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The STEEP4 Code for Computation of Specific Thermonuclear Reaction Rates from Pointwise Cross Sections

by

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THE STEEP4 CODE FOR COMPUTATION
OF SPECIFIC THERMONUCLEAR REACTION RATES
FROM POINTWISE CROSS SECTIONS

by

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ABSTRACT

A code module, STEEP4, is developed to calculate the fusion reaction rates in terms of the specific reactivity $\langle\sigma v\rangle$ which is the product of cross section and relative velocity averaged over the actual ion distributions of the interacting particles in the plasma. The module is structured in a way suitable for incorporation in thermonuclear burn codes to provide rapid and yet relatively accurate on-line computation of $\langle\sigma v\rangle$ as a function of plasma parameters. Ion distributions are modified to include slowing-down contributions which are characterized in terms of plasma parameters. Rapid and accurate algorithms are used for integrating $\langle\sigma v\rangle$ from cross sections and spectra. The main program solves for $\langle\sigma v\rangle$ by the method of steepest descent. However, options are provided to use Gauss-Hermite and dense trapezoidal quadrature integration techniques. Options are also provided for rapid calculation of screening effects on specific reaction rates. Although such effects are not significant in cases of plasmas of laboratory interest, the options are included to increase the range of applicability of the code. Gamow penetration form, log-log interpolation, and cubic interpolation routines are included to provide the interpolated values of cross sections.

Losses of plasma particles during slowing-down are neglected. Spatial and angular dependences of ion distributions are not treated in this version of the code. A basic assumption, considered in calculating the ion distribution, is that the slowing-down time is less than the confinement time of the projectile particles. However, incorporating effects such as losses in the computation is straightforward. The code has a great degree of flexibility which is provided by the various subroutines included. It can be used for reaction rate calculations in the study of a variety of fusion phenomena regardless of the plasma confinement scheme.

I. INTRODUCTION

The thermonuclear reaction is a central feature of astrophysics and of fusion device development. Fusion of light nuclei at the expense of mass provides the energy source for a wide range of physical phenomena. Most of these phenomena involve charged-particle reactions in plasmas, whether these be magnetically, inertially, or gravitationally confined. Hence, codes modeling a variety of fusion phenomena require modules for computation of thermonuclear reaction rates under specific plasma conditions.

Calculation of thermonuclear reaction rates requires not only knowledge of reaction cross sections, but also requires characterization of ion velocity distributions and of charge-screening effects in the plasma. Monte Carlo,¹ Fokker-Planck,² and other techniques³ can provide detailed predictions of ion velocity distributions, but at costs in complexity and computer time that may be incompatible with other aspects of the modeling. Thus, a widespread and continuing technique has been to describe thermonuclear reaction rates in terms of the specific reaction rate, $\langle\sigma v\rangle$, averaged over assumed ion distributions in the plasma. The functional dependence of $\langle\sigma v\rangle$ on plasma parameters may be computed and stored; then, when the burn code requires $\langle\sigma v\rangle$, only a rapid retrieval is required. This technique is especially useful when the ion slowing-down time is small compared with the time the ion spends in Maxwellian equilibrium with other ions.⁴ In this case, the ion distributions can be assumed to be Maxwellian at a common temperature T_i and $\langle\sigma v\rangle$ is computed, stored, and retrieved as a function of T_i alone. Here the initial computation of $\langle\sigma v\rangle$ reduces to a careful integration over energy of the product of the steeply rising fusion cross section and of the steeply falling Maxwellian distribution.

Non-Maxwellian contributions to the specific reaction rate are substantial in a number of applications. For these cases, a computation of specific reaction rate that included ion slowing-down contributions, yet was rapid compared with Monte Carlo, Fokker-Planck, and similar techniques, would be useful. Such a rapid, relatively accurate computation could be implemented as a code module suitable for incorporation into thermonuclear burn codes. The improved specific reaction rate module would contain:

- (a) An updated library of evaluated thermonuclear cross sections as functions of ion energies;
- (b) A characterization of ion spectra in terms of plasma parameters that can be provided by the burn code;
- (c) A rapid and accurate algorithm for integrating $\langle\sigma v\rangle$ from cross sections and spectra; and
- (d) A rapid calculation of screening effects on specific reaction rate.

In this report we examine alternative techniques for implementing requirements (a) through (d). The rapidity, accuracy, and storage requirements of alternative techniques are studied by developing and coding them into a test code STEEP4. Selected sections of STEEP4 then can be removed and combined to form the desired burn code module for improved on-line computation of $\langle\sigma v\rangle$. The desired balance of computational accuracy against rapidity and storage requirements must reflect the uncertainties and inaccuracies in the fusion cross sections and in modeling other aspects of the burn.

Alternative characterizations of ion spectra are examined in Section II-A. The stopping power for ions in a plasma decreases sharply with increasing electron temperature until nuclear Coulomb interference and nuclear scattering actually can dominate the slowing-down process.^{1,5} In this case, there can be a substantial contribution to $\langle\sigma v\rangle$ from non-

Maxwellian ions. Non-Maxwellian ions can contribute relatively effectively also in certain two-component fusion devices.⁶ Slowing-down ion spectra are characterized in STEEP4 by functional forms derived from balance equations under various conditions.^{7,8}

The representation and storage of evaluated fusion cross sections are considered in Section II-B. Cross sections are represented in STEEP4 by cross-section and energy pairs in an ENDF/B format.⁹ Cross sections are obtained at other energies by ENDF/B interpolation and extrapolation formulae,¹⁰ except at low energies, where a Gamow interpolation and extrapolation formula is more appropriate. In addition, at higher energies, a cubic formula is examined. Functional representations of fusion cross sections that are simpler than R-matrix (or equivalent) representations^{11,12} are considered to be inadequate, and R-matrix calculations are too lengthy for determination of cross sections at arbitrary energies. Hence, R-matrix and other techniques are used to generate a grid of fusion cross sections,¹⁰ σ at particular energies, E , which are stored in the code as (E, σ) pairs in ENDF/B format. Values of the cross sections at arbitrary energies are then computed with suitable interpolation and extrapolation formulae.

Integration techniques should be accurate, even when cross sections are uncertain, so as to permit intelligible comparison of results from different workers. The integration techniques examined in Section II-C include the conventional steepest descent method¹⁴ and a 19-point Gauss-Hermite quadrature, neither generally satisfactory. A self-terminating dense trapezoidal integration and an adaptive trapezoidal integration both perform well in this application.

Charge screening in the plasma diminishes the ion-ion Coulomb barrier, thus augmenting reaction rates particularly at high plasma densities and low temperatures. These effects are considered in Sec. II-D. Options are available in STEEP4 to calculate and apply correction factors to $\langle\sigma v\rangle$ to account for screening effects. These factors may be calculated according to:

- (a) "weak" screening theory of Salpeter,¹⁵
- (b) "weak" and "strong" screening results of Salpeter and Van Horn¹⁶ with interpolation for "intermediate" screening, or
- (c) the generalized screening theory of DeWitt, Graboske et al.^{17,18}

Screening is of little importance in some applications, but the screening options in STEEP4 are useful even in this case in confirming the lack of importance.

Coding and tests of STEEP4 are described in Sections II-E and II-F, respectively. For user convenience, an input check list for the present version of the STEEP4 code is provided in Section III. Input and output are outlined in Sections III and IV, respectively. Results are summarized in Section V along with comments regarding the selection of various STEEP4 options. The main program variables are defined in Appendix A, and a listing of the source deck is given. Input and output for a five case sample problem are given in Appendixes B and C, respectively. Appendix D contains a code abstract.

II. CALCULATIONS

The rate of change of the number of ions of type i in a unit volume of a plasma can be expressed as

$$\frac{\partial N_i}{\partial t} = - \sum_{j=1}^j \frac{N_i (N_j - \delta_{ij})}{1 + \delta_{ij}} \langle \sigma v \rangle_{ij} + S_i - L_i. \quad (1)$$

Here, N_j represents the number of ions of type j ($j = 1, 2, \dots, j$) in a cubic centimeter of plasma, while δ_{ij} is the usual Kronecker delta, S_i represents an external source of type i ions per unit volume and time, and L_i represents the net leakage of the i ions per unit volume and time. The specific reaction rate (sometimes referred to as the reactivity or the reaction rate per particle pair i and j) is given by

$$\langle \sigma v \rangle_{ij} = \frac{1}{N_i N_j} \int d\mathbf{v}_i^L \int d\mathbf{v}_j^L n_i(\mathbf{v}_i^L) n_j(\mathbf{v}_j^L) \sigma_{ij}(\mathbf{v}_i^L, \mathbf{v}_j^L) |\mathbf{v}_i^L - \mathbf{v}_j^L|, \quad (2)$$

where $n_j(\mathbf{v}_j^L) d\mathbf{v}_j^L$ represents the average number of ions of type j per unit volume in the laboratory system velocity interval $d\mathbf{v}_j^L$ at $\mathbf{v}_j^L$, N_i is the total number of nuclei per unit volume, and $\sigma_{ij}(\mathbf{v}_i^L, \mathbf{v}_j^L)$ is the reaction cross section.

We ignore relativistic effects here and express the integrations in Eq. (2) in terms of the relative velocity,

$$\mathbf{v}_r = \mathbf{v}_i^L - \mathbf{v}_j^L, \quad (3)$$

and the center-of-mass velocity in the laboratory system,

$$\mathbf{v}_{CM}^L = \frac{m_i \mathbf{v}_i^L + m_j \mathbf{v}_j^L}{m_i + m_j}. \quad (4)$$

The Jacobian of the transformation is unity so that $dv_r dv_{CM}^L$ equals $dv_i^L dv_j^L$.

Since the cross section is a function, $\sigma(v_r)$, of only the magnitude of the relative velocity, the specific reaction rate integral for the reactants $i + j$ becomes

$$\langle \sigma v \rangle = \frac{1}{N_i N_j} \int dv_{CM}^L \int dv_r n_i \left(v_{CM}^L + \frac{m_j}{m_i + m_j} v_r \right) n_j \left(v_{CM}^L - \frac{m_i}{m_i + m_j} v_r \right) \sigma(v_r) v_r. \quad (5)$$

Here and later, the particle labels i and j are dropped wherever possible. Equations (2) and (5) are alternative basic expressions for representing the specific reaction rate. The sixfold integrals in these expressions can be simplified through physical assumptions which are examined next.

A. Ion Distributions

1. Maxwellian Ion Distributions

Suppose first that the ion distributions are Maxwellian at temperature T , i.e.,

$$n_j \left(\frac{v_j^L}{v_j} \right) = N_j \left(\frac{m_j}{2\pi kT} \right)^{3/2} e^{-\frac{m_j v_j^L^2}{2kT}}, \quad (6)$$

where k is Boltzmann's constant. Under plasma conditions for which a Maxwellian distribution is appropriate at all, it is a good approximation to assume a common temperature for all types.¹⁹ Then the specific reaction rate can be rearranged as

$$\langle \sigma v \rangle = \left[\int dv_{CM}^L \left(\frac{m_i + m_j}{2\pi kT} \right)^{3/2} e^{-\frac{(m_i + m_j) v_{CM}^L^2}{2kT}} \right] \int dv_r \left(\frac{m_r}{2\pi kT} \right)^{3/2} e^{-\frac{m_r v_r^2}{2kT}} \sigma(v_r) v_r, \quad (7)$$

where the reduced mass is represented by m_r ,

$$m_r = \frac{m_i m_j}{m_i + m_j} \quad (8)$$

The integral in brackets is unity and the result is simply

$$\langle \sigma v \rangle = \int d\mathbf{v}_r \left(\frac{m_r}{2\pi kT} \right)^{3/2} e^{-\frac{m_r \mathbf{v}_r^2}{2kT}} \sigma(v_r) v_r \quad (9)$$

The distribution here is again a Maxwellian at temperature T using the reduced mass, m_r .

We shall represent cross sections as functions of the relative energy, E_r ,

$$E_r = m_r v_r^2 / 2, \quad (10)$$

so that it is useful to express Eq. (9) in terms of E_r . In terms of the relative energy, Eq. (9) becomes the single integral,

$$\langle \sigma v \rangle = \int_0^\infty dE_r M_T(E_r) \sigma(E_r) v_r(E_r), \quad (11)$$

where the Maxwellian distribution in energy is

$$M_T(E) = \frac{2}{\pi^{1/2}} \frac{E^{1/2}}{(kT)^{3/2}} e^{-E/kT}, \quad (12)$$

and the relative speed as a function of E_r is

$$v_r(E_r) = \sqrt{2E_r/m_r}. \quad (13)$$

The Maxwellian relation, Eq. (11), is widely used for computation of

specific reaction rate in thermonuclear systems. Its execution presents two sorts of numerical problems, both stemming from the fact that charged-particle cross sections vary extremely rapidly at energies for which Coulomb barrier penetration is dominant. In the first place, cross sections may be supplied as energy-cross section pairs, and interpolation of cross sections between pairs is made difficult by the rapid variation of cross section with energy. Suitable interpolation techniques are discussed in Section B. In the second place, the integrand in Eq. (11) is the product of a rapidly decreasing function, $M_T(E_r)$, times a rapidly increasing function, $\sigma(E_r)$, so that the integrand may be substantial only over a small energy range. Useful integration techniques, discussed in Section C, must reflect this variation.

2. Slowing-In Ion Distributions

The charged ions produced by thermonuclear reactions and by injection into two-component plasmas generally appear at energies substantially higher than Maxwellian energies. Collisions with other plasma particles then slow the ions until those which survive the slowing-in process become thermalized. In ordinary matter the slowing-in component of the particle flux is very small, but in plasmas the slowing-in component can be much larger and can contribute substantially to the specific reaction rate. As we noted in the introduction, one can calculate the ion spectra by Monte Carlo or Fokker-Planck methods, then compute reaction rates from the ion spectra thus determined.^{20,21} However, in many applications the slowing-in contribution often is not large, so that an approximate correction for slowing-in may be useful. Here we use an expression derived by Hussein, Sabri, and Harris.⁷ Such an approximate correction

is used when the slowing-in option ($KTEMP \neq \pm 1$) of STEEP4 is selected.

The number of ions of type i in a unit volume of the plasma with laboratory system kinetic energies between E and $E + dE$ is represented by $n_i(E)dE$. The ion number density will be assumed to be independent of position, direction, and time, and to result from a uniform isotropic source, $S_i(E_{oi})$, of ions injected at energy E_o into the homogeneous plasma. At ion energies for which slowing processes dominate, the number of ions of type i with energies in the interval E to dE then is

$$n_i(E)dE = \frac{S_i(E_{oi})}{v_i(E)k_i(E)} dE \quad , \quad (14)$$

where $k_i(E)$ is the stopping power and represents the total rate of change of ion energy with track length x ,

$$k_i(E) = - \left(\frac{dE}{dx} \right)_i \quad , \quad (15)$$

including the effects of ion-electron Coulomb interactions, ion-ion Coulomb and strong elastic interactions, and other (usually negligible) processes. Energy straggling will be ignored.

Equation (14) ignores particle losses from the slowing-down component of the ion distribution both from nuclear reactions and from leakage from the system. In principle these effects could be incorporated into Eq. (14). In that case the slowing-down ion density distribution could typically be obtained by rederiving (the modified) Eq. (14) in successive energy increments downward from the source energy. However, the assumption of negligible particle losses during slowing-down is consistent with the assumption that the slowing-down processes dominate

and is, therefore, employed in STEEP4. Other slowing-down distributions are developed in Refs. 7 and 8 for various situations.

The ion source may be external, as in the case of injection heating, or internal, as when type i ions are produced from nuclear reactions in the plasma. In the latter case the source strength may be estimated from data from a previous calculation using

$$S_i = \sum_{k=1}^K \sum_{j=k}^j \frac{N_k N_j}{1 + \delta_{jk}} \langle \sigma v \rangle_{jk(i)} \quad , \quad (16)$$

where $\langle \sigma v \rangle_{jk(i)}$ represents the specific reaction rate for the interactions of ions of type j and k which results in the production of an ion of type i . In any case the total source strength and source energy of ions of type i are presumed known.

The slowing-in distribution joins smoothly to the Maxwellian, and thus the total ion distribution is of the form

$$n_i(E) \approx N_i^0 M_T(E) + f_s(E) \frac{S_i}{v_i(E) k_i(E)} \quad , \quad (17)$$

where $f_s(E)$ is a smoothing function varying from 0 to 1 over the joining interval. The basic result, Eq. (17), is applied in STEEP4 only with further approximations which are described next.

In a number of applications the electron temperature remains sufficiently low in the plasma that slowing of energetic ions is accomplished largely through ion-electron interactions. In this case,¹⁹

$$k_i(E) = 4\pi^{1/2} Z_i^2 e^4 N_e \ln \left(\frac{2}{\theta} \right) \sqrt{\frac{m_e}{m_i}} \frac{\left(\frac{E}{2} kT_e \right)^{-1}}{(EkT_e)^{1/2}} \quad , \quad (18)$$

where $Z_i e$ is the charge on the ion, N_e is the electron number density,

m_e is the electron mass, m_i is the ion mass, kT_e is the electron temperature in energy units, and θ_m is a minimum scattering angle. When the ion energy E is large compared with the plasma temperature, while the electron thermal velocity is larger than the ion velocity, the stopping power is proportional to $E^{1/2}$, according to Eq. (18). The ion speed also is proportional to $E^{1/2}$, so that Eq. (17) can be approximated by

$$n_i(E) \approx N_i' M_T(E) + f_s(E) C/E, \quad (19)$$

$$\text{where } C \approx \text{constant} = \frac{3(kT_e)^{3/2} m_i S_i}{8 \sqrt{2\pi} z_i^2 e^4 \ln\left(\frac{2}{\theta_m}\right) \sqrt{m_e} N_e}$$

This expression can be compared, at least qualitatively, with Culham calculations²⁰ of energy distribution functions for particles in an electron, deuteron, alpha-particle plasma. The electrons (although at a much lower temperature than the deuterons) and deuterons showed an essentially Maxwellian spectrum, but the alphas (assumed to be produced in the plasma at ~ 3.5 MeV) showed a $1/E$ -like slowing-in distribution joining smoothly to a Maxwellian whose temperature was similar to that of the deuteron distribution.

It is convenient to express the ion distribution in normalized form:

$$n_i(E) = \begin{cases} N_i(1 - a_i) M_T(E), & 0 \leq E < \check{E}_i \text{ and } E > \hat{E}_i \\ N_i \left[(1 - a_i) M_T(E) + a_i \frac{1}{E \ln(\hat{E}_i/\check{E}_i)} \right], & \check{E}_i \leq E \leq \hat{E}_i. \end{cases} \quad (20)$$

This expression is properly normalized since

$$\int_0^\infty n_i(E) dE = N_i \left\{ (1 - a_i) \int_0^\infty M_T(E) dE + a_i \int_{\check{E}_i}^{\hat{E}_i} \frac{dE}{E \ln(\hat{E}_i/\check{E}_i)} \right\} = N_i$$

A more elaborate choice of the smoothing function $f_s(E)$ appearing in Eq. (17) would seem to be unjustified in view of the overall approximate slowing-down treatment employed.

A reasonable choice for the upper limit, $\hat{E}_i$, of the interval for the slowing-in component is the source energy of the "injected" ions, E_0 . This is equivalent to assuming that the asymptotic solution to the slowing-in distribution [Eq. (15)] is valid up to energy E_0 . The lower limit, $\check{E}_i$, has been taken, somewhat arbitrarily, as $2kT_i$ where T_i is the temperature of the background plasma ions. This selection is fairly conventional for the lower limit of the slowing-in regime^{6,22} and provides some consistency with our previous assumption that $E_i \gg \frac{3}{2} kT_e$. Moreover, as will be shown later, our final results are somewhat insensitive to this choice.

To estimate the value of a_i , Eqs. (19) and (20) are compared for energies near the source energy

$$n_i(E) \approx \frac{C}{E} \approx \frac{a_i N_i}{E \ln(\hat{E}_i/\check{E}_i)} \quad (21)$$

Equating these results,

$$a_i = \frac{C \ln(\hat{E}_i/\check{E}_i)}{N_i} = \frac{3(kT_e)^{3/2} m_i S_i \ln(\hat{E}_i/\check{E}_i)}{8 \sqrt{2\pi} Z_i^2 e^4 \ln\left(\frac{2}{\theta_m}\right) \sqrt{m_e} N_e N_i} \quad (22)$$

In certain situations (e.g., two component fusion devices) the slowing-in component dominates the total ion distribution. Such cases are characterized by source strength and/or slowing-down times inconsistent with our implicit assumptions that leakage effects are negligible and that the slowing-in component is small compared with the Maxwellian

component for the ion density. Such cases will also result in a value of a_i greater than unity as calculated by Eq. (22). This may be seen as follows. From Eqs. (14) and (15) we have

$$n_i(E) = \frac{-S_i}{dE/dt} = \frac{C}{E}. \quad (23)$$

Solving this equation for the energy of the ions as a function of time, t , after injection results in

$$E(t) = E_o \exp\left(-\frac{S_i}{C}t\right), \quad (24)$$

so that the slowing-down time to energy E_m is given by

$$\Delta t_{SD} = \frac{\ln(E_o/E_m)C}{S_i}. \quad (25)$$

Comparing Eq. (25) with Eq. (21) shows that, if the total ion density, N_i , or the lower limit selected for the slowing-in distribution, $\check{E}_i$, are inconsistent with the source strength, S_i , then a_i will be larger than unity. When such cases are encountered in STEEP4 it is assumed that the slowing-in component is the total distribution, a_i is set equal to unity, and $\check{E}_i$ is readjusted to be consistent with the input value of N_i and Eq. (22).

Finally, it is noted that Eq. (22) also requires a knowledge of the electron temperature, T_e . In "optically thin" plasmas in which the dominant energy loss is due to electron bremsstrahlung, the electron temperature may be determined by equating the bremsstrahlung energy loss to the ion-electron energy transfer rate. This results in²³

$$\frac{T_e}{T_i} = G \left[\sqrt{1 + \frac{2}{G}} - 1 \right], \quad (26)$$

$$\text{where } G = \sqrt{\frac{3}{8}} \frac{\ln\left(\frac{2}{\theta_m}\right) \hbar c^3 m_e^2}{e^2 m_i k T_i}$$

Note that, in many applications, $G \gg 2$, so that Eq. (26) becomes

$$\frac{T_e}{T_i} = G \left[1 + \frac{1}{G} + \dots - 1 \right] \approx 1 \quad (27)$$

In some applications the above result may not hold, however. Consequently, it is assumed in STEEP4 that $T_e = T_i$, with programmed options to override this assumption by providing, as input, T_e as a function of T_i . As will be noted in Section III, options are also provided in STEEP4 to override the use of Eq. (22) by inputting the values of a_i and to input values for $\tilde{E}_i$.

3. Specific Reaction Rates for the Slowing-In Components

The ion distribution expressed by Eq. (20) is in terms of laboratory system energies. Inserting this relation into the general relationship for $\langle \sigma v \rangle$ given by Eq. (2) results in

$$\begin{aligned} \langle \sigma v \rangle = & (1 - a_i)(1 - a_j) \int d\mathbf{v}_i \int d\mathbf{v}_j \frac{(m_i m_j)^{3/2}}{(2\pi kT)^3} \exp \left[-\frac{m_i v_i^2 + m_j v_j^2}{2kT} \right] \sigma_{ij}(\mathbf{v}_r) \mathbf{v}_r \\ & + 2a_i(1 - a_j) \int d\mathbf{v}_i \int d\mathbf{v}_j \frac{\left(\frac{m_i}{2\pi kT}\right)^{3/2} \exp\left(-\frac{m_i v_i^2}{2kT}\right) \sigma_{ij}(\mathbf{v}_r) \mathbf{v}_r}{4\pi v_i^3 \ln(\tilde{E}_i/\tilde{E}_i)} \\ & + 2a_j(1 - a_i) \int d\mathbf{v}_i \int d\mathbf{v}_j \frac{\left(\frac{m_j}{2\pi kT}\right)^{3/2} \exp\left(-\frac{m_j v_j^2}{2kT}\right) \sigma_{ij}(\mathbf{v}_r) \mathbf{v}_r}{4\pi v_j^3 \ln(\tilde{E}_j/\tilde{E}_j)} , \end{aligned} \quad (28)$$

where collisions between the two slowing-in distributions have been ignored. Equation (28) may be written as

$$\langle \sigma v \rangle = (1 - a_i)(1 - a_j) I_M + a_i(1 - a_j) I_{ij} + a_j(1 - a_i) I_{ji}, \quad (29)$$

where I_M is the integral of Eq. (11) and

$$I_{ij} = 2 \int_0^\infty dv_j \int_{\tilde{v}_i}^{\hat{v}_i} dv_i \frac{\left(\frac{m_j}{2\pi kT}\right)^{3/2} \exp\left(-\frac{m_j v_j^2}{2kT}\right) \sigma_{ij}(v_r) v_r}{4\pi v_i^3 \ln(\hat{E}_i/\tilde{E}_i)}. \quad (30)$$

The limits $\hat{v}_i$ and $\tilde{v}_i$ correspond to the energy limits $\hat{E}_i$ and $\tilde{E}_i$. Integration of Eq. (30) using spherical velocity coordinates and assuming isotropic distributions results in

$$I_{ij} = 2 \int_0^\infty dv_j \int_{\tilde{v}_i}^{\hat{v}_i} dv_i \int_{-1}^1 d\mu \frac{8\pi^2 v_i^2 v_j^2 \left(\frac{m_j}{2\pi kT}\right)^{3/2} \exp\left(-\frac{m_j v_j^2}{2kT}\right) \sigma_{ij}(v_r) v_r}{4\pi v_i^3 \ln(\hat{E}_i/\tilde{E}_i)}, \quad (31)$$

where μ equals the cosine of the angle between the interacting ions. By noting that $v_r^2 = v_i^2 + v_j^2 - 2v_i v_j \mu$, Eq. (31) can be reduced to

$$I_{ij} = 4\pi \int_{\tilde{v}_i}^{\hat{v}_i} dv_i \left[\int_0^{v_i} dv_j \int_{v_i - v_j}^{v_j + v_i} dv_r g(v_i, v_j, v_r) + \int_{v_i}^\infty dv_r \int_{v_j - v_i}^{v_j + v_i} dv_j g(v_i, v_j, v_r) \right], \quad (32)$$

$$\text{where } g(v_i, v_j, v_r) = \frac{v_j \left(\frac{m_j}{2\pi kT}\right)^{3/2} \exp\left(-\frac{m_j v_j^2}{2kT}\right) v_r^2 \sigma_{ij}(v_r)}{v_i^2 \ln(\hat{E}_i/\tilde{E}_i)}.$$

Using Figure 1, the order of integration may be changed.

$$I_{ij} = 4\pi \int_{\tilde{v}_i}^{\hat{v}_i} dv_i \left[\int_0^{v_i} dv_r \int_{v_i - v_r}^{v_r + v_i} dv_j g(v_i, v_j, v_r) + \int_{v_i}^\infty dv_r \int_{v_r - v_i}^{v_r + v_i} dv_j g(v_i, v_j, v_r) \right] \quad (33)$$

Figure 1. Change of Order of Integration in Eq. (32) from v_r, v_j to v_j, v_r .

Integration of Eq. (33) over v_j then results in

$$I_{ij} = \sqrt{\frac{2m_j}{\pi kT}} \int_{\check{v}_i}^{\hat{v}_i} \frac{dv_i}{v_i^2 \ln(\hat{E}_i/\check{E}_i)} \int_0^\infty dv_r v_r^2 \sigma_{ij}(v_r) \left\{ \exp\left[-\frac{m_j(v_r - v_i)^2}{2kT}\right] - \exp\left[-\frac{m_j(v_r + v_i)^2}{2kT}\right] \right\} \quad (34)$$

The solution of Eq. (34) requires a somewhat time-consuming double numerical integration. Substantial simplification is provided if one assumes in the integration of Eq. (30) that the Maxwellian ions are at rest (i.e., $v_j = 0$). In that case the integration reduces to

$$I_{ij} \approx 2 \int_{\check{v}_i}^{\hat{v}_i} \frac{dv_i}{4\pi v_i^3 \ln(\hat{E}_i/\check{E}_i)} \frac{4\pi v_i^2 v_r \sigma_{ij}(v_r)}{4\pi v_i^3 \ln(\hat{E}_i/\check{E}_i)} \approx 2 \int_{\check{v}_i}^{\hat{v}_i} \frac{dv_r \sigma_{ij}(v_r)}{\ln(\hat{E}_i/\check{E}_i)} \quad (35)$$

Numerical studies (see Section II-F), however, indicate that considerable inaccuracy is introduced by the assumption leading to Eq. (35). As a result, Eq. (34) has been employed in STEEP4.

B. Cross Sections

Fusion cross sections can be represented as

$$\sigma(E) = \frac{S(E)}{E} e^{-B/\sqrt{E}}, \quad (36)$$

where $S(E)$ is a nuclear cross-section factor, and B is a constant given later by Eq. (42).

Although Eq. (36) uses the approximate Gamow penetration exponential, it can also be thought of as defining $S(E)$. When simple, even resonant, forms are adopted for $S(E)$, the specific reaction rate equation, Eq. (11),

can be integrated by steepest descent methods and analytic expressions result for the specific reaction rate. This is very convenient both for rapid computation and for lending to understanding. Unfortunately, many nuclear cross-section factors cannot be simply represented, particularly when complicated resonance and interference effects are present. R-matrix calculations provide, in general, good representations of cross sections but these are too complicated for simple integration.

Thus, as was noted earlier, R-matrix analyses^{11,12} and other methods¹³ are used to determine fusion cross sections at particular energies. These are provided in an energy-cross section pair format, and suitable interpolation and extrapolation formulae are used to obtain cross sections at other energies. This approach requires numerical integration techniques for evaluating the reaction rate integrals.

Evaluated cross sections for a selected charged-particle reaction $X_2(x_1, x_3)X_4$ are normally (KDATA = 1) input to STEEP4 as a set of energy (eV)-cross section (barns) pairs in ENDF/B format. Such data are read in by subroutine RENDF2 from punched cards or tape. (An additional subroutine RENDF1 has been provided to read normal header information up to the desired reaction cross sections from an assumed library of charged-particle cross sections. However, since such a library is currently not available, the subroutine RENDF1 is bypassed in the present version of STEEP4.) The energy-cross section data are ordered by monotone-increasing energy commencing with a nonzero energy. The integrations described in the previous section utilize the cross section as a function of relative energy, E_r , whereas ENDF/B data are input in terms of the laboratory system

energy, E_1^L , assuming that the target particle (X_2) is stationary. Combining Eqs. (3) and (10) we have for this case,

$$E_r = \frac{m_2}{m_1 + m_2} E_1^L, \quad (37)$$

and the input energies are transformed to relative energies by this expression. Relative energies are converted from eV to keV and cross sections are converted from barns to cm^2 . After this the transformed relative energy (keV)-cross section (cm^2) pairs may be edited for inspection (KPRNT $\neq$ 1).

