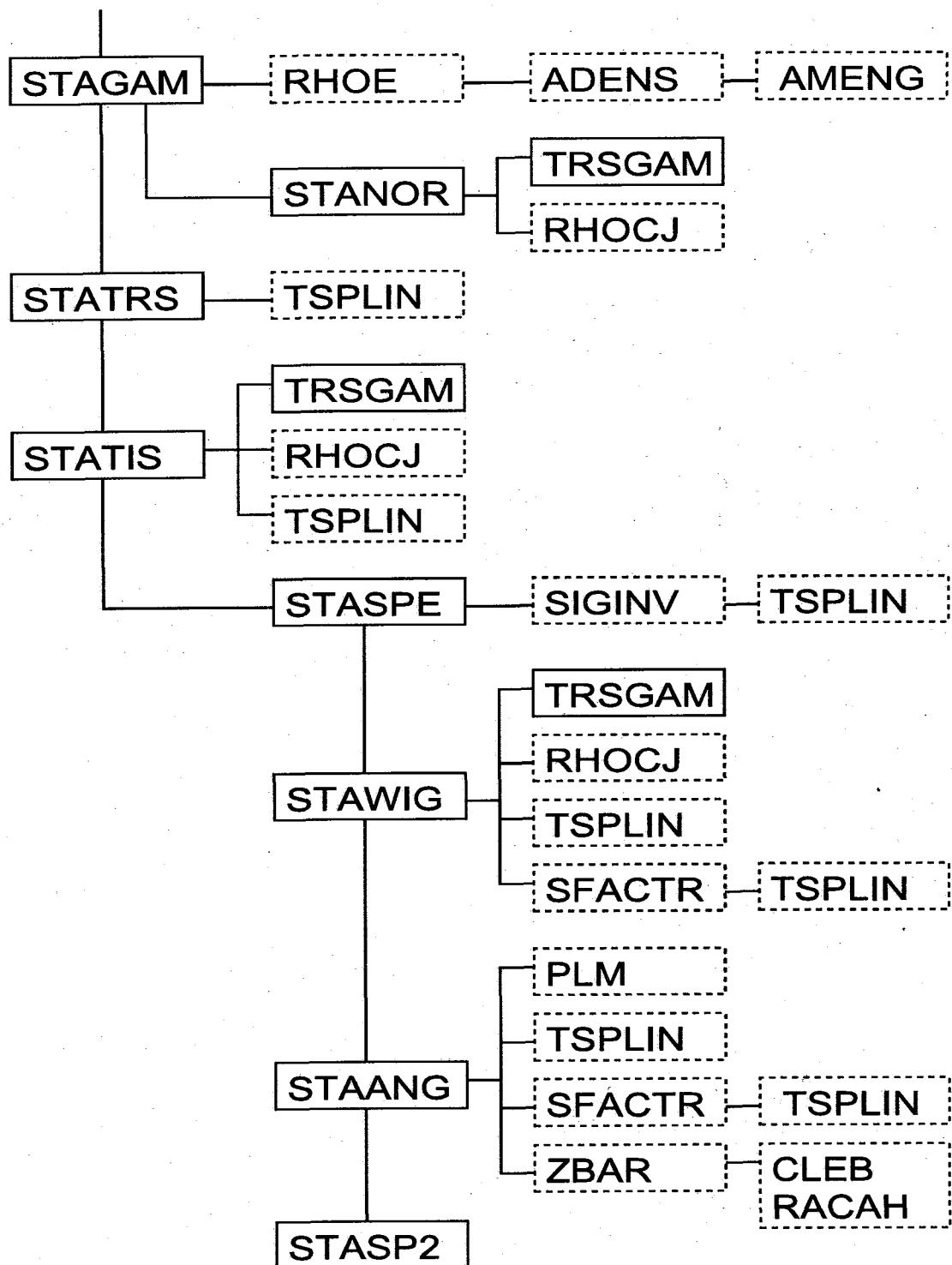


Fig. 1: Continued

3.2 Subroutines

L001

CONST Basic constants are defined and stored in COMMON /CNST/,

$$\text{EUNT} = \mu_0 c^2 = 931.494013 \text{ MeV}, \quad (45)$$

$$\text{CEK} = \frac{\hbar^2}{2\mu_0} = 20.900794 \text{ MeV} \cdot \text{fm}^2, \quad (46)$$

$$\text{COUL} = \frac{2\mu_0 e^2}{\hbar^2} = 0.068895200 \text{ fm}^{-1}, \quad (47)$$

$$\text{CSPO} = \left(\frac{\hbar}{m_\pi c} \right)^2 = 2.0 \text{ fm}^2, \quad (48)$$

where μ_0 , c , \hbar , e , m_π are atomic mass unit, speed of light, Planck's constant divided by 2π , elementary charge, and pion mass, respectively.

AUDI This subroutine reads atomic masses from the table of Audi et al.[16] (FILE 13). Atomic mass for charge Z and mass number A is stored in AMASS(Z*1000+A) of COMMON /MASS/. Nuclear masses are approximated by corresponding atomic masses in this code.

FACTRL Factorials (FC) and their square roots (SFC) are calculated and stored in COMMON /FCTL/.

INPUT Input parameters are read from FILE 5 and they are stored in the COMMON arrays /ENGY/, /INPT/, /OMP0/, /OMP1/, /ST00/, /ST01/, /ST05/, and /ST06/. See Sec.4 for definitions of input parameters.

L101 L101 calls subroutines which calculate cross sections and analyzing powers for the shape-elastic scattering. Detailed explanations of the subroutines called by L101 are given in [15].

ANGLE Angle-differential cross sections and analyzing powers for the shape-elastic scattering are calculated with the scattering phase-shifts (CYETA) obtained in the subroutine INTEG[15].

BESSEL The spherical Neumann and the spherical Bessel functions (G and F) are evaluated on the matching radius (RHOM) where the scattering phase-shifts are calculated[15]. Obtained values and their derivatives (GP and FP) are stored in COMMON/WF01/.

COULA The Coulomb wave functions for the angular momentum quantum number $l = 0$ are evaluated at the asymptotic radius (RHOA)[15].

COULI The Coulomb wave functions in the subroutine COULA are extrapolated from the asymptotic radius (RHOA) to the matching radius (RHOM) where the scattering phase-shifts are calculated[15].

COULL The Coulomb functions and their derivatives for the angular momentum quantum number $l \geq 1$ are evaluated at the matching radius (RHOM)[15]. Obtained values are stored in COMMON /WF01/.

CSPCOF Coefficients of the cubic spline fits[17] are calculated.

GLOBAL The parameters of optical model potential (OMP) are evaluated, and they are stored in the COMMON arrays /OMP1/ and /OMP2/[15]. The global OMP parameters of Koning and Delaroche[3] are used for neutron and proton if the local OMP parameters are unavailable. For deuteron, triton, ^3He , and ^4He , the OMP parameters developed by Lohr and Haeberli, Lemos, and Becchetti and Greenlees are employed. These parameters were taken from [18] and [19]. The user may change this subroutine to use other OMP parameter values.

INTEG The scattering phase-shifts (CYETA) are calculated, and they are stored in COMMON /WF03/[15]. With these phase shifts, the transmission coefficients (TRS), the reaction cross section (SIGRI), and the shape-elastic scattering cross section (SIGEL) are calculated. The results are stored in COMMON /WF03/.

LOCAL The local OMP parameters are stored with the tables of Koning and Delaroche [3]. If the local OMP parameters are unavailable, the global OMP parameters are evaluated in the subroutine GLOBAL, and they are utilized in the calculation. These parameters are stored in COMMON /OMP1/ and /OMP2/.

OMPOT The OMP values are calculated, and they are stored in COMMON /OMP3/[15].

PHASE The phase shifts of the Coulomb scattering (DELL) are calculated, and they are stored in COMMON /WF02/[15].

RHOMAT The matching radius (RHOM) where the scattering phase shifts (CYETA) are calculated is determined, and they are stored in COMMON /WF00/[15].

L401 L401 calls subroutines which calculate energy spectra and neutron angular distributions by the statistical model.

OUTTR1 Transmission coefficients calculated in the subroutine PREREA are averaged over the total angular momentum j , and they are recorded in FILE 41. The averaged transmission coefficient T_l is obtained by

$$T_l = \frac{1}{(2l+1)} \left[lT_l^{l-1/2} + (l+1)T_l^{l+1/2} \right], \quad (49)$$

for the spin $s = 1/2$ particles, and

$$T_l = \frac{1}{3(2l+1)} \left[(2l-1)T_l^{l-1} + (2l+1)T_l^l + (2l+3)T_l^{l+1} \right], \quad (50)$$

for the spin $s = 1$ particles.

PAIRIN Pairing energies are stored in COMMON /PAIR/ with the table of Gilbert and Cameron[10].

PREREA Particle transmission coefficients are calculated on the energy meshes defined in the code. The strucure of PREREA is similar to that of L101[15].

RHOC The energy-dependent level density $\rho(E)$ is calculated with Eqs. (20)-(22).

SHELIN Shell factors are stored in COMMON /SHEL/ with the table of Gilbert and Cameron[10].

STAANG The angle-differential cross sections (SIGDA) for the neutron elastic- and inelastic-scattering over target discrete states are calculated with Eqs. (11) and (12). The Legendre expansion coefficients (BL) of Eq. (12) are stored in COMMON /ST12/. The coefficients can be evaluated with the width fluctuation correction. Since the width fluctuation correction is applied only for neutron and γ -ray emissions, the total decay width $N(E, J, \Pi)$ in Eq. (12) refers to the total (neutron + γ -ray) decay width (WIDNG) stored in COMMON /ST10/.

STACHN The nuclear index (COMPNI) and the index of reaction branch (BRANCH) are stored in COMMON /ST02/. The Q-value of reaction (QVAL) and the particle separation energy (SEPE) are stored with numbers of reactions (NREACT) and nuclei (NCOMP) in /ST02/.

STAGAM The γ -ray strength functions described in Eqs. (39) and (40) are defined, and $2\pi < \Gamma_{\gamma 0} > / < D_0 >$ is calculated with Eqs. (42)-(44). The parameters of strength functions are stored in COMMON /ST06/.

STANOR The factor K_{Xl} (GAMFAC) of γ -ray strength function in Eqs. (39) and (40) is calculated with Eq. (41), and it is stored in COMMON /ST06/.

STAGC Pairing energy (PAIRR) [4, 10] and the Gilbert-Cameron level density parameter (GCDEN) of Eq. (24) are stored in COMMON /ST01/.

STAL The discrete level data of nuclei are read from FILE 8. Discrete energies (ENLEV), spins (AJLEV), and parities (AJPAR) are stored in COMMON/ST03/. The format of FILE 8 is given in Sec.4.1. For each nucleus, the number of discrete levels (NLEV), number of γ -ray transition branches from each level (NUMDC), the level indicator to which a γ -ray transition takes place (LEVDC), and the branching ratio (PRBDC) are stored in COMMON /ST03/.

STALMX The maximum of nuclear spin J_{max} (JJMAX) is determined with the same manner as the SINCROS-II code[13], and the value is stored in COMMON /ST07/. Assuming the spherical nucleus, J_{max} is obtained using the excitation energy U and the momentum of inertia I by

$$J_{max} = \sqrt{2UI/\hbar^2}. \quad (51)$$

The value of I is estimated as

$$I = \frac{2}{5} AR^2, \quad (52)$$

where $R = 0.88A^{1/3}$ is used.

In STALMX, the level density $\rho(E)$ (RHO0) in Eq. (17) and the spin cutoff function $\sigma(U)^2$ (SCUT2) in Eqs. (23) and (31) are calculated on each energy bin of the continuum state. They are stored in COMMON /ST07/ with the number of energy bins (NUMEN) for each residual nucleus.

STAMT1, STAMT2 The nuclear temperature T (TMATCH) and the constant E_0 (E0CNST) in Eq. (20), and the matching energy E_M (EMATCH) in Eq. (34) are calculated from Eqs. (33), (34), (36) and (37) with the discrete energies E_L and E_U whose states (LLOC and LUPC) are specified in the input data. The calculated values are stored in COMMON /ST05/.

If the temperature T can not be obtained by the above method for the Gilbert-Cameron level density parameter a , the value of T is estimated by the Yamamuro's formula [13] as

$$T = 7.50a^{-0.84}. \quad (53)$$

E_0 and E_M are calculated from Eqs. (34) and (36).

STASPE The branching ratio $\Gamma_{a'}(E, J, \Pi; E', I', P')/\Gamma(E, J, \Pi)$ are evaluated with Eq. (8). The cross section for the reaction (a, a') , $\sigma_{a,a'}$ (STOT), and the energy spectra (energy-differential cross sections) (SPECT) are calculated with the branching ratio and the cross section for compound nucleus formation which is computed by Eq. (7). Calculated values (STOT,SPECT) are stored in COMMON /ST11/.

STASP2 The output file of energy spectra after the width fluctuation correction is produced. The outputs for the neutron elastic- and inelastic-scattering cross sections after the width fluctuation correction are also generated in this subroutine.

STATIS The partial and total decay widths in Eqs. (6) and (8) are calculated. The total decay width (TOT), and the partial widths for decays into residual discrete states (TL) and continuum states (TC) are stored in COMMON /ST09/. The total (neutron + γ -ray) decay width (WIDNG) and the total γ -ray decay width (WIDTG) are stored in COMMON /ST10/.

STATRE Particle transmission coefficients T_l^j are read from FILE 27 and FILE 28 if the input option IDREAD=1 is selected. The formats of these files are given in Sec.4.2. The transmission coefficients T_l^j are averaged over the total angular momentum j , and they are written down in FILE 41. The averaged transmission coefficients are obtained by Eq. (49) for spin=1/2 particles, and Eq. (50) for spin=1 particles.

STATRS Transmission coefficients for incoming neutrons (TRS0) in Eq. (7) are calculated by the cubic spline interpolation, and they are stored in COMMON /ST08/. The particle transmission coefficients for continuum states (TRSC) are also calculated by the cubic spline interpolation, and they are stored in COMMON /ST08/.

STATR2 The coefficients (SCOF) of cubic spline functions to interpolate transmission coefficients (STRS) are calculated, and they are stored in COMMON /ST04/. The transmission coefficients which are smaller than the threshold (THHRE=1.D-5) are neglected in the calculation for all incoming- and outgoing-particles. The energy mesh (SENGY) and the mesh number (NSENG) for the spline interpolation are also stored in COMMON /ST04/ with the maximum of orbital angular momentum quantum number (LSMAX).