In the course of the integrations carried out by STEEP4, cross sections are retrieved from the transformed $\{E, \sigma(E)\}$ pairs by alternative user-specified interpolation routines. Up to six energy-dependent interpolation regions are permitted in STEEP4. These are specified by input values of: (1) energies (EBRK (INX)) in keV (lab system) which define the end points of the interpolation regions and (2) indices (KXINT (INX)) which identify the interpolation options to be employed within each region (i.e., option KXINT (1) is used for $0.0 \leq E_1^L \leq \text{EBRK} (1)$, option KXINT (2) is used for $\text{EBRK} (1) \leq E_1^L \leq \text{EBRK} (2)$, etc.).

Three interpolation routines are provided by the present version of STEEP4:

- (1) a two-point Gamow penetration interpolation (KXINT = 1),
- (2) a two-point log-log interpolation (KXINT = 2), and
- (3) a four-point cubic interpolation (KXINT = 3).

Additional routines are easily coded but are not supplied with STEEP4. The subroutine XINTER is used to call the appropriate interpolation routine in STEEP4.

At low energies the Coulomb barrier penetration is expected to

dominate the cross-section shape while at higher energies nuclear structure effects become pronounced. Efficient interpolation techniques have been provided to reflect this behavior. It is convenient to represent the cross section as

$$\sigma(E) = \pi \lambda^2 N(E) C(E) , \quad (38)$$

where λ is the de Broglie wavelength, $N(E)$ is a nuclear factor, and $C(E)$ is a Coulomb penetration factor. This expression can be rewritten as Eq. (36) by noting that $\pi \lambda^2$ is proportional to $1/E$ and by employing the Gamow form $\exp(-2\pi Z_1 Z_2 e^2 / \hbar v)$ for the Coulomb penetration factor.

At low energies (e.g., below EBRK (1)) the Gamow penetration form interpolation is, therefore, appropriate. This interpolation routine is consistent with Eq. (36) with the nuclear factor, $S(E)$, taken as a constant between adjacent input energy cross-section pairs. That is, between (E_{i-1}, σ_{i-1}) and (E_i, σ_i) ,

$$\sigma(E) = \frac{S_i}{E} e^{-B_i/E^{1/2}} , \quad (39)$$

where

$$B_i = \frac{\ln(E_i \sigma_i / E_{i-1} \sigma_{i-1})}{\frac{1}{E_{i-1}^{1/2}} - \frac{1}{E_i^{1/2}}} , \quad (40)$$

and

$$S_i = E_i \sigma_i e^{B_i/E_i^{1/2}} . \quad (41)$$

If the Gamow penetration form interpolation is selected for any of the interpolation regions, tables of B_i and S_i are precomputed (and optionally edited) before any integrations are carried out. These tables

are held in labeled COMMON (CROSS) and the Gamow penetration form interpolation [Eq. (39)] is carried out by subroutine INTEPG.

Because $S(E)$ actually varies with energy and because the Gamow penetration expression is an approximation, it is found that, even at low energies, the computed B_i varies somewhat from one energy pair to another and is not quite equal to the Gamow value, BGAM

$$BGAM = \frac{\pi Z_1 Z_2 e^2 (931478 \cdot A_r)^{1/2}}{\hbar c} \text{ keV}^{1/2} . \quad (42)$$

Here A_r represents a reduced atomic weight

$$A_r = \frac{A_1 A_2}{A_1 + A_2} , \quad (43)$$

and $Z_i e$ is the charge on particle i . Table I illustrates the situation for a preliminary evaluation of $T(d,n)\alpha$ used as a sample problem in this report. While more accurate penetration factors can be computed readily by the WKB method,¹⁴ the Gamow interpolation formula, Eq. (39), is sufficiently accurate for interpolation when enough energy-cross section pairs are provided as input. In summary, charged-particle cross sections vary steeply at low energies and the Gamow penetration interpolation form, Eq. (39), is a physically appropriate interpolation formula; but it is still necessary to input a sufficiently dense table of evaluated energy-cross section pairs.

For higher energies two additional interpolation subroutines are provided. Subroutine INTEPL (KXINT = 2) computes cross sections by log-log interpolation,

$$\sigma(E) = A_i E^{C_i} , \quad (44)$$

TABLE I
EFFECTIVE GAMOW FACTOR, B_i , AND NUCLEAR FACTOR, S_i , FOR
PRELIMINARY EVALUATION OF THE $T(d,n)\alpha$ CROSS SECTION

Energy Interval (E_i, E_{i+1}) (keV)	Effective Gamow Factor, ^a B_i (keV ^{1/2})	Nuclear Factor, $S_i \times 10^{20}$ (cm ² keV)
0.6 - 1.2	34.41	1.183
1.2 - 1.8	34.44	1.220
1.8 - 2.4	34.48	1.258
2.4 - 3.0	34.53	1.298
3.0 - 6.0	34.69	1.425
6.0 - 9.0	35.13	1.702
9.0 - 12.0	35.71	2.070
12.0 - 15.0	36.44	2.551
15.0 - 18.0	37.27	3.161
18.0 - 21.0	38.18	3.902
21.0 - 24.0	39.06	4.750
24.0 - 27.0	39.89	5.630
27.0 - 30.0	40.58	6.423
30.0 - 33.0	41.04	6.981
33.0 - 36.0	41.15	7.116

^aFor this reaction the Gamow factor BGAM from Eq. (42) is 34.38 keV^{1/2}.

$$\text{where } C_i = \frac{\ln(\sigma_i/\sigma_{i-1})}{\ln(E_i/E_{i-1})}, \quad (45)$$

and

$$A_i = \sigma_i/E_i^{C_i} \quad (46)$$

Alternatively, subroutine INTEPC (KXINT = 3) computes the cross sections using a four-point cubic interpolation formula,

$$\sigma(E) = D_i + H_i E + F_i E^2 + G_i E^3, \quad (47)$$

for E in the interval E_{i-1} to E_i . Here,

$$G_i = \frac{1}{E_{i+1} - E_{i-2}} \left\{ \frac{1}{E_i - E_{i-2}} \left[\frac{\sigma_{i-1} - \sigma_{i-2}}{E_{i-1} - E_{i-2}} - \frac{\sigma_i - \sigma_{i-1}}{E_i - E_{i-1}} \right] - \frac{1}{E_{i+1} - E_{i-1}} \left[\frac{\sigma_i - \sigma_{i-1}}{E_i - E_{i-1}} - \frac{\sigma_{i+1} - \sigma_i}{E_{i+1} - E_i} \right] \right\}, \quad (48)$$

$$F_i = \frac{1}{E_i - E_{i-2}} \left[\frac{\sigma_{i-1} - \sigma_{i-2}}{E_{i-1} - E_{i-2}} - \frac{\sigma_i - \sigma_{i-1}}{E_i - E_{i-1}} \right] - G_i (E_{i-2} + E_{i-1} + E_i), \quad (49)$$

$$H_i = \frac{\sigma_i - \sigma_{i-1}}{E_i - E_{i-1}} - F_i (E_{i-1} + E_i) - G_i (E_{i-1}^2 + E_{i-1} E_i + E_i^2), \quad (50)$$

$$D_i = \sigma_i - H_i E_i - F_i E_i^2 - G_i E_i^3. \quad (51)$$

Tables of A_i and C_i (D_i , H_i , F_i , and G_i) are precomputed and held in labelled COMMON (CROSS) for rapid use by the interpolation subroutines if log-log interpolation (cubic interpolation) has been selected.

At energies below the first input energy and above the last input energy for the cross-section description, the cross sections are

computed by extrapolation using the specified interpolation equation. Consequently, it is recommended practice to specify the Gamow penetration form (KXINT = 1) for the first interpolation region ($0.0 \leq E \leq \text{EBRK}(1)$). In addition, no check is made in subroutine INTEPC to assure that the computed cross section is positive. Thus it is recommended practice to specify log-log interpolation (KXINT = 2) for the last interpolation region ($\text{EBRK}(\text{NXS}-1) \leq E \leq \infty$).

C. Integration Techniques

When the ions are characterized by Maxwellian distributions of low temperature, it is customary to compute the specific reaction rate by steepest descent integration. The integrand in Eq. (11) is separated into a slowly varying part times a rapidly varying exponential,

$$\langle \sigma v \rangle = \int_0^{\infty} dE_r \left[\frac{2}{\pi^{1/2}} \frac{E_r^{1/2}}{(kT)^{3/2}} \frac{S(E_r)}{E_r} v_r(E_r) \right] e^{-\left(\frac{E_r}{kT} + \frac{B}{E_r^{1/2}} \right)}, \quad (52)$$

by introducing the Maxwellian, $M_T(E)$, and the Gamow penetration expression for $\sigma(E)$ from Eqs. (12) and (36), respectively. The exponent has a minimum at the Gamow energy,

$$E_G = (BkT/2)^{2/3}, \quad (53)$$

and near this minimum the bulk of the integral is concentrated. Expanding the exponent in a Taylor series about the Gamow energy, truncating at the $(E_r - E_G)^2$ term, and evaluating the slowly varying factor at the Gamow energy, the steepest descent integral is evaluated as

$$\langle \sigma v \rangle = M_T(E_G) \sigma(E_G) v_r(E_G) \left(\frac{8\pi}{3B} \right) E_G^{5/4} . \quad (54)$$

This expression is used in STEEP4 to evaluate the Maxwellian component of $\langle \sigma v \rangle$ when the KINTE = 1 integration option is selected.

1. Gauss-Hermite Quadrature

At low temperatures the integrand in Eq. (52) has an approximately Gaussian shape of the form

$$M_T(E) \sigma(E) v_r(E) \approx f(E) \exp \left(-\frac{(E-E_G)^2}{\Delta/2} \right) , \quad (55)$$

where

$$\frac{\Delta}{2} = \left(\frac{8}{3B} \right)^{1/2} E_G^{5/4} , \quad (56)$$

and $f(E)$ is a slowly varying function. This suggests the use of a Gauss-Hermite quadrature about E_G for the evaluation of the integral of Eq. (11),

$$\int_{-2E_G/\Delta}^{\infty} e^{-x^2} f(x) dx \approx \int_{-\infty}^{\infty} e^{-x^2} f(x) dx \approx \sum_{k=1}^N w_k^{(N)} f(x_k^{(N)}) , \quad (57)$$

where the $w_k^{(N)}$ and $x_k^{(N)}$ are the appropriate weights and nodes for Gauss-Hermite quadrature of order N . The substitution $x = \frac{E - E_G}{\Delta/2}$ has been made to obtain Eq. (57) so that

$$f(x) = \frac{\Delta}{2} M_T(E_G + \frac{\Delta}{2} x) \sigma(E_G + \frac{\Delta}{2} x) v_r(E_G + \frac{\Delta}{2} x) e^{x^2} . \quad (58)$$

A 19-point Gauss-Hermite quadrature integration has been incorporated into STEEP4 (KINTE = 2) and is carried out by subroutine INTEG1. Integrand shapes for three different temperatures (5, 200, and 500 keV) are plotted

in Figures 2, 3, and 4 for the $T(d,n)\alpha$ reaction of one of the sample problems. The Gaussian shape of the integrand is evident for a plasma temperature of 5 keV (Figure 2). Figures 3 and 4 show the departure from Gaussian of the integrand shape as the plasma temperature increases. Consequently, as will be shown in Section II.F., the Gauss-Hermite quadrature is adequate at low temperatures, but in general a dense trapezoidal quadrature is necessary for accuracy over the entire temperature range typically of interest.

2. Self-terminating Trapezoidal Integration

The self-terminating trapezoidal integration subroutine INTEG2 is used in STEEP4 when the KINTE = 3 option is selected. A trapezoidal quadrature is used to integrate Eq. (11) to the right and left of a selected point (in this case the Gamow energy). A dense mesh of panels is employed with a uniform spacing of

$$\Delta E = \frac{\Delta}{2} * SCALF \quad , \quad (59)$$

where the parameter SCALF is internally set equal to 0.01, but may be overridden by optional input. Integration to the right and left is terminated when (a) the number of panels exceeds ND1 (= 10,000), (b) the area of the last panel is less than EP1 (= 0.000001) times the integral so far accumulated, or (c) the independent variable is zero. The internally specified values of EP1 and ND1 may be overridden by optional input. INTEG2 assumes that the integral is desired over the interval $(0,\infty)$ and that the dependent quantity is nonnegative..

Figure 2. Integrand Shape for $kT = 5 \text{ keV}$, $T(d, n) \alpha$ Reaction.

Figure 3. Integrand Shape for $kT = 200 \text{ keV}$, T(d,n) α Reaction.

Figure 4. Integrand Shape for $kT = 500$ keV, T(d, n) α Reaction.

3. Adaptive Trapezoidal Integration

An adaptive (self-correcting and self-adjusting), self-terminating trapezoidal quadrature subroutine INTEG3 has also been provided in STEEP4 (KINTE = 4) for the integration of Eq. (11). INTEG3 is similar to INTEG2 in that the integration is carried out first to the right and then to the left of the Gamow energy.

The integration is adaptive in the following sense. Integration first advances an interval of width $\Delta E = \frac{\Delta}{2} * SCALG$ with SCALG (= 0.10) internally specified. The area of the panel is computed assuming that the integrand varies linearly across the panel. Then the panel is divided in two and the areas of each half-panel are computed assuming a linear integrand across each half-panel. If the sum of the half-panel areas is within a fraction, EPS1 (= 0.0001), of the full-panel area, the integration steps ahead; if not, the full-panel width is halved and the process is repeated. In addition, the initial panel width tried at each step is adjusted as the integration proceeds. This is done in the following manner: The initial full-panel widths for the two preceding integration steps are compared with the last resultant width. The initial panel width tried for the next step is set equal to the previous resultant width unless this width is greater than or equal to the previous initial width and that width is also greater than or equal to its preceding initial width. In that case a width double that of the last resultant width is tried. (In no case, however, is the full-panel width permitted to exceed $\frac{\Delta}{2} * SCALG$.)

Similar to the INTEG2 subroutine, INTEG3 terminates integration to the right and left when (a) the number of panels exceeds NI (= 10,000), (b) the area of the last full panel is less than EPS2 (= 0.000001)

times the integral so far accumulated, or (c) the independent variable is zero. Also, the internally specified values of SCALG, EPS1, EPS2, and NI may be overridden by optional user input.

As will be shown in Section II.F the addition of the adaptive self-correcting and self-adjusting features in INTEG3 permits a reduction in computing time without sacrificing accuracy. These techniques can err, however, for certain forms of integrands. For example, a very narrow resonance in the cross-section shape could be skipped entirely or a deep minimum in the cross-section shape could falsely terminate the integration. (Since such characteristics are not typical of charged-particle reactions, straightforward techniques to guard against such errors have not been built into INTEG3.) In addition, the sensitive interaction between the various integration parameters may also prematurely terminate the integration. Because of this, it is recommended that extensive testing be carried out beforehand whenever this option is employed.

4. Double Integration for Slowing-In Components

To obtain the slowing-in contribution to the specific reaction rate requires the computation of Eq. (34), which requires a double integration technique. Subroutines INTGS1 and INTGS2 are used to perform this integration in STEEP4.

First the order of integration in Eq. (34) is changed from v_r, v_i to v_i, v_r . For a specific value of v_r , INTGS1 calls INTGS2 to perform the inner integration over v_i . An iterative Simpson's rule integration is used in INTGS2. The interval $(\check{v}_i, \hat{v}_i)$ is divided into ND3 (= 200) uniform panels and integration is performed using Simpson's rule. The

integration is then repeated using twice the number of panels. If the relative difference between the two results is less than or equal to EP4 (= 0.000001) the process is terminated and the result returned to INTGS1; otherwise the number of panels is again doubled and the process repeated.

The outer integration over v_r is performed by the INTGS1 subroutine. A trapezoidal integration quadrature with the adaptive features of the previously described INTEG3 subroutine is used. The integration is performed to the right and left of VO (presently specified as $\sqrt{(\hat{E}_1 + \check{E}_1)/m_r}$). The maximum panel size is $VO * SCALD$ ($SCALD = 0.01$), the panel width area criterion is EP2 (= 0.0001), the termination area criterion is EP3 (= 0.000001), and the maximum number of panels to the right and to the left is ND2 (= 10,000). As in the case of other routines, the values of these internally specified parameters may be altered by optional user input.

D. Screening Effects

Charged-particle reaction rates in dense plasmas are increased because the electron cloud around each ion reduces the Coulomb barrier between ions. This reduction in the Coulomb barrier in effect increases the reaction cross section and the corresponding specific reaction rate. This may be seen as follows. Consider the specific reaction rate for the unscreened condition,

$$\langle \sigma v \rangle_{us} = \int_0^{\infty} M_T(E) v_r(E) \sigma(E) dE = \int_0^{\infty} M_T(E) v_r(E) S(E) P(E) dE, \quad (60)$$

where the cross section $\sigma(E)$ has been written as the product of a penetration factor $P(E)$ times a nuclear shape factor $S(E)$. The effect of screening is to perturb the total Coulomb interaction energy, U_{tot} , by an amount U_0 where $|U_0| \ll U_{\text{tot}}$ and U_0 is essentially constant over the range of interaction. Since U_0 is negative, the potential U_0 has the effect of increasing the kinetic energy of the interacting particles by an amount $-U_0$ in the determination of the interaction cross section. Thus Eq. (60) for the screened condition may be written

$$\begin{aligned} \langle \sigma v \rangle_s &= \int_0^{\infty} M_T(E) v_r(E) S(E - U_0) P(E - U_0) dE \\ &= \int_{-U_0}^{\infty} M_T(E' + U_0) v_r(E' + U_0) S(E') P(E') dE' . \end{aligned} \quad (61)$$

Equation (61) may be simplified by noting that in practice $-U_0$ is small compared to the most effective energy ($\sim E_G$) so that

$$M_T(E' + U_0) v_r(E' + U_0) \approx e^{-U_0/kT} M_T(E') v_r(E') . \quad (62)$$

Furthermore, the value of $P(-U_0)$ is sufficiently small so that the lower limit of the integral may be extended to zero without significant error. The equation for the screened specific reaction rate then becomes

$$\langle \sigma v \rangle_s \approx \int_0^{\infty} e^{-U_0/kT} M_T(E') v_r(E') S(E') P(E') dE' \approx f_s \langle \sigma v \rangle_{us} , \quad (63)$$

$$\text{where } f_s = e^{-U_o/kT} \quad (64)$$

Thus the calculation of the effect of screening is reduced to the computation of U_o , substitution of U_o into Eq. (64) to obtain the screening factor f_s , and multiplication of the calculated unscreened $\langle \sigma v \rangle$ by f_s to obtain $\langle \sigma v \rangle$ corrected for screening.

Equation (64) has formed the basis for several different approaches to evaluate the effects of screening.¹⁵⁻¹⁸ It is noted that, in obtaining Eq. (64), a Maxwellian ion distribution has been assumed. In addition, most investigations of screening effects have implicitly assumed "non-resonant" reaction rates. Both of these assumptions have been carried over into the options available in STEEP4 to treat the effects of screening (even though, for example, the assumption of Maxwellian ion distributions is not employed in other parts of the evaluation of $\langle \sigma v \rangle$). This approach is judged to be reasonable based on the approximations to be involved in the evaluation of U_o and the relatively small elevation of f_s from unity in applications where the ion distributions might be expected to be strongly non-Maxwellian.

1. Weak Screening

For many applications the plasma density is sufficiently low and the temperature is sufficiently high so that kT is much greater than the average Coulomb energy between adjacent ions. In such cases the Debye-Hückel theory gives a good representation of the potential associated with the shielding cloud for the two interacting ions. This leads to the "weak-screening" approximation for the reaction rate rigorously described by Salpeter.¹⁵

From Debye-Hückel theory the potential around an ion of charge Z_1 is

$$v = \frac{eZ_1}{r} \exp\left(-\frac{r}{\lambda_D}\right) = \frac{eZ_1}{r} \left[1 - \frac{r}{\lambda_D} + \dots\right], \quad (65)$$

where λ_D is the Debye screening length. If an ion of charge Z_2 passes close, the interaction energy is given by

$$eZ_2 v = \frac{Z_1 Z_2 e^2}{r} - \frac{Z_1 Z_2 e^2}{\lambda_D} + \dots \quad (66)$$

The first term in Eq. (66) is just the unscreened Coulomb potential, so that (to first order) the potential perturbation for the weak-screening condition, U_w , is given by

$$-U_w = \frac{Z_1 Z_2 e^2}{\lambda_D}, \quad (67)$$

where $\lambda_D = (kT/4\pi e^2 \tilde{z})^{1/2}$, (68)

and $\tilde{z} = \sum_{j=1}^j N_j (Z_j^2 + Z_j) = N_e + \sum_{j=1}^j N_j Z_j^2$. (69)

The conditions of applicability of Eq. (67) have been discussed by Salpeter.¹⁵ Therein, the effects of electron degeneracy were also discussed. For an arbitrary degree of degeneracy, Salpeter showed Eq. (67) to be valid with Eq. (69) rewritten as

$$\tilde{z} = \theta_e N_e + \sum_{j=1}^j N_j Z_j^2, \quad (70)$$

where θ_e is the electron degeneracy factor, which is equal to the logarithmic derivative of the Fermi-Dirac distribution function with

respect to its argument,

$$\theta_e = \frac{F'(\eta)}{F(\eta)} \quad , \quad (71)$$

$$\text{where } F(\eta) = \int_0^\infty \frac{x^{1/2} dx}{\exp(x-\eta) + 1} = \frac{\pi^2 \hbar^3 N_e}{\sqrt{2}(m_e kT)^{3/2}} \quad . \quad (72)$$

For significant degeneracy ($\eta > 1$) the electrons at the bottom of the Fermi distribution are unable to participate in the screening. This is reflected by the degeneracy factor θ_e in Eq. (70) since θ_e vanishes in the limit of large degeneracy and is unity for fully nondegenerate electrons.

Equations (67), (68), and (70) are used with Eq. (64) in STEEP4 for the weak-screening option (KSCRN = 2). The electron degeneracy factor is provided by the subroutine EDGEN which solves Eq. (72) for η from tabulated values of $F(\eta)$,²⁴ numerically differentiates to obtain $F'(\eta)$, and finally solves Eq. (71) for θ_e .

2. Salpeter Formulation

When the plasma density becomes relatively high and the temperature is low, the strong-screening regime is encountered. In this case, Salpeter¹⁵ assumes that the large Coulomb repulsive energy results in ion spheres which contain no background ions, only a uniform electron density. The total electrostatic energy for this sphere for ions of charge Z_1 is

$$U_{\text{tot}} = - \frac{9}{10} \left(\frac{4\pi N_e}{3} \right)^{1/3} e^2 Z_1^{5/3} \quad . \quad (73)$$

The screening contribution to the potential, U_s , (strong screening) is then given by the differences in U_{tot} for two interacting spheres of arbitrary charges Z_1 and Z_2 (i.e., their centers are assumed to be within a very small distance of each other) and U_{tot} for the two spheres at non-interacting distances (i.e., separated by infinity).

$$U_s = -\frac{9}{10} \left(\frac{4\pi N e}{3} \right)^{1/3} e^2 \left[(Z_1 + Z_2)^{5/3} - Z_1^{5/3} - Z_2^{5/3} \right]. \quad (74)$$

An approximate correction to Eq. (74) to account for differences in initial and final configurations of the spheres is given by Salpeter and Van Horn.¹⁶

$$U'_s = U_s + U''_s, \quad (75)$$

where U_s is given by Eq. (74) and

$$\exp\left(-\frac{U''_s}{kT}\right) = \frac{\left(1 + 0.3\Gamma_{12} + \frac{1}{3}\left(\frac{2}{\pi}\right)^{1/2} \frac{3/2}{\Gamma_{12}}\right)}{\left(1 + 0.3\Gamma_1 + \frac{1}{3}\left(\frac{2}{\pi}\right)^{1/2} \frac{3/2}{\Gamma_1}\right) \left(1 + 0.3\Gamma_2 + \frac{1}{3}\left(\frac{2}{\pi}\right)^{1/2} \frac{3/2}{\Gamma_2}\right)}, \quad (76)$$

where

$$\Gamma_1 = \left(\frac{4\pi N e}{3} \right)^{1/3} \frac{e^2}{kT} Z_1^{5/3}, \quad (77)$$

$$\Gamma_2 = \left(\frac{4\pi N e}{3} \right)^{1/3} \frac{e^2}{kT} Z_2^{5/3}, \quad (78)$$

and

$$\Gamma_{12} = \left(\frac{4\pi N e}{3} \right)^{1/3} \frac{e^2}{kT} (Z_1 + Z_2)^{5/3}. \quad (79)$$

A general screening treatment (weak, intermediate, and strong regimes) was also obtained by Salpeter¹⁵ for the special case of ions with large charge and low abundance by solving the Poisson-Boltzmann equation. For this special case, the intermediate regime values (U_{sw}) were found¹⁶ to agree fairly well with the simple interpolation formula

$$- U_{sw} = U'_s U'_w / \sqrt{U'^2_s + U'^2_w} \quad (80)$$

Finally, Salpeter and Van Horn¹⁶ obtained a correction for the higher end of the strong-screening regime when the pycnonuclear regime is approached (e.g., $-U_s/3E_G > 1$). The correction is valid for $-3E_G/U_s < 1$ (but not necessarily for $-3E_G/U_s \ll 1$). From numerical evaluation of the barrier penetration integral (using a WKB approximation) for two special cases ($Z_1 = Z_2$ and $Z_1 \gg Z_2$), their work suggests, for near the pycnonuclear regime, the use of

$$U_{sp} = U'_s - U'_p \quad (81)$$

in Eq. (64) where U'_s is given by Eq. (75) and

$$- \frac{U'_p}{kT} = 3E_G \frac{(0.84 Z_1 + 3.46 Z_2) \beta^3 + 95.6 Z_2 \beta^9}{(Z_1 + Z_2) + (1.45 Z_1 + 32.8 Z_2) \beta^3} \quad (82)$$

In Eq. (82) it is assumed that $Z_1 \geq Z_2$ and β is given by

$$\beta = - U_s / 3E_G \quad (83)$$

The foregoing formulations for the screening effect in various regimes are employed in STEEP4 with the Salpeter screening option

(KSCRN = 3). The weak screening treatment of the previous section is used when the Coulomb energy is much less than kT . When the Coulomb energy is much greater than kT but still much less than E_G , the strong screening treatment is used. For the intermediate regime Eq. (80) is used. When the Coulomb energy approaches E_G , Eq. (81) is used. More specifically, Eqs. (67), (68), and (70) are used with Eq. (64) when

$$0.9 \Gamma_1 \leq SF \quad . \quad (84)$$

Equations (80), (75), and (67) are used with Eq. (64) when

$$SF < 0.9 \Gamma_1 < 1/SF \quad . \quad (85)$$

Equations (75), (74), and (76) through (79) are used with Eq. (64) when

$$1/SF \leq 0.9 \Gamma_1 < SF * E_G / kT \quad . \quad (86)$$

Finally, Eqs. (81) through (83) and (75) are used with Eq. (64) when

$$0.9 \Gamma_1 \geq SF * E_G / kT \quad . \quad (87)$$

The value of $SF(= 0.10)$ is internally specified in the program (optionally overridden by input) and it is assumed that $\Gamma_1 \geq \Gamma_2$ in the above equations. In conclusion, it is noted that in terrestrial fusion devices the condition of Eq. (84) is almost always satisfied, and the previous weak-screening treatment is appropriate. There are, however, numerous stellar applications where Eqs. (85), (86), or even (87) may be satisfied. Consequently, the above, rather complete, treatment for screening effects has been incorporated into the STEEP4 Code.

3. Graboske-DeWitt Screening Factors

Recently, a more unified theory for the screening potential has been developed by Graboske, DeWitt, and collaborators.^{17,18} On the basis of arguments of statistical mechanics, they derive forms of the screening potential analogous to the special cases treated rigorously by Salpeter.^{15,16} Their approach, moreover, provides a rigorous and general formulation for the screening factor that, with the aid of numerical evaluation, can be extended to arbitrary plasma conditions. The results of their work indicate that the factor $-\frac{U_o}{kT}$ in Eq. (64) can be expressed as the product of four factors

$$-\frac{U_o}{kT} = k_b \eta_b \zeta_b \Lambda_g^b, \quad (88)$$

where

$$\Lambda_g = \frac{2 \sqrt{\pi} e^3}{(kT)^{3/2}} \sqrt{\sum_{j=1}^j N_j} \quad (89)$$

and the values of k_b , η_b , ζ_b , and b depend on the strength of the screening.

For the Graboske-DeWitt screening option (KSCRN = 4) of STEEP4, Eqs. (89) and (88) are used with Eq. (64) to account for the effects of screening. The values and expressions for b , k_b , η_b , and ζ_b are as follows. For the weak-screening regime,

$$b = 1,$$

$$k_b = 1/2,$$

$$\eta_b = z^* = \sqrt{\frac{\tilde{z}}{\sum_{j=1}^j N_j}},$$

$$\zeta_b = 2 Z_1 Z_2. \quad (90)$$

This reproduces the previous weak-screening results. For the "intermediate" regime,

$$\begin{aligned}
 b &= 0.860, \\
 k_b &= 0.380, \\
 \eta_b &= \langle z^{3b-1} \rangle / \left[(z^*)^{(3b-2)} (\bar{z})^{(2-2b)} \right], \\
 \zeta_b &= \left[(z_1 + z_2)^{1+b} - z_1^{1+b} - z_2^{1+b} \right].
 \end{aligned} \tag{91}$$

Finally for the strong-screening regime,

$$\begin{aligned}
 b &= 2/3, \\
 k_b &= 0.624, \\
 \eta_b &= \left(\frac{\bar{z}}{z} \right)^{1/3}, \text{ and} \\
 \zeta_b &= \left[(z_1 + z_2)^{5/3} - z_1^{5/3} - z_2^{5/3} \right] \\
 &\quad + 0.316 \left(\frac{\bar{z}}{z} \right)^{1/3} \left[(z_1 + z_2)^{4/3} - z_1^{4/3} - z_2^{4/3} \right] \\
 &\quad + 0.737 \left(\frac{\bar{z}}{z} \right)^{-1} \left[(z_1 + z_2)^{2/3} - z_1^{2/3} - z_2^{2/3} \right] / \Lambda_g^{2/3}.
 \end{aligned} \tag{92}$$

In the preceding expressions,

$$\langle z^{3b-1} \rangle = \left(\frac{\sum_{j=1}^j N_j z_j^{3b-1}}{\sum_{j=1}^j N_j} \right), \tag{93}$$

and

$$\bar{z} = \left(\frac{\sum_{j=1}^j N_j z_j}{\sum_{j=1}^j N_j} \right). \tag{94}$$

Following the procedure suggested by DeWitt and Graboske,¹⁸ the weak screening parameters [Eq. (90)] are used when $\Lambda_{12} (\equiv - \frac{U_0}{kT}$ evaluated for the weak screening parameters) is less than or equal to 0.1. The intermediate parameters [Eq. (91)] are used for the range

$0.1 < \Lambda_{12} \leq 2$, and the strong screening parameters [Eq. (92)] are used when $\Lambda_{12} \geq 5.0$. For $2.0 < \Lambda_{12} < 5.0$, both intermediate- and strong-screening factors are computed and the smaller of the two is applied.