STA WIG The (n, γ) energy spectra are recalculated by Eq.(10) with the width fluctuation correction. Since the width fluctuation correction is applied only for neutron and γ -ray emissions, the total decay width $N(E, J, \Pi)$ in Eq. (10) refers to the total (neutron + γ -ray) decay width (WIDNG) stored in COMMON /ST10/.

TRSGAM The γ -ray strength functions f_{E1} and f_{M1} are calculated from Eqs. (39) and (40) by using parameters stored in COMMON /ST06/.

3.3 Functions

ADENS(NZ,NA,IP,U) The level density parameter a is determined for the nucleus (IP) with charge number NZ and mass number NA. The function AMENG is called in order to obtain Mengoni-Nakajima level density parameter[4] at the excitation energy U, if IDENSE=2 is selected in the input data. The excitation energy U is defined as Eq. (22) by subtracting the pairing energy.

AMENG(NZ,NA,U) The Mengoni-Nakajima level density parameter a [4] is calculated for the nucleus with charge number NZ, mass number NA, and excitation energy U by using Eqs. (25) to (30). The excitation energy U is defined as Eq. (22) by subtracting the pairing energy.

CLEB(J1,M1,J2,M2,J3,M3) The Clebsch-Gordan coefficient is calculated with the formula of Abramowitz and Stegun[20].

$$\begin{aligned} & \langle j_1, j_2, m_1, m_2 | j_3, m_3 \rangle = \delta(m_3, m_1+m_2) \sqrt{\frac{(j_1 + j_2 - j_3)!(j_3 + j_1 - j_2)!(j_3 + j_2 - j_1)!(2j_3 + 1)}{(j_1 + j_2 + j_3 + 1)!}} \\ & \sum_k \frac{(-1)^k \sqrt{(j_1 + m_1)!(j_1 - m_1)!(j_2 + m_2)!(j_2 - m_2)!(j_3 + m_3)!(j_3 - m_3)!}}{k!(j_1 + j_2 - j_3 - k)!(j_1 - m_1 - k)!(j_2 + m_2 - k)!(j_3 - j_2 + m_1 + k)!(j_3 - j_1 - m_2 + k)!} \end{aligned} \quad (54)$$

Arguments $j_1, m_1, j_2, m_2, j_3, m_3$ (J1,M1,J2,M2,J3,M3) must be real and multiples of 1/2 or 0.

RACAH(A,B,C,D,E,F) The W coefficient of Racah is calculated by[8]

$$\begin{aligned} W(abcd, ef) &= (-1)^{-(a+b+c+d)} \Delta(abe) \Delta(acf) \Delta(dbf) \Delta(dce) \\ &\quad \sum_k \frac{(-1)^k}{(k - a - b - e)!(k - a - c - f)!(k - d - b - f)!(k - d - c - e)!} \\ &\quad \times \frac{(k + 1)!}{(a + b + c + d - k)!(b + e + c + f - k)!(e + a + f + d - k)!}, \end{aligned} \quad (55)$$

where

$$\Delta(abe) = \sqrt{\frac{(a + b - e)!(a - b + e)!(-a + b + e)!}{(a + b + e + 1)!}}. \quad (56)$$

The arguments a, b, c, d, e, f (A,B,C,D,E,F) must be real and positive (multiples of 1/2) or 0.

PLM(L,MBAR,X) The Legendre function $P_l^m(x)$ for $l, m \geq 0$ and $x = \cos \theta$ is calculated with[21]

$$P_l^m = 0, \quad \text{for } l < m, \quad (57)$$

$$P_m^m = (-1)^m (2m - 1)!! (1 - x^2)^{m/2}, \quad (58)$$

$$P_{m+1}^m = x(2m + 1)P_m^m, \quad (59)$$

$$P_l^m = \{x(2l - 1)P_{l-1}^m - (l + m - 1)P_{l-2}^m\}/(l - m). \quad (60)$$

In the code, arguments $l(L)$ and $m(MBAR)$ are integers, and $x = \cos \theta(X)$ must be $-1 \leq x \leq 1$.

RHOCJ(AJ,SCUT2) The spin distribution F_J of Eq. (19) is calculated with the spin quantum number J (AJ) and the spin cutoff function σ^2 (SCUT2).

RHOE(E,AJ,I,NZ,NA) The continuum level density $\rho(E(E), J(AJ), \Pi)$ of Eq. (17) is calculated for the nucleus (I) with the charge number NZ and mass number NA at the excitation energy E by using Eqs. (18) to (22).

SFACTR(X,W,ENGY,XJ0,J1,L1,J2,L2,LEV,JJ,IPI) The width fluctuation factor $W_{ajla'j'l'}^J$ is calculated using Eqs. (15) and (16). The definitions of arguments are as follows.

X : the transmission coefficient for incoming particle

W : the transmission coefficient for outgoing particle

ENGY : the center-of-mass collision (neutron) energy

XJ0 : 0.0 for the even mass compound nucleus and 0.5 for the odd mass compound

J1 : index of the total angular momentum of incoming particle

L1 : index of the orbital angular momentum of incoming particle

J2 : index of the total angular momentum of outgoing particle

L2 : index of the orbital angular momentum of outgoing particle

LEV : level number of the target nucleus

JJ : index of the compound nuclear spin

IPI : parity of the compound nucleus

The width fluctuation factor for the (n, γ) reaction is calculated by setting W=0.0, J2=0, L2=0, and LEV=0.

SIGINV(IPI,XJ,EN2) The cross section for compound nucleus formation $\sigma(E, J, \Pi)$ is calculated for the compound spin J (XJ), parity Π (IPI), and the center-of-mass collision (neutron) energy E (EN2) by using Eq. (7).

TSPLIN(N,X,F,S,R) The cubic spline fit is carried out with the coefficients S obtained in the subroutine CSPCOF [17]. The symbol N is the number of data points, X is the argument array of the function F to be fitted, and R is the argument value on which the function value F(R) is calculated.

ZBAR(L1,J1,L2,J2,IA,IB,LL,JJ) This function calculates the coefficient $Z(L1,J1,L2,J2,IA,IB,LL,JJ)$ in Eq.(14) with the Clebsch-Gordan coefficient and the W coefficients of Racah. All arguments must be real and positive (multiples of 1/2), or 0.

3.4 Common Arrays

Labeled common arrays are used in the code. They are defined as follows. (Detailed explanations are given in [15] for the common arrays OMP0 to OMP3 and WF00 to WF03.)

- CNST** The basic constants are defined in the subroutine CONST.
- ENGY** Input data for collision energies (ENL) are stored in the subroutine INPUT.
- FCTL** Factorials and their square roots are stored in the subroutine FACTRL.
- INPT** The option IDREAD is stored in the subroutine INPUT. Transmission coefficients are calculated in the subroutine PREREA if IDREAD=0. Transmission coefficients are read from FILE 27 and FILE 28 if IDREAD=1. See Sec.4.2 for the explanation of FILES 27 and 28.
- MASS** Atomic masses are stored in the subroutine AUDI.
- OMP0** Basic parameters of calculation are stored in the subroutine INPUT.
- OMP1** The OMP parameters are stored in the subroutines LOCAL and GLOBAL.
- OMP2** The potential depth and radius are calculated, and they are stored in the subroutines LOCAL and GLOBAL.
- OMP3** The OMP values are calculated, and they are stored in the subroutine OMPOT.
- PAIR** The pairing energies (PZ,PN) of [10] are stored in the subroutine PAIRIN.
- PR00** The input data for the preequilibrium model calculation are stored in the subroutine INPUT. This common array is not used in the present version.
- PR03** The coefficients of the cubic spline functions to interpolate reaction cross sections are calculated, and they are stored in the subroutine PREREA. This common array is not used in the present version.
- SHEL** The shell factors (SZ,SN) to obtain the Gilbert-Cameron level density parameter[10] are stored in the subroutine SHELIN.
- ST0N** The j -dependent neutron transmission coefficients T_l^j (TRSN1,TRSN2) are stored in the subroutine STATRE if IDREAD=1. The transmission coefficients for the $j = l - 1/2$ component are stored in the array TRSN1, and the coefficients for $j = l + 1/2$ are stored in TRSN2. Coefficients for the cubic spline interpolation (COFN1,COFN2) are calculated in the subroutine STATTR2. Transmission coefficients on the energy bins (TRSCN1,TRSCN2) are interpolated in the subroutine STATRS. The interpolated j -dependent neutron transmission coefficients are used in the statistical model calculation if IDREAD=1.
- ST00** Basic parameters of the statistical model calculation are stored in the subroutine INPUT.
- ST01** The Gilbert-Cameron level density parameter (GCDEN) is stored in the subroutine INPUT or STAGC. The pairing energy (PAIRR) is stored in the subroutine INPUT or

STAGC. The lower and upper nuclear discrete levels (LLOC,LUPC) in Eq. (33) are stored in the subroutine INPUT or STAMT1. The choice of them affects the tendency of continuum level densities.

ST02 The nuclear index (COMPNI), the index of reaction branch (BRANCH), the Q-value of reaction (QVAL) and the particle separation energy (SEPE) are stored in the subroutine STACHN with the numbers of nuclei and reaction, NCOMP and NREACT.

ST03 Nuclear discrete energies (ENLEV), spins (AJLEV), and parities (AJPAR) are stored in the subroutine STAL. For each nucleus, the number of discrete levels (NLEV), the number of γ -ray transitions from each level (NUMDC), the level indicator to which a γ -ray transition takes place (LEVDC), and the transition ratio (PRBDC) are stored in STAL.

ST04 The transmission coefficients are averaged over the total angular momentum j (STRS) in the subroutine STATRE or OUTTR1. The transmission coefficients whose values are larger than the threshold (TTHRE=1.D-5) are written down in the FILE41. The energy mesh (SENGY), number of the energy mesh (NSENG), and the cubic spline coefficients (SCOF) to interpolate transmission coefficients are stored in the subroutine STATR2. The maximum of orbital angular momentum l_{max} (LSMAX) is also stored in STATR2.

ST05 The nuclear temperature T (TMATCH), the matching energy E_M (EMATCH) where level densities of the constant temperature and Fermi-gas forms are connected, and the constant E_0 (E0CNST) in the constant temperature density in Eq. (20) are stored in the subroutine INPUT and STAMT1.

ST06 Parameters in the γ -ray strength functions are stored in the subroutine INPUT, STAGAM and STANOR.

ST07 The maximum of nuclear spin (JJMAX) and the number of energy bins (NUMEN) for continuum states are stored in the subroutine STALMX. The values of energy dependent level density $\rho(E)$ (RHO0) and the spin cutoff function σ^2 (SCUT2) on each energy bin are stored in STALMX.

ST08 The transmission coefficients of incoming neutrons (TRS0) and outgoing particles on energy bins (TRSC) are interpolated in STATRS. The spins and parites of the projectile (neutron) and target (SP01,SP02,PI01,PI02) are stored in STATRS with the factor FRONTF = $\pi/k^2/(2\cdot SP01+1)/(2\cdot SP02+1)\times 10$, where k is the wave number of the incoming neutron.

ST09 The total decay width (TOT) are stored in the subroutine STATIS with the partial widths for decays into residual discrete states (TL) and continuum states (TC).

ST10 The total (neutron + γ -ray) decay width (WIDNG) and the total γ -ray decay width (WIDTG) are stored in the subroutine STATIS.

ST11 The cross section for the (a, a') reaction $\sigma_{a,a'}$ (STOT) and the energy spectra (energy-differential cross sections) (SPECT) are calculated in the subroutines STASPE,

STAWIG, and STAANG. The inelastic scattering cross section for target continuum states (STOT0) and the energy spectra (SPECT0) without the width fluctuation correction are stored in STASPE.

ST12 The angle-differential cross sections for neutron elastic- and inelastic-scattering (SIGDA) are calculated in the subroutine STAANG. Their Legendre expansion coefficients (BL) and angle-integrated cross sections (SIGDIS) are stored in STAANG.

WF00 The wave number (WN) is stored in the subroutines L101 and PRERA. The matching radius (RHOM) on which the scattering phase shifts (CYETA) are calculated is determined in the subroutines RHOMAT and COULI. The radius (RHOA) where the asymptotic Coulomb functions are evaluated is determined in the subroutine COULA.

WF01 The spherical Neumann and Bessel functions (G,F) and their derivatives (GP,FP) are evaluated in the subroutine BESSEL to obtain the neutron reaction cross section. For charged particles, the Coulomb functions and their derivatives (G,F,GP,FP) are evaluated in the subroutines COULA, COULI and COULL. The maximum of the orbital angular momentum quantum number (LMAX) is determined in the subroutine BESSEL for neutrons, and COULL for charged particles.

WF02 The Coulomb parameter (YETA) and the phase shifts of the Coulomb scattering (DELL) are calculated in the subroutine PHASE.

WF03 The scattering phase shifts (CYETA), the transmission coefficients (TRS), the reaction (inverse) cross sections (SIGRI) and the shape-elastic scattering cross sections (SIGEL) are calculated in the subroutine INTEG.

4 Explanation of Input Data

This code reads input parameters from three files.

FILE 5 Job control options and other fundamental parameters.

FILE 8 Nuclear discrete level data.

FILE 13 Mass table of Audi et al.[16] The data were downloaded from following address.

<http://csnwww.in2p3.fr/amdc/>

The data for FILE 5 are read with following format.

```

READ(5,*)IPRJ,ISPIN,ITAG,NTE,NEN,IP1,NR,NTH
READ(5,1000)(ENL(IE),IE=1,NEN)
1000 FORMAT(8E10.0)
READ(5,*)NDWBA,IDWBA
READ(5,*)IPRECO,JPRECO,IDREAD

```

IPRJ Set IPRJ=1 to specify the neutron-induced reaction.

ISPIN Twice the projectile spin quantum number (SPIN). Set ISPIN=1.

ITAG ZT × 1000 + AT, where ZT is the target charge and AT is the target mass number.

NTE

0 : Collision energy is given in the center of mass system.

1 : Collision energy is given in the laboratory system.

NEN Number of collision energies to be calculated. (The maximum is 30.)

IP1 The OMP input option. Set IP1=0.

NR Number of radial mesh for wave function. (The maximum is 1000.)

NTH Number of angular mesh for angle-differential cross section. (The maximum is 100.)

ENL Collision energies in MeV.

NDWBA Set NDWBA=0.

IDWBA Set IDWBA=0.

IPRECO Set IPRECO=0.

JPRECO Set JPRECO=0.

IDREAD

0 : Transmission coefficients are calculated using the built-in OMP parameters.

1 : Transmission coefficients are read from FILE 27 and FILE 28.