E. Coding

STEEP4 is programmed in FORTRAN-IV for the CDC-6600 and CDC-7600 computers. The program consists of about 1700 statement lines plus about 300 comment lines. All program variables are defined in comment lines in alphabetical order at the front of the program; these are listed in Appendix A. A code abstract is included as Appendix D.

The main program reads most of the input data, reduces the data and converts to appropriate units, and selectively edits the input. Subroutine RENDF2 is called to read the cross section-energy pairs (in ENDF/B format). All interpolation parameters which will later be required for the evaluation of cross sections are computed by MAIN early in the program and stored to facilitate rapid subsequent use.

Much of the actual computation is also performed by the main program. The computations for the slowing-down contributions to $\langle \sigma v \rangle$ versus plasma temperature are performed first. Subroutines INTGS1 and INTGS2 are repeatedly called to evaluate the double integral of Eq. (34) for a given plasma temperature. Next, the Maxwellian contributions versus temperature are computed. The main program solves for $\langle \sigma v \rangle$ by the method of steepest descent. The evaluation of $\langle \sigma v \rangle$ by other integration techniques is accomplished by repeated calls to the appropriate integration subroutines. Subroutine INTEG1 is used for Gauss-Hermite

quadrature solution; subroutine INTEG2 is used for the self-terminating dense trapezoidal quadrature; and subroutine INTEG3 is used for the adaptive trapezoidal integration option.

Within the various routines, subroutine XINTER is called to retrieve the cross-section value of a particular energy. XINTER then calls the appropriate cross-section interpolation routine as specified by user input for the energy value in consideration. Subroutine INTEPG (Gamow penetration form), INTEPL (log-log interpolation), or INTEPC (cubic interpolation) is used to provide the interpolated cross-section value.

The main program combines the various contributions to $\langle\sigma v\rangle$ and proceeds, if requested, to compute a screening factor according to the option specified by user input. Subroutine EDGEN is called during this computation to provide values of the electron degeneracy factor, θ_e , (Eq. (71)). Final results for $\langle\sigma v\rangle$ versus plasma temperature are then computed and printed.

If requested by user input, the main program then proceeds to call the library subroutine PLOTM²⁵ to provide (SC 4020 Film) plot output. The subroutine PLOIT has been provided in STEEP4 to return to the main program certain parameters required in the call of PLOTM. Subsequently, the main program also punches data as specified by user input. Finally, the main program reads an additional case card whose single parameter (NCSID) is tested for the existence of additional cases (i.e., additional case if NCSID = 1).

STEEP4 makes extensive use of the communication of variable quantities between the main program and subroutines through labelled COMMON blocks. CROSS is used to store and transfer the cross-section

interpolation parameters, while XINT stores and transfers (to XINTER) the information describing the interpolation regions. GRATES holds and transfers to the integration routines a variety of "fixed" parameters (e.g., values of SCALF, ND1, and EP1 in the INTEG2 routine). A considerable amount of storage (19 arrays with fixed dimensions of 200) is also used in the main program to save, by plasma temperature, intermediate and final results in the computation of $\langle \sigma v \rangle$.

F. Code Tests

A number of tests of the STEEP4 code have been made (1) to verify the correctness of the coding and (2) to study the accuracy of the various techniques employed. In general these tests were performed by comparing code results (1) to "exact" results for certain special problems with analytic solutions and (2) to "more accurate" numerical results obtained by employing more stringent numerical convergence criteria.

1. Maxwellian $\langle \sigma v \rangle$ Integration

Initial code tests were performed by generating STEEP4 Maxwellian $\langle \sigma v \rangle$ integration results for specific cross-section shapes for which analytic $\langle \sigma v \rangle$ results could be obtained. The most interesting cross-section shape examined corresponds to a Gamow penetration cross-section form, namely;

$$\sigma(E) = \frac{C_0}{E} \exp(-BGAM/\sqrt{E}) , \quad (95)$$

where BGAM is given by Eq. (42). Critchfield²⁶ has shown that a closed form solution of Eq. (11), with $\sigma(E_r)$

given by Eq. (95), may be obtained by differentiating the integral equations to obtain a differential equation which is then solved by applying the method of Frobenius. The result of this procedure is a power series solution for $\langle \sigma v \rangle$,

$$\langle \sigma v \rangle = - C_o \sqrt{\frac{8}{\pi m_r kT}} \left[\sqrt{\pi} \phi_1(x) + \phi_3(x) \right], \quad (96)$$

where

$$\phi_1(x) = \sqrt{\pi} \sum_{k=0}^{\infty} \frac{(-1)^k x^{2k+1}}{\Gamma(k+1/2) \Gamma(2k+2)}, \quad (97)$$

$$\phi_3(x) = \phi_2(x) \ln x - 1 - \sum_{k=0}^{\infty} \frac{(-1)^k x^{2k+2}}{\Gamma(k+1) \Gamma(2k+3)} \left[2\phi(2k+3) + \phi(k+1) \right], \quad (98)$$

$$\phi_2(x) = 2 \sum_{k=0}^{\infty} \frac{(-1)^k x^{2k+2}}{\Gamma(k+1) \Gamma(2k+3)}, \quad (99)$$

$$\phi(n) = \frac{d}{dn} \ln \Gamma(n), \quad (100)$$

$$\text{and } x = BGAM / \sqrt{kT}. \quad (101)$$

For our purposes we have let

$$C_o = \sqrt{\frac{\pi m_r}{32}} BGAM, \quad (102)$$

so that Eq. (96) becomes

$$\langle \sigma v \rangle = - \frac{x}{2} \left[\sqrt{\pi} \phi_1(x) + \phi_3(x) \right]. \quad (103)$$

To obtain the analytic solution [i.e., Eq. (103)], a small separate code (PREST) was written to solve Eqs. (97) through (103). This code

was also used to generate and punch the pointwise cross sections for the STEEP4 input. For the STEEP4 test problem a 200-point cross-section set logarithmically spaced between 0.5 keV and 3.0 MeV was used corresponding to plasma ions with masses of 2.0 and 3.0 amu and unity charge.

STEPP4 Maxwellian $\langle\sigma v\rangle$ integration results are compared to the analytic PREST code results in Table II for each of the four available STEEP4 integration routines. For temperatures (kT) greater than 4 keV, both trapezoidal integration routines give excellent agreement (to better than 0.02%) with the analytic results. The poor agreement with the analytic results below 4 keV is believed to be due to the neglect of an additional term in the analytic solution. That is, Eq. (103) should be

$$\langle\sigma v\rangle = -\frac{x}{2} \left[\sqrt{\pi} \phi_1(x) + \phi_3(x) + \epsilon \phi_2(x) \right], \quad (104)$$

where Critchfield²⁶ numerically determined $|\epsilon|$ to be $< 10^{-12}$. However, at low temperatures the functions $\sqrt{\pi} \phi_1$ and ϕ_3 are very large, are of opposite sign, and are approximately equal in absolute magnitude. Thus, even though $|\epsilon|$ is small, the quantity $\epsilon \phi_2$ may be significant compared to the sum $\sqrt{\pi} \phi_1 + \phi_3$ as exemplified by the following data for $kT = 2.0$ keV.

$$\begin{aligned} \phi_1 &= 3.558 \times 10^3, \\ \phi_3 &= -6.306 \times 10^3, \\ \sqrt{\pi} \phi_1 + \phi_3 &= -6.735 \times 10^{-7}, \\ \phi_2 &= 4.755 \times 10^2. \end{aligned}$$

Confidence in the validity of the low-temperature trapezoidal integration results was obtained through additional code testing.

TABLE II

COMPARISON OF STEEP4 INTEGRATION METHODS FOR CALCULATING
MAXWELLIAN AVERAGED $\langle\sigma v\rangle$ WITH GAMOW CROSS SECTION

$$\text{Form: } \sigma(E) = (C_0/E) \exp(-BGAM/\sqrt{E})$$

Tempe- rature (keV)	$\langle\sigma v\rangle$ (arbitrary units)				
	STEEP4 Integration Method				
	Analytic Solution	Steepest Descent	Gauss-Hermite Quadrature	Dense Trapezoidal	Adaptive Trapezoidal
1	0.70820-5	0.19738-6	0.20147-6	0.20145-6	0.20144-6
2	0.81625-5	0.76103-5	0.78083-5	0.78071-5	0.78069-5
3	0.44275-4	0.42958-4	0.44233-4	0.44227-4	0.44226-4
4	0.12966-3	0.12557-3	0.12965-3	0.12964-3	0.12964-3
5	0.27561-3	0.26632-3	0.27556-3	0.27559-3	0.27559-3
10	0.19417-2	0.18604-2	0.19396-2	0.19416-2	0.19416-2
50	0.31875-1	0.29701-1	0.31796-1	0.31873-1	0.31874-1
100	0.62369-1	0.57159-1	0.62555-1	0.62365-1	0.62366-1
300	0.11578+0	0.10260+0	0.11710+0	0.11577+0	0.11577+0
500	0.13384+0	0.11637+0	0.13552+0	0.13383+0	0.13383+0
1000	0.14590+0	0.12310+0	0.14725+0	0.14588+0	0.14589+0
Av Computing					
Time/Temperature		0.00128	0.00286	0.1238	0.2190
(CDC 7600-sec)					

From Table II, the alternate integration routines, while providing approximately two orders of magnitude advantage in running time, are shown to be relatively poorer in computational accuracy. The steepest descent (saddle point) results are consistently lower than the analytic results, being $\sim 3\%$ low at 4 keV and becoming as much as 18.5% low at 1 MeV. The Gauss-Hermite quadrature results are considerably better, being within $\sim 0.01\%$ of the analytic result at 4 keV, $\sim 0.25\%$ low at 50 keV, and becoming as much as 1.25% high at 500 keV.

Tables III and IV compare STEEP4 Maxwellian $\langle\sigma v\rangle$ integration results for two additional analytic cross-section forms. In Table III, a cross section of the form

$$\sigma(E) = (BGAM)^2 E - 0.3 E^2 \quad (105)$$

has been used to compare integration results at low temperatures. (The value of $\sigma(E)$ from Eq. (105) becomes negative at high energy such that a negative contribution to the analytic $\langle\sigma v\rangle$ result becomes significant at temperatures above ~ 300 keV.) In Table IV, comparative results are shown for the cross-section form:

$$\sigma(E) = 2(BGAM) - (BGAM/E) + 1.0/E^{3/2} \quad (106)$$

Since $\sigma(E)$ from Eq. (106) becomes negative at low energies, these results provide a test of the integration methods at relatively high temperatures (above ~ 10 keV).

The cross-section forms of Eqs. (105) and (106) were selected on the basis of (1) possessing exact analytic solutions for $\langle\sigma v\rangle$, (2) exhibiting shapes similar to actual cross-section shapes, and

TABLE III

COMPARISON OF STEEP4 INTEGRATION METHODS FOR
CALCULATING MAXWELLIAN AVERAGED $\langle \sigma v \rangle$ WITH CROSS SECTION

$$\text{Form: } \sigma(E) = \alpha_1 E - \alpha_2 E^{\frac{1}{2}}$$

Temperature (keV)	$\langle \sigma v \rangle$ (arbitrary units)				
	STEPP4 Integration Method				
Analytic Solution	Steepest Descent	Gauss-Hermite Quadrature	Dense Trapezoidal	Adaptive Trapezoidal	
1	0.10626+12	0.16055+11	0.10596+12	0.10626+12	0.10626+12
2	0.30031+12	0.10034+12	0.30142+12	0.30031+12	0.30031+12
3	0.55129+12	0.25596+12	0.55956+12	0.55128+12	0.55127+12
4	0.84811+12	0.47226+12	0.85337+12	0.84810+12	0.84809+12
5	0.11844+13	0.73936+12	0.11808+13	0.11844+13	0.11843+13
10	0.33370+13	0.26096+13	0.33223+13	0.33369+13	0.33368+13
50	0.36157+14	0.27053+14	0.36011+14	0.36154+14	0.36155+14
100	0.98195+14	0.61450+14	0.97609+14	0.98183+14	0.98185+14
300	0.42559+15	0.19017+15	0.42365+15	0.42771+15	0.47723+15
500	0.73360+15	0.30185+15	0.76831+15	0.78369+15	0.78369+15
1000	0.78711+15	0.52946+15	0.16436+16	0.16482+16	0.16482+16
Av Computing					
Time/Temperature	0.00127	0.00266	0.1085	0.1722	
(CDC 7600-sec)					

TABLE IV

COMPARISON OF STEEP4 INTEGRATION METHODS FOR
CALCULATING MAXWELLIAN AVERAGED $\langle\sigma v\rangle$ WITH CROSS SECTION

$$\text{Form: } \sigma(E) = \alpha_1 - \alpha_2/E + (\alpha_3/E)^{3/2}$$

$\langle\sigma v\rangle$ (arbitrary units)					
Temper- ature (keV)	STEPP4 Integration Method				
	Analytic Solution	Steepest Descent	Gauss-Hermite Quadrature	Dense Trapezoidal	Adaptive Trapezoidal
1	0.16313+10	0.13066+9	0.16938+10	0.19082+10	0.19082+10
2	0.33305+10	0.53015+9	0.34207+10	0.34365+10	0.34363+10
3	0.45044+10	0.10450+10	0.48221+10	0.45635+10	0.45626+10
4	0.54489+10	0.16030+10	0.58304+10	0.54878+10	0.54872+10
5	0.62591+10	0.21734+10	0.65632+10	0.62872+10	0.62863+10
10	0.93275+10	0.48935+10	0.87002+10	0.93375+10	0.93370+10
50	0.21718+11	0.17809+11	0.22120+11	0.21718+11	0.21718+11
100	0.30868+11	0.25894+11	0.29989+11	0.30867+11	0.30867+11
300	0.53642+11	0.40246+11	0.53621+11	0.53639+11	0.53641+11
500	0.69298+11	0.47038+11	0.69451+11	0.69293+11	0.69296+11
1000	0.98051+11	0.55935+11	0.97338+11	0.98045+11	0.98050+11
Av Computing					
Time/Temperature		0.00128	0.00283	0.1284	0.1778
(CDC 7600-sec)					

(3) providing a suitable range of temperatures with meaningful results. Again the PREST code was used to compute the analytic results as well as to provide punched cross-section data for STEEP4 input (200 values logarithmically spaced between 0.5 keV and 3.0 MeV for Table III results; 188 values logarithmically spaced between ~ 0.8 keV and 3.0 MeV for Table IV results). Cubic cross-section interpolation was used for the Table III STEEP4 results; log-log interpolation was used for the Table IV results.

As was the case for the Gamow cross-section form, the trapezoidal integration results are in excellent agreement (to within 0.01%) with the applicable analytic results of Tables III and IV. Again the alternate integration routines exhibit substantially poorer accuracy. The Gauss-Hermite quadrature results differ from the applicable analytic results by as much as 2 to 3%. Since the steepest descent integration method is based upon a very specific cross-section shape, it is not surprising that the steepest descent results vary from the applicable analytic results of Tables III and IV by as much as a factor of 6.5. From these results it is concluded that the trapezoidal integration is required for highly accurate $\langle\sigma v\rangle$ results. For situations where less accuracy (2-3%) in $\langle\sigma v\rangle$ is acceptable and a very fast computation time is required, the Gauss-Hermite quadrature integration option may be appropriate.

For the preceding code tests the default parameters were used in the trapezoidal integration routines. To develop some insight to the tradeoff between computational time and accuracy, additional code tests were made for the Gamow cross-section form and for the sample problem of the

T(d,n) α reaction for which the default integration parameters were overridden

Table V presents results for the sensitivity of computational time and accuracy to the integration parameters for the self-terminating dense trapezoidal integration option. These results indicate that the computational time is generally more sensitive to the value of SCALF and that computational accuracy is insensitive to the value of EP1 as long as $EP1 \leq 10^{-4} SCALF$. Thus, a suitable combination of values to achieve a high degree of accuracy ($\sim 0.01\%$) appears to be the default values of $SCALF = 0.01$ and $EP1 = 0.1E-5$.

Tables VI and VII present similar results for the adaptive trapezoidal integration routine. For this routine, accuracy and running time appear to be least sensitive to the value of EPS2. From these and previous results, the running time for this integration option with default parameters is about twice the time required for the straightforward dense trapezoidal integration (with default parameters), and comparable accuracy is achieved. The results of Tables VI and VII suggest that no running time improvements can be attained by altering the value of SCALG. However, the results of Table VI suggest that a substantial improvement in computational time with the adaptive trapezoidal integration can be achieved while accuracy is maintained by relaxing the value of EPS1 (Case B1). The results (Case B1) of Table VII also show this for the case of a realistic reaction cross section. Moreover, these results show the sensitive interaction between the various integration parameters. For example, note the improved accuracy at 10 and 100 keV for Case B1 (compare to Table V values) even though the value of EPS1 has been relaxed from the "standard case."

TABLE V

STEEP4 DENSE TRAPEZOIDAL INTEGRATION MAXWELLIAN AVERAGED $\langle\sigma v\rangle$ RESULTS
VERSUS VARIATION IN INTEGRATION ROUTINE PARAMETERS

Integration Parameters		Gamow Cross-Section Form				T(d,n) α Fusion Cross Section				
SCALE	EPl	$\langle\sigma v\rangle$ (arb. units)		Av Time/Temp (CDC 7600-sec)	Comp. Time/Temp (CDC 7600-sec)	$\langle\sigma v\rangle$ (cm ³ /sec)				Av Time/Temp (CDC 7600-sec)
		(10 keV)	(100 keV)			(1 keV)	(10 keV)	(100 keV)	(1 MeV)	
"Standard Case"	0.01	0.1E-5	0.19416-2	0.62365-1	0.1238	0.65828-20	0.10965-15	0.83707-15	0.27648-15	0.0798
A1	0.01	0.1E-4	0.19410-2	0.62335-1	0.1095	0.65810-20	0.10962-15	0.83687-15	0.27632-15	0.0653
A2	0.01	0.1E-6	0.19417-2	0.62368-1	0.1389	0.65830-20	0.10966-15	0.83704-15	0.27649-15	0.0929
A3	0.02	0.1E-5	0.19416-2	0.62367-1	0.0652	0.65829-20	0.10966-15	0.83703-15	0.27646-15	0.0426
A4	0.001	0.1E-5	0.19409-2	0.62334-1	1.0708	0.65809-20	0.10962-15	0.83687-15	0.27630-15	0.6381
A5	0.001	0.1E-6	--	--	--	0.65828-20	0.10965-15	0.83703-15	0.27646-15	0.7791
A6	0.001	0.1E-7	--	--	--	--	0.10966-15	0.83705-15	--	--

TABLE VI

STEEP4 ADAPTIVE TRAPEZOIDAL INTEGRATION RESULTS FOR MAXWELLIAN AVERAGED
 $\langle\sigma v\rangle$ FOR GAMOW CROSS SECTION VERSUS VARIATION IN INTEGRATION ROUTINE PARAMETERS

	<u>Integration Parameters</u>			<u>$\langle\sigma v\rangle$ (arbitrary units)</u>				Av Comp. Time/Temp (CDC 7600-sec)
	SCALG	EPS1	EPS2	(1 keV)	(10 keV)	(100 keV)	(1 MeV)	
"Standard Case"	0.10	0.1E-3	0.1E-5	0.20145-6	0.19416-2	0.62366-1	0.14589+0	0.2190
B1	0.10	0.1E-2	0.1E-5	0.20145-6	0.19416-2	0.62366-1	0.14589+0	0.0749
B2	0.10	0.1E-4	0.1E-5	0.20143-6	0.19414-2	0.62358-1	0.14588+0	0.6076
B3	0.10	0.1E-3	0.1E-4	0.20137-6	0.19406-2	0.62345-1	0.14583+0	0.1779
B4	0.10	0.1E-3	0.1E-6	0.20145-6	0.19417-2	0.62368-1	0.14589+0	0.2622
B5	0.20	0.1E-3	0.1E-5	0.20144-6	0.19416-2	0.62366-1	0.14589+0	0.2202
B6	0.01	0.1E-3	0.1E-5	0.20145-6	0.19416-2	0.62364-1	0.14588+0	0.4086

TABLE VII

STEEP4 ADAPTIVE TRAPEZOIDAL INTEGRATION RESULTS FOR MAXWELLIAN AVERAGED $\langle\sigma v\rangle$ FOR
 $T(d,n)\alpha$ REACTION CROSS SECTION VERSUS VARIATION IN INTEGRATION ROUTINE PARAMETERS

	Integration Parameters			$\langle\sigma v\rangle$ (cm ³ /sec)				Av Comp. Time/Temp (CDC 7600-sec)
	SCALG	EPS1	EPS2	(1 keV)	(10 keV)	(100 keV)	(1 MeV)	
"Standard Case"	0.10	0.1E-3	0.1E-5	0.65826-20	0.10509-15	0.83701-15	0.26536-15	0.1497
B1	0.10	0.1E-2	0.1E-5	0.65827-20	0.10965-15	0.83715-15	0.27649-15	0.0561
B2	0.10	0.1E-4	0.1E-5	0.65820-20	0.10508-15	0.58398-15	0.26536-15	0.2631
B3	0.10	0.1E-3	0.1E-4	0.65802-20	0.10506-15	0.83679-15	0.26531-15	0.1298
B4	0.10	0.1E-3	0.1E-6	0.65829-20	0.10509-15	0.83704-15	0.26537-15	0.1587
B5	0.20	0.1E-3	0.1E-5	0.65826-20	0.10509-15	0.83701-15	0.26536-15	0.1499
B6	0.01	0.1E-3	0.1E-5	0.65827-20	0.10509-15	0.62119-15	0.27645-15	0.2597

The reduced accuracy of the standard case at the intermediate temperatures is due to a premature termination of the integration that apparently results from the small integration panel sizes imposed by the smaller EPS1 value. Because of the sensitive nature of this integration option, it is recommended that the more straightforward dense trapezoidal integration option be used in general, unless extensive testing is carried out beforehand.

2. Slowing-Down $\langle\sigma v\rangle$ Integration

The slowing-down component of $\langle\sigma v\rangle$ requires a double integration (Eq. 34). This integration can be simplified to a single integral for the case of a constant cross section (e.g., $\sigma(v_r) = 1.0$). In this case, I_{ij} of Eq. (34) reduces to

$$I_{ij} = \frac{2}{\sqrt{\pi} \ln(\hat{E}/\check{E})} \int_{\check{v}_i}^{\hat{v}_i} \frac{dv_i}{v_i^2} \left[\frac{\sqrt{\pi}(\alpha^2 + 2v_i^2)}{2} \operatorname{erf}\left(\frac{v_i}{\alpha}\right) + \alpha v_i \exp\left(-v_i^2/\alpha^2\right) \right], \quad (107)$$

$$\text{where } \alpha = \sqrt{\frac{2kT}{m_j}}. \quad (108)$$

A small separate code (CHINT) was written to numerically integrate Eq. (107) using Simpson's rule. These "analytic" results are compared to corresponding STEEP4 results in Table VIII for the case where $A_i = 2.0$ amu, $A_j = 3.0$ amu, $kT = 5.0$ keV, $\hat{E} = 80.0$ keV, and $\check{E} = 10.0$ keV. Also shown are the results from an additional program (DINT1) which solves the simplified Eq. (35). These results confirm the adequacy of the STEEP4 double integration routines. They also show that even for this rather simple case the use of Eq. (35) can lead to considerable

TABLE VIII
RESULTS OF STEEP4 SLOWING-DOWN $\langle\sigma v\rangle$ INTEGRATION
FOR UNITY CROSS-SECTION TEST CASES

	Slowing-Down $\langle\sigma v\rangle$ (arbitrary units)	CDC-7600 Comp. Time
1. "Analytic" Solution	0.18292×10^{-15}	(~ 46 sec)
2. Equation 35	0.17274×10^{-15}	0.1 sec
3. STEEP4 (Eq. 34)	0.18290×10^{-15}	19 sec

inaccuracy (26%).

Additional test calculations were made, as shown in Table IX, to further compare the uses of Eqs. (34) and (35) and to examine the sensitivity of the final $\langle\sigma v\rangle$ results to the value assumed for $\check{E}$. Results are shown in Table X. The slowing-down $\langle\sigma v\rangle$ component [i.e., I_{ij} of Eqs. (34) and (35)] is seen to be underpredicted by as much as 30% with the use of Eq. (35). The slowing-down $\langle\sigma v\rangle$ component is also seen to be fairly sensitive to the value of $\check{E}$. For example, in test case 1, $\check{E}$ varies from 1.4 kT to 4.0 kT, and the slowing-down $\langle\sigma v\rangle$ varies from 0.38×10^{-2} to 0.64×10^{-2} . However, the net effect on the total $\langle\sigma v\rangle$ value is diminished due to a compensating change in the $\langle\sigma v\rangle$ fractions (i.e., a_i in Eqs. (22) and (29)). For example, a_i varies from 0.206 to 0.117 for the $\check{E}$ variation for case 1 noted above. Thus, in cases 1 and 3, for a variation of 1.4 kT to 4.0 kT in $\check{E}$, the variation in $\langle\sigma v\rangle$ is less than 2% about the $\check{E} = 2.0$ kT value. In test cases 2 and 4, the slowing-down $\langle\sigma v\rangle$ component fraction is relatively small (≈ 0.0003) and the net effect of the variation in the value of $\check{E}$ is negligible.

3. Screening Factors

The screening factor options of the STEEP4 code were tested by comparison to hand calculations for a D-T plasma (with 50% D, 50% T) over an ion density range from 10^{14} cm^{-3} to 10^{26} cm^{-3} and over a plasma temperature range from 10 eV to 10 MeV. These ranges cover the extent of screening strengths incorporated in the various screening factor formulations.

TABLE IX

STEEP4 SLOWING-DOWN <ov> TEST CASE PARAMETERS

	Test Case 1	Test Case 2	Test Case 3	Test Case 4
1. Cross section	Pure Gamow	Pure Gamow	T(d,n) α	T(d,n) α
2. Slowing-down particle			D	T
Mass (a m u)	2.0	3.0	2.01355	3.01550
Charge	1.0	1.0	1.0	1.0
Source Strength (sec ⁻¹ cm ⁻³)	0.333×10^{14}	0.3×10^{10}	0.333×10^{14}	0.3×10^{10}
Source Energy (keV)	80.0	1000.0	80.0	1000.0
3. Maxwellian particle			T	D
Mass (a m u)	3.0	2.0	3.01550	2.01355
Charge	1.0	1.0	1.0	1.0
Density (cm ⁻³) ^a	0.5×10^{14}	0.5×10^{14}	0.5×10^{14}	0.5×10^{14}
4. Plasma Ion Temperature (keV)	5.0	20.0	5.0	20.0
5. Slowing-down <ov>				
Integration Parameters	Default values			
Electron Temperature	Default value (= kT _i)			
Slowing-Down Fraction	Default value (Eq. 22)			
Slowing-Down Cutoff Energy, $\tilde{E}$	Variable			
6. Maxwellian <ov>				
Integration	Dense Trapezoidal with Default Parameter Values.			

^a An equal density Maxwellian component of the slowing-down particle also assumed.

TABLE X
STEEP4 SLOWING-DOWN $\langle\sigma v\rangle$ TEST CASE RESULTS

	Slowing- Down ^a $\langle\sigma v\rangle$ (Eq. 35)	<u>STEEP4 Results</u>		Total $\langle\sigma v\rangle$	STEEP4 Slowing-Down Comp. Time (CDC 7600-sec)
		Slowing-Down $\langle\sigma v\rangle$ Component	Maxwellian $\langle\sigma v\rangle$ Component		
<u>Test Case 1</u>					
a. $\tilde{E} = 7$ keV	0.25827-2	0.38282-2	0.27559-3	0.10077-2	20.9
b. 10	0.30254-2	0.44494-2	0.27559-3	0.10098-2	20.9
c. 20	0.45064-2	0.63732-2	0.27559-3	0.99066-3	20.9
<u>Test Case 2</u>					
a. $\tilde{E} = 25$ keV	0.43276-1	0.50523-1	0.83435-2	0.83567-2	17.8
b. 40	0.49548-1	0.56666-1	0.83435-2	0.83567-2	17.6
c. 80	0.62393-1	0.68457-1	0.83435-2	0.83563-2	18.0
<u>Test Case 3</u>					
a. $\tilde{E} = 7$ keV	-	0.21875-15	0.12982-16	0.55675-16	12.8
b. 10	-	0.25477-15	0.12982-16	0.55802-16	13.0
c. 20	-	0.36818-15	0.12982-16	0.54919-16	13.0
<u>Test Case 4</u>					
a. $\tilde{E} = 25$ keV	-	0.49595-15	0.42426-15	0.42428-15	14.8
b. 40	-	0.55403-15	0.42426-15	0.42429-15	15.4
c. 80	-	0.64813-15	0.42426-15	0.42431-15	15.0

^aTypical CDC 7600 computing time for this solution is ~ 0.05 sec.

For plasma temperatures and ion densities characteristic of those expected in future fusion reactors, the screening factor is essentially unity. Even for plasma conditions within a few orders of magnitude of these, the factors are very close to unity and there is no difference among the three screening factor formulations incorporated in STEEP4 as shown in Figures 5 and 6. Only at fairly low temperatures (< 1 keV) and extremely high densities ($\gtrsim 10^{22} \text{ cm}^{-3}$) do the factors differ substantially from unity and from one another for the three different formulations (see Figures 7 and 8). The screening factors as a function of temperature and density over the ranges examined are shown in Figures 9, 10, and 11 for the weak Salpeter, full range Salpeter, and Graboske-DeWitt formulations respectively.

Typical STEEP4 CDC-7600 computation time is ~ 0.002 second per screening factor.

Figure 5. STEEP4 Screening Factors for $T(d, n) \alpha$ Reaction
Test Problem with $N_i = 10^{14} \text{ cm}^{-3}$.

Figure 6. STEEP4 Screening Factors for T(d, n) α Reaction
Test Problem with $N_i = 10^{20} \text{ cm}^{-3}$.

Figure 7. STEEP4 Screening Factors for $T(d, n) \alpha$ Reaction
Test Problem with $N_i = 10^{22} \text{ cm}^{-3}$.

Figure 8. STEEP4 Screening Factors for $T(d, n) \alpha$ Reaction
Test Problem with $N_1 = 10^{26} \text{ cm}^{-3}$.

Figure 9. Weak Salpeter Screening Factor Versus Plasma Temperature and Density for $T(d, n) \alpha$ Reaction Test Problem.

Figure 10. Full Range Salpeter Screening Factor Versus Plasma Temperature and Density for $T(d, n) \alpha$ Reaction Test Problem.

Figure 11. Graboske De Witt Screening Factor Versus Plasma Temperature and Density for $T(d, n) \alpha$ Reaction Test Problem.

III. INPUT

This section describes the required input data cards for the STEEP4 code. A detailed input check list and summary are provided on subsequent pages. The first card of every data case is a title card. Subsequent cards (2 through 8) describe the desired STEEP4 options. Cards 9 through 31 provide the actual data to be used in computations. Finally, every input data case must be terminated by an end-of-case card which signals whether additional input data cases follow.

A sample input is listed in Appendix B. This multibase problem was selected to illustrate the variety of options provided in the STEEP4 code. Case 1 illustrates a "standard" option selection for the calculation of $\langle\sigma v\rangle$ for Maxwellian distribution for the $D(d,n)^3\text{He}$ reaction. In Case 2 the Maxwellian $\langle\sigma v\rangle$ computation for the $D(d,p)^3\text{He}$ reaction by all four of the available integration techniques is requested (KINTE = 5 on card 2). Also, selected plot output is requested (KPLØT = 2 and card 3 is present). Case 3 requests that Maxwellian $\langle\sigma v\rangle$ for the $^3\text{He}(d,p)\alpha$ reaction be computed with screening factor calculations for all three screening treatments (KSCRN = 5). In addition, a selected set of expanded print output has been requested (KPRNT = 3 and cards 6-7 are present). Case 4 input indicates the calculations of $\langle\sigma v\rangle$ for the $T(d,n)\alpha$ reaction at logarithmically spaced plasma temperature intervals (KTEMP = -1). Full expanded print output is requested (KPRNT = 2) as well as selected punched card output (KPNCH = 2 and presence of cards 4-5). Finally, Case 5 requests an evaluation of the slowing down component of $\langle\sigma v\rangle$ for D slowing into a D-T plasma

(KTEMP = 2) and certain internal program parameters are asked to be overridden by user input (KCNTRL = 2, and cards 8, 13, and 30 are present). Note also that no cross section-energy pair data have been input in this case since the use of these data from the previous case has been requested (KDATA = 2).

STEEP4 Input Check List

Card 1   TITLE (Format: 8A10)

Card 2   KDATA, KINTE, KTEMP, KSCRN, KPLØT, KPNCH, KPRNT, KCNTL
(Format: 8I6)

Program option parameters:

KDATA = 1, Cross sections input in ENDF/B Format in this case.

= 2, Use cross sections from previous case.

KINTE = 1,   Use Steepest Descent integration option.

```
= 2,      Use Gauss-Hermite integration option.
```

= 3,   Use Self-terminating Dense Trapezoidal integration.

= 4,   Use Adaptive Trapezoidal

integration.

= 5,   Use all of the above integration options.

(Note: when KINTE = 5, no slowing-down or screening calculations are performed.)

KTEMP = ± 1 , Calculate Maxwellian component of $\langle \sigma v \rangle$ only.

= ± 2 , Compute slowing-down component of $\langle \sigma v \rangle$ for

"projectile" nuclei and total Maxwellian component.

= ± 3 , Compute slowing-down component of $\langle \sigma v \rangle$ for

"target" nuclei and total Maxwellian component.

= ± 4 , Compute slowing-down components of $\langle \sigma v \rangle$ for both nuclei as well as Maxwellian.

(Note: when KTEMP < 0 temperature intervals are incremented logarithmically; linear intervals otherwise.)

MPLØT (1): Input cross section (barns) vs. lab energy (keV).

MPLØT (2): Separate figures of slowing-down components of $\langle \sigma v \rangle$ (cm^3/sec) vs. plasma temperature (keV).

MPLØT (3): Above plots, all on same figure.

(Note: the two preceding options available only if $KTEMP \geq 2$ or $KTEMP \leq -2$.)

MPLØT (4): Separate figures of Maxwellian component of $\langle \sigma v \rangle$ (cm^3/sec) vs. plasma temperature (keV).

(Note: only one figure plotted unless $KINTE = 5$.)

MPLØT (5): Above plots, all on same figure (available only if $KINTE = 5$).

MPLØT (6): Separate figures of screening factor vs. plasma temperature (keV) (only one figure plotted unless $KSCRN = 5$, not available if $KSCRN = 1$).

MPLØT (7): Above plots, all on same figure (available only if $KSCRN = 5$).

MPLØT (8): Total (screened) $\langle \sigma v \rangle$ (cm^3/sec) vs. plasma temperature (keV) (not available if $KINTE = 5$).

MPLØT (9): Total (screened) $\langle \sigma v \rangle$ s (cm^3/sec) vs. plasma temperature (keV) on same figure for various screening treatments (available only if $KSCRN = 5$).

Cards 4-5

MPNCH (IMPNC = 1,19)

(Format: 12I6)

Punched card output option parameters. These cards present if and only if KPNCH = 2. The following punched card output options may be requested by the value of the indicated

parameter. Parameter value = 0 for option not desired, = 1 when option is desired:

- MPNCH (1): Punch lab energies (keV) of input cross section.
- MPNCH (2): Punch input cross sections (barns).
- MPNCH (3): Punch plasma temperatures (keV).
- MPNCH (4): Punch values of projectile slowing-down $\langle\sigma v\rangle$ fraction a_1 of Eq. (22). (Available only if $KTEMP = \pm 2$ or $KTEMP = \pm 4$.)
- MPNCH (5): Punch values of target slowing-down $\langle\sigma v\rangle$ fractions. (Available only if $KTEMP = \pm 3$ or $KTEMP = \pm 4$.)
- MPNCH (6): Punch values of total $\langle\sigma v\rangle$ slowing-down components (cm^3/sec). (Not available if $KTEMP = \pm 1$.)
- MPNCH (7): Punch values of projectile slowing-down component of $\langle\sigma v\rangle$ (cm^3/sec). (Available only if $KTEMP = \pm 2$ or $KTEMP = \pm 4$.)
- MPNCH (8): Punch values of target slowing-down component of $\langle\sigma v\rangle$ (cm^3/sec). (Available only if $KTEMP = \pm 3$ or $KTEMP = \pm 4$.)
- MPNCH (9): Punch values of Maxwellian $\langle\sigma v\rangle$ (cm^3/sec) for Steepest Descent integration. (Available for all KINTE values.)
- MPNCH (10): Punch values of Maxwellian $\langle\sigma v\rangle$ (cm^3/sec) for Gauss-Hermite integration (KINTE must = 2 or 5).
- MPNCH (11): Punch values of Maxwellian $\langle\sigma v\rangle$ (cm^3/sec) for

Dense Trapezoidal integration (KINTE must = 3 or 5).

MPNCH (12): Punch values of Maxwellian $\langle \sigma v \rangle$ (cm^3/sec) for Adaptive Trapezoidal integration (KINTE must = 4 or 5).

MPNCH (13): Punch values of Weak Salpeter screening factors (KSCRN must = 2 or 5).

MPNCH (14): Punch values of Full Range Salpeter screening factors (KSCRN must = 3 or 5).

MPNCH (15): Punch values of Graboske-DeWitt screening factors (KSCRN must = 4 or 5).

MPNCH (16): Punch values of total $\langle \sigma v \rangle$ (cm^3/sec). (Not available for KINTE = 5; total screened $\langle \sigma v \rangle$ punched unless KSCRN = 1 or 5, then unscreened $\langle \sigma v \rangle$ is punched.)

MPNCH (17): Punch values of total screened $\langle \sigma v \rangle$ (cm^3/sec) for Weak Salpeter screening.

MPNCH (18): Punch values of total screened $\langle \sigma v \rangle$ (cm^3/sec) for Full Range Salpeter screening.

MPNCH (19): Punch values of total screened $\langle \sigma v \rangle$ (cm^3/sec) for Graboske-DeWitt screening.

(Note: the three preceding options are available only if KSCRN = 5.)

Cards 6-7

MPRNT (IMPRT = 1,13)

(Format: 12I6)

Selected expanded printed output option parameters. These

cards present if and only if KPRNT = 3. A parameter value = 1 indicates the additional print option is requested (= 0 otherwise). The following additional print options are available:

- MPRNT (1):   Print input cross section-energy pairs after conversion of cross section to cm^2 units and energy to center of mass keV units.
- MPRNT (2):   Print cross-section interpolation internal break energies (EBRK) in center of mass keV units.
- MPRNT (3):   Print Gamow cross-section interpolation factors (B_i, S_i). (Available only if Gamow interpolation requested for some interval; KXINT = 1 on card 22.)
- MPRNT (4):   Print log-log cross-section interpolation factors (C_i, A_i). (Available only if KXINT = 2 for some interval.)
- MPRNT (5):   Print cubic cross-section interpolation factors (D_i, H_i, F_i, G_i). (Available only if KXINT = 3 for some interval.)
- MPRNT (6):   Print (calculated) results for selected parameters in slowing-down $\langle \sigma v \rangle$ calculation. (Not available if KTEMP = ± 1 .)
- MPRNT (7):   Print diagnostic results for slowing-down $\langle \sigma v \rangle$ integration (not currently available).
- MPRNT (8):   Print intermediate results for Maxwellian $\langle \sigma v \rangle$ Steepest Descent integration.

- = 3, Use NT values of $\check{E}_i$ specified on card(s) 29 in slowing-down calculation; NT = number of plasma temperature evaluations.
- MCNTL (2) = 1, Use value of CTE specified on card 30 to determine $kT_e (= CTE * kT_i)$ in slowing-down calculation.
- = 2, Use single value of kT_e specified on card 30 in slowing-down calculation for all plasma temperatures.
- = 3, Use NT values of kT_e specified on card(s) 30 in slowing-down calculation.
- MCNTL (3) = 1, Use two single values of a_i for slowing-down $\langle \sigma v \rangle$ fractions as specified on card 31 instead of evaluating a_i 's with Eq. (22); first value corresponds to projectile slowing down, second value to target slowing-down.
- = 2, Use 2 * NT values of a_i for slowing-down $\langle \sigma v \rangle$ fractions as specified on card(s) 31; NT = number of plasma temperature evaluations.
- MCNTL (4) = 1, Use value of SF specified on card 9 instead of 0.10 in Full Range Salpeter screening calculation (Eqs. 84-87).
- MCNTL (5) = 1, Use values of integration parameters (SCALD, EP2, EP3, ND2) specified on card 10 instead of internally specified values (0.01, 0.0001, 0.000001, 10000) for slowing-down $\langle \sigma v \rangle$ integration.

MCNTL (6) = 1, Use values of integration parameters (EP4, ND3) specified on card 11 instead of internal values (0.000001, 200) for slowing-down $\langle\sigma v\rangle$ integration.

MCNTL (7) = 1, Use values of integration parameters (SCALF, EP1, ND1) specified on card 12 instead of internal values (0.01, 0.000001, 10000) for Dense Trapezoidal $\langle\sigma v\rangle$ integration.

MCNTL (8) = 1, Use values of integration parameters (SCALG, EPS1, EPS2, NI) specified on card 13 instead of internal values (0.10, 0.0001, 0.000001, 10000) for Adaptive Trapezoidal integration.

Card 9 SF (Format: E12.3)

User specified value of SF in Full Range Salpeter calculation (Eqs. 84-87) to be used in lieu of internally specified value (0.10). This card present if and only if MCNTL (4) = 1.

Card 10 SCALD, EP2, EP3, ND2 (Format: 3E12.6, I6)

User specified values for slowing-down $\langle\sigma v\rangle$ integration to be used in lieu of internally specified values (0.01, 0.0001, 0.000001, 10000). This card present if and only if MCNTL (5) = 1.

Card 11 EP4, ND3 (Format: E12.6, I6)

User specified values to be used in slowing-down $\langle\sigma v\rangle$ integration

in lieu of internal values (0.000001, 200). This card present
if and only if MCNTL (6) = 1.

Card 12   SCALF, EP1, ND1   (Format: 2E12.6, I6)

User specified values to be used in Dense Trapezoidal $\langle \text{ov} \rangle$ integration instead of internal values (0.01, 0.000001, 10000). This card present if and only if MCNTL (7) = 1.

Card 13 SCALG, EPS1, EPS2, NI (Format: 3E12.6, I6)

User specified values to be used in Adaptive Trapezoidal ☐ integration in place of internal values (0.10, 0.0001, 0.000001, 10 000). This card present if and only if MCNTL (8) = 1.

Card 14   NMAT, IMATT, IMATP   (Format: 3I6)

Values for the number of ion types (NMAT), index of 'target ion (IMATT), and index of 'projectile ion (IMATP). Subsequent cross-section data are input versus energy in "lab" system whereby the energy values correspond to the projectile ion kinetic energy relative to the (stationary) target ion. Subsequent data cards specify the composition (i.e., number density, charge, atomic mass) of the plasma in lists of NMAT (≤ 12) values. The values of IMATT and IMATP specify the position in these lists of the appropriate properties of the target and projectile ions, respectively.

Cards 15-16 ZMAT (IMAT = 1, NMAT) (Format: 6E12.3)

NMAT values for the ion charge numbers (dimensionless).

ZMAT (IMAT)*e (where e is the charge of an electron)

is the charge for the IMAT plasma ion type. (Note: Card 16 present if and only if NMAT > 6.)

Cards 17-18 AMAT (IMAT = 1, NMAT) (Format: 6E12.3)

NMAT values for the ion masses ((units: amu), where AMAT

(IMAT) = the mass for the IMAT plasma ion type. (Note:

Card 18 present if and only if NMAT > 6.)

Cards 19-20 DMAT (IMAT = 1, NMAT) (Format: 6E12.3)

NMAT values for the ion number densities (units: cm^{-3}),

where DMAT (IMAT) = the number density for the IMAT plasma ion type. (Note: Card 20 present if and only if NMAT > 6.)

Card 21 NS, NXS (Format: 2I6)

NS is the number of energy-cross section pairs to be specified subsequently to describe the variation of cross section versus energy. NXS is the number of intervals desired in the cross-section interpolation scheme. (Note: $NS \leq 200$, $NXS \leq 6$.)

Card 22 KXINT (IX = 1, NXS) (Format: 6I6)

Specification for the type of cross-section interpolation to be used for each of the NXS interpolation intervals:

KXINT (IX) = 1, use Gamow interpolation in the IX interval,
 KXINT (IX) = 2, use log-log interpolation in the IX interval,
 KXINT (IX) = 3, use cubic interpolation in the IX interval.

Card 23   EBRK (IX = 1, (NXS-1))   (Format: 5E12.3)

Breakpoint energy values (keV in lab system) that specify
 the cross-section interpolation intervals:

First interval: 0 to EBRK (1),

IXth interval: EBRK (IX-1) to EBRK (IX),

Last (NXSth) interval: EBRK (NXS-1) to ∞ .

Card(s) 24   (ES, XS) (IS = 1, NS)   (Format: 6E11.5)

Energy-cross section pointwise data pairs (ENDF/B format)
 that describe the variation of cross section versus energy.
 Energy units are eV (lab system); cross-section units are
 barns (10^{-24} cm^2). A total of $2 * NS$ values (see Card 21)
 must be specified. Several data cards, therefore, are
 usually required. The data pairs must be in order by
 ascending energy. Card(s) 24 should not be present if
KDATA = 2 on Card 2.

Card 25   NT   (Format: I6)

NT is the number of plasma temperature values for which
 results are to be calculated. (Not : $NT \leq 200$.)

Card 26   TMIN, TMAX   (Format: 2E12.3)

TMIN is the first plasma ion temperature value for which

results are to be calculated. TMAX is the last temperature value. NT-2 additional temperature values, evenly spaced between TMIN and TMAX, will also be evaluated. (The intervals will be logarithmically spaced if KTEMP < 0.) The values of TMIN and TMAX should be in keV energy units (i.e., kT).

Card 27   SRCE(1), ESRC(1)   (Format: 2E12.3)

SRCE(1) is the projectile ion source strength ($\text{cm}^{-3}\text{sec}^{-1}$), S_i , and ESRC(1) is the projectile ion source energy (keV), E_o , to be used in computing the projectile ion slowing-down $\langle\sigma v\rangle$ component. This card present if and only if KTEMP = ± 2 or ± 4 .

Card 28   SRCE(2), ESRC(2)   (Format: 2E12.3)

SRCE(2) and ESRC(2) are the target ion source strength ($\text{cm}^{-3}\text{sec}^{-1}$), S_i , and source energy (keV), E_o , to be used in computing the target ion slowing-down $\langle\sigma v\rangle$ component. This card present if and only if KTEMP = ± 3 or ± 4 .

Card(s) 29   EL~~OW~~F (if MCNTL(1) = 1)   (Format: E12.3)
                  or EL~~OW~~1, EL~~OW~~2 (if MCNTL(1) = 2)   (Format: 2E12.3)
                  or EL~~OW~~A (IT = 1, NT) (if MCNTL(1) = 3)   (Format: 6E12.3)

The data on this card define the values of $\check{E}_i$ to be used in computing the ion slowing-down distributions. The

standard calculation (corresponds to default value of

$EL\emptyset WF = 2.0$) assumes $\check{E}_i = 2 kT_i$. However, when $MCNTL(1) \neq 0$

(Card 8) $\check{E}_i$ is defined as follows:

$MCNTL(1) = 1$ (on Card 8): $\check{E}_i = EL\emptyset WF * kT_i$.

$MCNTL(1) = 2$ (on Card 8):

$\check{E}_i = EL\emptyset W1$ (keV) for projectile slowing-down for all plasma temperatures, and $\check{E}_i = EL\emptyset W2$ (keV) for target slowing down for all plasma temperatures.

$MCNTL(1) = 3$ (on Card 8): $\check{E}_i = EL\emptyset WA(IT)$, (keV) for the IT th plasma temperature. This card present if and only if $MCNTL(1) = 1, 2$, or 3 on Card 8. (Note: when $NT > 6$ and $MCNTL(1) = 3$, more than one card will be required.)

Card(s) 30 CTE (if $MCNTL(2) = 1$) (Format: E12.3)
or TE (if $MCNTL(2) = 2$) (Format: E12.3)
or TEA ($IT = 1$, NT) (if $MCNTL(2) = 3$) (Format: 6E12.3)

The data on this card define the values of kT_e , the electron temperature, to be used in computing the ion slowing-down distributions. The standard calculation (corresponds to default value of $CTE = 1.0$) assumes that $kT_e = kT_i$. When $MCNTL(2) \neq 0$ (Card 8) kT_e is determined as follows:

$MCNTL(2) = 1$ (on Card 8): $kT_e = CTE * kT_i$.

$MCNTL(2) = 2$ (on Card 8): $kT_e = TE$ (keV) for all plasma temperatures.

MCNTL(2) = 3 (on Card 8): $KT_e = TEA(IT)$, (keV) for the ITth plasma temperature. This card present if and only if MCNTL(2) = 1, 2, or 3 on Card 8. (Note: when NT > 6 and MCNTL(2) = 3, more than one card will be required.)

Card(s) 31 AMXW1, AMXW2 (if MCNTL(3) = 1) (Format: 2E12.3)
 or AMXW1 (IT = 1, NT), AMXW2 (IT = 1, NT) (if MCNTL(3) = 2)
 (Format: 6E12.3)

The data on this card define the values of a_i , the slowing-down $\langle \sigma v \rangle$ fractions, in lieu of using Eq. (22). If MCNTL(3) = 1 (on Card 8), then AMXW1 is the value of a_i for projectile slowing-down distributions and AMXW2 is the value for target slowing down for all plasma temperatures. If MCNTL(3) = 2 (on Card 8), then the projectile slowing-down $a_i = AMXW1 (IT)$ for the ITth plasma temperature and the target $a_i = AMXW2 (IT)$ for the ITth plasma temperature. This card present if and only if MCNTL(3) = 1 or 2 on Card 8. (Note: more than one card will be required when NT > 3 and MCNTL(3) = 2.)

Card 32 NCSID (Format: I6)

End-of-case indicator. If NCSID = 1, data cards for additional cases follow. NCSID = 0 at end of last case to be calculated.

Unless otherwise specified the preceding cards are required for all data cases. In particular Card 1 (alphanumeric title card),

Card 2 (basic option card), Cards 14 through 23, and 25 and 26 (basic data cards), and Card 32 (end-of-case card) are required in every data case. The presence of additional option cards (3 through 8) and additional data cards (24, 27, and 28) is determined by the values of the parameters on the basic option card (2). Finally, the ability to override certain internal program parameters is provided by cards 9 through 13 and 29 through 31. The presence of these cards is determined by the values of the parameters on the additional option card 8. This use is summarized in Table XI.

TABLE XI
INPUT DATA CARD SUMMARY FOR STEEP4

Card Function		Remarks	
<u>Required Cards</u>			
1	Title		
2	Basic Options		
14 - 26 ^a	Basic Data		
32	End of Case		
<u>Additional Cards</u> (Presence Determined by Parameter Values on Card 2)			
3	Additional Options	Present if KPLØT=2	on Card 2
4 - 5	Additional Options	Present if KPNCH=2	on Card 2
6 - 7	Additional Options	Present if KPRNT=3	on Card 2
8	Additional Options	Present if KCNTL=2	on Card 2
27	Additional Data	Present if KTEMP= ± 2 or ± 4	on Card 2
28	Additional Data	Present if KTEMP= ± 3 or ± 4	on Card 2
<u>Internal Parameter Override Cards</u> (Presence Determined by Parameter Values on Card 8)			
9	Parameter Override Data	Present if MCNTL(4)=1	on Card 8
10	Parameter Override Data	Present if MCNTL(5)=1	on Card 8
11	Parameter Override Data	Present if MCNTL(6)=1	on Card 8
12	Parameter Override Data	Present if MCNTL(7)=1	on Card 8
13	Parameter Override Data	Present if MCNTL(8)=1	on Card 8
29	Parameter Override Data	Present if MCNTL(1)=1, 2, or 3	on Card 8
30	Parameter Override Data	Present if MCNTL(2)=1, 2, or 3	on Card 8
31	Parameter Override Data	Present if MCNTL(3)=1 or 2	on Card 8

88 ^a Card(s) 24 must not be present if KDATA = 2 on Card 2.

IV. OUTPUT

Input and final calculated results are printed for all cases. In addition, a number of intermediate results may also be printed as specified by user input. A punched card option is available for specified variables as well as certain plot capabilities. Punched card output uses a 6E12.6 format. All final output quantities are labelled with physical units also printed. The basic final output consists of a tabulation of total $\langle \sigma v \rangle$ provided by plasma temperature (in both 10^6 °K and keV energy units) with the total value also broken down into Maxwellian, slowing-down, and screening factor components.

Listed in Appendix C is the output from the sample problem whose input is listed in Appendix B. The total CDC-7600 running time for the sample problem was 152.1 seconds. Of this a total of 141.5 seconds were required for computation: 4.7 seconds for case 1; 13.8 seconds for case 2; 5.0 seconds for case 3; 4.8 seconds for case 4; and 113.2 seconds for case 5. The film plot output from the second case and the punched card output from the fourth case of this problem are shown in Appendix C, Secs. C-II and C-III.

V. SUMMARY

Two unique features are introduced in STEEP4 for calculating charged-particle reaction rates. First, the high-energy tail of the energy distribution of plasma ions is joined smoothly with their Maxwellian component to account for high-energy ions released in the plasma by injection or as fusion reaction products, Eq. (20). The $1/E$ -like slowing-in distribution used here is limited to plasma environments for which:

- (a) the slowing-down time is smaller than the confinement time;
- (b) no leakage or absorption takes place during slowing-down;
- (c) the slowing-down ion is faster than background plasma ions but slower than plasma electrons;
- (d) the energy of the slowing-down ions is higher than the plasma temperature; and
- (e) Fokker-Planck calculations are applicable.

Nevertheless, these limitations can be relaxed through further development following the same steps as in Sec. II-A-2. The slowing-down component computed by STEEP4 is in good agreement with analytic solutions which confirm the adequacy of the double integration routines used in STEEP4. The code also includes provisions for cases with slowing-down dominated distributions.

The addition of slowing-down components to the ion distribution and the rapid computation algorithms provided in the code allow for examination of:

- (a) the effects of secondary reactions on the energy balance in fusion plasma devices;

(b) the contribution of the high-energy tail to the specific reactivity of exotic fuel cycles;

(c) the feasibility of two-component systems; and

(d) the feasibility of advanced fusion reactors incorporating advanced fuels, such as catalyzed D-D, D-³He, and p-¹¹B reactions.

The code can be used for rapid and relatively accurate computation of $\langle\sigma v\rangle$ for any reaction of interest whether the slowing-down component option is selected or not. The results can be stored and retrieved for on-line burn calculations or for energy balance and for evaluation of design parameters of reference and experimental fusion reactors.

The second feature provided in STEEP4 is the option of examining screening effects. This extends the applicability of the code to problems of astrophysical nature. Cases of weak, strong, and intermediate screening can be handled adequately by STEEP4.

Different algorithms are provided in the main program and the accompanying subroutines for integrating $\langle\sigma v\rangle$. The test of the alternative integration methods shows that trapezoidal integration is required for highly accurate results, and the Gauss-Hermite quadrature integration option is more appropriate for very fast computation with less accurate results. The steepest descent method is yet the fastest but the least accurate since it is based on a very specific cross-section shape. The balance between computational time and accuracy depends on the specific problem and on the objective of the calculations.

Three interpolation options are provided, the Gamow penetration form for low energies, and the log-log and the cubic interpolation for higher energies. Charged-particle reaction cross sections are input

to STEEP4 as a set of energy-cross section pairs in ENDF/B format. This permits the use of cross sections that have been evaluated by R-matrix analyses or other methods. In addition, a subroutine is provided to read normal header information up to the desired cross sections from an assumed library of charged-particle cross sections. These facilities can be used in calculating values of $\langle\sigma v\rangle$ for reactions other than fusion in laboratory systems.

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PROGRAM SIF294(1NP,OUT,PUN,FILM)

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C      E11 = VALUE OF THE CHARGE OF AN ELECTRON IN KEV-CM
C      E20001 = ENERGY(KEV) IN SLOWING DOWN PROJECTILE ION SOURCE
C      E20002 = ENERGY(KEV) IN SLOWING DOWN TARGET ION SOURCE
C      E20003 = CHARACTERISTIC (HYDROGEN TYPE) ENERGY IN FULL RANGE SALPETER SCREEN
C              FORMULATION
C      E21 = VALUE OF E11 IN GRABUSKE-DEWITT INTERMEDIATE SCREENING FORMULATION
C      FAC100 = 10-TH EXPONENTIAL FACTOR IN GAUSS-HERMITE QUADRATURE INTEGRATION
C              FORMULA
C      F20001 = FACTOR IN STEEPEST DESCENT INTEGRATION
C      F20002 = ENERGY OF ENERGY FACTOR IN SCREENING COMPUTATION RETURNED FROM
C              SUBROUTINE
C      F20003 = CURIC PARAMETER IN CURIC CROSS-SECTION INTERPOLATION
C      GAM = VALUE OF GAMMA IN GRABUSKE-DEWITT SCREENING FORMULATION
C      G112 = VALUE OF GAMMA-SQUARED IN GRABUSKE-DEWITT SCREENING FORMULATION
C      G21(S) = 15-TH PARAMETER IN CURIC CROSS-SECTION INTERPOLATION
C      G21 = VALUE OF GAMMA-1 IN SALPETER STRONG SCREENING FORMULATION
C      G22 = VALUE OF GAMMA-1-2 IN SALPETER STRONG SCREENING FORMULATION
C      G22 = VALUE OF GAMMA-2 IN SALPETER STRONG SCREENING FORMULATION
C      HBAR = PLANCKS CONSTANT/(C*HPI) IN KEV-SEC
C      HGI = (INTERACTION ENERGY PERTURBATION)/(MEAN THERMAL ENERGY) IN GRABUSKE-
C      DEWITT INTERMEDIATE SCREENING FORMULATION
C      HGS = (INTERACTION ENERGY PERTURBATION)/(MEAN THERMAL ENERGY) IN GRABUSKE-
C      DEWITT STRONG SCREENING FORMULATION
C      HGA = (INTERACTION ENERGY PERTURBATION)/(MEAN THERMAL ENERGY) IN GRABUSKE-
C      DEWITT WEAK SCREENING FORMULATION
C      H5(15) = 15-TH PARAMETER IN CURIC CROSS-SECTION INTERPOLATION
C      I0(1) = NUMBER OF INTEGRATION PANELS TO RIGHT OF EGAM IN TRAPEZOIDAL INTE-
C      GRATION RETURNED FROM INTEG2 OR INTEG3 SUBROUTINES
C      I0(2) = NUMBER OF INTEGRATION PANELS TO LEFT OF EGAM IN TRAPEZOIDAL INTE-
C      GRATION RETURNED FROM INTEG2 OR INTEG3 SUBROUTINES
CCCCCCCCCCCCCCCCCCCC
C      INDICES
CCCCCCCCCCCCCCCCCCCC
C      IDE = TRAPEZOIDAL INTEGRATION PARAMETER, DE, INDEX
C      IN = 19-POINT GAUSS-HERMITE QUADRATURE INDEX
C      INAT = PLASMA MATERIAL TYPE INDEX
C      INATP = INAT OF PROJECTILE ION
C      INATT = INAT OF TARGET ION
C      INCI = INDEX FOR INTERNAL PARAMETER OVERRIDE CONTROL ARRAY, MENTL
C      INPLOT = INDEX FOR PLOT CONTROL ARRAY, MNPLOT
C      INPNC = INDEX FOR PUNCH CONTROL ARRAY, MNPNC
C      INPT = INDEX FOR OPTIONAL SELECTIVE PRINT CONTROL ARRAY
CCCCCCCCCCCCCCCCCCCC
C      INC = Y-AXIS LOG-LINEAR CONTROL VARIABLE FOR PLOT PLOTTING ROUTINE, VALUE
C      RETURNED FROM PLOT SUBROUTINE
C      = 1 FOR LINEAR SCALE
C      = -1 FOR LOGARITHMIC SCALE
CCCCCCCCCCCCCCCCCCCC
C      MORE INDEXES
CCCCCCCCCCCCCCCCCCCC
C      I1 = 1-TH VALUE OF DATA INDEX
C      I2 = 1-TH VALUE OF DATA INDEX
C      I3 = 1-TH VALUE OF DATA INDEX
C      I4 = 1-TH VALUE OF DATA INDEX
CCCCCCCCCCCCCCCCCCCC
CCCCCCCCCCCCCCCCCCCC
C      GENERAL VARIABLES
CCCCCCCCCCCCCCCCCCCC
C      MENTL FOR INDICATING INTERNAL DEFAULT PARAMETERS
C      = 1 TO USE ALL DEFAULT VALUES
C      = 2 TO OVERRIDE SPECIFIED PARAMETERS
C      MDATA FOR INPUT NUCLEAR DATA (ENERGY-CROSS-SECTION PAIRS)
C      = 1 TO INPUT DATA IN THIS CASE IN ENDF68 FORMAT
C      = 2 TO USE DATA FROM PREVIOUS CASE
C      MINTL FOR MAXWELLIAN INTEGRATION METHOD
C      = 1 TO USE STEEPEST-DESCENT INTEGRATION
C      = 2 TO USE GAUSS-HERMITE QUADRATURE INTEGRATION
C      = 3 TO USE SELF-TERMINATING DENSE TRAPEZOIDAL INTEGRATION
C      = 4 TO USE SELF-ADJUSTING-ADJUSTING TRAPEZOIDAL INTEGRATION