The input parameters of statistical model calculation are read as follows.

```

READ(5,*)IHAUSE, IDENSE, ITEMP, IGAMMA, JGAMMA, IWIDT
READ(5,*)DELBIN
IF(IHAUSE.EQ.1)NN= 2
IF(IHAUSE.EQ.2)NN= 7
IF(IDENSE.EQ.3)READ(5,1000)(GCDEN(I),I=1,NN)
IF(IDENSE.EQ.3)READ(5,1000)(PAIRR(I),I=1,NN)
IF(ITEMP .EQ. 1)READ(5,*)(LLOC(I),I=1,NN)
IF(ITEMP .EQ. 1)READ(5,*)(LUPC(I),I=1,NN)
IF(ITEMP .EQ. 2)READ(5,1000)(EMATCH(I),I=1,NN)
IF(ITEMP .EQ. 2)READ(5,1000)(TMATCH(I),I=1,NN)
IF(IGAMMA.EQ.1.OR.IGAMMA.EQ.2)READ(5,1000)(GAMNOR(I),I=1,1)
IF(JGAMMA.GE.1)READ(5,1000)(POSE1(I),I=1,1)
IF(JGAMMA.GE.1)READ(5,1000)(WIDE1(I),I=1,1)
IF(JGAMMA.GE.2)READ(5,1000)(POSM1(I),I=1,1)
IF(JGAMMA.GE.2)READ(5,1000)(WIDM1(I),I=1,1)
IF(JGAMMA.GE.2)READ(5,1000)(RATM1(I),I=1,1)

```

IHAUSE

- 0: The statistical model calculation is not performed.
- 1 : The (n, γ) and (n, n') reactions are considered in the statistical model calculation.
- 2 : The (n, γ) , (n, n') , (n, p) , (n, α) , (n, d) , (n, t) , and $(n, {}^3\text{He})$ reactions are considered in the statistical model calculation.

IDENSE

- 0 : The Gilbert-Cameron Fermi-gas density parameter of Eq. (24) where $C = 0.142 \text{ MeV}^{-1}$, is used in the nuclear continuum state.
- 1 : The Gilbert-Cameron Fermi-gas density parameter of Eq. (24) where $C = 0.120 \text{ MeV}^{-1}$, is used in the nuclear continuum state.
- 2 : The Mengoni-Nakajima Fermi-gas density parameter[4] is used in the nuclear continuum state.
- 3 : The Gilbert-Cameron type energy-independent density parameter (GCDEN) and the pairing energy (PAIRR) are read from the input data.

ITEMP

- 0 : The 3-rd and the 5-th discrete level data are used to connect the level densities of the constant temperature and the Fermi-gas form. (The discrete energies must be given in FILE 8.)
- 1 : Two discrete levels (LLOC,LUPC) are read from the input data in order to connect the level densities of the constant temperature and the Fermi-gas form. (The discrete energies must be given in FILE 8.)

2 : The matching energy (E_M) (EMATCH) and the nuclear temperature (T) (TMATCH) in Eqs. (20) and (34) are read from the input data in order to connect the level densities of the constant temperature and the Fermi-gas form.

IGAMMA

0 : The γ -ray strength function $2\pi \langle \Gamma_{\gamma 0} \rangle / \langle D_0 \rangle$ of Eq. (41) is calculated with the built-in parameters based on Eqs. (42) to (44).

1 : The γ -ray strength function (GAMNOR) $2\pi \langle \Gamma_{\gamma 0} \rangle / \langle D_0 \rangle$ of Eq. (41) is read from the input data[14].

2 : The radiative width (GAMNOR) $\langle \Gamma_{\gamma 0} \rangle$ is read from the input data to normalize the strength function. $\langle D_0 \rangle$ is evaluated by Eqs. (42) and (43).

JGAMMA

0 : The parameters E_{E1} and Γ_{E1} of the E1 γ -ray strength function f_{E1} in Eq. (39) (POSE1, WIDE1) are determined with the built-in parameters. The M1 radiation is not considered if JGAMMA=0.

1 : The parameters E_{E1} and Γ_{E1} of the E1 γ -ray strength function f_{E1} in Eq. (39) (POSE1, WIDE1) are read from the input data. The M1 radiation is not considered if JGAMMA=1.

2 : The parameters of the E1 and M1 γ -ray strength functions f_{E1}, f_{M1} in Eqs.(39) and (40) (POSE1, WIDE1, POSM1, WIDM1) are read from the input data. The M1/E1 ratio (RATM1) is also read from the input data for JGAMMA=2.

IWIDT

0 : The width fluctuation correction is not considered.

1 : The width fluctuation correction is considered, if the collision energy is smaller than the highest discrete energy of target.

DELBIN The width of energy bins in MeV for particle emissions.

GCDEN The energy-independent Fermi-gas level density parameter in MeV^{-1} for the option IDENSE=3.

In the input data, parameters for the compound nucleus are given in the first column. Parameters for residual nuclei are given in the 2-nd to 7-th columns in order of the reaction (n, n'), (n, p), (n, α), (n, d), (n, t), and ($n, {}^3\text{He}$).

PAIRR The pairing energy in MeV for the option IDENSE=3.

LLOC The lower discrete level for the option ITEMP=1.

LUPC The upper discrete level for the option ITEMP=1.

EMATCH The matching energy in MeV for the option ITEMP=2.

TMATCH The nuclear temperature in MeV for the option ITEMP=2.

GAMNOR GAMNOR is the value of the s-wave γ -ray strength function multiplied by the factor of 10^4 ($2\pi \langle \Gamma_{\gamma 0} \rangle / \langle D_0 \rangle \times 10^4$) for the option IGAMMA=1, and the radiative width ($\langle \Gamma_{\gamma 0} \rangle$) in eV for IGAMMA=2.

POSE1 The parameter E_{E1} in MeV for the option JGAMMA=1 or 2.

WIDE1 The parameter Γ_{E1} in MeV for the option JGAMMA=1 or 2.

POSM1 The parameter E_{M1} in MeV for the option JGAMMA=2.

WIDM1 The parameter Γ_{M1} in MeV for the option JGAMMA=2.

RATM1 The relative contribution of M1 radiation (the M1/E1 ratio) for JGAMMA=2.

4.1 Discrete Level Data

Nuclear discrete level data are read from FILE 8 in the subroutine STAL as the same manner with the GNASH code[6].

The discrete states must be given in the ascending order from the ground state. Data are given as follows.

83209	11				
1	0.000000	-4.5			0
2	0.896290	-3.5			1
	1	1	1.000000	1.000000	
3	1.608580	6.5			1
	1	1	1.000000	1.000000	
4	2.442860	0.5			1
	1	2	1.000000	1.000000	
5	2.492820	1.5			1
	1	1	1.000000	1.000000	
6	2.564160	4.5			1
	1	1	1.000000	1.000000	
7	2.583070	3.5			2
	1	1	0.306000	1.000000	
	2	2	0.694000	1.000000	
8	2.599900	5.5			1
	1	1	1.000000	1.000000	
9	2.600920	6.5			2
	1	1	0.012590	1.000000	
	2	3	0.987400	1.000000	
10	2.617310	2.5			3
	1	1	0.284200	1.000000	
	2	2	0.536200	1.000000	
	3	5	0.179600	1.000000	
11	2.741050	7.5			3
	1	1	0.432000	1.000000	
	2	3	0.297000	1.000000	
	3	9	0.271000	1.000000	
83210	11				
1	0.000000	-1.0			0
2	0.046539	-0.0			1
	1	1	1.000000	1.000000	
3	0.271310	-9.0			0
4	0.319740	-2.0			1
	1	1	1.000000	1.000000	
5	0.347930	-3.0			2
	1	1	0.511300	1.000000	
	2	4	0.488700	1.000000	
6	0.433490	-7.0			1
	1	3	1.000000	1.000000	
7	0.439200	-5.0			1
	1	5	1.000000	1.000000	
8	0.502810	-4.0			3
	1	4	0.046620	1.000000	
	2	5	0.832000	1.000000	
	3	7	0.121400	1.000000	
9	0.550000	-6.0			2
	1	6	0.530400	1.000000	
	2	7	0.469600	1.000000	
10	0.563070	-1.0			2
	1	1	0.690200	1.000000	
	2	2	0.309800	1.000000	
11	0.582530	-8.0			2
	1	3	0.500000	1.000000	
	2	6	0.500000	1.000000	

Above data are read with the following format.

```

READ(8,1100,END=170)IDCOM,LEVEL
DO 160 I=1,LEVEL
READ(8,1210)NLV,EL,(ACHR(K),K=1,6),NT
DO 150 J=1,NT
READ(8,1300)NF,P
150 CONTINUE
160 CONTINUE
170 CONTINUE
C
1100 FORMAT(I8,I5)
1210 FORMAT(I6,F12.6,6A1,18X,I6)
1300 FORMAT(12X,I6,F12.6)

```

- IDCOM : Nuclear index $1000^*Z + A$.
- LEVEL : Number of discrete levels (The maximum is 50).
- NLV : Level number. NLV=1 is the ground state and NLV=2 is the first excited state.
- EL : Excitaion energy in MeV for the NLV-th level.
- ACHR : Absolute value gives the spin quantum number of the NLV-th level.
The sign in ACHR indicates the parity.
- NT : Number of the γ -ray branches from the NLV-th to lower levels.
- NF : Level indicator to which the γ -ray transition takes place.
- P : The γ -ray branching ratio for the transition $NLV \rightarrow NF$.

4.2 Transmission Coefficients

The particle transmission coefficients are read from FILE 27 and File 28, if IDREAD=1 is set. The energy grids on which transmission coefficients are calculated are stored in FILE 27, and the transmission coefficients are stored in FILE 28. These data are read in the subroutine STATRE.

The energy data are given in FILE 27 as follows.

NEUTRON	31	80
2.50000E-02	5.00000E-02	1.00000E-01
1.00000E+00	1.50000E+00	2.00000E+00
4.00000E+00	5.00000E+00	6.00000E+00
1.20000E+01	1.40000E+01	1.60000E+01
2.60000E+01	3.00000E+01	3.50000E+01
PROTON	21	80
3.00000E+00	3.50000E+00	4.00000E+00
8.00000E+00	1.00000E+01	1.20000E+01
2.20000E+01	2.40000E+01	2.60000E+01
4.50000E+01	5.00000E+01	

These data are read with the following format.

```

      READ(27,2000)BCHR,NX,LX
      NE=NX-1
      READ(27,1100)(EDUM(IE),IE=1,NE)
C
      1100 FORMAT(1P6E12.4)
      2000 FORMAT(12X,A8,10X,I4,4X,I4)

```

- BCHR : Particle index defined by 8 characters "NEUTRON", "PROTON", "ALPHA", "DEUTERON", "TRITON", or "HELIUM3".
- NX : Number of energy points + 1 (The maximum is 31).
- LX : Twice the maximum of orbital angular momentum quantum number:
 $2 \times l_{max}$ (The maximum is 80).
- EDUM : Energy values in MeV in the center of mass system.

The transmission coefficients T_l^j are stored in FILE 28 as follows.

These data are read with the following format.

```

NE=NX-1
LL=LX+2
DO 400 IE=1,NE
READ(28,1100)EDUM(IE)
READ(28,1100)(TC(L),L=1,LL)
CONTINUE

FORMAT(1P6E12.4)

```

EDUM : Center of mass energy in MeV.

TC : Transmission coefficients.

T_l^j for the spin $s = 1/2$ particles is ordered as follows.

$$T_0^{1/2} \quad T_1^{1/2} \quad T_2^{3/2} \quad T_1^{3/2} \quad T_2^{5/2} \quad T_3^{5/2} \quad T_4^{7/2} \quad T_3^{7/2} \quad T_4^{9/2} \quad T_5^{9/2} \quad T_6^{11/2} \quad T_5^{11/2} \quad \dots$$

The transmission coefficients T_l for α particles with $s = 0$ are stored as follows.

$T_0 \quad 0.0 \quad 0.0 \quad T_1 \quad T_2 \quad 0.0 \quad 0.0 \quad T_3 \quad T_4 \quad 0.0 \quad 0.0 \quad T_5 \quad \dots$

The deuteron ($s = 1$) transmission coefficients must be averaged over j by Eq. (50) and stored as α particles.

5 Sample Calculations

Following two sample calculations were carried out, and the input and output data are given in Figs.2 to 5. The program was compiled by DIG FORTRAN 77 on DEC- α 600au.

- i) The neutron angular distributions and the energy spectra for the $n+^{209}\text{Bi}$ collisions at the center-of-mass collision energies $E_{CM}=1$ and 3 MeV calculated by the statistical model with the width fluctuation correction. The input and output data are given in Figs.2 and 3, respectively.
- ii) The neutron angular distributions and the particle emission spectra for the $n+^{120}\text{Sn}$ collisions at $E_{CM}=15$ MeV calculated by the statistical model. The input and output data are given in Figs.4 and 5, respectively. Parameter values in SINCROS-II[13] were used in the input data.

The following calculation was also done.

- iii) The angular distribution of elastic-scattering cross sections for $^{209}\text{Bi}(n,n)$ at 2.5 MeV. Calculated results are shown together with experimental data[22] in Fig.6. The shape-elastic scattering cross sections are computed by the optical model. One can see that the compound-elastic scattering contribution is indispensable to describe the low-energy behavior of the cross section.

1	1	83209	0	2	0	151	37
1.0		3.0					
0	0						
0	0	0					
1	2	1	0	0	1		
0.4							
2	5						
11	11						

Fig.2 Input data to calculate the neutron angular distributions and the energy spectra for the $n+^{209}\text{Bi}$ collisions at $E_{CM}=1$ and 3 MeV by the statistical model with the width fluctuation correction.

PROJECTILE CHARGE = 0.00 MASS NUMBER = 1.00 SPIN = 0.50
TARGET CHARGE = 83.00 MASS NUMBER = 209.00
IP1 = 0 NR = 151
IPRECO = 0 JPRECO = 0 IDREAD = 0
IHAUSE = 1 IDENSE = 2 ITEMP = 1 IGAMMA = 0 JGAMMA = 0 IWIDT = 1
DELBIN = 0.400

+++ ENTER L101 +++

ELAB = 1.005 MEV ECM = 1.000 MEV WAVE NUMBER = 0.21915
RHOM = 3.463 LMAX = 9 COULOMB PARAMETER = 0.000

ANGLE DIFFERENTIAL CROSS SECTION FOR ELASTIC SCATTERING

CM ANGLE DEG	CROSS SECTION MB/SR	ANALYZING POWER
0.00	8.548E+02	0.000E+00
5.00	8.442E+02	2.199E-02
10.00	8.131E+02	4.388E-02
15.00	7.635E+02	6.563E-02
20.00	6.987E+02	8.723E-02
25.00	6.228E+02	1.088E-01
30.00	5.406E+02	1.306E-01
35.00	4.570E+02	1.530E-01
40.00	3.771E+02	1.764E-01
45.00	3.052E+02	2.011E-01
50.00	2.449E+02	2.262E-01
55.00	1.989E+02	2.457E-01
60.00	1.685E+02	2.619E-01
65.00	1.536E+02	2.582E-01
70.00	1.529E+02	2.358E-01
75.00	1.638E+02	2.019E-01
80.00	1.828E+02	1.661E-01
85.00	2.058E+02	1.337E-01
90.00	2.284E+02	1.060E-01
95.00	2.467E+02	8.250E-02
100.00	2.573E+02	6.199E-02
105.00	2.581E+02	4.371E-02
110.00	2.484E+02	2.723E-02
115.00	2.289E+02	1.263E-02
120.00	2.018E+02	6.613E-04
125.00	1.704E+02	-6.881E-03
130.00	1.384E+02	-6.361E-03
135.00	1.096E+02	7.898E-03
140.00	8.729E+01	4.217E-02
145.00	7.354E+01	9.478E-02
150.00	6.901E+01	1.453E-01
155.00	7.281E+01	1.671E-01
160.00	8.273E+01	1.554E-01
165.00	9.562E+01	1.233E-01
170.00	1.080E+02	8.345E-02
175.00	1.169E+02	4.177E-02
180.00	1.201E+02	0.000E+00

SHAPE ELASTIC CROSS SECTION = 2.9586E+03 MB
REACTION CROSS SECTION = 1.6408E+03 MB

Fig.3 The neutron angular distributions and the energy spectra for the $n+^{209}\text{Bi}$ collisions at $E_{CM}=1$ and 3 MeV calculated by the statistical model with the width fluctuation correction.

ELAB = 3.014 MEV ECM = 3.000 MEV WAVE NUMBER = 0.37958
 RHOM = 5.726 LMAX = 12 COULOMB PARAMETER = 0.000

ANGLE DIFFERENTIAL CROSS SECTION FOR ELASTIC SCATTERING

CM ANGLE DEG	CROSS SECTION MB/SR	ANALYZING POWER
0.00	5.705E+03	0.000E+00
5.00	5.529E+03	-1.201E-02
10.00	5.027E+03	-2.327E-02
15.00	4.280E+03	-3.300E-02
20.00	3.396E+03	-4.036E-02
25.00	2.494E+03	-4.438E-02
30.00	1.675E+03	-4.383E-02
35.00	1.012E+03	-3.697E-02
40.00	5.335E+02	-2.096E-02
45.00	2.366E+02	8.797E-03
50.00	9.078E+01	4.834E-02
55.00	5.258E+01	-1.436E-02
60.00	7.737E+01	-4.445E-02
65.00	1.275E+02	-3.553E-02
70.00	1.763E+02	-7.961E-03
75.00	2.088E+02	2.330E-02
80.00	2.200E+02	5.511E-02
85.00	2.117E+02	8.664E-02
90.00	1.897E+02	1.178E-01
95.00	1.612E+02	1.486E-01
100.00	1.325E+02	1.773E-01
105.00	1.068E+02	1.964E-01
110.00	9.049E+01	1.893E-01
115.00	7.688E+01	1.346E-01
120.00	6.519E+01	1.534E-02
125.00	5.305E+01	-1.750E-01
130.00	4.016E+01	-4.164E-01
135.00	2.953E+01	-5.403E-01
140.00	2.744E+01	-7.266E-02
145.00	4.176E+01	6.465E-01
150.00	7.901E+01	8.532E-01
155.00	1.412E+02	7.769E-01
160.00	2.238E+02	6.285E-01
165.00	3.143E+02	4.684E-01
170.00	3.963E+02	3.097E-01
175.00	4.559E+02	1.840E-01
180.00	4.781E+02	0.000E+00

SHAPE ELASTIC CROSS SECTION = 4.9575E+03 MB
 REACTION CROSS SECTION = 2.6592E+03 MB

+++ ENTER L401 +++

+++ ENTER STACHN +++

NREACT = 26

NCOMP = 11

REACTION NO.	FINAL STATE	SEPARATION ENERGY MEV	Q-VALUE MEV
1	83210.	0.00000	4.60463
2	83209.	4.60463	0.00000

+++ ENTER STAL +++

83210	11		
1	0.000000	1.0 -1.0	0
2	0.046539	0.0 -1.0	1
		1.000000	
3	0.271310	9.0 -1.0	0
4	0.319740	2.0 -1.0	1
		1.000000	
5	0.347930	3.0 -1.0	2
		0.511300	
6	0.433490	4.0 -1.0	0.488700
		7.0 -1.0	1
7	0.439200	3.0 -1.0	1.000000
		5.0 -1.0	1
8	0.502810	4.0 -1.0	0.466620
		4.0 -1.0	3
9	0.550000	6.0 -1.0	0.832000
		6.0 -1.0	2
10	0.563070	7.0 -1.0	0.121400
		0.530400	2
11	0.582530	8.0 -1.0	0.469600
		8.0 -1.0	2
		0.309800	
		0.500000	
83209	11		
1	0.000000	4.5 -1.0	0
2	0.896290	3.5 -1.0	1
		1.000000	
3	1.608580	6.5 1.0	1
		1.000000	
4	2.442860	0.5 1.0	1
		1.000000	
5	2.492820	1.5 1.0	1
		1.000000	
6	2.564160	4.5 1.0	1
		1.000000	
7	2.583070	3.5 1.0	1
		0.306000	2
8	2.599900	5.5 1.0	0.694000
		1.000000	1
9	2.600920	6.5 1.0	0.012590
		1.000000	2
		0.987400	

Fig.3 Continued

10	2.617310	2.5	1.0	3
	1	0.284200		
	2	0.536200		
	5	0.179600		
11	2.741050	7.5	1.0	3
	1	0.432000		
	3	0.297000		
	9	0.271000		

+++ ENTER STATR2 +++
 PRJ TARGET CM-ENERGY REACTION CROSS SECTION LMAX
 MEV MB

1	83209	0.0250	1.621E+03	4
1	83209	0.0500	1.392E+03	4
1	83209	0.1000	1.321E+03	5
1	83209	0.2500	1.398E+03	6
1	83209	0.5000	1.468E+03	7
1	83209	0.7500	1.543E+03	8
1	83209	1.0000	1.641E+03	9
1	83209	1.5000	2.071E+03	10
1	83209	2.0000	2.535E+03	11
1	83209	2.5000	2.688E+03	11
1	83209	3.0000	2.659E+03	12
1	83209	3.5000	2.622E+03	13
1	83209	4.0000	2.620E+03	13
1	83209	5.0000	2.563E+03	14
1	83209	6.0000	2.456E+03	15
1	83209	7.0000	2.445E+03	15
1	83209	8.0000	2.506E+03	16
1	83209	10.0000	2.548E+03	17
1	83209	12.0000	2.535E+03	18
1	83209	14.0000	2.561E+03	19
1	83209	16.0000	2.555E+03	20
1	83209	20.0000	2.522E+03	22
1	83209	22.0000	2.533E+03	23
1	83209	24.0000	2.534E+03	23
1	83209	26.0000	2.516E+03	24
1	83209	30.0000	2.482E+03	25
1	83209	35.0000	2.445E+03	26
1	83209	40.0000	2.396E+03	28
1	83209	45.0000	2.350E+03	29
1	83209	50.0000	2.304E+03	30

+++ ENTER STAGC +++
 COMPOUND LEV. DENS. PARM. PAIRING ENERGY
 MEV (-1) MEV

83210.	0.0000	0.0000
83209.	0.0000	0.8301

+++ ENTER STAMT1 +++
 83210. T = 0.756 MEV EMATCH = 5.872 MEV E0 = -1.592 MEV NL= 2 NC=11
 83209. T = 0.726 MEV EMATCH = 4.869 MEV E0 = 0.539 MEV NL= 5 NC=11

+++ ENTER STAGAM +++
 83210. DO = 3.840E+03 GG = 8.834E-02 STRENGTH = 1.445E-04
 E1-GAMMA NORM.FAC. = 4.718E-05
 POSE1 = 1.373E+01 MEV WIDE1 = 6.000E+00 MEV

REACTION CROSS SECTION = 1.6408E+03 MB

+++ ENTER STATIS +++

HAUSER-FESHBACH ENERGY SPECTRA
 ECM = 1.00000 MEV

ENERGY MEV	GAMMA	NEUTRON	PROTON	ALPHA	DEUTERON	TRITON	HE-3
0.400	7.044E-03	2.316E+02					
0.800	6.673E-02	3.863E+03					
1.200	2.006E-01	0.000E+00					
1.600	3.777E-01	0.000E+00					
2.000	5.510E-01	0.000E+00					
2.400	6.850E-01	0.000E+00					
2.800	7.634E-01	0.000E+00					
3.200	7.859E-01	0.000E+00					
3.600	7.624E-01	0.000E+00					
4.000	7.062E-01	0.000E+00					
4.400	6.306E-01	0.000E+00					
4.800	5.362E-01	0.000E+00					
5.200	5.489E-01	0.000E+00					
5.600	5.583E-02	0.000E+00					

TOTAL(MB) 2.831E+00 1.638E+03
 TOTAL = 1.641E+03

CROSS SECTIONS FOR COMPOUND ELASTIC AND
 INELASTIC SCATTERINGS INTO DISCRETE STATES

N	STATE	ENERGY MEV	CROSS SECTION MB
0	-4.5	0.00000	1.545E+03
1	-3.5	0.89629	9.264E+01
2	6.5	1.60858	0.000E+00
3	0.5	2.44286	0.000E+00
4	1.5	2.49282	0.000E+00
5	2.5	2.56416	0.000E+00
6	3.5	2.58307	0.000E+00
7	5.5	2.59990	0.000E+00
8	6.5	2.60092	0.000E+00
9	2.5	2.61731	0.000E+00
10	7.5	2.74105	0.000E+00
	CONTINUUM		1.638E+03

Fig.3 Continued

<< CROSS SECTIONS AFTER THE WIDTH FLUCTUATION CORRECTION >>

+++ ENTER STAWIG +++

0.400	6.392E-03	7.044E-03
0.800	6.055E-02	6.673E-02
1.200	1.820E-01	2.006E-01
1.600	3.427E-01	3.777E-01
2.000	5.000E-01	5.510E-01
2.400	6.216E-01	6.850E-01
2.800	6.927E-01	7.634E-01
3.200	7.131E-01	7.859E-01
3.600	6.918E-01	7.624E-01
4.000	6.408E-01	7.062E-01
4.400	5.722E-01	6.306E-01
4.800	4.889E-01	5.362E-01
5.200	8.907E-01	9.489E-01
5.600	5.210E-02	5.583E-02
TOTAL(MB)	2.582E+00	2.831E+00

THE LEGENDRE EXPANSION COEFFICIENTS FOR THE
COMPOUND ELASTIC AND INELASTIC SCATTERINGS

0	-4.50	0.00000
2	1.245E+02	
4	1.793E+01	
6	2.959E+00	
8	5.420E-01	
10	9.684E-03	
SIGMA	1.563E+03	1.565E+03 MB
1	-3.50	0.89629
0	5.658E+00	
2	-2.501E-02	
4	-4.711E-03	
SIGMA	7.357E+01	7.361E+01 MB

ANGLE DIFFERENTIAL CROSS SECTIONS FOR COMPOUND ELASTIC AND INELASTIC SCATTERINGS INTO DISCRETE STATES
ANGLE DEG CROSS SECTION MB/SR

0	1.460E+02	5.828E+00
5.00	1.456E+02	5.828E+00
10.00	1.445E+02	5.830E+00
15.00	1.429E+02	5.832E+00
20.00	1.407E+02	5.835E+00
25.00	1.383E+02	5.839E+00
30.00	1.356E+02	5.842E+00
35.00	1.329E+02	5.846E+00
40.00	1.302E+02	5.850E+00
45.00	1.277E+02	5.854E+00
50.00	1.254E+02	5.857E+00
55.00	1.234E+02	5.860E+00
60.00	1.216E+02	5.862E+00
65.00	1.201E+02	5.865E+00
70.00	1.188E+02	5.866E+00
75.00	1.178E+02	5.867E+00
80.00	1.171E+02	5.868E+00
85.00	1.166E+02	5.869E+00
90.00	1.165E+02	5.869E+00
95.00	1.166E+02	5.869E+00
100.00	1.171E+02	5.868E+00
105.00	1.178E+02	5.867E+00
110.00	1.188E+02	5.866E+00
115.00	1.201E+02	5.865E+00
120.00	1.216E+02	5.862E+00
125.00	1.234E+02	5.860E+00
130.00	1.254E+02	5.857E+00
135.00	1.277E+02	5.854E+00
140.00	1.302E+02	5.850E+00
145.00	1.329E+02	5.846E+00
150.00	1.356E+02	5.842E+00
155.00	1.383E+02	5.839E+00
160.00	1.407E+02	5.835E+00
165.00	1.429E+02	5.832E+00
170.00	1.445E+02	5.830E+00
175.00	1.456E+02	5.829E+00
180.00	1.460E+02	5.828E+00

HAUSER-FESHBACH ENERGY SPECTRA
ECM = 1.00000 MEV

ENERGY MEV	GAMMA MB/MEV	NEUTRON	PROTON	ALPHA	DEUTERON	TRITON	HE-3
0.400	6.392E-03	1.840E+02					
0.800	6.055E-02	3.912E+03					
1.200	1.820E-01	0.000E+00					
1.600	3.427E-01	0.000E+00					
2.000	5.000E-01	0.000E+00					
2.400	6.216E-01	0.000E+00					
2.800	6.927E-01	0.000E+00					
3.200	7.131E-01	0.000E+00					
3.600	6.918E-01	0.000E+00					
4.000	6.408E-01	0.000E+00					
4.400	5.722E-01	0.000E+00					
4.800	4.889E-01	0.000E+00					
5.200	8.907E-01	0.000E+00					
5.600	5.210E-02	0.000E+00					
TOTAL(MB)	2.582E+00	1.639E+03					
TOTAL =	1.641E+03	MB					