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C      = 5 TO USE ALL OF THE ABOVE
C      KPLT   FOR PLOT OPTIONS
C      = 1 TO REQUEST NO PLOT OUTPUT
C      = 2 TO REQUEST PLOT OUTPUT
C      KPNCH  FOR PUNCHED CARD OUTPUT OPTIONS
C      = 1 TO REQUEST NO PUNCHED CARD OUTPUT
C      = 2 TO REQUEST PUNCHED CARD OUTPUT
C      KPRNT  FOR PRINT OUTPUT OPTIONS
C      = 1 TO REQUEST REDUCED PRINT OUTPUT
C      = 2 TO REQUEST FULL PRINT OUTPUT
C      = 3 TO REQUEST SELECTED PRINT OUTPUT
C      KSCRN  FOR SCREENING COMPUTATION
C      = 1 TO REQUEST NO SCREENING CALCULATION
C      = 2 TO USE WEAK SCREENING FORMULATION
C      = 3 TO USE FULL RANGE SALPETER SCREENING FORMULATION
C      = 4 TO USE GRABOSKE-DEWITT SCREENING FORMULATION
C      = 5 TO USE ALL OF THE ABOVE
C      KTEMP  FOR ION DISTRIBUTION TYPES
C      =100-1 IF BOTH IONS ARE MAXWELLIAN
C      =200-2 IF PROJECTILE ION HAS SLOWING DOWN COMPONENT
C      =300-3 IF TARGET ION HAS SLOWING DOWN COMPONENT
C      =400-4 IF BOTH IONS HAVE SLOWING DOWN COMPONENTS
C      NOTE NEGATIVE VALUE OF KTEMP SIGNIFIES LOGARITHMICALLY SPACED TEMPER-
C      TURE ARRAY
C      KXINT(I) FOR CROSS-SECTION INTERPOLATION SCHEME FOR IX-TH REGION
C      = 1 TO USE GAMMA INTERPOLATION
C      = 2 TO USE LOG-LOG INTERPOLATION
C      = 3 TO USE CUBIC INTERPOLATION
C      KNTL(INC) IS USED TO SPECIFY WHICH INTERNAL PARAMETERS ARE TO BE OVER-
C      RIDEN--AND HOW (WHEN KNTL = 2)
C      = 0 IF DEFAULT VALUE TO BE USED
C      IS GREATER THAN 0 IF DEFAULT VALUE TO BE OVERRIDDEN
C      KPLT(IMPL) IS USED TO SPECIFY PLOT OPTIONS REQUESTED (WHEN KPLT = 2)
C      = 0 IF PLOT IS NOT REQUESTED
C      = 2 IF LINEAR(X)-LINEAR(Y) PLOT IS REQUESTED
C      = 1 IF LINEAR(X)-LOG(Y) PLOT IS REQUESTED
C      =-1 IF LOG(X) -LOG(Y) PLOT IS REQUESTED
C      =-2 IF LOG(X) -LINEAR(Y) PLOT IS REQUESTED
C      KPNCH(IMPL) IS USED TO SPECIFY PUNCHED CARD OPTIONS REQUESTED (WHEN
C      KPNCH = 2)
C      = 0 IF PUNCHED DATA FOR IMPL-TH OPTION IS NOT REQUESTED
C      = 1 IF PUNCHED DATA FOR IMPL-TH OPTION IS REQUESTED
C      KPRNT(IMPL) IS USED TO SPECIFY PRINT OPTIONS REQUESTED (WHEN KPRNT = 3)
C      = 0 IF PRINT OUTPUT FOR IMPL-TH OPTION IS NOT REQUESTED
C      = 1 IF PRINT OUTPUT FOR IMPL-TH OPTION IS REQUESTED
C      NCASE  IS END OF CASE INDICATOR
C      = 0 IF THIS IS END OF LAST DATA CASE
C      = 1 IF ADDITIONAL DATA CASE FOLLOWS
CCCCCCCCCCCCCCCCCCCCCCCCCCCC
C      NDP  = NO. OF DATA POINTS CONTROL VARIABLE FOR PLOT/ PLOTTING ROUTINE, VALUE
C      RETURNED FROM PLOT SUBROUTINE (NOTE NEGATIVE VALUE RETURNED FOR LOG-
C      ARITHMETIC X-AXIS)
C      ND1  = MAXIMUM NO. OF PANELS IN DENSE TRAPEZOIDAL INTEGRATION SUBROUTINE,
C      INTEG2 (TO RIGHT OR LEFT OF EGAM)
C      ND2  = MAXIMUM NO. OF PANELS IN SLOWING DOWN TRAPEZOIDAL INTEGRATION SUB-
C      ROUTINE, INTEG3 (TO RIGHT OR LEFT OF VSTRT)
C      ND3  = INITIAL NO. OF PANELS IN SLOWING DOWN SIMPSONS RULE INTEGRATION SUB-
C      ROUTINE, INTEG2
C      NI   = MAXIMUM NO. OF PANELS IN SELF-CORRECTING-ADJUSTING TRAPEZOIDAL INTE-
C      GRATION SUBROUTINE, INTEG3 (TO RIGHT OR LEFT OF EGAM)
C      NMT  = NO. OF PLASMA MATERIAL(ION) TYPES
C      NS  = NO. OF INPUT NUCLEAR DATA POINTS
C      NSND = PLOT SYMBOL INDICATOR FOR PLOT/ PLOTTING ROUTINE
C      NSMI = NS-1
C      NSP  = SYMBOL FREQUENCY INDICATOR FOR PLOT/ PLOTTING ROUTINE RETURNED FROM
C      PLOT SUBROUTINE
C      NT  = NO. OF PLASMA TEMPERATURES
C      NX  = NO. OF CROSS-SECTIONS INTERPOLATION REGIONS
C      NXSI = NX-1

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C PI = (AREA OF ANY CIRCLE)/(SQUARE OF ITS RADIUS)
 C R = VALUE OF MAXWELLIAN SPECIFIC REACTION RATE RETURNED INTEGRATION SUB-
 C ROUTINE INTEG1, INTEG2, OR INTEG3
 C RATE0(IT) = DENSE TRAPEZOIDAL MAXWELLIAN REACTION RATE FOR IT-TH PLASMA
 C TEMPERATURE
 C RATE0(IT) = STEEPEST DESCENT MAXWELLIAN REACTION RATE FOR IT-TH PLASMA
 C TEMPERATURE
 C RATEH(IT) = GAUSS-HERMITE QUADRATURE MAXWELLIAN REACTION RATE FOR IT-TH
 C PLASMA TEMPERATURE
 C RATES(IT) = TOTAL SLOWING DOWN REACTION RATE COMPONENT FOR IT-TH PLASMA
 C TEMPERATURE
 C RATES1(IT) = PROJECTILE SLOWING DOWN REACTION RATE COMPONENT FOR IT-TH
 C PLASMA TEMPERATURE
 C RATES2(IT) = TARGET SLOWING DOWN REACTION RATE COMPONENT FOR IT-TH PLASMA
 C TEMPERATURE
 C RATE1(IT) = SELF-CORRECTING-ADJUSTING TRAPEZOIDAL MAXWELLIAN REACTION RATE
 C FOR IT-TH PLASMA TEMPERATURE
 C RUME = REDUCED MASS FOR ION AND ELECTRON IN KEV-SEC**2/CM**2
 C RLDA = REDUCED ATOMIC WEIGHT FOR TARGET AND PROJECTILE IONS IN AMU
 C REDM = REDUCED MASS FOR TARGET AND PROJECTILE IONS IN KEV-SEC**2/CM**2
 C RSTAR = CHARACTERISTIC (RYDBERG TYPE) RADIUS IN FULL RANGE SALPETER SCREEN-
 C ING FORMULATION
 C SCALD = SCALING FACTOR FOR PANEL WIDTHS IN SLOWING DOWN TRAPEZOIDAL INTE-
 C GRATION SUBROUTINE INTEG1 = (MAXIMUM WIDTH) / VSTRT
 C SCALE = SCALING ENERGY IN MAXWELLIAN RATE INTEGRATION = WIDTH MEASURE OF
 C GAMOW PEAK
 C SCALE = SCALING FACTOR FOR PANEL WIDTHS IN DENSE TRAPEZOIDAL INTEGRATION
 C SUBROUTINE INTEG2 = (PANEL WIDTH) / SCALE
 C SCALG = SCALING FACTOR FOR PANEL WIDTHS IN SELF-CORRECTING-ADJUSTING TRAP-
 C EZOIDAL INTEGRATION SUBROUTINE INTEG3 = (MAXIMUM PANEL WIDTH)/SCALE
 C SF = SCREENING FACTOR REGIME CRITERION FACTOR IN FULL RANGE SALPETER FORM-
 C ULATION
 C SFALG(IT) = GRABOSKE-DEWITT SCREENING FACTOR FOR IT-TH PLASMA TEMPERATURE
 C SFARNG(IT) = FULL RANGE SALPETER SCREENING FACTOR FOR IT-TH PLASMA TEMP.
 C SFACN(IT) = WEAK SALPETER SCREENING FACTOR FOR IT-TH PLASMA TEMPERATURE
 C SRCE(1) = SOURCE STRENGTH OF SLOWING DOWN PROJECTILE IONS IN 1.0/CM**3-SEC
 C SRCE(2) = SOURCE STRENGTH OF SLOWING DOWN TARGET IONS IN 1.0/(CM**3-SEC)
 C SS(IJ) = IS-TH LOCAL VALUE OF NUCLEAR FACTOR FOR GAMOW CROSS-SECTION INTER-
 C POLATION
 C T(IT) = IT-TH PLASMA TEMPERATURE IN MILLIONS OF DEGREES KELVIN
 C TAU = DIMENSIONLESS PARAMETER IN FULL RANGE SALPETER SCREENING FORMULATION
 C = (3.2JALGAM)/(MEAN THERMAL ENERGY)
 C TE = PLASMA ELECTRON TEMPERATURE IN KEV
 C TEAC(IT) = IT-TH INPUT PLASMA ELECTRON TEMPERATURE IN KEV
 C TEMP1 = TEMPORARY OR INTERMEDIATE VALUE FOR SOME VARIABLE
 C TEMP2 = TEMPORARY OR INTERMEDIATE VALUE FOR SOME VARIABLE
 C TEMP3 = TEMPORARY OR INTERMEDIATE VALUE FOR SOME VARIABLE
 C TEMP4 = TEMPORARY OR INTERMEDIATE VALUE FOR SOME VARIABLE
 C TEMP5 = TEMPORARY OR INTERMEDIATE VALUE FOR SOME VARIABLE
 C TINC = LINEAR OR LOG INCREMENT BETWEEN IT-TH AND (IT+1)-TH TEMPERATURE
 C TITL = TITLE (HEADING) FOR CASE
 C TKEV = TEMPERATURE IN KEV
 C TLG = COULOMB LOGARITHM IN SLOWING DOWN COMPUTATION
 C TMAX = INPUT MAXIMUM(LAST) TEMPERATURE (IN KEV) IN TEMPERATURE ARRAY
 C TMIN = INPUT MINIMUM(FIRST) TEMPERATURE (IN KEV) IN TEMPERATURE ARRAY
 C TN = TOTAL PLASMA ION DENSITY (SUM OVER ALL IONS) IN CM**3
 C TRATE(IT) = TOTAL SPECIFIC REACTION RATE WITH SCREENING AND SLOWING DOWN
 C CORRECTIONS FOR IT-TH TEMPERATURE (NO SCREENING WHEN KSCRN = 5)
 C TRAT1(IT) = TOTAL SPECIFIC REACTION RATE WITH WEAK SCREENING AND SLOWING
 C DOWN CORRECTIONS FOR IT-TH TEMPERATURE (WHEN KSCRN = 5)
 C TRAT2(IT) = TOTAL SPECIFIC REACTION RATE WITH FULL RANGE SALPETER SCREEN-
 C ING AND SLOWING DOWN CORRECTIONS FOR IT-TH TEMPERATURE (WHEN KSCRN = 5)
 C TRAT3(IT) = TOTAL SPECIFIC REACTION RATE WITH GRABOSKE-DEWITT SCREENING
 C AND SLOWING DOWN CORRECTIONS FOR IT-TH TEMPERATURE (WHEN KSCRN = 5)
 C US = EXPONENTIAL FACTOR IN STRONG SALPETER SCREENING FORMULATION
 C USP = EXPONENTIAL FACTOR IN PYCNONUCLEAR SALPETER SCREENING FORMULATION
 C USPS = PYCNONUCLEAR ADJUSTMENT TO US
 C USN = EXPONENTIAL FACTOR IN INTERMEDIATE SALPETER SCREENING INTERPOLATION
 C USP = PRIMARY FACTOR IN US
 C US1 = CORRECTION FACTOR TO US0 TO OBTAIN US
 C UN = EXPONENTIAL FACTOR IN WEAK SALPETER SCREENING FORMULATION

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C      VEGAM = RELATIVE VELOCITY CORRESPONDING TO EGAM
C      VRE = RELATIVE VELOCITY FOR SOURCE IONS AND MAXWELLIAN ELECTRONS
C      VSTRY = STARTING VELOCITY IN SLOWING DOWN INTEGRATION = 0.5*(SOURCE VELO-
C              CITY + LOWER LIMIT VELOCITY)
C      WIH(IH) = IH-TH WEIGHTING FACTOR IN GAUSS-HERMITE QUADRATURE INTEGRATION
C      XEGAM = CROSS-SECTION AT EGAM
C      XIR = WEIGHTED CHARGE DENSITY FACTOR IN SCREENING FORMULATIONS
C      XIRG = WEIGHTED CHARGE DENSITY FACTOR IN SCREENING FORMULATIONS
C      XS(18) = 18-TH VALUE OF INPUT CROSS-SECTION
C      ZBAR = AVERAGE CHARGE FACTOR IN SCREENING COMPUTATION
C      ZEH(IH) = IH-TH ZERO OF HERMITE POLYNOMIAL
C      ZETB = VALUE OF ZETA IN STRONG GRABOSKE-DEWITT SCREENING FORMULATION
C      ZMAT(IMAT) = ELECTRONIC CHARGE NUMBER FOR IMAT-TH PLASMA MATERIAL(ION)
C      ZRHO = WEIGHTED CHARGE DENSITY FACTOR IN SCREENING FORMULATIONS
C      Z1 = ELECTRONIC CHARGE NUMBER OF PROJECTILE ION
C      Z2 = ELECTRONIC CHARGE NUMBER OF TARGET ION
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C      UNITS(INTERNAL AND OUTPUT)
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C      CHANGE IN SQRT(KEV-CM)
C      CROSS-SECTION IN CM**2
C      ENERGY IN KEV
C      MASS IN KEV-SEC**2/CM**2
C      PARTICLE DENSITY IN 1./CM**3
C      REACTION RATE IN CM**3/SEC
C      SPEED IN CM/SEC
C      TEMPERATURE IN MILLIONS OF DEGREES KELVIN OR KEV
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C      STORAGE AND VARIABLE TRANSFER
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C-----ARRAYS ASSOCIATED WITH DIMENSION NXSI
C      COMMON/XINT/ NYS1,FBRK(5),KXINT(6)
C-----ARRAYS ASSOCIATED WITH DIMENSION OF G-H QUADRATURE
C      COMMON/GRATE/ WIH(10),ZEH(10),FACH(10)
C      1,NFDM,CUNI,SCALO,SCALF,SCALG,EP1,EP2,EP3,EP4,ND1,ND2,ND3
C      2,EPS1,EPS2,NI
C-----ARRAYS ASSOCIATED WITH DIMENSION NS
C      COMMON/CROSS/NS,ES(200),AS(200),CS(200),SS(200),BS(200)
C      1,DS(200),HS(200),FS(200),GS(200)
C-----CONTROL DATA ARRAYS
C      DIMENSION TITLE(8),MPLQ1(9),MPNCH(19),MPNHT(13),MCNTL(8)
C-----ARRAYS WITH DIMENSION,GE,NMAT
C      DIMENSION ZMAT(12),AMAT(12),DMAT(12)
C-----ARRAYS WITH DIMENSION,GE,NS
C      DIMENSION XS(200)
C-----ARRAYS WITH DIMENSION,GE,NT
C      DIMENSION ANXW1(200),ANXW2(200),T(200),IEA(200),ELONA(200)
C      1,RATES1(200),RATES2(200),RATES(200),RATEG(200),RATEH(200)
C      2,RATE0(200),RATE1(200),SFACH(200),SFACS(200),SFACG(200)
C      3,IRATE(200),IRAT1(200),IRAT2(200),IRAT3(200)
C-----MISC ARRAYS
C      DIMENSION SRCE(2),ESRC(2),ID(2),DE(9),ARNAH(19)

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      IF(MCNTL(7).EQ.1) READ428, SCALF, P1,N01
      IF(MCNTL(8).EQ.1) READ426, SCALG, FPS1, EPS2, NI
100  CONTINUE
      IF(KINTE.EQ.5) KSCRN = 1
      IF(KINTE.EQ.5.AND.KTEMP.LT.0) KTEMP = -1
      IF(KINTE.EQ.5.AND.KTEMP.GT.0) KTEMP = 1
      IF(KDATA.EQ.1) PRINT 400
      IF(KDATA.EQ.2) PRINT 401
      IF(KINTE.EQ.1) PRINT 402
      IF(KINTE.EQ.2) PRINT 403
      IF(KINTE.EQ.3) PRINT 404
      IF(KINTE.EQ.4) PRINT 405
      IF(KINTE.EQ.5) PRINT 406
      IF(ABS(KTEMP).EQ.1)PRINT 407, KTEMP
      IF(ABS(KTEMP).EQ.2)PRINT 408, KTEMP
      IF(ABS(KTEMP).EQ.3)PRINT 409, KTEMP
      IF(ABS(KTEMP).EQ.4)PRINT 410, KTEMP
      IF(KTEMP.LT.0) PRINT 411
      IF(KSCRN.EQ.1) PRINT 412
      IF(KSCRN.EQ.2) PRINT 413
      IF(KSCRN.EQ.3) PRINT 414
      IF(KSCRN.EQ.4) PRINT 415
      IF(KSCRN.EQ.5) PRINT 416
      IF(KPL0T.EQ.1) PRINT 417
      IF(KPL0T.EQ.2) PRINT 418
      IF(KPNCH.EQ.1) PRINT 419
      IF(KPNCH.EQ.2) PRINT 420
      IF(KPRNT.EQ.1) PRINT 421
      IF(KPRNT.EQ.2) PRINT 422
      IF(KPRNT.EQ.3) PRINT 423
      IF(KCNTL.EQ.1) PRINT 424
      IF(KCNTL.EQ.2) PRINT 425
C-----PARTICLE DATA
      READ 12, NMAT, IMAT, JMATP
      READ 11, (ZMAT(IMAT), IMAT=1, NMAT)
      READ 11, (AMAT(IMAT), IMAT=1, NMAT)
      READ 11, (DMAT(IMAT), IMAT=1, NMAT)
      PRINT450, NMAT
      PRINT451, (IMAT, ZMAT(IMAT), AMAT(IMAT), DMAT(IMAT), IMAT=1, NMAT)
      PRINT451, IMAT, JMATP
      DO 155 IMAT = 1, NMAT
155  AMAT(IMAT) = AMAT(JMATP)*AMU
      A1 = AMAT(IMATP)
      Z1 = ZMAT(IMATP)
      D1 = DMAT(IMATP)
      A2 = AMAT(IMAT)
      Z2 = ZMAT(IMAT)
      D2 = DMAT(IMAT)
      REDM = A1*A2/(A1+A2)
      REDA = REDM/AMU
      BGAM = PI*Z1*Z2*ESQASQRT(2.0*REDM)/HBAR
      PRINT452, REDA, REDM, BGAM
C-----CROSS SECTION DATA
      READ 12, NS, NXS
      NSM1 = NS -1
      NXS1 = NXS -1
      READ 12, (KXINT(IX), IX=1, NXS)
      READ 11, (EBRK(IX), IX=1, NXS1)
      PRINT453, NS, NXS
      PRINT454, (KXINT(IX), EBRK(IX), IX=1, NXS1), KXINT(NXS)
      GO TO (160, 161), KDATA
160 PRINT455
      CALL HENDF2(NS, ES, XS)
C-----PLASMA TEMPERATURE DATA
161 READ 12, NT
      READ 11, TMIN, TMAX
      PRINT456, NT, TMIN, TMAX
      IF(ABS(KTEMP).EQ.1) GO TO 170
      IF(ABS(KTEMP).EQ.3) GO TO 171
      READ 11, SRCE(1), ESRC(1)

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612 CALL INTEG2(SCALE,VEGAM,DEGAM,XEGAM,EGAM,TKEV,ID,DE,R)
   RATED(IT) = R
   GO TO (616,617,618),KPRNT
618 IF(MPRNT(9),EQ,0) GO TO 616
617 PRINT 505,DE(1),ID(1),ID(2),(DE(IDE),IDE=2,8),R
616 IF(KINTE,EQ,5) GO TO 613
   GO TO 600
613 CALL INTEG3(SCALE,EGAM,TKEV,ID,DE,R)
   RATET(IT) = R
   GO TO (600,619,620),KPRNT
620 IF(MPRNT(10),EQ,0) GO TO 600
619 PRINT 506,DE(1),DE(2),ID(1),ID(2),(DE(IDE),IDE=3,9),R
600 CONTINUE
C-----PRINT COMPARISON OF MAXWELLIAN RATES
   IF(KINTE,NE,5) GO TO 631
   PRINT 477
   DO 625 IT=1,NT
   TKEV = T(IT)*BOLTZK
625 PRINT 507,IT,T(IT),TKEV,RATEG(IT),RATEH(IT),RATED(IT),RATET(IT)
   GO TO 630
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C ADJUST (AND PRINT) RATE RESULTS
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
631 CONTINUE
   IF(KTEMP,EQ,1) GO TO 630
   PRINT 449
   DO 640 IT =1,NT
   TKEV = T(IT)*BOLTZK
   GO TO (640,641,642,643),KTEMP
641 RATES1(IT) = AMXW1(IT)*RATES1(IT)
   GO TO (621,622,623,624,640),KINTE
621 TEMP1 = RATEG(IT)
   RATEG(IT) = (1.-AMXW1(IT))*RATEG(IT)
   PRINT 520,IT,TKEV,RATES(IT),AMXW1(IT),TEMP1,RATEG(IT)
   GO TO 640
622 TEMP1 = RATEH(IT)
   RATEH(IT) = (1.-AMXW1(IT))*RATEH(IT)
   PRINT 520,IT,TKEV,RATES(IT),AMXW1(IT),TEMP1,RATEH(IT)
   GO TO 640
623 TEMP1 = RATED(IT)
   RATED(IT) = (1.-AMXW1(IT))*RATED(IT)
   PRINT 520,IT,TKEV,RATES(IT),AMXW1(IT),TEMP1,RATED(IT)
   GO TO 640
624 TEMP1 = RATET(IT)
   RATET(IT) = (1.-AMXW1(IT))*RATET(IT)
   PRINT 520,IT,TKEV,RATES(IT),AMXW1(IT),TEMP1,RATET(IT)
   GO TO 640
642 RATES2(IT) = AMXW2(IT)*RATES2(IT)
   GO TO (626,627,628,629,640),KINTE
626 TEMP1 = RATEG(IT)
   RATEG(IT) = (1.0-AMXW2(IT))*RATEG(IT)
   PRINT 521,IT,TKEV,RATES(IT),AMXW2(IT),TEMP1,RATEG(IT)
   GO TO 640
627 TEMP1 = RATEH(IT)
   RATEH(IT) = (1.0-AMXW2(IT))*RATEH(IT)
   PRINT 521,IT,TKEV,RATES(IT),AMXW2(IT),TEMP1,RATEH(IT)
   GO TO 640
628 TEMP1 = RATED(IT)
   RATED(IT) = (1.0-AMXW2(IT))*RATED(IT)
   PRINT 521,IT,TKEV,RATES(IT),AMXW2(IT),TEMP1,RATED(IT)
   GO TO 640
629 TEMP1 = RATET(IT)
   RATET(IT) = (1.0-AMXW2(IT))*RATET(IT)
   PRINT 521,IT,TKEV,RATES(IT),AMXW2(IT),TEMP1,RATET(IT)
   GO TO 640

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643 RATES1(IT) = AMXW1(IT)*RATES1(IT)*(1,0-AMXW2(IT))
    RATES2(IT) = AMXW2(IT)*RATES2(IT)*(1,0-AMXW1(IT))
    GO TO (646,647,648,649,640),KINTE
646 TEMP1 = RATEG(IT)
    RATEG(IT) = (1,0-AMXW1(IT))*(1,0-AMXW2(IT))*TEMP1
    PRINT 522,IT,TKEV,RATES(IT),AMXW1(IT),AMXW2(IT),TEMP1,RATEG(IT)
    GO TO 640
647 TEMP1 = RATEH(IT)
    RATEH(IT) = (1,0-AMXW1(IT))*(1,0-AMXW2(IT))*TEMP1
    PRINT 522,IT,TKEV,RATES(IT),AMXW1(IT),AMXW2(IT),TEMP1,RATEH(IT)
    GO TO 640
648 TEMP1 = RATED(IT)
    RATED(IT) = (1,0-AMXW1(IT))*(1,0-AMXW2(IT))*TEMP1
    PRINT 522,IT,TKEV,RATES(IT),AMXW1(IT),AMXW2(IT),TEMP1,RATED(IT)
    GO TO 640
649 TEMP1 = RATEI(IT)
    RATEI(IT) = (1,0-AMXW1(IT))*(1,0-AMXW2(IT))*TEMP1
    PRINT 522,IT,TKEV,RATES(IT),AMXW1(IT),AMXW2(IT),TEMP1,RATEI(IT)
640 CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C COMPUTE (AND PRINT) SCREENING FACTOR(S)
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
630 CONTINUE
    IF(KSCRN.EQ.1) GO TO 635
    RSTAR = HBAR**2/(2,0*EDM*Z1*Z2*ESQ)
    ESTAR = Z1*Z2*ESQ/RSTAR
    XIR = 0,0
    XIRG = 0,0
    TN = 0,0
    DO 656 IMAT=1,NMAT
        XIR = XIR + DMAT(IMAT)*ZMAT(IMAT)
        XIRG = XIRG + DMAT(IMAT)*ZMAT(IMAT)**(1,50)
656 TN = TN + DMAT(IMAT)
    ZBAR = XIR / TN
    GO TO (651,652,653) , KPRNT
653 IF(MPRNT(11)+MPRNT(12)+MPRNT(13),EQ,0) GO TO 651
652 PRINT 478
    PRINT 482
    PKINT 508 ,TN,XIR,XIRG,ZBAR,RSTAR,ESTAR
    PRINT 479
    GO TO (651,654,655) , KPRNT
655 IF(MPRNT(12).EQ.1) PRINT 480
    IF(MPRNT(13).EQ.1) PRINT 481
    GO TO 651
654 PRINT 480
    PRINT 481
651 DO 650 IT = 1,NT
    TKEV = T(IT)*BOLTZK
    DGEN = (2,0/3,0)*(HBAR**2*(3,0*PI**2*XIR)**(2,0/3,0) /
1 (2,0*EM*TKEV)**1,5
    CALL EDGEN(DGEN,FPF)
    ZRHO = 0,0
    DO 660 IMAT = 1,NMAT
660 ZRHO = ZRHO + DMAT(IMAT)*ZMAT(IMAT)*(FPF + ZMAT(IMAT))
    UW = Z1*Z2*SGRT(ZRHO*4,0*PI*ESQ**3/TKEV**3)
    SFACH(IT) = EXP(UW)
    GO TO (661,662,663) , KPRNT
663 IF(MPRNT(11)+MPRNT(12)+MPRNT(13),EQ,0) GO TO 661
662 PRINT 509, IT,T(IT),TKEV,DGEN,FPF,ZRHO,UW,SFACH(IT)
661 GO TO (650,650,665,670,665) KSCRN
665 TAU = (27,0*PI**2*ESTAR/(4,0*TKEV))** (1,0/3,0)
    GZ1 = (4,0*PI*ELND*AMAX1(Z1,Z2)**5/3,0)**(1,0/3,0) *ESQ/TKEV
    GZ2 = (4,0*PI*ELND*AMIN1(Z1,Z2)**5/3,0)**(1,0/3,0) *ESQ/TKEV
    GZ12 = (4,0*PI*ELND*(Z1+Z2)**5 /3,0)**(1,0/3,0) *ESQ/TKEV
    US0 = 0,9*(GZ12 -GZ1 -GZ2)

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      US1 = ALOG( (1,0+0,3*GZ12 + CONS*GZ12**1,5) / ((1,0+0,3*GZ1+
1  CONS*GZ1**1,5)*(1,0 + 0,3*GZ2 + CONS*GZ2**1,5)) )
      US = US0 + US1
      USW = US*UW / SQRT(US**2 + UW**2)
      RT = US3 / TAU
      USPS = 1AU*((0,84*AMAX1(Z1,Z2)+3,46*AMIN1(Z1,Z2))*RT**3 + 95,0*
1  AMIN1(Z1,Z2)*RT**9) / ((Z1+Z2) + (1,05*AMAX1(Z1,Z2) + 32,0*AMIN1
2  (Z1,Z2))*RT**3)
      USP = US0 + US1 - USPS
      IF(GZ1,LE, SF/0,9)      SFACS(IT) = EXP(UW)
      IF(GZ1,GT, SF/0,9)      SFACS(IT) = EXP(USW)
      IF(GZ1,GE,1,0/SF*0,9)   SFACS(IT) = EXP(US)
      IF(GZ1,GE,S1*TAU/2,7)   SFACS(IT) = EXP(USP)
      GO TO (666,667,668) ,KPRNT
668 IF(MPRNT(12),EQ,0) GO TO 666
667 PRINT 510,TAU,GZ1,GZ2,GZ12,US0,US1,USPS,SFACS(IT)
666 IF(KSCRN,NF,5) GO TO 650
670 GLAM = SQRT(4,0*PI*ESQ**3*TN/TKEV**3)
      GL12 = Z1+Z2*GLAM*SQRT(ZRHO/TN)
      HGW = GL12
      ETAB = XIRG/(TN**((0,43)*ZRHU**((0,29)*XIR**((0,28))
      HGI = 0,38*FIAB*GLAM**((0,86)*((Z1+Z2)**1,86-Z1**1,86-Z2**1,86)
      ZETB = ((Z1+Z2)**(5,0/3,0) -Z1**((5,0/3,0) -Z2**((5,0/3,0) )
1  +0,316*ZBAR**((1,0/3,0)* ((Z1+Z2)**((4,0/3,0) -Z1**((4,0/3,0)
2  -Z2**((4,0/3,0)))
3  +0,737/ZBAR*((Z1+Z2)**((2,0/3,0) -Z1**((2,0/3,0) -Z2**((2,0/3,0)))
4  / GLAM**((2,0/3,0)
      HGS = 0,624*ZBAR**((1,0/3,0)*ZETB*GLAM**((2,0/3,0)
      IF(GL12,LE,0,1)      SFACG(IT) = EXP(HGW)
      IF(GL12,GT,0,1)      SFACG(IT) = EXP(HGI)
      IF(GL12,GT,2,0)      SFACG(IT) = EXP( AMIN1(HGI,HGS) )
      IF(GL12,GE,5,0)      SFACG(IT) = EXP(HGS)
      GO TO (650,671,672) ,KPRNT
672 IF(MPRNT(13),EQ,0) GO TO 650
671 PRINT 511,GLAM,GL12,ETAB,ZETB,HGW,HGI,HGS,SFACG(IT)
650 CONTINUE
C-----PRINT COMPARISON OF SCREENING FACTORS
      IF(KSCRN,NE,5) GO TO 635
      PRINT 483
      DO 673 IT =1,NT
      TKEV = T(IT)*BOLTZK
      673 PRINT 511,IT,T(IT),TKEV,SFACW(IT),SFACS(IT),SFACG(IT)
      635 CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C (COMPUTE) AND PRINT FINAL RESULTS
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(KINTE,EQ,5) GO TO 675
      PRINT 484
      GO TO (681,682,683,684),KTEMP
681 PRINT 485
      GO TO 685
682 PRINT 486
      GO TO 685
683 PRINT 487
      GO TO 685
684 PRINT 488
685 GO TO (686,687,688,689,690), KINTE
686 PRINT 489
      GO TO 690
687 PRINT 490
      GO TO 690
688 PRINT 491
      GO TO 690
689 PRINT 492
690 GO TO (691,692,693,694,695) ,KSCRN
691 PRINT 493
      GO TO 696