Fig.3 Continued

CROSS SECTIONS FOR COMPOUND ELASTIC AND INELASTIC SCATTERINGS INTO DISCRETE STATES

N	STATE	ENERGY MEV	CROSS SECTION MB
0	-4.5	0.00000	1.565E+03
1	-3.5	0.89629	7.361E+01
2	6.5	1.60858	0.000E+00
3	0.5	2.44286	0.000E+00
4	-1.5	2.49282	0.000E+00
5	-4.5	2.56416	0.000E+00
6	-3.5	2.58307	0.000E+00
7	5.5	2.59990	0.000E+00
8	6.5	2.60092	0.000E+00
9	2.5	2.61731	0.000E+00
10	7.5	2.74105	0.000E+00

+++ ENTER STAGAM +++
 83210. DO = 3.840E+03 GG = 8.834E-02 STRENGTH = 1.445E-04
 E1-GAMMA NORM FAC. = 4.718E-05
 POSE1 = 1.373E+01 MEV WIDE1 = 6.000E+00 MEV

REACTION CROSS SECTION = 2.6592E+03 MB

+++ ENTER STATIS +++

HAUSER-FESHBACH ENERGY SPECTRA
ECM = 3.00000 MEV

ENERGY MEV	GAMMA	NEUTRON	PROTON	ALPHA	DEUTERON	TRITON	HE-3
		MB/MEV					
0.400	1.889E-02	1.071E+03					
0.800	1.735E-01	0.000E+00					
1.200	5.013E-01	8.724E+02					
1.600	8.992E-01	0.000E+00					
2.000	1.288E+00	1.615E+03					
2.400	1.602E+00	0.000E+00					
2.800	1.785E+00	3.070E+03					
3.200	1.837E+00	0.000E+00					
3.600	1.782E+00	0.000E+00					
4.000	1.651E+00	0.000E+00					
4.400	1.474E+00	0.000E+00					
4.800	1.276E+00	0.000E+00					
5.200	1.082E+00	0.000E+00					
5.600	8.984E-01	0.000E+00					
6.000	7.338E-01	0.000E+00					
6.400	5.896E-01	0.000E+00					
6.800	4.262E-01	0.000E+00					
7.200	9.623E-01	0.000E+00					
7.600	3.639E-02	0.000E+00					
TOTAL(MB)	7.608E+00	2.652E+03					
TOTAL	=	2.659E+03					

CROSS SECTIONS FOR COMPOUND ELASTIC AND INELASTIC SCATTERINGS INTO DISCRETE STATES

N	STATE	ENERGY MEV	CROSS SECTION MB
0	-4.5	0.00000	1.228E+03
1	-3.5	0.89629	6.462E+02
2	6.5	1.60858	3.490E+02
3	0.5	2.44286	1.255E+01
4	-1.5	2.49282	2.703E+01
5	-4.5	2.56416	7.679E+01
6	-3.5	2.58307	5.697E+01
7	5.5	2.59990	7.965E+01
8	6.5	2.60092	8.269E+01
9	2.5	2.61731	3.476E+01
10	7.5	2.74105	5.613E+01
CONTINUUM			0.000E+00
			2.652E+03

THE LEGENDRE EXPANSION COEFFICIENTS FOR THE COMPOUND ELASTIC AND INELASTIC SCATTERINGS

0	-4.50	0.00000
0	9.772E+01	
2	2.110E+01	
4	5.706E+00	
6	1.450E+00	
8	2.210E-01	
10	6.046E-02	1.228E+03 MB
SIGMA	1.227E+03	
1	-3.50	0.89629
0	5.142E+01	
2	5.365E+00	
4	9.469E-02	
6	-3.293E-01	
8	-9.559E-02	
10	-7.071E-03	6.462E+02 MB
SIGMA	6.457E+02	
2	6.50	1.60858
0	2.777E+01	
2	8.846E-01	
4	-5.095E-01	
6	-9.181E-02	
8	-7.905E-03	
10	-1.702E-04	3.490E+02 MB
SIGMA	3.487E+02	

Fig.3 Continued

3	0.50	2.44286
2	-6.191E-02	
4	6.188E-03	
6	-1.511E-04	
SIGMA	1.254E+01	1.255E+01 MB
4	1.50	2.49282
0	2.152E+00	
2	-1.452E-01	
4	1.136E-02	
6	4.222E-04	
SIGMA	2.702E+01	2.703E+01 MB
5	4.50	2.56416
0	6.110E+00	
2	4.126E-01	
4	3.937E-02	
6	3.978E-04	
SIGMA	7.673E+01	7.679E+01 MB
6	3.50	2.58307
0	4.535E+00	
2	8.170E-02	
4	-1.074E-02	
6	-1.748E-04	
SIGMA	5.693E+01	5.697E+01 MB
7	5.50	2.59990
0	6.338E+00	
2	3.377E-01	
4	1.983E-02	
6	1.633E-04	
SIGMA	7.959E+01	7.965E+01 MB
8	6.50	2.60092
0	6.581E+00	
2	4.689E-02	
4	-4.447E-02	
6	-7.415E-04	
SIGMA	8.264E+01	8.269E+01 MB
9	2.50	2.61731
0	2.766E+00	
2	-1.384E-01	
4	-1.603E-02	
6	-1.089E-04	
SIGMA	3.474E+01	3.476E+01 MB
10	7.50	2.74105
0	4.626E+00	
2	6.121E-02	
4	1.840E-02	
6	1.747E-04	
SIGMA	5.809E+01	5.813E+01 MB

ANGLE DIFFERENTIAL CROSS SECTIONS FOR COMPOUND ELASTIC AND INELASTIC SCATTERINGS INTO DISCRETE STATES
CROSS SECTION MB/SR

ANGLE DEG	0	1	2	3	4	5	6	7
0.00	1.263E+02	5.653E+01	2.804E+01	9.424E-01	2.018E+00	6.563E+00	4.604E+00	6.696E+00
5.00	1.256E+02	6.649E+01	2.806E+01	9.429E-01	2.019E+00	6.567E+00	4.604E+00	6.691E+00
10.00	1.239E+02	6.638E+01	2.811E+01	9.444E-01	2.022E+00	6.598E+00	4.602E+00	6.678E+00
15.00	1.212E+02	6.618E+01	2.818E+01	9.468E-01	2.028E+00	6.599E+00	4.599E+00	6.656E+00
20.00	1.179E+02	5.587E+01	2.825E+01	9.502E-01	2.037E+00	6.469E+00	4.596E+00	6.626E+00
25.00	1.142E+02	5.545E+01	2.831E+01	9.546E-01	2.047E+00	6.422E+00	4.591E+00	6.590E+00
30.00	1.104E+02	5.490E+01	2.835E+01	9.598E-01	2.060E+00	6.369E+00	4.584E+00	6.550E+00
35.00	1.068E+02	5.426E+01	2.834E+01	9.660E-01	2.075E+00	6.312E+00	4.577E+00	6.506E+00
40.00	1.035E+02	5.353E+01	2.830E+01	9.729E-01	2.092E+00	6.255E+00	4.568E+00	6.460E+00
45.00	1.005E+02	2.277E+01	2.821E+01	9.804E-01	2.110E+00	6.198E+00	4.558E+00	6.414E+00
50.00	9.794E+01	2.200E+01	2.808E+01	9.883E-01	2.129E+00	6.143E+00	4.548E+00	6.370E+00
55.00	9.573E+01	1.27E+01	2.794E+01	9.963E-01	2.148E+00	6.093E+00	4.537E+00	6.328E+00
60.00	9.387E+01	0.62E+01	2.778E+01	1.004E+00	2.166E+00	6.048E+00	4.526E+00	6.290E+00
65.00	9.234E+01	0.06E+01	2.762E+01	1.012E+00	2.183E+00	6.009E+00	4.516E+00	6.257E+00
70.00	9.110E+01	4.961E+01	2.747E+01	1.018E+00	2.198E+00	5.976E+00	4.507E+00	6.228E+00
75.00	9.014E+01	4.928E+01	2.734E+01	1.024E+00	2.211E+00	5.951E+00	4.499E+00	6.206E+00
80.00	8.945E+01	4.905E+01	2.724E+01	1.028E+00	2.220E+00	5.933E+00	4.493E+00	6.190E+00
85.00	8.904E+01	4.882E+01	2.718E+01	1.031E+00	2.226E+00	5.922E+00	4.490E+00	6.180E+00
90.00	8.890E+01	4.887E+01	2.716E+01	1.032E+00	2.228E+00	5.919E+00	4.489E+00	6.177E+00
95.00	8.904E+01	4.892E+01	2.718E+01	1.031E+00	2.226E+00	5.922E+00	4.490E+00	6.180E+00
100.00	9.454E+01	4.905E+01	2.724E+01	1.028E+00	2.220E+00	5.933E+00	4.493E+00	6.190E+00
105.00	9.014E+01	4.928E+01	2.734E+01	1.024E+00	2.211E+00	5.951E+00	4.499E+00	6.206E+00
110.00	9.110E+01	4.961E+01	2.747E+01	1.018E+00	2.198E+00	5.976E+00	4.507E+00	6.228E+00
115.00	9.234E+01	0.06E+01	2.762E+01	1.012E+00	2.183E+00	6.009E+00	4.516E+00	6.257E+00
120.00	9.387E+01	0.62E+01	2.778E+01	1.004E+00	2.166E+00	6.048E+00	4.526E+00	6.290E+00
125.00	9.573E+01	1.27E+01	2.794E+01	9.963E-01	2.148E+00	6.093E+00	4.537E+00	6.328E+00
130.00	9.794E+01	2.00E+01	2.808E+01	9.883E-01	2.129E+00	6.133E+00	4.548E+00	6.370E+00
135.00	1.005E+02	2.27E+01	2.821E+01	9.804E-01	2.110E+00	6.188E+00	4.558E+00	6.414E+00
140.00	1.036E+02	3.53E+01	2.830E+01	9.729E-01	2.092E+00	6.255E+00	4.560E+00	6.460E+00
145.00	1.086E+02	4.26E+01	2.834E+01	9.660E-01	2.075E+00	6.312E+00	4.577E+00	6.506E+00
150.00	1.142E+02	4.90E+01	2.835E+01	9.598E-01	2.060E+00	6.369E+00	4.584E+00	6.550E+00
155.00	1.142E+02	5.45E+01	2.831E+01	9.546E-01	2.047E+00	6.422E+00	4.591E+00	6.590E+00
160.00	1.179E+02	5.587E+01	2.825E+01	9.502E-01	2.037E+00	6.469E+00	4.596E+00	6.626E+00
165.00	1.212E+02	6.188E+01	2.818E+01	9.468E-01	2.028E+00	6.509E+00	4.599E+00	6.656E+00
170.00	1.239E+02	6.638E+01	2.811E+01	9.444E-01	2.022E+00	6.538E+00	4.602E+00	6.678E+00
175.00	1.256E+02	6.649E+01	2.806E+01	9.429E-01	2.019E+00	6.557E+00	4.604E+00	6.696E+00
180.00	1.263E+02	6.653E+01	2.804E+01	9.424E-01	2.018E+00	6.563E+00	4.604E+00	6.696E+00
	8	9	10					
0.00	6.582E+00	2.612E+00	4.706E+00					
5.00	6.584E+00	2.614E+00	4.704E+00					
10.00	6.587E+00	2.620E+00	4.700E+00					
15.00	6.592E+00	2.631E+00	4.694E+00					
20.00	6.598E+00	2.644E+00	4.685E+00					
25.00	6.604E+00	2.661E+00	4.675E+00					
30.00	6.609E+00	2.679E+00	4.666E+00					
35.00	6.612E+00	2.699E+00	4.654E+00					
40.00	6.613E+00	2.719E+00	4.643E+00					
45.00	6.611E+00	2.738E+00	4.634E+00					
50.00	6.605E+00	2.756E+00	4.625E+00					

Fig.3 Continued

55.00	6.597E+00	2.773E+00	4.619E+00
60.00	6.587E+00	2.788E+00	4.613E+00
65.00	6.576E+00	2.801E+00	4.609E+00
70.00	6.565E+00	2.811E+00	4.605E+00
75.00	6.555E+00	2.819E+00	4.604E+00
80.00	6.545E+00	2.825E+00	4.603E+00
85.00	6.542E+00	2.828E+00	4.602E+00
90.00	6.541E+00	2.829E+00	4.602E+00
95.00	6.542E+00	2.828E+00	4.602E+00
100.00	6.545E+00	2.829E+00	4.602E+00
105.00	6.555E+00	2.819E+00	4.604E+00
110.00	6.565E+00	2.811E+00	4.606E+00
115.00	6.576E+00	2.801E+00	4.609E+00
120.00	6.587E+00	2.788E+00	4.613E+00
125.00	6.597E+00	2.773E+00	4.619E+00
130.00	6.605E+00	2.756E+00	4.625E+00
135.00	6.611E+00	2.738E+00	4.634E+00
140.00	6.613E+00	2.719E+00	4.643E+00
145.00	6.612E+00	2.699E+00	4.654E+00
150.00	6.609E+00	2.679E+00	4.665E+00
155.00	6.604E+00	2.661E+00	4.675E+00
160.00	6.595E+00	2.644E+00	4.685E+00
165.00	6.592E+00	2.631E+00	4.694E+00
170.00	6.587E+00	2.620E+00	4.700E+00
175.00	6.584E+00	2.614E+00	4.704E+00
180.00	6.582E+00	2.612E+00	4.706E+00

Fig.3 Continued

1	1	50120	0	1	0	153	37
15.0	0	0	0	0	0		
	2	3	2	1	1	0	
0.5							
16.5	16.5	21.0	22.8	20.0	19.0	23.0	
1.19	2.43	0.0	1.36	1.24	0.0	2.6	
6.361290	8.014338	4.468326	6.728820	5.571592	4.728440	7.992968	
0.7145407	0.7348741	0.5812957	0.5923323	0.5927498	0.6322783	0.5902181	
4.3964162							
15.328615							
6.000000							
+++++1++++++2+++++3++++++4+++++5+++++6+++++7							
50121	50120	49120	48117	49119	49118	48118	