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692 PRINT 494
GO TO 696
693 PRINT 495
GO TO 696
694 PRINT 496
GO TO 696
695 PRINT 497
696 IF(KSCRN,NE,5) PRINT 498
IF(KSCRN,EQ,5) PRINT 499
DO 700 IT=1,NT
TKEV = T(IT)*BOLTZK
IF(KTEMP,EQ,1) GO TO 735
GO TO (710,715,720,725,730),KSCRN
710 GO TO (711,712,713,714,700),KINTE
711 TRATE(IT) = (RATEG(IT)+RATES(IT))
PRINT 514, IT, T(IT), TKEV, RATES(IT), RATEG(IT), TRATE(IT)
GO TO 700
712 TRATE(IT) = (RATEH(IT)+RATES(IT))
PRINT 514, IT, T(IT), TKEV, RATES(IT), RATEH(IT), TRATE(IT)
GO TO 700
713 TRATE(IT) = (RATEO(IT)+RATES(IT))
PRINT 514, IT, T(IT), TKEV, RATES(IT), RATEO(IT), TRATE(IT)
GO TO 700
714 TRATE(IT) = (RATEI(IT)+RATES(IT))
PRINT 514, IT, T(IT), TKEV, RATES(IT), RATEI(IT), TRATE(IT)
GO TO 700
715 GO TO (716,717,718,719,700),KINTE
716 TRATE(IT) = SFACW(IT)*(RATEG(IT)+RATES(IT))
PRINT 515, IT, T(IT), TKEV, RATES(IT), RATEG(IT), SFACW(IT), TRATE(IT)
GO TO 700
717 TRATE(IT) = SFACW(IT)*(RATEH(IT)+RATES(IT))
PRINT 515, IT, T(IT), TKEV, RATES(IT), RATEH(IT), SFACW(IT), TRATE(IT)
GO TO 700
718 TRATE(IT) = SFACW(IT)*(RATEO(IT)+RATES(IT))
PRINT 515, IT, T(IT), TKEV, RATES(IT), RATEO(IT), SFACW(IT), TRATE(IT)
GO TO 700
719 TRATE(IT) = SFACW(IT)*(RATEI(IT)+RATES(IT))
PRINT 515, IT, T(IT), TKEV, RATES(IT), RATEI(IT), SFACW(IT), TRATE(IT)
GO TO 700
720 GO TO (721,722,723,724,700),KINTE
721 TRATE(IT) = SFACS(IT)*(RATEG(IT)+RATES(IT))
PRINT 515, IT, T(IT), TKEV, RATES(IT), RATEG(IT), SFACS(IT), TRATE(IT)
GO TO 700
722 TRATE(IT) = SFACS(IT)*(RATEH(IT)+RATES(IT))
PRINT 515, IT, T(IT), TKEV, RATES(IT), RATEH(IT), SFACS(IT), TRATE(IT)
GO TO 700
723 TRATE(IT) = SFACS(IT)*(RATEO(IT)+RATES(IT))
PRINT 515, IT, T(IT), TKEV, RATES(IT), RATEO(IT), SFACS(IT), TRATE(IT)
GO TO 700
724 TRATE(IT) = SFACS(IT)*(RATEI(IT)+RATES(IT))
PRINT 515, IT, T(IT), TKEV, RATES(IT), RATEI(IT), SFACS(IT), TRATE(IT)
GO TO 700
725 GO TO (726,727,728,729,700),KINTE
726 TRATE(IT) = SFACG(IT)*(RATEG(IT)+RATES(IT))
PRINT 515, IT, T(IT), TKEV, RATES(IT), RATEG(IT), SFACG(IT), TRATE(IT)
GO TO 700
727 TRATE(IT) = SFACG(IT)*(RATEH(IT)+RATES(IT))
PRINT 515, IT, T(IT), TKEV, RATES(IT), RATEH(IT), SFACG(IT), TRATE(IT)
GO TO 700
728 TRATE(IT) = SFACG(IT)*(RATEO(IT)+RATES(IT))
PRINT 515, IT, T(IT), TKEV, RATES(IT), RATEO(IT), SFACG(IT), TRATE(IT)
GO TO 700
729 TRATE(IT) = SFACG(IT)*(RATEI(IT)+RATES(IT))
PRINT 515, IT, T(IT), TKEV, RATES(IT), RATEI(IT), SFACG(IT), TRATE(IT)
GO TO 700
730 GO TO (731,732,733,734,700),KINTE
731 TRATE(IT) = (RATEG(IT)+RATES(IT))
TRATE2(IT) = SFACW(IT)*(RATEG(IT)+RATES(IT))
TRATE2(IT) = SFACS(IT)*(RATEG(IT)+RATES(IT))

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      TRAT3(IT) = SFACG(IT)*(RAT1G(IT)+RATES(IT))
      PRINT 517, IT, T(IT), TKEV, RATES(IT), RATEG(IT), TRATE(IT), TRAT1(IT),
1      TRAT2(IT), TRAT3(IT)
      GO TO 700
732 TRATE(IT) = (RATEH(IT)+RATES(IT))
      TRAT1(IT) = SFACH(IT)*(RATEH(IT)+RATES(IT))
      TRAT2(IT) = SFACS(IT)*(RATEH(IT)+RATES(IT))
      TRAT3(IT) = SFACG(IT)*(RATEH(IT)+RATES(IT))
      PRINT 517, IT, T(IT), TKEV, RATES(IT), RATEH(IT), TRATE(IT), TRAT1(IT),
1      TRAT2(IT), TRAT3(IT)
      GO TO 700
733 TRATE(IT) = (RATEU(IT)+RATES(IT))
      TRAT1(IT) = SFACH(IT)*(RATEU(IT)+RATES(IT))
      TRAT2(IT) = SFACS(IT)*(RATEU(IT)+RATES(IT))
      TRAT3(IT) = SFACG(IT)*(RATEU(IT)+RATES(IT))
      PRINT 517, IT, T(IT), TKEV, RATES(IT), RATEU(IT), TRATE(IT), TRAT1(IT),
1      TRAT2(IT), TRAT3(IT)
      GO TO 700
734 TRATE(IT) = (RATET(IT)+RATES(IT))
      TRAT1(IT) = SFACH(IT)*(RATET(IT)+RATES(IT))
      TRAT2(IT) = SFACS(IT)*(RATET(IT)+RATES(IT))
      TRAT3(IT) = SFACG(IT)*(RATET(IT)+RATES(IT))
      PRINT 517, IT, T(IT), TKEV, RATES(IT), RATET(IT), TRATE(IT), TRAT1(IT),
1      TRAT2(IT), TRAT3(IT)
      GO TO 700
735 GO TO (740,745,750,755,760),KSCRN
740 GO TO (741,742,743,744,700),KINTE
741 TRATE(IT) = RATEG(IT)
      PRINT 512, IT, T(IT), TKEV, RATEG(IT), TRATE(IT)
      GO TO 700
742 TRATE(IT) = RATEH(IT)
      PRINT 512, IT, T(IT), TKEV, RATEH(IT), TRATE(IT)
      GO TO 700
743 TRATE(IT) = RATEU(IT)
      PRINT 512, IT, T(IT), TKEV, RATEU(IT), TRATE(IT)
      GO TO 700
744 TRATE(IT) = RATET(IT)
      PRINT 512, IT, T(IT), TKEV, RATET(IT), TRATE(IT)
      GO TO 700
745 GO TO (746,747,748,749,700),KINTE
746 TRATE(IT) = SFACH(IT)*RATEG(IT)
      PRINT 513, IT, T(IT), TKEV, RATEG(IT), SFACH(IT), TRATE(IT)
      GO TO 700
747 TRATE(IT) = SFACH(IT)*RATEH(IT)
      PRINT 513, IT, T(IT), TKEV, RATEH(IT), SFACH(IT), TRATE(IT)
      GO TO 700
748 TRATE(IT) = SFACH(IT)*RATEU(IT)
      PRINT 513, IT, T(IT), TKEV, RATEU(IT), SFACH(IT), TRATE(IT)
      GO TO 700
749 TRATE(IT) = SFACH(IT)*RATET(IT)
      PRINT 513, IT, T(IT), TKEV, RATET(IT), SFACH(IT), TRATE(IT)
      GO TO 700
750 GO TO (751,752,753,754,700),KINTE
751 TRATE(IT) = SFACS(IT)*RATEG(IT)
      PRINT 513, IT, T(IT), TKEV, RATEG(IT), SFACS(IT), TRATE(IT)
      GO TO 700
752 TRATE(IT) = SFACS(IT)*RATEH(IT)
      PRINT 513, IT, T(IT), TKEV, RATEH(IT), SFACS(IT), TRATE(IT)
      GO TO 700
753 TRATE(IT) = SFACS(IT)*RATEU(IT)
      PRINT 513, IT, T(IT), TKEV, RATEU(IT), SFACS(IT), TRATE(IT)
      GO TO 700
754 TRATE(IT) = SFACS(IT)*RATET(IT)
      PRINT 513, IT, T(IT), TKEV, RATET(IT), SFACS(IT), TRATE(IT)
      GO TO 700
755 GO TO (756,757,758,759,700),KINTE
756 TRATE(IT) = SFACG(IT)*RATEG(IT)
      PRINT 513, IT, T(IT), TKEV, RATEG(IT), SFACG(IT), TRATE(IT)
      GO TO 700

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757 TRATF(IT) = SFACG(IT)*RATEH(IT)
PRINT 513,IT,T(IT),TKEV,RATEH(IT),SFACG(IT),TRATE(IT)
GO TO 700
758 TRATE(IT) = SFACG(IT)*PATED(IT)
PRINT 513,IT,T(IT),TKEV,RATED(IT),SFACG(IT),TRATE(IT)
GO TO 700
759 TRATE(IT) = SFACG(IT)*RATET(IT)
PRINT 513,IT,T(IT),TKEV,RATET(IT),SFACG(IT),TRATE(IT)
GO TO 700
760 GO TO (761,762,763,764,700),KINTE
761 TRATE(IT) = RATEG(IT)
TRAT1(IT) = SFACW(IT)*RATEG(IT)
TRAT2(IT) = SFACS(IT)*RATEG(IT)
TRAT3(IT) = SFACG(IT)*RATEG(IT)
PRINT 516,IT,T(IT),TKEV,RATEG(IT),TRATE(IT),TRAT1(IT),TRAT2(IT),
1 TRAT3(IT)
GO TO 700
762 TRATE(IT) = RATEH(IT)
TRAT1(IT) = SFACW(IT)*RATEH(IT)
TRAT2(IT) = SFACS(IT)*RATEH(IT)
TRAT3(IT) = SFACG(IT)*RATEH(IT)
PRINT 516,IT,T(IT),TKEV,RATEH(IT),TRATE(IT),TRAT1(IT),TRAT2(IT),
1 TRAT3(IT)
GO TO 700
763 TRATE(IT) = RATED(IT)
TRAT1(IT) = SFACW(IT)*RATED(IT)
TRAT2(IT) = SFACS(IT)*RATED(IT)
TRAT3(IT) = SFACG(IT)*RATED(IT)
PRINT 516,IT,T(IT),TKEV,RATED(IT),TRATE(IT),TRAT1(IT),TRAT2(IT),
1 TRAT3(IT)
GO TO 700
764 TRATE(IT) = RATET(IT)
TRAT1(IT) = SFACW(IT)*RATET(IT)
TRAT2(IT) = SFACS(IT)*RATET(IT)
TRAT3(IT) = SFACG(IT)*RATET(IT)
PRINT 516,IT,T(IT),TKEV,RATET(IT),TRATE(IT),TRAT1(IT),TRAT2(IT),
1 TRAT3(IT)
700 CONTINUE
675 CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C CALL PLOT ROUTINES
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
IF(MPLOT,EQ,1)GO TO 775
IF(MPLOT(1),EQ,0) GO TO 780
CALL PLOTT(NS,MPLOT(1),1,NDP,INC,NSP,NSMB)
DO 781 IS=1,NS
ES(IS) = ES(IS)*(A1+A2)/A2
781 XS(IS) = XS(IS)*1.E+24
CALL PLOTH(ES,XS,NDP,INC,NSP,NSMB,0,0,10,0,10,0,TITLE,79,
1 16MLAB ENERGY (KEV),16,13MSIGMA (BARN),13)
DO 782 IS=1,NS
ES(IS) = ES(IS)*A2/(A1+A2)
782 XS(IS) = XS(IS)*1.E-24
780 MPLOTT = 0
DO 783 IP=2,9
783 MPLOTT = MPLOTT + IABS(MPLOT(IP))
IF(MPLOTT,EQ,0) GO TO 775
DO 784 IT=1,NT
784 T(IT) = T(IT)*BOLTZK
IF(KTEMP,EQ,1) GO TO 820
IF(MPLOT(2),EQ,0) GO TO 810
CALL PLOTT(NT,MPLOT(2),2,NDP,INC,NSP,NSMB)
IP = 1
801 CALL PLOTH(T,RATES,NDP,INC,NSP,NSMB,0,0,10,0,10,0,TITLE,79,
1 17TEMPERATURE (KEV),17,33MSLOWING IN SIGMA=V BAR(CM**3/SEC),33)
GO TO (804,811),IP
804 GO TO (820,802,803,802),KTEMP

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802 CALL PLOTM(T,RATES1,NDP,INC,NSP,NSMB,0,0,10,0,10,0,TITLE,79,
1 17HTEMPERATURE (KEV),17,4HPROJECTILE SLOWING IN SIGMA=V BAR(CH**
23/SEC),44)
GO TO (820,810,803,803),KTEMP
803 CALL PLOTM(T,RATES2,NDP,INC,NSP,NSMB,0,0,10,0,10,0,TITLE,79,
1 17HTEMPERATURE (KEV),17,4HTARGET SLOWING IN SIGMA=V BAR(CH**3/SE
2C),40)
810 IF(MPLOT(3),EQ,0) GO TO 820
CALL PLOTI(NT,MPLOT(3),3,NDP,INC,NSP,NSMB)
IP = 2
GO TO 801
811 NSMB = -NSMB-1
GO TO (820,812,813,812),KTEMP
812 CALL PLOTM(T,RATES1,NDP,INC,NSP,NSMB,0,,10,,1H ,1,1H ,1,1H ,1)
NSMB = NSMB-1
GO TO (820,820,813,813),KTEMP
813 CALL PLOTM(T,RATES2,NDP,INC,NSP,NSMB,0,,10,,1H ,1,1H ,1,1H ,1)
820 CONTINUE
IF(MPLOT(4),EQ,0) GO TO 830
CALL PLOTI(NT,MPLOT(4),4,NDP,INC,NSP,NSMB)
IP = 1
GO TO (821,822,823,824,825),KINTF
821 CALL PLOTM(T,RATE6,NDP,INC,NSP,NSMB,0,0,10,0,10,0,TITLE,79,
1 17HTEMPERATURE (KEV),17,3HMAXWELLIAN SIGMA=V BAR(CH**3/SEC),33)
GO TO (830,822,831),IP
822 CALL PLOTM(T,RATEH,NDP,INC,NSP,NSMB,0,0,10,0,10,0,TITLE,79,
1 17HTEMPERATURE (KEV),17,3HMAXWELLIAN SIGMA=V BAR(CH**3/SEC),33)
GO TO (830,823,832),IP
823 CALL PLOTM(T,RATEI,NDP,INC,NSP,NSMB,0,0,10,0,10,0,TITLE,79,
1 17HTEMPERATURE (KEV),17,3HMAXWELLIAN SIGMA=V BAR(CH**3/SEC),33)
GO TO (830,824,833),IP
824 CALL PLOTM(T,RATEJ,NDP,INC,NSP,NSMB,0,0,10,0,10,0,TITLE,79,
1 17HTEMPERATURE (KEV),17,3HMAXWELLIAN SIGMA=V BAR(CH**3/SEC),33)
GO TO (830,830,840),IP
825 IP = 2
GO TO 821
830 CONTINUE
IF(KINTE,NF,5) GO TO 840
IF(MPLOT(5),EQ,0) GO TO 840
CALL PLOTI(NT,MPLOT(5),5,NDP,INC,NSP,NSMB)
IP = 3
GO TO 821
831 NSMB = -NSMB-1
GO TO 822
832 NSMB = NSMB-1
GO TO 823
833 NSMB = NSMB-1
GO TO 824
840 CONTINUE
IF(KSCRN,EQ,1) GO TO 860
IF(MPLOT(6),EQ,0) GO TO 850
CALL PLOTI(NT,MPLOT(6),6,NDP,INC,NSP,NSMB)
IP = 1
GO TO (860,842,843,844,845),KSCRN
842 CALL PLOTM(T,SFACN,NDP,INC,NSP,NSMB,0,0,10,0,10,0,TITLE,79,
1 17HTEMPERATURE (KEV),17,16HSCREENING FACTOR,16)
GO TO (850,843,851),IP
843 CALL PLOTM(T,SFACS,NDP,INC,NSP,NSMB,0,0,10,0,10,0,TITLE,79,
1 17HTEMPERATURE (KEV),17,16HSCREENING FACTOR,16)
GO TO (850,844,852),IP
844 CALL PLOTM(T,SFACC,NDP,INC,NSP,NSMB,0,0,10,0,10,0,TITLE,79,
1 17HTEMPERATURE (KEV),17,16HSCREENING FACTOR,16)
GO TO (850,850,860),IP
845 IP = 2
GO TO 842
850 CONTINUE
IF(KSCRN,NE,5) GO TO 860
IF(MPLOT(7),EQ,0) GO TO 860
CALL PLOTI(NT,MPLOT(7),7,NDP,INC,NSP,NSMB)
IP = 3
GO TO 842

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A51 NSMB = -NSMB-1  

GO TO 843  

A52 NSMB = NSMB +1  

GO TO 844  

A60 CONTINUE  

IF(KINTE,EQ,5) GO TO 870  

IF(MPLOT(8),EQ,0) GO TO 865  

IP = 1  

CALL PLOIT(NT,MPLT(8),8,NDP,INC,NSP,NSMB)  

A61 CALL PLOTMT(T,TRAT,NDP,INC,NSP,NSMB,0,0,10,0,10,0,TITLE,79,  

1 17HTEMPERATURE (KEV),17,28HTOTAL SIGMA-V BAR(CM**3/SEC),28)  

GO TO (865,866),IP  

A65 CONTINUE  

IF(KSCRN,NE,5) GO TO 870  

IF(MPLOT(9),FQ,0) GO TO 870  

IP = 2  

CALL PLOIT(NT,MPLT(9),9,NDP,INC,NSP,NSMB)  

GO TO 861  

A66 NSMB = -NSMB +1  

CALL PLUTM(T,TRAT1,NDP,INC,NSP,NSMB,0,,10,,10,,1H ,1,1H ,1,1H ,1)  

NSMB = NSMB -1  

CALL PLOTM(T,TRAT2,NDP,INC,NSP,NSMB,0,,10,,10,,1H ,1,1H ,1,1H ,1)  

NSMB = NSMB -1  

CALL PLOTM(T,TRAT3,NDP,INC,NSP,NSMB,0,,10,,10,,1H ,1,1H ,1,1H ,1)  

A70 CONTINUE  

DO 785 IT=1,NT  

785 T(IT) = T(IT)/BOLIZK  

775 CONTINUE  

C  

C PUNCH REQUESTED DATA  

C  

C  

C  

IF(KPNCH,EQ,1) GO TO 910  

DO 880 IP =1,19  

IF(MPNCH(IP),EQ,0) GO TO 880  

PUNCH 51R,ARNAM(IP)  

GO TO (8A1,8A2,8A3,8A4,8A5,8A6,8A7,8A8,8A9,890,891,892,893,894,895  

1,896,897,898,899),IP  

A80 CONTINUE  

GO TO 910  

A81 DO 871 IS=1,NS  

A71 ES(IS) = ES(IS)*(A1+A2)/A2  

PUNCH 51Q,(ES(IS),IS=1,NS)  

DO 872 IS=1,NS  

A72 ES(IS) = ES(IS)*A2/(A1+A2)  

GO TO 880  

A82 DO 873 IS=1,NS  

A73 XS(IS) = XS(IS)+1.E+24  

PUNCH 51Q,(XS(IS),IS=1,NS)  

DO 874 IS=1,NS  

A74 XS(IS) = XS(IS)+1.E-24  

GO TO 880  

A83 DO 875 IT=1,NI  

A75 T(IT) = T(IT)*BOLIZK  

PUNCH 51Q,(T(IT),IT=1,NT)  

DO 876 IT=1,NI  

A76 T(IT) = T(IT)/BOLIZK  

GO TO 880  

A84 GO TO (8A0,877,890,877),KTEMP  

A77 PUNCH 51Q,(AMXW1(IT),IT=1,NI)  

GO TO 880  

A85 GO TO (8A0,880,878,878),KTEMP  

A78 PUNCH 51Q,(AMXW2(IT),IT=1,NI)  

GO TO 880  

A86 CONTINUE  

IF(KTEMP,EQ,1) GO TO 880  

PUNCH 51Q,(HATES(IT),IT=1,NT)  

GO TO 880

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400 FORMAT(1H , 1H KTEMP =,I3,36H TARGET NUCLEI SLOWING IN )
410 FORMAT(1H , 1H KTEMP =,I3,36H BOTH NUCLEI SLOWING IN )
411 FORMAT(1H ,51H (LOGARITHMIC PLASMA TEMP INCREMENTS) )
412 FORMAT(1H ,51H KSCRN = 1 NO SCREENING CALCULATION )
413 FORMAT(1H ,51H KSCRN = 2 SALPETER WEAK SCREENING CALCULATION )
414 FORMAT(1H ,51H KSCRN = 3 SALPETER FULL RANGE SCREENING )
415 FORMAT(1H ,51H KSCRN = 4 GRABOSKE-DEWITT FULL RANGE SCREENING )
416 FORMAT(1H ,51H KSCRN = 5 COMPARISON OF SCREENING TREATMENTS )
417 FORMAT(1H ,51H KPLOT = 1 NO PLOT OUTPUT )
418 FORMAT(1H ,51H KPLOT = 2 PLOT OUTPUT )
419 FORMAT(1H ,51H KPNCH = 1 NO PUNCHED OUTPUT )
420 FORMAT(1H ,51H KPNCH = 2 PUNCHED OUTPUT )
421 FORMAT(1H ,51H KPRNT = 1 REDUCED PRINTED OUTPUT )
422 FORMAT(1H ,51H KPRNT = 2 FULL PRINTED OUTPUT )
423 FORMAT(1H ,51H KPRNT = 3 SELECTED PRINTED OUTPUT )
424 FORMAT(1H ,51H KCNTL = 1 USE ALL INTERNAL PARAMETERS )
425 FORMAT(1H ,51H KCNTL = 2 SELECTED INTERNAL PARAMETERS INPUT )
426 FORMAT(3E12,6,I6)
427 FORMAT(E12,6,I6)
428 FORMAT(2E12,6,I6)
440 FORMAT(1H,51H ADJUSTMENT OF MAXWELLIAN SIGMA=VBAR /
1 52X,26H PRE-ADJUSTED ADJUSTED /
2 70H IT T(KEV) RATE(S) AMXW1 AMXW2 RATE(
3M) RATE(M) )
450 FORMAT(1H,51H PLASMA MATERIAL NUMBER OF PARTICLE TYPES =,
1 I3, / 95H IMAT Z(IMAT) A(IMAT) NO.DENSITY IMAT
2 Z(IMAT) A(IMAT) NO.DENSITY )
451 FORMAT(1H ,10H TARGET IMAT =,I3,6X,18H PROJECTILE IMAT =,I3)
452 FORMAT(1H , 1H WEDA = ,E12,6,4H AMU,6X,8H REOM = ,E12,6,17H KEV SE
1C**2/CM**2,6X,1H HGAM = ,E12,6,9H KEV**0,5 )
453 FORMAT(1H,46H CROSS SECTION INPUT NUMBER OF DATA (NS) =,I5, /
124X,40H NUMBER OF INTERPOLATION REGIONS (NXS) =,I3, /
224X,42H INTERPOLATION SCHEME (1 = GAMOW FORM) , /
324X,42H (2 = LOG-LOG ) , /
424X,42H (3 = CURIC ) )
454 FORMAT(1H ,24X,1H(,12,2H) ,5E10,4,7H KEV (,12,2H) )
455 FORMAT(1H, 75H ENDF/B CROSS SECTION DATA PAINS ENERGY(EV)/SIGMA
1(6A9NS) (1S),IS=1,NS )
456 FORMAT(1H,24H PLASMA TEMPERATURES (40. = ,I3, 9H, TMIN = ,E12,6,
113H KEV, TMAX = ,E12,6,1H) )
457 FORMAT(1H ,21H PROJECTILE SOURCE = ,F12,6,37H PARTICLES/SEC-CM**3
1 WITH ENERGY OF ,E12,6,5H KEV )
458 FORMAT(1H ,21H TARGET SOURCE = ,F12,6,37H PARTICLES/SEC-CM**3
1 WITH ENERGY OF ,E12,6,5H KEV )
459 FORMAT(1H,74H CENTER OF MASS CROSS SECTION DATA ENERGY(KEV)/SIG
1MA(CM**2) (1S),IS=1,NS )
460 FORMAT(1H,51H INTERPOLATION BREAK ENERGIES IN CENTER OF MASS SY)
461 FORMAT(1H,51H CROSS SECTION INTERPOLATION DATA BS(1S),IS=1,NS )
462 FORMAT(1H,51H CROSS SECTION INTERPOLATION DATA CS(1S),IS=2,NS )
463 FORMAT(1H,51H CROSS SECTION INTERPOLATION DATA CS(1S),IS=2,NS )
464 FORMAT(1H,51H CROSS SECTION INTERPOLATION DATA AS(1S),IS=2,NS )
465 FORMAT(1H,51H CROSS SECTION INTERPOLATION DATA DS(1S),IS=3,NSM1)
466 FORMAT(1H,51H CROSS SECTION INTERPOLATION DATA HS(1S),IS=3,NSM1)
467 FORMAT(1H,51H CROSS SECTION INTERPOLATION DATA FS(1S),IS=3,NSM1)
468 FORMAT(1H,51H CROSS SECTION INTERPOLATION DATA GS(1S),IS=3,NSM1)
469 FORMAT(1H,51H SLOWING DOWN CONTRIBUTION FROM PROJECTILE PARTICLE/
1 16H REDUCED MASS = ,E12,6,19H KEV SEC**2/CM**2 / 10H 1E(KEV)
2 FLOW(KEV) VRE(CM/SEC) DML(CM) L/ LA=90A AMXW1 )
470 FORMAT(1H,51H SLOWING DOWN CONTRIBUTION FROM TARGET PARTICLE /
1 16H REDUCED MASS = ,E12,6,19H KEV SEC**2/CM**2 / 70H 1E(KEV)
2 FLOW(KEV) VRE(CM/SEC) DML(CM) L/ LA=90A AMXW2 )
471 FORMAT(1H,25H SLOWING DOWN RESULTS / 90H 11 T(DEC K) T
1(KEV) A(1) RATES(1) A(2) RATES(2) RATES(TOT
2) )
472 FORMAT(1H,51H MAXWELLIAN DISTRIBUTION INTEGRATION CALCULATIONS )
473 FORMAT(1H ,81H IT T(DEC K) T(KEV) EGAM(KEV) VEGAM(CM/
1S) DEGAM(1/KEV) XEGAM(CM**2),14X,14H RATEG(CC/SEC))
474 FORMAT(1H ,198H DE(KEV) TOL/10H FOL/EDR(KEV)
1 XOL/XOR(CM**2) EPL/EPR EPS RATED )