Fig.4 Input data to calculate the neutron angular distributions and the particle emission spectra for the $n + ^{120}\text{Sn}$ collisions at $E_{CM} = 15$ MeV by the statistical model.

```

PROJECTILE CHARGE = 0.00 MASS NUMBER = 1.00 SPIN = 0.50
TARGET CHARGE = 50.00 MASS NUMBER = 120.00
IP1 = 0 NR = 153
IPRECO = 0 JPRECO = 0 IDREAD = 0
IHAUSE = 2 IDENSE = 3 ITTEMP = 2 IGAMMA = 1 JGAMMA = 1 IWIDT = 0
DELBIN = 0.500
+++ ENTER L101 ***
ELAB = 15.126 MEV ECM = 15.000 MEV WAVE NUMBER = 0.84726
RHOM = 10.893 LMAX = 19 COULOMB PARAMETER = 0.000
ANGLE DIFFERENTIAL CROSS SECTION FOR ELASTIC SCATTERING


| CM ANGLE<br>DEG | CROSS SECTION<br>MB/SR | ANALYZING<br>POWER |
|-----------------|------------------------|--------------------|
| 0.00            | 9.508E+03              | 0.000E+00          |
| 5.00            | 8.729E+03              | 5.152E-03          |
| 10.00           | 6.720E+03              | 3.538E-03          |
| 15.00           | 4.268E+03              | 2.848E-03          |
| 20.00           | 2.149E+03              | 1.832E-03          |
| 25.00           | 7.933E+02              | 6.390E-03          |
| 30.00           | 1.744E+02              | 3.434E-03          |
| 35.00           | 1.652E+01              | 3.668E-01          |
| 40.00           | 3.441E+01              | 6.256E-01          |
| 45.00           | 6.675E+01              | 5.179E-01          |
| 50.00           | 7.171E+01              | 4.920E-01          |
| 55.00           | 6.022E+01              | 3.789E-01          |
| 60.00           | 4.533E+01              | 1.125E-01          |
| 65.00           | 3.047E+01              | 2.650E-01          |
| 70.00           | 1.716E+01              | 6.815E-01          |
| 75.00           | 9.100E+00              | 7.910E-01          |
| 80.00           | 8.709E+00              | 2.039E-02          |
| 85.00           | 1.372E+01              | 3.692E-01          |
| 90.00           | 1.905E+01              | 2.365E-01          |
| 95.00           | 2.111E+01              | 3.922E-02          |
| 100.00          | 1.952E+01              | 3.614E-01          |
| 105.00          | 1.568E+01              | -6.175E-01         |
| 110.00          | 1.103E+01              | -6.453E-01         |
| 115.00          | 7.031E+00              | -2.881E-01         |
| 120.00          | 5.444E+00              | 2.317E-01          |
| 125.00          | 7.255E+00              | 1.271E-01          |
| 130.00          | 1.101E+01              | -9.599E-02         |
| 135.00          | 1.302E+01              | -1.407E-01         |
| 140.00          | 1.137E+01              | -1.192E-01         |
| 145.00          | 6.790E+00              | -2.455E-01         |
| 150.00          | 3.851E+00              | -8.617E-01         |
| 155.00          | 5.856E+00              | -5.453E-01         |
| 160.00          | 1.172E+01              | 1.849E-01          |
| 165.00          | 1.701E+01              | 6.613E-01          |
| 170.00          | 1.838E+01              | 9.229E-01          |
| 175.00          | 1.668E+01              | 7.699E-01          |
| 180.00          | 1.545E+01              | 0.000E+00          |


```

SHAPE ELASTIC CROSS SECTION = 2.5794E+03 MB
 REACTION CROSS SECTION = 1.9940E+03 MB

Fig.5 The neutron angular distributions and the particle emission spectra for the $n + ^{120}\text{Sn}$ collisions at $E_{CM} = 15$ MeV calculated by the statistical model.

+++ ENTER L401 +++

+++ ENTER STACHN +++

NREACT = 26

NCOMP = 11

REACTION NO.	FINAL STATE	SEPARATION ENERGY MEV	Q-VALUE MEV
1	50121	0.00000	6.17032
2	50120	6.17032	0.00000
3	49120	10.75797	-4.58765
4	48117	5.20369	-0.96663
5	49119	14.63531	-8.46499
6	49118	16.92354	-10.75322
7	48118	17.42673	-11.25641

+++ ENTER STAL +++

50121	10			
1	0.000000	1.5	1.0	0
2	0.006300	5.5	-1.0	0
3	0.060300	0.5	1.0	1
		1	1.000000	
4	0.663600	3.5	-1.0	1
		2	1.000000	
5	0.869200	1.5	1.0	2
		3	0.167000	
		1	0.833000	
6	0.908900	1.5	1.0	1
		1	1.000000	
7	0.925600	3.5	1.0	4
		5	0.002000	
		4	0.080000	
		2	0.042000	
		1	0.876000	
8	0.949200	3.5	-1.0	1
		2	1.000000	
9	1.101200	1.5	1.0	2
		3	0.371000	
		1	0.629000	
10	1.121200	2.5	1.0	2
		3	0.099000	
		1	0.901000	
50120	15			
1	0.000000	0.0	1.0	0
2	1.171300	2.0	1.0	1
		1	1.000000	
3	1.875000	0.0	1.0	1
		2	1.000000	
4	2.097100	2.0	1.0	2
		2	0.503000	
		1	0.497000	
5	2.159200	0.0	1.0	1
		2	1.000000	
6	2.172900	2.0	1.0	2
		1	0.500000	
		0	0.500000	
7	2.194500	4.0	1.0	1
		4	1.000000	
8	2.284300	5.0	-1.0	2
		7	0.990000	
		2	0.010000	
9	2.290000	0.0	1.0	1
		2	1.000000	
10	2.323000	4.0	1.0	1
		3	1.000000	
11	2.355300	2.0	1.0	2
		2	0.735000	
		1	0.265000	
12	2.399700	3.0	1.0	2
		2	0.990000	
		1	0.010000	
13	2.421300	1.0	1.0	2
		2	0.483000	
		1	0.517000	
14	2.465900	4.0	1.0	1
		2	1.000000	
15	2.481600	7.0	-1.0	1
		8	1.000000	
49120	3			
1	0.000000	1.0	1.0	0
2	0.100000	5.0	1.0	0
3	0.200000	8.0	-1.0	0
48117	11			
1	0.000000	0.5	1.0	0
2	0.135400	1.5	1.0	1
		1	1.000000	
3	0.136400	5.5	-1.0	0
		3	1.000000	
4	0.278400	4.5	-1.0	1
		3	1.000000	
5	0.293500	3.5	1.0	1
		3	1.000000	
6	0.337700	1.5	1.0	2
		2	0.063000	
		1	0.937000	
7	0.426200	1.5	1.0	1
		1	1.000000	
8	0.442600	1.5	1.0	3
		6	0.055000	
		2	0.635000	
		1	0.311000	
9	0.498000	3.5	1.0	3
		5	0.535000	
		4	0.305000	
		3	0.160000	
10	0.509000	2.5	1.0	2
		1	0.300000	
		2	0.700000	

Fig.5 Continued

11	0.522100	2.5	1.0	3
	6	0.109000		
	2	0.725000		
	1	0.167000		
49119	12			
1	0.000000	4.5	1.0	0
2	0.311400	0.5	-1.0	1
3	0.604100	1.5	-1.0	
4	0.654100	1.5	1.0	2
	3	0.022000		
5	0.720700	0.978000		1
6	0.788200	2.5	1.0	3
	4	0.876000		
	3	0.027000		
	2	0.096000		
7	0.941400	2.5	1.0	4
	6	0.017000		
	4	0.105000		
	3	0.128000		
8	1.025000	4.5	1.0	2
	5	0.007000		
	1	0.993000		
9	1.044300	2.5	-1.0	2
	3	0.206000		
	2	0.794000		
10	1.050200	2.5	1.0	2
	3	0.219000		
	1	0.781000		
11	1.143000	3.5	1.0	2
	5	0.912000		
	1	0.088000		
12	1.203700	2.5	1.0	2
	8	0.065000		
	1	0.935000		
49118	5			
1	0.000000	1.0	1.0	0
2	0.060000	5.0	1.0	0
3	0.173000	2.0	1.0	1
	1	1.000000		
4	0.200000	8.0	-1.0	2
5	0.234000	4.0	1.0	
	2	0.500000		
48118	9			
1	0.000000	0.0	1.0	0
2	0.487800	2.0	1.0	1
	1	1.000000		
3	1.164800	4.0	1.0	1
	2	1.000000		
4	1.269000	7.0	-1.0	0
5	1.269400	1.0	1.0	2
	2	0.575000		
	1	0.425000		
6	1.285600	0.0	1.0	1
	3	1.000000		
7	1.460000	0.0	1.0	1
	2	1.000000		
8	1.600000	2.0	1.0	2
	1	0.500000		
9	1.615000	0.0	1.0	2
	5	0.338000		
	2	0.662000		

+++ ENTER STATR2 +++
PRJ TARGET CM-ENERGY REACTION CROSS SECTION LMAX
MEV MB

1	50120	0.0250	2.815E+03	4
1	50120	0.0500	2.820E+03	
1	50120	0.1000	2.519E+03	
1	50120	0.2500	2.228E+03	
1	50120	0.5000	1.912E+03	
1	50120	0.7500	1.795E+03	
1	50120	1.0000	1.776E+03	
1	50120	1.5000	1.815E+03	
1	50120	2.0000	1.847E+03	10
1	50120	2.5000	1.876E+03	11
1	50120	3.0000	1.933E+03	11
1	50120	3.5000	2.025E+03	12
1	50120	4.0000	2.123E+03	12
1	50120	5.0000	2.214E+03	13
1	50120	6.0000	2.168E+03	14
1	50120	7.0000	2.093E+03	15
1	50120	8.0000	2.047E+03	15
1	50120	10.0000	2.035E+03	16
1	50120	12.0000	2.032E+03	17
1	50120	14.0000	2.010E+03	18
1	50120	16.0000	1.978E+03	19
1	50120	20.0000	1.940E+03	20
1	50120	22.0000	1.928E+03	21
1	50120	24.0000	1.905E+03	21
1	50120	26.0000	1.876E+03	22
1	50120	30.0000	1.822E+03	23
1	50120	35.0000	1.762E+03	23
1	50120	40.0000	1.702E+03	26
1	50120	45.0000	1.647E+03	27
1	50120	50.0000	1.597E+03	28
1001	49120	1.0000	8.168E-10	17
1001	49120	1.5000	3.419E-06	15
1001	49120	2.0000	4.907E-04	14
1001	49120	2.5000	1.380E-02	13
1001	49120	3.0000	1.543E-01	12
1001	49120	3.5000	9.598E-01	12
1001	49120	4.0000	3.379E+00	22
1001	49120	5.0000	2.940E+01	22

Fig.5 Continued

1001	49120	6.0000	9.987E+01	21
1001	49120	7.0000	2.112E+02	21
1001	49120	8.0000	3.488E+02	20
1001	49120	10.0000	6.483E+02	20
1001	49120	12.0000	9.043E+02	20
1001	49120	14.0000	1.073E+03	19
1001	49120	16.0000	1.86E+03	19
1001	49120	20.0000	1.347E+03	20
1001	49120	22.0000	1.400E+03	20
1001	49120	24.0000	1.439E+03	21
1001	49120	26.0000	1.471E+03	21
1001	49120	30.0000	1.520E+03	21
1001	49120	35.0000	1.543E+03	21
1001	49120	40.0000	1.545E+03	21
1001	49120	45.0000	1.532E+03	21
1001	49120	50.0000	1.511E+03	21
2004	48117	3.0000	3.215E-12	15
2004	48117	4.0000	5.108E-12	24
2004	48117	5.0000	1.412E-08	23
2004	48117	6.0000	3.02E-06	22
2004	48117	7.0000	1.027E-04	21
2004	48117	8.0000	3.55E-03	20
2004	48117	9.0000	7.97E-02	19
2004	48117	10.0000	7.683E-01	19
2004	48117	11.0000	5.250E+00	19
2004	48117	12.0000	2.547E+01	19
2004	48117	13.0000	8.588E+01	21
2004	48117	14.0000	1.989E+02	23
2004	48117	15.0000	3.417E+02	24
2004	48117	16.0000	4.866E+02	25
2004	48117	17.0000	6.213E+02	25
2004	48117	18.0000	6.425E+02	25
2004	48117	19.0000	6.502E+02	25
2004	48117	20.0000	9.476E+02	25
2004	48117	22.0000	1.112E+03	25
2004	48117	24.0000	1.246E+03	25
2004	48117	26.0000	1.356E+03	25
2004	48117	30.0000	1.526E+03	25
2004	48117	35.0000	1.676E+03	25
2004	48117	40.0000	1.782E+03	25
2004	48117	45.0000	1.860E+03	25
2004	48117	50.0000	1.918E+03	25
1002	49119	1.5000	7.922E-08	17
1002	49119	3.0000	5.292E-05	16
1002	49119	3.5000	5.582E-03	15
1002	49119	5.0000	7.092E-01	14
1002	49119	4.0000	3.918E+00	14
1002	49119	4.5000	1.496E+01	14
1002	49119	5.0000	4.384E+01	14
1002	49119	5.5000	1.015E+02	14
1002	49119	6.0000	1.933E+02	15
1002	49119	7.0000	4.526E+02	17
1002	49119	8.0000	7.372E+02	22
1002	49119	9.0000	9.907E+02	22
1002	49119	10.0000	1.203E+03	22
1002	49119	11.0000	1.378E+03	22
1002	49119	12.0000	1.524E+03	22
1002	49119	14.0000	1.749E+03	24
1002	49119	16.0000	1.907E+03	26
1002	49119	18.0000	2.023E+03	26
1002	49119	20.0000	2.114E+03	28
1002	49119	22.0000	2.184E+03	29
1002	49119	24.0000	2.236E+03	29
1002	49119	26.0000	2.277E+03	31
1002	49119	30.0000	2.338E+03	32
1002	49119	35.0000	3.838E+03	35
1002	49119	40.0000	4.094E+03	37
1002	49119	45.0000	4.233E+03	39
1002	49119	50.0000	4.275E+03	39
1003	49118	1.0000	9.494E-13	20
1003	49118	1.5000	3.777E-09	20
1003	49118	2.0000	4.455E-06	19
1003	49118	2.5000	5.852E-04	19
1003	49118	3.0000	1.797E-02	17
1003	49118	3.5000	2.259E-01	16
1003	49118	4.0000	1.569E+00	15
1003	49118	4.5000	7.304E+00	15
1003	49118	5.0000	2.619E+01	16
1003	49118	5.5000	7.182E+01	15
1003	49118	6.0000	1.564E+02	17
1003	49118	7.0000	4.265E+02	20
1003	49118	8.0000	7.300E+02	21
1003	49118	9.0000	9.853E+02	22
1003	49118	10.0000	1.212E+03	24
1003	49118	11.0000	1.386E+03	24
1003	49118	12.0000	1.530E+03	24
1003	49118	14.0000	1.745E+03	28
1003	49118	16.0000	1.895E+03	28
1003	49118	18.0000	2.003E+03	31
1003	49118	20.0000	2.083E+03	30
1003	49118	22.0000	2.142E+03	33
1003	49118	24.0000	2.185E+03	34
1003	49118	26.0000	2.218E+03	36
1003	49118	30.0000	2.258E+03	37
1003	49118	35.0000	2.277E+03	39
1003	49118	40.0000	2.273E+03	39
1003	49118	45.0000	2.511E+03	39
1003	49118	50.0000	2.122E+03	39
2003	48118	3.0000	6.684E-11	23
2003	48118	4.0000	1.225E-07	21
2003	48118	5.0000	1.977E-04	21
2003	48118	6.0000	9.655E-03	20
2003	48118	7.0000	1.383E-01	19
2003	48118	8.0000	1.064E+00	18
2003	48118	9.0000	5.999E+00	19
2003	48118	10.0000	2.474E+01	18
2003	48118	11.0000	3.745E+01	22
2003	48118	12.0000	1.687E+02	23
2003	48118	13.0000	3.089E+02	24

Fig.5 Continued

2003	48118	14.	0000	4.	742E+02	23
2003	48118	15.	0000	6.	227E+02	26
2003	48118	16.	0000	9.	016E+02	28
2003	48118	17.	0000	1.	611E+02	28
2003	48118	18.	0000	1.	075E+03	28
2003	48118	19.	0000	1.	191E+03	30
2003	48118	20.	0000	1.	204E+03	31
2003	48118	21.	0000	1.	468E+03	32
2003	48118	22.	0000	1.	468E+03	32
2003	48118	23.	0000	1.	908E+03	32
2003	48118	24.	0000	1.	908E+03	32
2003	48118	25.	0000	1.	723E+03	32
2003	48118	30.	0000	1.	896E+03	32
2003	48118	35.	0000	2.	043E+03	32
2003	48118	40.	0000	2.	140E+03	32
2003	48118	45.	0000	2.	204E+03	32
2003	48118	50.	0000	2.	246E+03	32

+++ ENTER STAGC +++
 COMPOUND LEV. DENS. PARM. PAIRING ENERGY
 MEV (-1) MEV

50121.	16.5000	1.1900
50120.	16.5000	2.4300
49120.	21.0000	0.0000
48117.	22.8000	1.3600
49119.	20.0000	1.2400
49118.	19.0000	0.0000
48118.	23.0000	2.6000

```

+++ ENTER STAMT1 +++
50121. T = 0.715 MEV EMATCH = 6.361 MEV EO = -1.359 MEV NL = 0 NC = 0
50120. T = 0.735 MEV EMATCH = 8.014 MEV EO = -0.395 MEV NL = 0 NC = 0
49120. T = 0.581 MEV EMATCH = 4.468 MEV EO = -2.274 MEV NL = 0 NC = 0
48117. T = 0.592 MEV EMATCH = 6.729 MEV EO = -1.601 MEV NL = 0 NC = 0
49119. T = 0.593 MEV EMATCH = 5.572 MEV EO = -0.909 MEV NL = 0 NC = 0
49118. T = 0.632 MEV EMATCH = 4.798 MEV EO = -2.376 MEV NL = 0 NC = 0
48118. T = 0.590 MEV EMATCH = 7.993 MEV EO = -0.384 MEV NL = 0 NC = 0

```

+++ ENTER STAGAM +++
50121. DO = 0.000E+00 GG = 0.000E+00 STRENGTH = 4.396E-04
E1-GAMMA NORM. FAC. = 3.793E-05
POSE1 = 1.533E+01 MEV WIDE1 = 6.000E+00 MEV

REACTION CROSS SECTION = 1.9938E+03 MB

+++ ENTER STATIS +++

HAUSER-FESHBACH ENERGY SPECTRA
ECM = 15.00000 MEV

TOTAL(MB) 1.390E+00 1.991E+03 1.100E+00 1.389E-01 3.648E-04 4.284E-06 0.000E+00
TOTAL = 1.994E+03

CROSS SECTIONS FOR COMPOUND ELASTIC AND INELASTIC SCATTERINGS INTO DISCRETE STATES

N	STATE	ENERGY MEV	CROSS SECTION MB
0	0.0	0.00000	1.662E-05
1	2.0	1.17130	6.745E-05
2	0.0	1.87500	1.564E-05
3	2.0	2.09710	6.521E-05
4	0.0	2.15920	1.546E-05

Fig.5 Continued

5	2.0	2.17290	6.501E-05
6	-4.0	2.19450	8.858E-05
7	-5.0	2.28430	8.946E-05
8	0.0	2.29000	1.538E-05
9	4.0	2.32300	8.807E-05
10	2.0	2.35530	6.453E-05
11	-3.0	2.39970	7.902E-05
12	1.0	2.42130	4.239E-05
13	4.0	2.46590	8.749E-05
14	-7.0	2.48160	7.113E-05
CONTINUUM		1.991E+03	1.991E+03

THE LEGENDRE EXPANSION COEFFICIENTS FOR THE COMPOUND ELASTIC AND INELASTIC SCATTERINGS

0	0.00	0.00000
SIGMA	1.658E-05	1.662E-05 MB
1	2.00	1.17130
SIGMA	6.741E-05	6.748E-05 MB
2	0.00	1.87500
SIGMA	1.560E-05	1.564E-05 MB
3	2.00	2.09710
SIGMA	6.514E-05	6.521E-05 MB
4	0.00	2.15920
SIGMA	1.542E-05	1.546E-05 MB
5	2.00	2.17290
SIGMA	6.494E-05	6.501E-05 MB
6	4.00	2.19450
SIGMA	8.852E-05	8.858E-05 MB
7	-5.00	2.28430
SIGMA	8.941E-05	8.946E-05 MB
8	0.00	2.29000
SIGMA	1.534E-05	1.538E-05 MB
9	4.00	2.32300
SIGMA	8.801E-05	8.807E-05 MB
10	2.00	2.35530
SIGMA	6.446E-05	6.453E-05 MB
11	-3.00	2.39970
SIGMA	7.896E-05	7.902E-05 MB
12	1.00	2.42130
SIGMA	4.232E-05	4.239E-05 MB
13	4.00	2.46590
SIGMA	8.743E-05	8.749E-05 MB
14	-7.00	2.48160
SIGMA	7.109E-05	7.113E-05 MB

ANGLE DIFFERENTIAL CROSS SECTIONS FOR COMPOUND ELASTIC AND INELASTIC SCATTERINGS INTO DISCRETE STATES

ANGLE DEG	CROSS SECTION MB/SR							
	0	1	2	3	4	5	6	7
0.00	5.576E-06	9.169E-06	5.052E-06	8.736E-06	4.962E-06	8.699E-06	6.919E-06	6.088E-06
5.00	5.279E-06	9.198E-06	4.801E-06	8.762E-06	4.719E-06	8.724E-06	6.939E-06	6.103E-06
10.00	4.511E-06	9.236E-06	4.147E-06	8.795E-06	4.084E-06	8.757E-06	6.998E-06	6.148E-06
15.00	3.563E-06	9.169E-06	3.325E-06	7.734E-06	3.282E-06	8.697E-06	7.101E-06	6.221E-06
20.00	2.720E-06	8.890E-06	2.570E-06	8.486E-06	2.543E-06	8.451E-06	7.250E-06	6.325E-06
25.00	2.122E-06	8.371E-06	2.014E-06	8.019E-06	1.995E-06	7.988E-06	7.438E-06	6.466E-06
30.00	1.758E-06	7.677E-06	1.662E-06	7.387E-06	1.645E-06	7.362E-06	7.634E-06	6.648E-06
35.00	1.538E-06	7.920E-06	1.424E-06	6.695E-06	1.432E-06	6.675E-06	7.790E-06	6.865E-06
40.00	1.386E-06	7.241E-06	1.304E-06	6.047E-06	1.290E-06	6.030E-06	7.850E-06	7.094E-06
45.00	1.265E-06	5.675E-06	1.194E-06	5.504E-06	1.181E-06	5.489E-06	7.788E-06	7.300E-06
50.00	1.168E-06	5.237E-06	1.103E-06	5.079E-06	1.092E-06	5.066E-06	7.613E-06	7.445E-06
55.00	1.092E-06	4.903E-06	1.030E-06	4.755E-06	1.020E-06	4.742E-06	7.368E-06	7.506E-06
60.00	1.030E-06	4.646E-06	9.718E-07	4.505E-06	9.616E-07	4.495E-06	7.107E-06	7.454E-06
65.00	9.811E-07	4.446E-06	9.258E-07	4.313E-06	9.161E-07	4.301E-06	6.868E-06	7.109E-06
70.00	9.451E-07	4.295E-06	8.918E-07	4.166E-06	8.825E-07	4.155E-06	6.670E-06	7.297E-06
75.00	9.209E-07	4.184E-06	8.686E-07	4.059E-06	8.594E-07	4.048E-06	6.518E-06	7.197E-06
80.00	9.052E-07	4.108E-06	8.535E-07	3.985E-06	8.444E-07	3.975E-06	6.409E-06	7.122E-06
85.00	8.956E-07	4.062E-06	8.446E-07	3.942E-06	8.356E-07	3.931E-06	6.344E-06	7.078E-06
90.00	8.921E-07	4.047E-06	8.415E-07	3.927E-06	8.326E-07	3.917E-06	6.323E-06	7.063E-06
95.00	8.956E-07	4.062E-06	8.446E-07	3.942E-06	8.356E-07	3.931E-06	6.344E-06	7.078E-06
100.00	9.052E-07	4.106E-06	8.535E-07	4.085E-06	8.444E-07	4.049E-06	6.518E-06	7.122E-06
105.00	9.209E-07	4.184E-06	8.686E-07	4.059E-06	8.594E-07	4.048E-06	6.670E-06	7.197E-06
110.00	9.451E-07	4.295E-06	8.918E-07	4.166E-06	8.925E-07	4.155E-06	6.868E-06	7.297E-06
115.00	9.811E-07	4.446E-06	9.258E-07	4.313E-06	9.161E-07	4.301E-06	7.368E-06	7.454E-06
120.00	1.030E-06	4.646E-06	9.718E-07	4.505E-06	9.616E-07	4.493E-06	7.107E-06	7.506E-06
125.00	1.092E-06	4.903E-06	1.030E-06	4.755E-06	1.020E-06	4.742E-06	7.368E-06	7.445E-06
130.00	1.168E-06	5.237E-06	1.103E-06	5.079E-06	1.092E-06	5.066E-06	7.613E-06	7.445E-06
135.00	1.265E-06	5.755E-06	1.194E-06	5.504E-06	1.181E-06	5.489E-06	7.788E-06	7.300E-06
140.00	1.386E-06	6.241E-06	1.304E-06	6.047E-06	1.290E-06	6.030E-06	7.850E-06	7.094E-06
145.00	1.538E-06	6.929E-06	1.448E-06	6.695E-06	1.432E-06	6.675E-06	7.790E-06	6.865E-06
150.00	1.758E-06	6.777E-06	1.662E-06	7.387E-06	1.645E-06	7.362E-06	7.634E-06	6.648E-06
155.00	2.122E-06	6.371E-06	2.014E-06	8.019E-06	1.995E-06	7.988E-06	7.438E-06	6.466E-06
160.00	2.120E-06	6.890E-06	2.570E-06	8.486E-06	2.543E-06	8.451E-06	7.250E-06	6.325E-06
165.00	3.563E-06	9.169E-06	3.325E-06	7.347E-06	2.822E-06	8.697E-06	7.101E-06	6.221E-06
170.00	4.511E-06	9.236E-06	4.147E-06	7.795E-06	4.084E-06	7.757E-06	6.998E-06	6.148E-06
175.00	5.279E-06	9.198E-06	4.801E-06	8.762E-06	4.719E-06	8.724E-06	6.899E-06	6.103E-06
180.00	5.576E-06	9.169E-06	5.052E-06	8.736E-06	4.962E-06	8.699E-06	6.919E-06	6.088E-06

Fig.5 Continued

	8	9	10	11	12	13	14
0.00	4.920E-06	6.872E-06	8.609E-06	7.709E-06	9.084E-06	6.818E-06	4.465E-06
5.00	4.680E-06	6.891E-06	8.633E-06	7.732E-06	8.888E-06	6.837E-06	4.475E-06
10.00	4.054E-06	6.950E-06	8.665E-06	7.801E-06	8.333E-06	6.895E-06	4.502E-06
15.00	3.262E-06	7.052E-06	8.606E-06	7.913E-06	7.508E-06	6.996E-06	4.542E-06
20.00	2.531E-06	7.199E-06	8.366E-06	8.034E-06	6.551E-06	7.141E-06	4.591E-06
25.00	1.986E-06	7.384E-06	7.914E-06	8.101E-06	5.608E-06	7.323E-06	4.651E-06
30.00	1.637E-06	7.578E-06	7.300E-06	8.047E-06	4.791E-06	7.516E-06	4.730E-06
35.00	1.425E-06	7.733E-06	6.625E-06	7.834E-06	4.155E-06	7.669E-06	4.831E-06
40.00	1.283E-06	7.795E-06	5.988E-06	7.480E-06	3.690E-06	7.733E-06	4.959E-06
45.00	1.175E-06	7.736E-06	5.453E-06	7.046E-06	3.355E-06	7.679E-06	1.16E-06
50.00	1.087E-06	7.566E-06	5.032E-06	6.606E-06	3.104E-06	7.514E-06	3.02E-06
55.00	9.015E-06	7.327E-06	4.710E-06	6.215E-06	2.910E-06	7.281E-06	5.14E-06
60.00	9.568E-07	7.070E-06	4.463E-06	5.894E-06	2.758E-06	7.028E-06	7.43E-06
65.00	9.115E-07	6.834E-06	4.273E-06	5.642E-06	2.638E-06	6.795E-06	5.970E-06
70.00	8.780E-07	6.638E-06	4.128E-06	5.449E-06	2.545E-06	6.601E-06	6.175E-06
75.00	8.550E-07	6.486E-06	4.022E-06	5.307E-06	2.474E-06	6.451E-06	6.339E-06
80.00	8.401E-07	6.379E-06	3.949E-06	5.210E-06	2.425E-06	6.344E-06	6.452E-06
85.00	8.314E-07	6.314E-06	3.905E-06	5.154E-06	2.397E-06	6.280E-06	6.516E-06
90.00	8.284E-07	6.293E-06	3.891E-06	5.136E-06	2.387E-06	6.259E-06	6.536E-06
95.00	8.314E-07	6.314E-06	3.905E-06	5.154E-06	2.397E-06	6.280E-06	6.516E-06
100.00	8.401E-07	6.379E-06	3.949E-06	5.210E-06	2.425E-06	6.344E-06	6.452E-06
105.00	8.550E-07	6.486E-06	4.022E-06	5.307E-06	2.474E-06	6.451E-06	6.339E-06
110.00	8.780E-07	6.638E-06	4.128E-06	5.449E-06	2.545E-06	6.601E-06	6.175E-06
115.00	9.115E-07	6.834E-06	4.273E-06	5.642E-06	2.638E-06	6.795E-06	5.970E-06
120.00	9.568E-07	7.070E-06	4.463E-06	5.894E-06	2.758E-06	7.028E-06	7.43E-06
125.00	1.015E-06	7.327E-06	4.710E-06	6.215E-06	2.910E-06	7.281E-06	5.14E-06
130.00	1.087E-06	7.566E-06	5.032E-06	6.606E-06	3.104E-06	7.514E-06	3.02E-06
135.00	1.175E-06	7.736E-06	5.453E-06	7.046E-06	3.355E-06	7.679E-06	1.16E-06
140.00	1.283E-06	7.795E-06	5.988E-06	7.480E-06	3.690E-06	7.733E-06	4.959E-06
145.00	1.425E-06	7.733E-06	6.625E-06	7.834E-06	4.155E-06	7.669E-06	4.831E-06
150.00	1.637E-06	7.578E-06	7.300E-06	8.047E-06	4.791E-06	7.516E-06	4.730E-06
155.00	1.986E-06	7.384E-06	7.914E-06	8.101E-06	5.608E-06	7.323E-06	4.651E-06
160.00	2.531E-06	7.199E-06	8.366E-06	8.034E-06	6.551E-06	7.141E-06	4.591E-06
165.00	3.262E-06	7.052E-06	8.606E-06	7.913E-06	5.088E-06	6.996E-06	4.542E-06
170.00	4.064E-06	6.950E-06	8.665E-06	7.806E-06	6.333E-06	6.889E-06	4.502E-06
175.00	4.680E-06	6.891E-06	8.633E-06	7.732E-06	6.888E-06	6.837E-06	4.475E-06
180.00	4.920E-06	6.872E-06	8.609E-06	7.709E-06	9.084E-06	6.818E-06	4.465E-06