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475 FORMAT(1H ,108H      DE MIN/MAX(KEV)   IDL/IDR   EDL/EDR(KEV)
      1 XDL/XDR(CM**2)      EPL/EPR      EPS   RATE1      )
476 FORMAT(1H , 24H      DE MIN/MAX(KEV)   ,71X,14H RATE1      )
477 FORMAT(1H0,51H COMPARISON OF MAXWELLIAN INTEGRATION METHODS      /
      1 90H IT      T(DEG K)      T(KEV)      RATEG(CC/SEC) RATEH(CC/SEC) R
      2ATED(CC/SEC) RATE1(CC/SEC)      )
478 FORMAT(1H0,51H SCREENING FACTOR CALCULATION      )
479 FORMAT(1H ,102H IT      T(DEG K)      T(KEV)      OGEN      DEGEN FAC
      1TOR ZETA*RH0      U(M)      SFACH(W=S)      )
480 FORMAT(1H ,102H      TAU      GAMMA(1)      GAMMA(2)      GAMMA(1+
      12)      U(S=0)      U(S=1)      U(SPS)      SFACS(FR=S))
481 FORMAT(1H ,102H      LAMBDA(0) LAMBDA(12)      ETA(B)      ZETA(B
      1)      U(W=G)      U(T=G)      U(S=G)      SFACG(FR=G))
482 FORMAT(1H ,72H TOT ION DEN      Z/CC      Z**1,50/CC      ZBAR      RS
      1TAR(CM)      ESTAR(KEV)      )
483 FORMAT(1H0,51H COMPARISON OF SCREENING FACTORS      /
      1 66H IT      T(DEG K)      T(KEV)      WLAK      SALPETER      GRABOS
      2KE      )
484 FORMAT(1H1,51H ***** FINAL RESULTS FOR SIGMA-VBAR ***** )
485 FORMAT(1H0,51H ION DISTRIBUTION-----BOTH IONS MAXWELLIAN      )
486 FORMAT(1H0,51H ION DISTRIBUTION-----PROJECTILE ION SLOWING IN      )
487 FORMAT(1H0,51H ION DISTRIBUTION-----TARGET ION SLOWING IN      )
488 FORMAT(1H0,51H ION DISTRIBUTION-----BOTH IONS SLOWING IN      )
489 FORMAT(1H ,51H MAXWELLIAN INTEGRATION--STEEPEST DESCENT      )
490 FORMAT(1H ,51H MAXWELLIAN INTEGRATION--GAUSS-HERMITE QUADRATURE      )
491 FORMAT(1H ,51H MAXWELLIAN INTEGRATION--DENSE TRAPEZOIDAL      )
492 FORMAT(1H ,51H MAXWELLIAN INTEGRATION--SELF-CORRECT/ADJUSTING TRP      )
493 FORMAT(1H ,51H SCREENING FACTOR-----NO CALCULATION      )
494 FORMAT(1H ,51H SCREENING FACTOR-----WEAK SALPETER      )
495 FORMAT(1H ,51H SCREENING FACTOR-----SALPETER (FULL RANGE)      )
496 FORMAT(1H ,51H SCREENING FACTOR-----GRABOSKE-DEWITT      )
497 FORMAT(1H ,51H SCREENING FACTOR-----COMPARISON OF TREATMENTS      )
498 FORMAT(1H0,31X,22H SIGMA-VBAR COMPONENTS,/,69X,6H TOTAL,/,80H IT
      1      TEMP      TEMP      SLOWING MAXWELLIAN SCREENING SIGM
      2A-VBAR      /,7X,20H(10**6 DEG K) (KEV),6X,5H DOWN,18X,24H FACTOR
      3 (CM**3/SEC) //)
499 FORMAT(1H0,31X,60H SIGMA-VBAR COMPONENTS      TOTAL SIGMA-VBA
      1R (CM**3/SFC)      /,70X,15H WITH SCREENING/,102H IT      TEMP
      2 TEMP      SLOWING MAXWELLIAN      NO      WEAK      SALPET
      3ER      GRABOSKE /,7X,20H(10**6 DEG K) (KEV),6X,5H DOWN,17X,47H SC
      4REENING SALPETER (FULL RANGE) DEWITT //)
500 FORMAT(1H ,16,2X,3E12,6,6X,16,2X,3E12,6)
501 FORMAT(1H ,14,2X,4E12,6,24X,E12,6)
502 FORMAT(1H ,14,2X,2E12,6,24X,3E12,6)
503 FORMAT(1H ,14,2X,7E12,6)
504 FORMAT(1H ,14,2X,3E12,6,3E13,7,14X,E13,7)
505 FORMAT(1H ,6X,E9,3,9X,214,7E9,3,E13,7)
506 FORMAT(1H ,6X,214,3,214,7E9,3,E13,7)
507 FORMAT(1H ,14,2X,2E12,6,4E13,8)
508 FORMAT(1H ,6E12,6)
509 FORMAT(1H ,14,2X,6E12,6,12X,E12,6)
510 FORMAT(1H ,6X,E12,6)
511 FORMAT(1H ,14,2X,5E12,6)
512 FORMAT(1H ,14,2X,2E12,6,12X,E12,6,12X,E12,6)
513 FORMAT(1H ,14,2X,2E12,6,12X,3E12,6)
514 FORMAT(1H ,14,2X,4E12,6,12X,E12,6)
515 FORMAT(1H ,14,2X,6E12,6)
516 FORMAT(1H ,14,2X,2E12,6,12X,5E12,6)
517 FORMAT(1H ,14,2X,8E12,6)
518 FORMAT(10H*****A10,10H***** )
519 FORMAT(6E12,6)
520 FORMAT(1H ,14,2X,3E12,6,12X,2E12,6)
521 FORMAT(1H ,14,2X,2E12,6,12X,3E12,6)
522 FORMAT(1H ,14,2X,6E12,6)
      END

```

C
C
C

```

      SUBROUTINE RENDF1(MAT,MF,MT)
C FUNCTION OF PROGRAM
C   READS AND PRINTS ENDF/B DATA UP TO AND INCLUDING FIRST LINE WITH
C   SELECTED MAT,MF, AND MT
C STORAGE
      DIMENSION TENDF(6)
C FORMATS
      30 FORMAT (6A11,I4,I2,I3,I5)
      40 FORMAT (1H ,6A11,I4,I2,I3,I5)
C BEGIN
      ILINE=0
100 ILINE=ILINE+1
      READ 30,TENDF,K1,K2,K3,K4
      PRINT40,TENDF,K1,K2,K3,K4
      IF (K1,NE,MAT) GO TO 100
      IF (K2,NE,MF ) GO TO 100
      IF (K3,NE,MT ) GO TO 100
      RETURN
      END

C
C
C   SUBROUTINE RENDF2(NPAIR,X,Y)
C FUNCTION OF PROGRAM
C   READ PAIRED DATA IN ENDF/B FORMAT
C STORAGE
      DIMENSION X(200 ),Y(200)
C FORMATS
      31 FORMAT (6E11,5,I4,I2,I3,I5)
      41 FORMAT (1H ,6E11,5,I4,I2,I3,I5)
C BEGIN
      LFLINE=NPAIR/3
      NREM=NPAIR-3*LFLINE+1
      DO 110 ILINE=1,LFLINE
        IEM=3*ILINE-2
        IEP=3*ILINE
        READ 31,(X(I),Y(I),I=JEM,IEP)
        PRINT41,(X(I),Y(I),I=IEM,IEP)
110 CONTINUE
      GO TO (100,101,102),NREM
100 GO TO 103
101 READ 31,X(NPAIR),Y(NPAIR)
      PRINT41,X(NPAIR),Y(NPAIR)
      GO TO 103
102 READ 31,X(NPAIR-1),Y(NPAIR-1),X(NPAIR),Y(NPAIR)
      PRINT41,X(NPAIR-1),Y(NPAIR-1),X(NPAIR),Y(NPAIR)
103 CONTINUE
      RETURN
      END

C
C
C   SUBROUTINE XINTER(E,X)
C FUNCTION OF PROGRAM
C   DETERMINE CROSS SECTION INTERPOLATION SUBROUTINE TO BE USED AS
C   SPECIFIED BY USER INPUT BY LAB SYSTEM      ENERGY REGIONS
C STORAGE
      COMMON/XINT/ NXS1,EBRK(5),KXINT(6)
C BEGIN
      DO 19 IXS = 1,NXS1
        KXS = IXS
        IF(E.LT,EBRK(IXS)) GO TO 20
10 CONTINUE
        KXS = NXS1 + 1
20 KXI = KXINT(KXS)
      GO TO (31,32,33) ,KXI
31 CALL INTERPG(E,X)
      RETURN
32 CALL INTEPL(E,X)

```



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      RETURN
33 CALL INTEPC(E,X)
      RETURN
      END

C
C
C
      SUBROUTINE INTEPC(E,X)
C FUNCTION OF PROGRAM
      INTERPOLATE TO FIND X AT E IN TABLE OF XS(IS) VERSUS ES(IS) BY FOUR POINT
      CUBIC INTERPOLATION, ES(IS) IS MONOTONE INCREASING AND POSITIVE
C STORAGE
      COMMON/CROSS/NS,ES(200),AS(200),CS(200),SS(200),BS(200)
      1,DS(200),HS(200),FS(200),GS(200)
C COMPUTE
      N1=NS-1
      N2=NS-2
      IF (E.LT,ES(3)) GO TO 110
      IF (E.GE,ES(N2)) GO TO 120
      DO 100 IS=4,N2
      IF (E.LT,ES(IS)) GO TO 101
100 CONTINUE
101 X=DS(IS)+HS(IS)*E+FS(IS)*E**2+GS(IS)*E**3
      GO TO 102
110 X=DS( 3)+HS( 3)*E+FS( 3)*E**2+GS( 3)*E**3
      GO TO 102
120 X=DS(N1)+HS(N1)*E+FS(N1)*E**2+GS(N1)*E**3
102 CONTINUE
      RETURN
      END

C
C
C
      SUBROUTINE INTEPL(E,X)
C FUNCTION OF PROGRAM
      INTERPOLATE TO FIND X AT E IN TABLE OF XS(IS) VERSUS ES(IS) USING
      C INTERPOLATION LOG E VERSUS LOG X. ES(IS) IS MONOTONE INCREASING
      AND ES(1) IS GREATER THAN ZERO
C STORAGE
      COMMON/CROSS/NS,ES(200),AS(200),CS(200),SS(200),BS(200)
      1,DS(200),HS(200),FS(200),GS(200)
C COMPUTE
      IF (E.LT,ES(1)) GO TO 110
      IF (E.GE,ES(NS)) GO TO 120
      DO 100 IS=2,NS
      IF (E.LT,ES(IS)) GO TO 101
100 CONTINUE
101 X=AS(IS)*E**CS(IS)
      GO TO 102
110 X=AS( 2)*E**CS( 2)
      GO TO 102
120 X=AS(NS)*E**CS(NS)
102 CONTINUE
      RETURN
      END

C
C
C
      SUBROUTINE INTEPG(F,X)
C FUNCTION OF PROGRAM
      INTERPOLATE TO FIND X AT E IN TABLE OF XS(IS) VERSUS ES(IS) USING
      C INTERPOLATION CONSISTENT WITH GAMOW PENETRATION. ES(IS) IS MONOTONE
      INCREASING AND FS(1) IS GREATER THAN ZERO
C STORAGE
      COMMON/CROSS/NS,ES(200),AS(200),CS(200),SS(200),BS(200)
      1,DS(200),HS(200),FS(200),GS(200)
C COMPUTE
      IF (F.LT,ES(1)) GO TO 110
      IF (F.GE,ES(NS)) GO TO 120

```

```

      DO 100 IS=2,NS
      IF (E,LI,ES(IS)) GO TO 101
100  CONTINUE
101  X=SS(IS)*EXP(-BS(IS)/SQRT(E))/E
      GO TO 102
110  X=SS( 2)*EXP(-BS( 2)/SQRT(E))/E
      GO TO 102
120  X=SS(NS)*EXP(-BS(NS)/SQRT(E))/E
102  CONTINUE
      RETURN
      END

C
C
C
      SUBROUTINE INTGS1(V0,E0,EM,A1,A2,T,AR)
C FUNCTION OF PROGRAM
C   CALCULATES SLOWING IN INTEGRAL FOR SIGMA-VBAR FOR A1 PARTICLE
C   SLOWING DOWN FROM ENERGY EM TO E0 FOR A2 WITH TEMPERATURE=T
C   DOUBLE INTEGRATION PERFORMED
C   (1) OUTSIDE BY SELF-TERMINATING/CORRECTING/ADJUSTING TRAPE-
C   ZOIDAL INTFGRATION ABOUT V0
C   (2) INSIDE BY SUBROUTINE INTGS2--SELF-CORRECTING SIMPSON RULE
C STORAGE
      COMMON/GRATE/ WTH(10),ZEH(10),FACH(10)
      1,REDM,CUN1,SCALD,SCALF,SCALG,EP1,EP2,EP3,EP4,ND1,ND2,ND3
      2,EPS1,EPS2,NI
C COMPUTE
      DV = SCALD*V0
      AR = 0.0
      RLF = -1.0
50  V1 = V0
      ID = 0
      DLT1 = DV
      DLT2 = DV
      DLT3 = DV
55  V2 = V1 + DLT1 *RLF
      IF(V2) 61,60,60
60  V3 = V1 + DLT1*RLF*0.5
      CALL INTGS2 (V1,T,E0,EM,A1,A2,X1)
      CALL INTGS2 (V2,T,E0,EM,A1,A2,X2)
      EN1 = 0.5 *A1*A2*V1**2/(A1+A2)
      EN2 = 0.5 *A1*A2*V2**2/(A1+A2)
      CALL XINTER(EN1,XS1)
      CALL XINTER(EN2,XS2)
      Y1 = X1*XS1*V1**2
      Y2 = X2*XS2*V2**2
67  CALL INTGS2 (V3,T,E0,EM,A1,A2,X3)
      EN3 = 0.5 *A1*A2*V3**2/(A1+A2)
      CALL XINTER(EN3,XS3)
      Y3 = X3*XS3*V3**2
      DA1 = (Y1+Y2)*DLT1*0.5
      DA2 = Y3*DLT1*0.5 - DA1*0.5
      IF(ABS(DA2)-DA1*EP2) 66,66,65
65  DLT1 = DLT1*0.5
      V2 = Y3
      V2 = V3
      V3 = V1 + DLT1*RLF*0.5
      GO TO 67
66  AR = AR + DA1 + DA2
      ID = ID + 1
      IF(ID,GT,ND2)GO TO 75
      IF(DA1+DA2 - AR*EP3)75,70,70
70  V1 = V1 + DLT1*RLF
      IF(DLT2,LT,DLT3) GO TO 76
      IF(DLT1,LT,DLT2) GO TO 76
      DLT3 = DLT2
      DLT1 = A*IN1(2,0*DLT1,DV)
      DLT2 = DLT1
      GO TO 55

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76 DLT3 = DLT2
   DLT2 = DLT1
   GO TO 55
75 IF(RLF,GT,0,0) GO TO 80
   RLF = 1.0
   GO TO 50
61 DLT1 = V1
   GO TO 55
80 RETURN
   END

```

C
C
C

```

SUBROUTINE INTGS2(VR,T,E0,EM,A1,A2,X)
C FUNCTION OF PROGRAM
C CALCULATES INNER INTEGRAL OF SLOWING IN DOUBLE INTEGRAL FOR SIGMA-
C VBAR USING SIMPSONS RULE
C STORAGE
COMMON/GRATE/ WTH(10),ZEH(10),FACH(10)
1,REDM,CON1,SCALD,SCALF,SCALG,EP1,EP2,EP3,EP4,ND1,ND2,ND3
2,EPS1,EPS2,NI
C COMPUTE
V0 = SQRT(2.0*E0/A1)
VM = SQRT(2.0*EM/A1)
N = ND3
X = 0.0
100 N1 = (N-2)/2
DV = (VM-V0)/FLOAT(N)
XT = 0.0
VI = V0
DO 105 I = 1,N1
VI = VI + DV
Y1 = EXP(-A2/(2.0*T))*(VI+VR)**2) * (EXP(2.0*A2*VI+VR/T) - 1.0)
XT = XT + 4.0*Y1 / (VI**2)
VI = VI + DV
Y1 = EXP(-A2/(2.0*T))*(VI+VR)**2) * (EXP(2.0*A2*VI+VR/T) - 1.0)
105 XT = XT + 2.0*Y1 / (VI**2)
VT = VT + DV
Y1 = EXP(-A2/(2.0*T))*(VI+VR)**2) * (EXP(2.0*A2*VI+VR/T) - 1.0)
V0 = EXP(-A2/(2.0*T))*(V0+VR)**2) * (EXP(2.0*A2*V0+VR/T) - 1.0)
Y2 = EXP(-A2/(2.0*T))*(VM+VR)**2) * (EXP(2.0*A2*VM+VR/T) - 1.0)
XT = XT + 4.0*Y1 / (VI**2) + Y0/V0**2 + Y2/VM**2
XT = XT*(DV/3.0)
ERR = (XT-X) / XT
X = XT
IF(ABS(ERR).LE,EP4)GO TO 200
N = 2*N
GO TO 100
200 RETURN
   END

```

C
C
C

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SUBROUTINE INTEG1(SCALE,VEG,DEG,XEG,EGAM,IKEV,R)
C FUNCTION OF PROGRAM
C CALCULATES MAXWELLIAN SIGMA-VBAR USING GAUSS-HERMITE QUADRATURE
C INTEGRATION ABOUT EGAM
C STORAGE
COMMON/GRATE/ WTH(10),ZEH(10),FACH(10)
1,REDM,CON1,SCALD,SCALF,SCALG,EP1,EP2,EP3,EP4,ND1,ND2,ND3
2,EPS1,EPS2,NI
C COMPUTE
R = SCALE*WTH(1)*VEG*DEG*XEG
DO 254 IH=2,10
EH=EGAM+SCALE*ZEH(IH)
VH=SQRT(2.*EH/REDM)
DH=CON1*SQRT(EH/IKEV**3)*EXP(-EH/IKEV)
CALL XINTER(EH,XH)
R = R + SCALE*WTH(IH)*VH*DH*XH*FACH(IH)
254

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254 CONTINUE
DO 274 IH=2,10
EH=EGAM+SCALE*ZEH(IH)
IF (FH.LE.0.) GO TO 270
VH=SQRT(2.*EH/REDM)
DH=CON1*SQRT(EH/TKEV**3)*EXP(-EH/TKEV)
CALL XINTER(EH,XH)
R = R + SCALE*WTH(IH)*VH*DH*XH*FACH(IH)
274 CONTINUE
270 RETURN
END

C
C
C
SUBROUTINE INTEG2(SCALE,VEG,DEG,XEG,EGAM,TKEV,IDM,DEM,R)
C FUNCTION OF PROGRAM
C CALCULATES MAXWELLIAN SIGMA-VBAR USING SELF-TERMINATING DENSE
C TRAPEZOIDAL INTEGRATION ABOUT EGAM
C STORAGE
DIMENSION DEM(9),IDM(2)
COMMON/GRATE/ WTH(10),ZEH(10),FACH(10)
1,REDM,CON1,SCALD,SCALF,SCALG,EP1,EP2,EP3,EP4,ND1,ND2,ND3
2,EPS1,EPS2,NT
C COMPUTE
DE=SCALE+SCALF
DEM(1) = DE
DEM(8) = EP1
R = DE*VFG*DEG*XEG
C-----INTEGRATE TO RIGHT
ID=0
ED=EGAM
320 ID=ID+1
ED=ED+DE
VD=SQRT(2.*ED/REDM)
DD=CON1*SQRT(ED/TKEV**3)*EXP(-ED/TKEV)
CALL XINTER(ED,XD)
DR=DE*VD*DD*XD
R = R + DR
IF(DR/R.LT.EP1) GO TO 329
IF (ID.GT.ND1)GO TO 329
GO TO 320
329 IDM(2) = ID
DEM(3) = ED
DEM(5) = XD
DEM(7) = DR/R
C-----INTEGRATE TO LEFT
IJ=0
ED=EGAM
330 IJ=IJ+1
ED=ED-DE
IF( ED.LE.0.)GO TO 333
VD=SQRT(2.*ED/REDM)
DD=CON1*SQRT(ED/TKEV**3)*EXP(-ED/TKEV)
CALL XINTER(ED,XD)
DR=DE*VD*DD*XD
R = R + DR
IF (DR/R .LT. EP1) GO TO 339
IF(IJ.GT.ND1) GO TO 339
GO TO 330
339 IDM(1) = IJ
DEM(2) = ED
DEM(4) = XD
DEM(6) = DR/R
RETURN
333 IDM(1) = ID - 1
DEM(2) = ED + DE
DEM(4) = 0.0
DEM(6) = DR/R
RETURN
END

```

```

C
C
C      SUBROUTINE INTEG3(SCALE,EG,TK,IDM,DEM,R)
C FUNCTION OF PROGRAM
C      CALCULATES MAXWELLIAN SIGMA-VBAR USING SELF-CORRECTING/SELF-ADJUST-
C      ING/SELF-TERMINATING TRAPEZOIDAL INTEGRATION ABOUT EG
C STORAGE
      DIMENSION DEM(9),IDM(2)
      COMMON/GRATE/ WTH(10),ZEH(10),FACH(10)
      1,REDM,CON1,SCALD,SCALF,SCALG,EP1,EP2,EP3,EP4,ND1,ND2,ND3
      2,LPS1,EPS2,NI
C COMPUTE
      DE = SCALG*SCALE
      R = 0.0
      RLF = 1.7
      DMIN = DE
      DMAX = DE
50  E1 = EG
      ID = 0
      DLT1 = DE
      DLT2 = DE
      DLT3 = DE
55  E2 = E1 + DLT1*RLF
      IF(E2) 61,60,60
60  E3 = E1 + DLT1*RLF*0.5
      CALL XTINTER(E1,X1)
      CALL XTINTER(E2,X2)
      Y1 = SORT(2.0+E1/REDM)*CON1*SORT(E1/TK**3)*EXP(-E1/TK)*X1
      Y2 = SORT(2.0+E2/REDM)*CON1*SORT(E2/TK**3)*EXP(-E2/TK)*X2
67  CALL XTINTER(E3,X3)
      Y3 = SORT(2.0+E3/REDM)*CON1*SORT(E3/TK**3)*EXP(-E3/TK)*X3
      DA1 = (Y1+Y2)*DLT1*0.5
      DA2 = Y3*DLT1*0.5 = DA1*0.5
      IF(ABS(DA2)-DA1*EPS1) 66,66,65
65  DLT1 = DLT1*0.5
      Y2 = Y3
      E2 = E3
      X2 = X3
      E3 = E1 + DLT1*RLF*0.5
      GO TO 67
66  R = R + DA1 + DA2
      ID = ID + 1
      IF(ID,GT,NI) GO TO 75
      IF(DA1+DA2-R*EPS2) 75,70,70
70  DMIN = AMIN1(DMIN,DLT1)
      DMAX = AMAX1(DMAX,DLT1)
      E1 = E1 + DLT1*RLF
      IF(DLT2.LT,DLT3) GO TO 76
      IF(DLT1.LT,DLT2) GO TO 76
      DLT3 = DLT2
      DLT1 = AMIN1(2.0*DLT1,DE)
      DLT2 = DLT1
      GO TO 55
76  DLT3 = DLT2
      DLT2 = DLT1
      GO TO 55
75  IF(RLF.LT,0.0) GO TO 80
      DMIN = AMIN1(DLT1,DMIN)
      DMAX = AMAX1(DLT1,DMAX)
      DEM(4) = E2
      DEM(6) = X2
      DEM(8) = (DA1+DA2)/R
      IDM(2) = ID
      RLF = -1.0
      GO TO 50

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```

01 DLT1 = E1
02 TO 5
00 DEM(1) = A4INI(DM14,DLT1)
01 DEM(2) = A4AVI(DM14,DLT1)
02 DEM(3) = E2
03 DEM(5) = X2
04 DEM(7) = (CA1+CA2)/4
05 DEM(9) = EPS2
06 IY(1) = 10
07 RETURN
08

C
C
C
C SUBROUTINE EDGEN(O,F)
C FUNCTION OF PROGRAM
C COMPUTES ELECTRON DEGENERACY FACTOR, F, IN WEAK SCREENING FACTOR,
C F = (DERIVATIVE OF FINT)/(FINT), WHEN FINT = FERMI-DIRAC
C INTEGRAL. FINT = FCN(ETA) * D, WHERE D = SALPETER DEGENERACY
C PARAMETER. ETA IS IMPLICITLY EVALUATED FROM INPUT VALUE OF D
C AND (DATA) TABLES OF FINT VERSUS ETA, THEN D(FINT)/D(ETA) IS
C EVALUATED AT ETA FROM THESE SAME TABLES.
C FOR ETA.LE.-10.,F=1.0 / FOR ETA.GE.103.,F= (5./2.*D)
C STORAGE
C DIMENSION FINT(242)
C-----VALUES OF FINT FOR -13.0,GE,ETA.LE. -4.9 DELTA(ETA) = 0.1
C DATA (FINT(I),I= 1, 50)/
1 .072304E-03, .009654E-04, .091017E-04, .543499E-03, .600716E-04
2 .063347E-03, .733102E-04, .010200E-04, .095476E-04, .904573E-04
3 .129362E-03, .120866E-03, .133577E-03, .147624E-03, .163140E-03
4 .180366E-03, .199266E-03, .220243E-03, .243302E-03, .268976E-03
5 .277261E-03, .320520E-03, .363006E-03, .401243E-03, .433435E-03
6 .409002E-03, .541502E-03, .578538E-03, .661474E-03, .731017E-03
7 .877472E-03, .022009E-03, .060600E-03, .120359E-02, .120502E-02
8 .133168E-02, .147145E-02, .162438E-02, .177725E-02, .190612E-02
9 .210041E-02, .220502E-02, .240923E-02, .260178E-02, .272078E-02
10 .361659E-02, .390634E-02, .401500E-02, .487942E-02, .539149E-02/
C-----VALUES OF FINT FOR -5.0,GE,ETA.LE. -0.1 DELTA(ETA) = 0.1
C DATA (FINT(I),I= 51,100)/
1 .595714E-02, .658206E-02, .727230E-02, .003469E-02, .007672E-02
2 .000606E-02, .100336E-01, .119676E-01, .132196E-01, .140019E-01
3 .161277E-01, .170114E-01, .196707E-01, .217217E-01, .239845E-01
4 .260046E-01, .292135E-01, .322690E-01, .356152E-01, .393031E-01
5 .433660E-01, .470419E-01, .527698E-01, .581938E-01, .641614E-01
6 .707243E-01, .779304E-01, .850600E-01, .945664E-01, .100116E+00
7 .114500E+00, .126036E+00, .138627E+00, .152373E+00, .167397E+00
8 .183022E+00, .201696E+00, .221193E+00, .242411E+00, .265471E+00
9 .290501E+00, .317630E+00, .346709E+00, .378714E+00, .412937E+00
10 .449793E+00, .489415E+00, .531932E+00, .577474E+00, .626153E+00/
C-----VALUES OF FINT FOR 0.0,GE,ETA.LE. 2.0 DELTA(ETA) = 0.1
C DATA (FINT(I),I=101,150)/
1 .678394E+00, .733402E+00, .792180E+00, .854520E+00, .920504E+00
2 .990208E+00, .106369E+01, .114101E+01, .122221E+01, .130733E+01
3 .139637E+01, .148937E+01, .158632E+01, .168722E+01, .179207E+01
4 .190203E+01, .201349E+01, .213072E+01, .225039E+01, .237454E+01
5 .250245E+01, .263607E+01, .276934E+01, .290822E+01, .305665E+01
6 .319659E+01, .330598E+01, .340907E+01, .365400E+01, .381432E+01/
C-----VALUES OF FINT FOR 3.0,GE,ETA.LE. 13.5 DELTA(ETA) = 0.5
C DATA (FINT(I),I=151,152)/
1 .397699E+01, .403707E+01, .577073E+01, .677257E+01, .703797E+01
2 .896299E+01, .101403E+02, .113790E+02, .126646E+02, .139991E+02
3 .153805E+02, .168471E+02, .182776E+02, .197904E+02, .213445E+02
4 .229386E+02, .245718E+02, .262432E+02, .279518E+02, .296968E+02
5 .314775E+02, .332931E+02 /
C-----VALUES OF FINT FOR 14.0,GE,ETA.LE. 50.0 DELTA(ETA) = 1.0
C DATA (FINT(I),I=153,197)/
1 .351430E+02, .389431E+02, .420730E+02, .469286E+02, .511061E+02
2 .554019E+02, .590128E+02, .643359E+02, .689684E+02, .737079E+02
3 .785518E+02, .834901E+02, .885445E+02, .936992E+02, .989333E+02
4 .104266E+03, .109645E+03, .115215E+03, .120825E+03, .126524E+03

```

```

5, .132302E+03, .138101E+03, .144157E+03, .150177E+03, .156299E+03
6, .162502E+03, .168745E+03, .175147E+03, .181568E+03, .188105E+03
7, .194699E+03, .201369E+03, .208113E+03, .214951E+03, .221821E+03
8, .228784E+03, .235819E+03, .242924E+03, .250099E+03, .257344E+03
9, .264657E+03, .272038E+03, .279487E+03, .287003E+03, .294585E+03/
C-----VALUES OF FINT FOR 49.0, 6F, FTA, LE, 103.0 DELTA(E1A) = 1.0
DATA (FINT(1)-1*196,2*2)/
1, .302232E+03, .309745E+03, .317722E+03, .325563E+03, .333468E+03
2, .341434E+03, .349447E+03, .357550E+03, .365713E+03, .373924E+03
3, .382204E+03, .390540E+03, .398935E+03, .407390E+03, .415904E+03
4, .424477E+03, .433108E+03, .441796E+03, .450542E+03, .459345E+03
5, .468204E+03, .477120E+03, .486091E+03, .495119E+03, .504201E+03
6, .513334E+03, .522530E+03, .531774E+03, .541076E+03, .550430E+03
7, .559837E+03, .569297E+03, .578809E+03, .588374E+03, .597992E+03
8, .607661E+03, .617301E+03, .627153E+03, .636976E+03, .646858E+03
9, .656774E+03, .666749E+03, .676773E+03, .686840E+03, .696972E+03/
C COMPUTE
EPS = 0.1E-4
IF(0,LE,FINT(3)) GO TO 500
IF(0,GE,FINT(240)) GO TO 600
DO 10 I=3,240
N1 = 1
IF(0,LT,FINT(I)) GO TO 15
10 CONTINUE
15 DE = 0.1
IF(N1,GT,129) DE = 0.5
IF(N1,GT,151) DE = 1.0
IF(N1,EQ,130) N1 = 131
IF(N1,EQ,152) N1 = 153
N2 = N1 + 1
N3 = N2 + 1
N = N1 - 1
IF(N1,EQ,131) N = N1 - 5
IF(N1,EQ,153) N = N1 - 2
M1 = N1 - 2
IF(N1,EQ,131) M1 = N - 5
IF(N1,EQ,132) M1 = N - 5
IF(N1,EQ,153) M1 = N - 2
IF(N1,EQ,154) M1 = N - 2
M2 = N1 - 3
IF(N1,EQ,131) M2 = M1 - 5
IF(N1,EQ,132) M2 = M1 - 5
IF(N1,EQ,133) M2 = M1 - 5
IF(N1,EQ,153) M2 = M1 - 2
IF(N1,EQ,154) M2 = M1 - 2
IF(N1,EQ,155) M2 = M1 - 2
ET1 = 0.0
ET2 = DE
F11 = FINT(N)
F12 = FINT(N1)
DF0 = FINT(N)
DF1 = FINT(N1)
DF2 = FINT(N2)-FINT(N1)-FINT(N) + FINT(M1)
DF3 = FINT(N2)-3.0*FINT(N1)+3.0*FINT(N)-FINT(M1)
DF4 = FINT(N2)-3.0*FINT(N2)+2.0*FINT(N1)+2.0*FINT(N)-3.0*FINT(M1)
1 + FINT(N2)
DIFF = DF1 - DF0
20 ET = (ET1+F12 - ET2*F11 + 0*(ET2-ET1))/(F12 - F11)
P = ET/DE
B1 = (1.0-P)
B2 = -B1*P/4.0
B3 = 2.0*B2*(P-0.5)/3.0
B4 = -0.180*B2
F1 = B1*DF0 + P*DF1 + B2*DF2 + B3*DF3 + B4*DF4
IF(ABS((0-F1)/DIFF),LE,EP8) GO TO 50
IF(0,LT,F1) GO TO 30
ET1 = ET
F11 = F1
GO TO 20

```