Fig.5 Continued

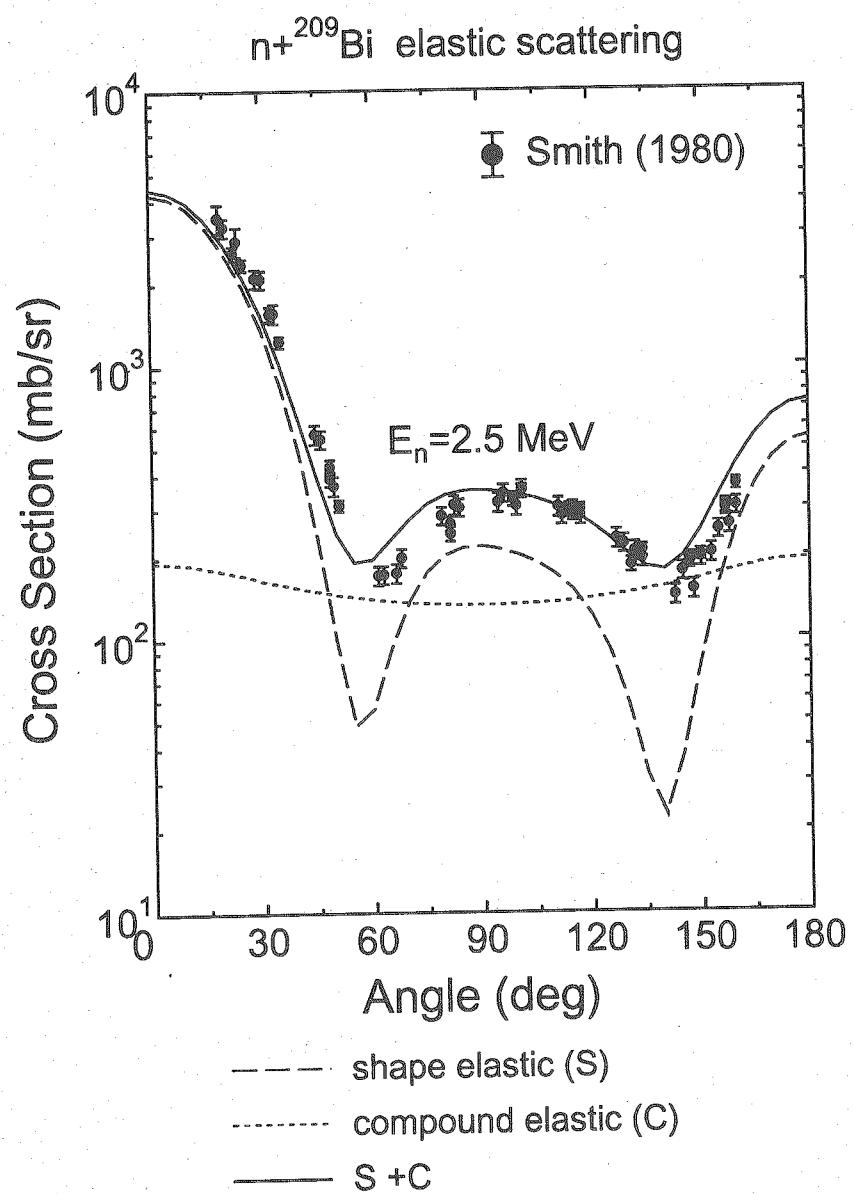


Fig.6 The calculated angular distribution of elastic-scattering cross sections for ${}^{209}\text{Bi}(n,n)$ at 2.5 MeV together with experimental data[22].

6 Summary

A computer code was developed to calculate cross sections for the neutron-induced nuclear reactions with the statistical model. With the code, energy spectra (energy-differential cross sections) can be calculated for the reactions (n, γ) , (n, n') , (n, p) , (n, α) , (n, d) , (n, t) and $(n, {}^3\text{He})$. Angular distributions (angle-differential cross sections) can also be calculated for the neutron compound elastic- and inelastic-scattering over the low-lying discrete states.

The model calculation is performed with following quantities:

- Transmission coefficients of incident neutrons and ejected particles
- Discrete level data for target, compound, and residual nuclei
- Level densities for the target, compound, and residual nuclei
- The γ -ray strength functions for the compound nucleus

The transmission coefficients are obtained with the optical model. In order to obtain transmission coefficients for neutrons and protons, the local/global OMPs of Koning and Delaroche[3] were built in the code. For deuteron, triton, ${}^4\text{He}(\alpha)$, and ${}^3\text{He}$, the OMPs of Lohr and Haeberli, Lemos, and Becchetti and Greenlees were built in. These OMP parameters were taken from Refs. [18] and [19].

The discrete level data are read from the input data as the same manner with the GNASH code[6]. The excited states above the highest discrete level are described with the level density formula. In this code, the level density of the constant temperature form is used in lower excitation energy region, while the Fermi-gas form is utilized over higher energy region[6]. To determine the level densities of the Fermi-gas form, the level density parameters of Gilbert and Cameron[10] were built in. The level density parameters of Mengoni and Nakajima[4] in which the nuclear shell effects are considered in the Fermi-gas form were also built in.

The γ -ray strength function is evaluated on the basis of the detailed balance for the inverse photoabsorption process and the Brink-Axel hypothesis[6], where the cross section for photoabsorption by an excited state is equated with that of the ground state. The standard Lorentzian form can be used for the γ -ray multipolarities E1 and M1.

In calculating transmission coefficients, the maximum of orbital angular momentum quantum number considered is set equal to 40. Thus the code may be applicable to neutron energies up to about 30 MeV.

It should be noted that this code can be extended to calculate multiple particle emission. The extension of code to include the reactions $(n, 2n)$, $(n, 3n)$, (n, np) , (n, nd) and (n, na) is in progress.

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国際単位系 (SI)

表 1. SI 基本単位

基本量	SI 基本単位	
	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd

表 2. 基本単位を用いて表されるSI組立単位の例

組立量	SI 基本単位	
	名称	記号
面積	平方メートル	m ²
体積	立方メートル	m ³
速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	m/s ²
波数	メートル	m ⁻¹
密度(質量密度)	キログラム毎立法メートル	kg/m ³
質量体積(比体積)	立法メートル毎キログラム	m ³ /kg
電流密度	アンペア毎平方メートル	A/m ²
(物質量の)濃度	モル毎立方メートル	mol/m ³
輝度	カンデラ毎平方メートル	cd/m ²
屈折率	(数の)1	1

表 5. SI 接頭語

乗数	接頭語	記号	乗数	接頭語	記号
10 ²⁴	ヨーダ	Y	10 ⁻¹	デシ	d
10 ²¹	ゼタ	Z	10 ⁻²	センチ	c
10 ¹⁸	エク	E	10 ⁻³	ミリ	m
10 ¹⁵	ペクタ	P	10 ⁻⁶	マイクロ	μ
10 ¹²	テラ	T	10 ⁻⁹	ナノ	n
10 ⁹	ギガ	G	10 ⁻¹²	ピコ	p
10 ⁶	メガ	M	10 ⁻¹⁵	フェムト	f
10 ³	キロ	k	10 ⁻¹⁸	アatto	a
10 ²	ヘク	h	10 ⁻²¹	ゼット	z
10 ¹	デカ	da	10 ⁻²⁴	ヨクト	y

表 3. 固有の名称とその独自の記号で表されるSI組立単位

組立量	SI 組立単位		
	名称	記号	他のSI単位による表し方
平面角	ラジアン ^(a)	rad	$m \cdot m^{-1}=1^{(b)}$
立体角	ステラジアン ^(a)	sr ^(c)	$m^2 \cdot m^{-2}=1^{(b)}$
周波数	ヘルツ	Hz	s ⁻¹
压力	ニュートン	N	$m \cdot kg \cdot s^{-2}$
エネルギー、仕事、熱量	ジユール	J	$m^2 \cdot kg \cdot s^{-2}$
工率、放熱	ワット	W	$m^2 \cdot kg \cdot s^{-3}$
電荷、電気量	クーロン	C	$m^2 \cdot A \cdot s$
電位差(電圧)、起電力	ボルト	V	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
静電容量	ファラード	F	$m^2 \cdot kg^{-1} \cdot s^4 \cdot A^2$
電気抵抗	オーム	Ω	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
コンダクタンス	シemenス	S	$m^2 \cdot kg^{-1} \cdot s^3 \cdot A^2$
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリ	H	Wb/A
セルシウス温度	セルシウス度 ^(d)	°C	K
照度	ルーメン	lm	$cd \cdot sr^{(e)}$
(放射性核種の)放射能	ベクレル	Bq	lm/m^2
吸収線量、質量エネルギー	グレイ	Gy	J/kg
ギ一率、カーマ			$m^2 \cdot s^{-2}$
線量当量、周辺線量当量			
方向性線量当量、個	シーベルト	Sv	
人線量当量、組織線量当量			

表 6. 国際単位系と併用されるが国際単位系に属さない単位

名称	記号	SI 単位による値
分	min	1 min=60s
時	h	1h = 60 min=3600 s
日	d	1 d=24 h=86400 s
度	°	1° = $(\pi/180)$ rad
分	'	1' = $(1/60)^\circ$ = $(\pi/10800)$ rad
秒	"	1" = $(1/60)'$ = $(\pi/648000)$ rad
リットル	L	1L = 1 dm ³ =10 ⁻³ m ³
トン	t	1t=10 ³ kg
ネーパ	Np	1Np=1
ペル	B	1B=(1/2)ln10 (Np)

表 7. 国際単位系と併用されこれに属さない単位でSI単位で表される数値が実験的に得られるもの

名称	記号	SI 単位であらわされる数値
電子ボルト	eV	$1eV=1.60217733(49) \times 10^{-19} J$
統一原子質量単位	u	$1u=1.6605402(10) \times 10^{-27} kg$
天文単位	ua	$1ua=1.49597870691(30) \times 10^{11} m$

表 8. 国際単位系に属さないが国際単位系と併用されるその他の単位

名称	記号	SI 単位であらわされる数値
海里	里	1海里=1852m
ノット	ト	1ノット=1海里每時=(1852/3600)m/s
アール	a	$1a=1 dam^2=10^2 m^2$
ヘルツ	ha	$1ha=1 hm^2=10^4 m^2$
バル	bar	$1 bar=0.1 MPa=100kPa=1000hPa=10^5 Pa$
オングストローム	Å	$1 Å=0.1nm=10^{-10} m$
バーン	b	$1 b=100 fm^2=10^{-28} m^2$

表 9. 固有の名称を含むCGS組立単位

名称	記号	SI 単位であらわされる数値
エルグ	erg	$1 erg=10^{-7} J$
ダイナ	dyn	$1 dyn=10^{-5} N$
ボアズ	P	$1 P=1 dyn \cdot s/cm^2=0.1 Pa \cdot s$
ストークス	St	$1 St=1 cm^2/s=10^{-4} m^2/s$
ガウス	G	$1 G=10^{-4} T$
エルステッド	Oe	$1 Oe=(1000/4\pi) A/m$
マクスウェル	Mx	$1 Mx=10^{-8} Wb$
スチル	sb	$1 sb=1 cd/cm^2=10^4 cd/m^2$
ホガル	ph	$1 ph=10^4 lx$
	Gal	$1 Gal=1cm/s^2=10^{-2} m/s^2$

表 10. 国際単位に属さないその他の単位の例

名称	記号	SI 単位であらわされる数値
ギュントゲン	Ci	$1 Ci=3.7 \times 10^{10} Bq$
ラド	R	$1 R=2.58 \times 10^{-2} C/kg$
レム	rad	$1 rad=1cGy=10^{-2} Gy$
X線単位	rem	$1 rem=1 cSv=10^{-2} Sv$
ガンマ	γ	$1 \gamma=1 nT=10^{-9} T$
ジヤンスキー	Jy	$1 Jy=10^{-26} W \cdot m^{-2} \cdot Hz^{-1}$
フェルミ	fermi	$1 fermi=1 fm=10^{-15} m$
メートル系カラット	Torr	$1 metric carat=200 mg=2 \times 10^{-4} kg$
ト標準大気圧	atm	$1 Torr=(101325/760) Pa$
カリ	cal	$1 atm=101325 Pa$
ミクロ	μ	$1 μ=1 um=10^{-6} m$