```

30 ET2 = ET
   FI2 = FI
   GU TO 20
50 ETP = ET + 0.01
   I = 1
   IF(ETP,GT,DE) GO TO 100
   P = ETP/DE
60 B1 = (1,0-P)
   B2 = -B1*P/4.0
   B3 = 2.0*B2*(P-0.5)/3.0
   B4 = -0.184*B2
   FIT = B1*DF0 + P*DF1 + B2*DF2 + B3*DF3 + B4*DF4
   GO TO (61,62,63,64), I
61 FIP1 = FIT
   ET1 = ET - 0.01
   I = 2
   IF(ET1,LT,0.0)GO TO 200
   P = ET1/DE
   GO TO 50
62 FIM1 = FIT
   ETP2 = ET + 0.02
   I = 3
   IF(ETP2,GT,DE) GO TO 100
   P = ETP2/DE
   GO TO 60
63 FIP2 = FIT
   ET2 = ET - 0.02
   I = 4
   IF(ET2,LT,0.0)GO TO 200
   P = ET2/DE
   GO TO 60
64 FIM2 = FIT
   F = (FIM2/12.0 + 2.0*FIM1/3.0 + 2.0*FIP1/3.0 - FIP2/12.0) /FI
   F = 100.*F
   RETURN
100 DEX = DE
   IF(N3,EQ,242) GO TO 600
   IF(N1,EQ,129) GO TO 150
   IF(N1,EQ,151) GO TO 160
   NX1 = N1+ 1
   NX2 = N1+ 2
   NX3 = N1+ 3
   NX = N1
   MX1 = N1- 1
   IF(N1,EQ,131) MX1 = N1-5
   IF(N1,EQ,143) MX1 = N1-2
   MX2 = N1- 2
   IF(N1,EQ,151) MX2 = MX1 - 5
   IF(N1,EQ,132) MX2 = MX1 - 5
   IF(N1,EQ,143) MX2 = MX1 - 2
   IF(N1,EQ,154) MX2 = MX1 - 2
110 DFX = FINT(NX)
   DFX1 = FINT(NX1)
   DFX2 = FINT(NX2)-FINT(NX1)-FINT(NX)+FINT(MX1)
   DFX3 = FINT(NX2)-3.0*FINT(NX1)+3.0*FINT(NX)-FINT(MX1)
   DFX4 = FINT(NX3)-3.0*FINT(NX2)+2.0*FINT(NX1)+2.0*FINT(NX)
   I = -3.0*FINT(MX1)+FINT(MX2)
   GO TO(111,211,112,212) I
111 P = (ETP-DE)/DEX
   GO TO 113
112 P = (ETP2-DE)/DEX
113 B1 = (1,0-P)
   B2 = -B1*P/4.0
   B3 = 2.0*B2*(P-0.5)/3.0
   B4 = -0.184*B2
   FIT = B1*DFX + P*DFX1 + B2*DFX2 + B3*DFX3 + B4*DFX4
   GO TO (61,62,63,64), I
150 NX1 = 131
   DEX = 0.5
   IF(I,EQ,3) GO TO 151

```



```

      ETP = ETP + 0.3
      GO TO 155
151 ETP2 = ETP2 + 0.3
155 NX = NX1 - 5
      NX1 = NX - 5
      NX2 = NX1 - 5
      GO TO 174
160 NX1 = 153
      DEK = 1.0
      NX = NX1 - 2
      NX1 = NX - 2
      NX2 = NX1 - 2
170 NX2 = NX1 + 1
      NX3 = NX2 + 1
      GO TO 114
200 CONTINUE
      IF (MPT, EQ, 1) GO TO 504
      NX3 = NX3 - 1
      NX2 = NX2 - 1
      NX1 = NX1 - 1
      IF (N1, EQ, 153) NX1 = NX1 - 2
      NX = NX - 1
      IF (N1, EQ, 132) NX = NX1 + 5
      IF (N1, EQ, 153) NX = NX1 - 2
      IF (N1, EQ, 154) NX = NX1 - 2
      NX1 = NX - 1
      IF (N1, EQ, 132) NX1 = NX - 5
      IF (N1, EQ, 133) NX1 = NX - 5
      IF (N1, EQ, 153) NX1 = NX - 2
      IF (N1, EQ, 154) NX1 = NX + 2
      IF (N1, EQ, 155) NX1 = NX + 2
      NX2 = NX1 - 1
      IF (N1, EQ, 132) NX2 = NX1 - 5
      IF (N1, EQ, 133) NX2 = NX1 - 5
      IF (N1, EQ, 134) NX2 = NX1 - 5
      IF (N1, EQ, 153) NX2 = NX1 - 2
      IF (N1, EQ, 154) NX2 = NX1 - 2
      IF (N1, EQ, 155) NX2 = NX1 - 2
      IF (N1, EQ, 156) NX2 = NX1 + 2
      GO TO 110
211 P = (FT4 + DE) / DE
      GO TO 113
212 P = (FT42 + DE) / DE
      GO TO 113
500 F = 1.0
      RETURN
600 F = 2.0 / (3.0 * (1.5 * n) ** (2.0 / 3.0))
      RETURN
      END

```

C
C
C

```

      SUBROUTINE PLOIT(NX, MPT, INX, NDP, INC, NSP, NSMB)
C FUNCTION OF PROGRAM
C RETURN APPROPRIATE INDEX VARIABLES FOR SUBROUTINE PLOTM
C Y=AXIS = LOG / INC = 01
C X=AXIS = LOG / NDP = -NX
C MULTIPLE PLOTS / NSP = NX/10
C BEGIN
      INC = 1
      IF (ARS(MPT), EQ, 1) INC = -1
      NDP = NX
      IF (MPT, LT, 0) NDP = -NX
      GO TO (10, 10, 20, 10, 20, 10, 20, 10, 20), INX
10 NSP = 0
      GO TO 30
20 NSP = NX/10
30 NSMB = 20
      RETURN
      END

```

APPENDIX B

INPUT FOR STEEP4 SAMPLE PROBLEM

SAMPLE PROBLEM CASE 1 D(D,N)HES FUSION REACTION

```

1 3 1 1 1 1 1 1
2 2 1
1.0 1.0
2.01355 2.01355
0.5E+14 0.5E+14
30 3
1 3 2
6P.0 3000.0
0.045E+06 0.512E-07 0.010E+06 0.0670E-05 0.015E+06 0.7711E-04
0.020E+06 0.2725E-03 0.025E+06 0.6307E-03 0.030E+06 1.156E-03
0.040E+06 2.603E-03 0.050E+06 4.567E-03 0.060E+06 6.770E-03
0.070E+06 9.101E-03 0.080E+06 11.35E-03 0.090E+06 13.65E-03
0.100E+06 15.04E-03 0.120E+06 20.51E-03 0.150E+06 26.61E-03
0.200E+06 37.73E-03 0.240E+06 38.02E-03 0.300E+06 43.65E-03
0.400E+06 53.04E-03 0.500E+06 59.57E-03 0.600E+06 63.93E-03
0.700E+06 68.39E-03 0.800E+06 71.97E-03 0.900E+06 74.99E-03
1.000E+06 76.86E-03 1.200E+06 82.22E-03 1.500E+06 87.67E-03
2.000E+06 89.42E-03 2.400E+06 90.60E-03 3.000E+06 91.20E-03
100 100.0

```

1.0 100.0

SAMPLE PROBLEM CASE 2 D(D,P)T FUSION REACTION

```

1 5 1 1 2 1 1 1
-2 0 0 1 -1 0 0 0
2 2 1
1.0 1.0
2.01355 2.01355
0.5E+14 0.5E+14
30 3
1 3 2
6P.0 3000.0
0.045E+06 0.512E-07 0.010E+06 0.0673E-05 0.015E+06 0.7710E-04
0.020E+06 0.2725E-03 0.025E+06 0.6307E-03 0.030E+06 1.156E-03
0.040E+06 2.603E-03 0.050E+06 4.567E-03 0.060E+06 6.770E-03
0.070E+06 9.101E-03 0.080E+06 11.35E-03 0.090E+06 13.65E-03
0.100E+06 15.04E-03 0.120E+06 20.51E-03 0.150E+06 26.61E-03
0.200E+06 37.73E-03 0.240E+06 38.02E-03 0.300E+06 43.65E-03
0.400E+06 53.04E-03 0.500E+06 59.57E-03 0.600E+06 63.93E-03
0.700E+06 68.39E-03 0.800E+06 71.97E-03 0.900E+06 74.99E-03
1.000E+06 76.86E-03 1.200E+06 82.22E-03 1.500E+06 87.67E-03
2.000E+06 89.42E-03 2.400E+06 90.60E-03 3.000E+06 91.20E-03
100 100.0

```

1.0 100.0

SAMPLE PROBLEM CASE 3 HES(D,P)ALPHA FUSION REACTION

```

1 3 1 5 1 1 3 1
1 1 1 0 0 0 0 1 0 0 0
0 2 2 1
1.0 2.0
2.01355 3.01493
0.5E+26 0.5E+26
66 3
1 3 2
166.79 583.75
5.0000E+03 1.2374E-14 1.0000E+04 7.0447E-10 2.0000E+04 1.3452E-06 1271 3 0 31
4.0000E+04 2.3703E-04 6.0000E+04 2.1937E-03 8.0000E+04 8.1163E-03 1271 3 0 32
1.0000E+05 1.9785E-02 1.2000E+05 3.8389E-02 1.4000E+05 6.4763E-02 1271 3 0 33
1.6000E+05 9.9552E-02 1.8000E+05 1.4324E-01 2.0000E+05 1.9674E-01 1271 3 0 34
2.2000E+05 2.5776E-01 2.4000E+05 3.2756E-01 2.6000E+05 4.0372E-01 1271 3 0 35
2.8000E+05 4.2353E-01 3.0000E+05 5.6335E-01 3.2000E+05 6.3691E-01 1271 3 0 36
3.4000E+05 7.0595E-01 3.6000E+05 7.6083E-01 3.8000E+05 8.0121E-01 1271 3 0 37

```

4.2320E+05	8.2627E-01	4.1727E+05	8.3324E-01	4.2227E+05	8.3673E-01	1271	3	0	36
4.3727E+05	8.3727E-01	4.4727E+05	8.3831E-01	4.5227E+05	8.2922E-01	1271	3	0	39
4.6000E+05	8.7123E-01	4.7000E+05	8.1187E-01	4.8000E+05	8.0000E-01	1271	3	0	40
4.9000E+05	7.8333E-01	5.0000E+05	7.7432E-01	5.2000E+05	7.0453E-01	1271	3	0	41
5.4000E+05	7.1288E-01	5.6000E+05	6.8061E-01	5.8000E+05	6.0061E-01	1271	3	0	42
6.0000E+05	6.1747E-01	6.2000E+05	5.8159E-01	6.4000E+05	5.5918E-01	1271	3	0	43
6.6000E+05	5.3237E-01	6.8000E+05	5.0711E-01	7.0000E+05	4.8368E-01	1271	3	0	44
7.2000E+05	4.6158E-01	7.4000E+05	4.4103E-01	7.6000E+05	4.2187E-01	1271	3	0	45
7.8000E+05	4.0402E-01	8.0000E+05	3.8738E-01	8.5000E+05	3.5050E-01	1271	3	0	46
9.0000E+05	3.1938E-01	9.5000E+05	2.9297E-01	1.0000E+06	2.7044E-01	1271	3	0	47
1.2000E+06	2.0664E-01	1.4000E+06	1.6832E-01	1.6000E+06	1.4534E-01	1271	3	0	48
1.8000E+06	1.2657E-01	2.0000E+06	1.1651E-01	2.2000E+06	1.0065E-01	1271	3	0	49
2.4000E+06	1.0224E-01	2.6000E+06	9.7292E-02	2.8000E+06	9.3528E-02	1271	3	0	50
3.0000E+06	9.2600E-02	3.2000E+06	8.8567E-02	3.4000E+06	8.7013E-02	1271	3	0	51
3.6000E+06	8.5912E-02	3.8000E+06	8.5176E-02	4.0000E+06	8.4736E-02	1271	3	0	52

100

1.0 100.0

SAMPLE	PROBLEM	CASE	4	T(D,N)ALPHA	FUSION	REACTION
1	3	-1	1	1	2	1
0	0	1	0	0	0	0
0	0	0	0	0	0	0
2	2	1				

1.0

2.01355 3.01550

0.5E+14 0.5E+14

69

1

116.74

1.0000E+03

4.0000E+03

1.5000E+04

3.0000E+04

4.5000E+04

6.0000E+04

8.0000E+04

1.0500E+05

1.2000E+05

1.8000E+05

2.4000E+05

3.0000E+05

3.6000E+05

4.2000E+05

4.8000E+05

6.0000E+05

7.5000E+05

9.0000E+05

1.2000E+06

1.8000E+06

2.4000E+06

3.0000E+06

3.6000E+06

100

1.0 100.0

SAMPLE	PROBLEM	CASE	5	T(D,N)ALPHA	FUSION	REACTION	WITH D SLOWING DOWN
2	3	2	1	1	1	2	
0	1	0	0	0	1	0	
0.001		0.1E-7	100000				
2	2	1					

1.0

2.01355 3.01550

0.5E+14 0.5E+14

69

1

116.74

9

2.0 10.0

1.0E+12 120.0

1.2

0

OUTPUT FOR STEEP4 SAMPLE PROBLEM

I. PRINT OUT OF OUTPUT FOR CASES 1 THROUGH 5

SAMPLE PROBLEM CASE 1 OLD-MIXED FUSION REACTION

CROSS SECTION INPUT IN ENDF6 FORMAT

NUMBER OF PARTICLE TYPES = 5

NUMBER OF MATERIALS = 1

NUMBER OF SCHEMES = 1

NUMBER OF INTERPOLATION SCHEMES = 1

NUMBER OF DATA (NSI) = 3

NUMBER OF INTERPOLATION SCHEMES (INSI) = 3

INTERPOLATION SCHEME (I) = GAUSS FORM

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***** FINAL RESULTS FOR SIGMA-VBAR *****
 ION DISTRIBUTION-----BOTH IONS MAXWELLIAN
 MAXWELLIAN INTEGRATION-----NO CALCULATION
 SCREENING FACTOR-----
 SIGMA-VBAR COMPONENTS
 SLOWING MAXWELLIAN
 DOWN
 SCREENING FACTOR
 SIGMA-VBAR
 TOTAL
 (CM**3/SEC)

1	11649E+02	10000E+01	965850E-25	965850E-22
2	272099E+02	20000E+01	303967E-25	303967E-22
3	34614E+02	30000E+01	157269E-19	157269E-19
4	466137E+02	40000E+01	438310E-19	438310E-19
5	587246E+02	50000E+01	903463E-19	903463E-19
6	69236E+02	60000E+01	156322E-18	156322E-18
7	81234E+02	70000E+01	241690E-18	241690E-18
8	92339E+02	80000E+01	345567E-18	345567E-18
9	104444E+02	90000E+01	465810E-18	465810E-18
10	116047E+02	10000E+02	604137E-18	604137E-18
11	127654E+02	11000E+02	754290E-18	754290E-18
12	139259E+02	12000E+02	922095E-18	922095E-18
13	149844E+02	13000E+02	110043E-17	110043E-17
14	162459E+02	14000E+02	129052E-17	129052E-17
15	174074E+02	15000E+02	149133E-17	149133E-17
16	185679E+02	16000E+02	172133E-17	172133E-17
17	197284E+02	17000E+02	192222E-17	192222E-17
18	208889E+02	18000E+02	215093E-17	215093E-17
19	220494E+02	19000E+02	238768E-17	238768E-17
20	232099E+02	20000E+02	263191E-17	263191E-17
21	243703E+02	21000E+02	289377E-17	289377E-17
22	255309E+02	22000E+02	314070E-17	314070E-17

21	264313E+03	34432F-17
22	224511E+03	3073A7E-17
23	224127E+03	3947A3E-17
24	224511E+03	3947A3E-17
25	224127E+03	3947A3E-17
26	311333E+03	422695E-17
27	311333E+03	422695E-17
28	311333E+03	422695E-17
29	311333E+03	422695E-17
30	311333E+03	422695E-17
31	311333E+03	422695E-17
32	311333E+03	422695E-17
33	311333E+03	422695E-17
34	311333E+03	422695E-17
35	311333E+03	422695E-17
36	311333E+03	422695E-17
37	311333E+03	422695E-17
38	311333E+03	422695E-17
39	311333E+03	422695E-17
40	311333E+03	422695E-17
 

SAMPLE PROBLEM CASE 2 D(D,P)T FUSION REACTION

KDATA = 1 CROSS SECTIONS INPUT IN ENDF/B FORMAT
 KINTE = 4 COMPARISON OF INTEGRATION METHODS
 KTEMP = 1 BOTH NUCLEI MAXWELLIAN
 KSCPA = 1 NO SCREENING CALCULATION
 KPLOT = 2 PLOT OUTPUT
 KPNCH = 1 NO PUNCH OUTPUT
 KPPNT = 1 REDUCED PRINTED OUTPUT
 KCNTL = 1 USE ALL INTERNAL PARAMETERS

PLASMA MATERIAL NUMBER OF PARTICLE TYPES = 5
 IMAT 7(IMAT) A(IMAT) NO.DENSITY IMAT Z(IMAT) A(IMAT) NO.DENSITY
 1 .100000E+01 .201355E+01 .500000E+14 2 .100000E+01 .201355E+01 .500000E+14
 TARGET IMAT = 2 PROJECTILE IMAT = 1
 REOA = .100677E+01 AMU REUM = .104343E-14 KEV SEC=2/CM**2 BOAM = .313979E+02 KEV**0.5

CROSS SECTION INPUT NUMBER OF DATA (NS) = 30
 NUMBER OF INTERPOLATION REGIONS (NYS) = 3
 INTERPOLATION SCHEME (1) = GAMMA FORM
 (2) = LOG-LOG
 (3) = CURIC
 (1) .6000E+02 KEV (3) .3000E+04 KEV (2)

ENDF/B CROSS SECTION DATA PAIRS ENERGY(EV)/SIGMA(BARNS) (15) IS=1 NS
 .5000E+04 .5120E+07 .1000E+05 .86730E-05 .15000E+05 .7710E-04
 .2000E+05 .2725E+03 .25000E+05 .63070E-03 .3000E+05 .1156E-02
 .4000E+05 .26430E-02 .5000E+05 .45670E-02 .6000E+05 .6770E-02
 .7000E+05 .90160E-02 .8000E+05 .11350E-01 .9000E+05 .13050E-01
 .1000E+06 .15850E-01 .12400E+06 .20510E-01 .15870E+06 .2601E-01
 .2000E+06 .32730E-01 .24490E+06 .38020E-01 .3000E+06 .44050E-01
 .4000E+06 .53090E-01 .5000E+06 .59570E-01 .6000E+06 .67830E-01
 .7000E+06 .68390E-01 .8000E+06 .71970E-01 .9000E+06 .74490E-01
 .1000E+07 .76860E-01 .12600E+07 .82220E-01 .15870E+07 .87470E-01
 .2000E+07 .89420E-01 .24490E+07 .90660E-01 .3000E+07 .97200E-01

PLASMA TEMPERATURES (NO. = 100. 1MIN = .100000E+01 KEV. TMAX = .100000E+03)

COMPARISON OF MAXWELLIAN INTEGRATION METHODS

IT	T(DFG K)	T(KEV)	RATEG(CC/SEC)	RATEH(CC/SEC)	RATED(CC/SEC)	RATET(CC/SEC)
1	.11049E+02	.10000E+01	.94978423E-22	.96582979E-22	.96576397E-22	.96573419E-22
2	.232090E+02	.20000E+01	.29278951E-20	.30390933E-20	.30385498E-20	.30394638E-20
3	.348148E+02	.30000E+01	.15815435E-19	.15724416E-19	.15722682E-19	.15722298E-19
4	.464197E+02	.40000E+01	.41521877E-19	.43756532E-19	.43765864E-19	.43764942E-19
5	.588246E+02	.50000E+01	.84917932E-19	.89935442E-19	.89945590E-19	.89944101E-19
6	.696298E+02	.60000E+01	.14578494E-18	.15491899E-18	.15504562E-18	.15504267E-18
7	.812345E+02	.70000E+01	.22379471E-18	.23843541E-18	.23849937E-18	.23849622E-18
8	.928394E+02	.80000E+01	.31767522E-18	.33893315E-18	.33912839E-18	.33912595E-18
9	.104444E+03	.90000E+01	.4272289E-18	.4551518E-18	.45572115E-18	.45571396E-18
10	.116049E+03	.10000E+02	.55009450E-18	.58650944E-18	.58664702E-18	.5866332E-18
11	.127654E+03	.11000E+02	.68424524E-18	.72956175E-18	.73054991E-18	.73052968E-18
12	.139253E+03	.12000E+02	.82709993E-18	.88411485E-18	.88614573E-18	.88612654E-18
13	.150864E+03	.13000E+02	.97798116E-18	.10495720E-17	.10522420E-17	.10522192E-17
14	.162469E+03	.14000E+02	.11611446E-17	.12279761E-17	.12277735E-17	.12277435E-17
15	.174074E+03	.15000E+02	.13110805E-17	.14094436E-17	.14117774E-17	.14117433E-17
16	.185679E+03	.16000E+02	.14851840E-17	.15973424E-17	.16033075E-17	.16033644E-17
17	.197294E+03	.17000E+02	.16653210E-17	.17937075E-17	.18018720E-17	.18018371E-17
18	.208889E+03	.18000E+02	.18513204E-17	.19992714E-17	.20065194E-17	.20064776E-17
19	.220494E+03	.19000E+02	.20422542E-17	.22139008E-17	.22167411E-17	.22166894E-17
20	.232099E+03	.20000E+02	.22338425E-17	.24327570E-17	.24319827E-17	.24319601E-17
21	.243703E+03	.21000E+02	.24275753E-17	.26525984E-17	.26517726E-17	.26517580E-17
22	.255308E+03	.22000E+02	.26266665E-17	.28774478E-17	.28756792E-17	.28756565E-17
23	.266913E+03	.23000E+02	.28109104E-17	.31027463E-17	.31033034E-17	.31032979E-17
24	.278518E+03	.24000E+02	.29788143E-17	.33278675E-17	.33303332E-17	.33303090E-17
25	.290123E+03	.25000E+02	.31514371E-17	.35589151E-17	.35683698E-17	.35683055E-17
26	.301728E+03	.26000E+02	.33293167E-17	.37962294E-17	.38052206E-17	.38052319E-17
27	.313333E+03	.27000E+02	.35129971E-17	.40314633E-17	.40445995E-17	.40445997E-17
28	.324938E+03	.28000E+02	.37030258E-17	.42620134E-17	.42842570E-17	.42842430E-17
29	.336543E+03	.29000E+02	.38999515E-17	.44975633E-17	.45300051E-17	.45300157E-17
30	.348148E+03	.30000E+02	.4093228E-17	.47406484E-17	.47756316E-17	.4775623E-17
31	.359753E+03	.31000E+02	.43166965E-17	.49898855E-17	.50229671E-17	.5023066E-17
32	.371358E+03	.32000E+02	.45244562E-17	.52445628E-17	.52718761E-17	.52715032E-17
33	.382963E+03	.33000E+02	.47425127E-17	.54995794E-17	.55221676E-17	.55222073E-17
34	.394568E+03	.34000E+02	.49511113E-17	.57584607E-17	.57737438E-17	.57737481E-17
35	.406172E+03	.35000E+02	.51604483E-17	.60175332E-17	.60264414E-17	.60264861E-17
36	.417777E+03	.36000E+02	.53703023E-17	.62763442E-17	.62801873E-17	.62802312E-17
37	.429382E+03	.37000E+02	.55804266E-17	.65376316E-17	.65348280E-17	.65348932E-17
38	.440987E+03	.38000E+02	.57906183E-17	.67955487E-17	.67983210E-17	.67983167E-17
39	.452592E+03	.39000E+02	.60006191E-17	.70503837E-17	.70465985E-17	.70466999E-17
40	.464197E+03	.40000E+02	.62102149E-17	.73065233E-17	.73037673E-17	.73034554E-17
41	.475802E+03	.41000E+02	.64191846E-17	.75633387E-17	.75608844E-17	.75608844E-17
42	.487407E+03	.42000E+02	.66273126E-17	.78227206E-17	.78187180E-17	.78187669E-17
43	.499012E+03	.43000E+02	.68343864E-17	.80846470E-17	.80770678E-17	.80771515E-17
44	.510617E+03	.44000E+02	.70401973E-17	.83471688E-17	.83357763E-17	.83358873E-17
45	.522222E+03	.45000E+02	.72445004E-17	.86115736E-17	.85948642E-17	.85949143E-17
46	.533827E+03	.46000E+02	.74204882E-17	.88682801E-17	.88548662E-17	.88541942E-17

47	.545432E+03	.470000E+02	.75972233E-17	.91249492E-17	.91135745E-17	.91136483E-17
48	.557403E+03	.480000E+02	.77755744E-17	.93843508E-17	.93771651E-17	.93737093E-17
49	.564401E+03	.490000E+02	.79553777E-17	.96467083E-17	.96328827E-17	.96336222E-17
50	.580246E+03	.500000E+02	.81368882E-17	.99093303E-17	.98926526E-17	.98928383E-17
51	.591451E+03	.510000E+02	.83208795E-17	.10162022E-16	.10152493E-16	.10152647E-16
52	.603456E+03	.520000E+02	.85049942E-17	.10418000E-16	.10412306E-16	.10412415E-16
53	.615461E+03	.530000E+02	.86916740E-17	.10676262E-16	.10672046E-16	.10672166E-16
54	.627466E+03	.540000E+02	.88801591E-17	.10932441E-16	.10931747E-16	.10931877E-16
55	.639471E+03	.550000E+02	.90704891E-17	.11190409E-16	.11191334E-16	.11191412E-16
56	.649876E+03	.560000E+02	.92627824E-17	.11448253E-16	.11450768E-16	.11450895E-16
57	.661481E+03	.570000E+02	.94568366E-17	.11701733E-16	.11710056E-16	.11710173E-16
58	.673084E+03	.580000E+02	.96529283E-17	.11957743E-16	.11969123E-16	.11969286E-16
59	.684691E+03	.590000E+02	.98510135E-17	.12216731E-16	.12228855E-16	.12229155E-16
60	.696296E+03	.600000E+02	.10051127E-16	.12476043E-16	.12486659E-16	.12486819E-16
61	.707901E+03	.610000E+02	.10257103E-16	.12740276E-16	.12745888E-16	.12745242E-16
62	.719505E+03	.620000E+02	.10457576E-16	.13006275E-16	.13003230E-16	.13003344E-16
63	.731110E+03	.630000E+02	.10667077E-16	.13274242E-16	.13261662E-16	.13261181E-16
64	.742715E+03	.640000E+02	.10855051E-16	.13540775E-16	.13518575E-16	.13518764E-16
65	.754320E+03	.650000E+02	.11015620E-16	.13798033E-16	.13775803E-16	.13774001E-16
66	.765925E+03	.660000E+02	.11173780E-16	.14058314E-16	.14037680E-16	.14032883E-16
67	.777530E+03	.670000E+02	.11332780E-16	.14312809E-16	.14289228E-16	.14289458E-16
68	.789135E+03	.680000E+02	.11493554E-16	.14551562E-16	.14545488E-16	.14545527E-16
69	.800740E+03	.690000E+02	.11654339E-16	.14792595E-16	.14801197E-16	.14801372E-16
70	.812345E+03	.700000E+02	.11816566E-16	.15034123E-16	.15055618E-16	.15056893E-16
71	.823950E+03	.710000E+02	.11979174E-16	.15277469E-16	.15311888E-16	.15311878E-16
72	.835555E+03	.720000E+02	.12143088E-16	.15522775E-16	.15566272E-16	.15566539E-16
73	.847160E+03	.730000E+02	.12307772E-16	.15769284E-16	.15822861E-16	.15822751E-16
74	.858765E+03	.740000E+02	.12473430E-16	.16017726E-16	.16074295E-16	.16074777E-16
75	.870370E+03	.750000E+02	.12640108E-16	.16267411E-16	.16327624E-16	.16327872E-16
76	.881974E+03	.760000E+02	.12807833E-16	.16518015E-16	.16580516E-16	.16580815E-16
77	.893579E+03	.770000E+02	.12976642E-16	.16771027E-16	.16832967E-16	.16833280E-16
78	.905184E+03	.780000E+02	.13146655E-16	.17024766E-16	.17085888E-16	.17086316E-16
79	.916789E+03	.790000E+02	.13317634E-16	.17279000E-16	.17334651E-16	.17334852E-16
80	.928394E+03	.800000E+02	.13489880E-16	.17535005E-16	.17587340E-16	.17587975E-16
81	.939999E+03	.810000E+02	.13663331E-16	.17793617E-16	.17838246E-16	.17838588E-16
82	.951604E+03	.820000E+02	.1383819E-16	.18052444E-16	.18098430E-16	.18098727E-16
83	.963209E+03	.830000E+02	.14013972E-16	.18312688E-16	.18339879E-16	.18339399E-16
84	.974814E+03	.840000E+02	.14191220E-16	.18574802E-16	.18587238E-16	.18587558E-16
85	.986419E+03	.850000E+02	.14369791E-16	.18838055E-16	.18835091E-16	.18836312E-16
86	.998024E+03	.860000E+02	.14549713E-16	.19102748E-16	.19084911E-16	.19084566E-16
87	.100763E+04	.870000E+02	.14707101E-16	.19361219E-16	.19371847E-16	.19372295E-16
88	.102123E+04	.880000E+02	.14854463E-16	.19615088E-16	.19579121E-16	.19575332E-16
89	.103788E+04	.890000E+02	.15001783E-16	.19870153E-16	.19825781E-16	.19826245E-16
90	.104444E+04	.900000E+02	.15149214E-16	.20124019E-16	.20072857E-16	.20072362E-16
91	.105405E+04	.910000E+02	.15296789E-16	.20368145E-16	.20317727E-16	.20318059E-16
92	.106765E+04	.920000E+02	.15444524E-16	.20610771E-16	.20562944E-16	.20562411E-16
93	.107926E+04	.930000E+02	.15592431E-16	.20853370E-16	.20808747E-16	.20808115E-16
94	.109086E+04	.940000E+02	.15740023E-16	.21095836E-16	.21051788E-16	.21052349E-16
95	.110247E+04	.950000E+02	.15888813E-16	.21338088E-16	.21295403E-16	.21295990E-16
96	.111407E+04	.960000E+02	.16037315E-16	.21582437E-16	.21538866E-16	.21539216E-16
97	.112568E+04	.970000E+02	.16186040E-16	.21826430E-16	.21781273E-16	.21781823E-16
98	.113728E+04	.980000E+02	.16335022E-16	.22069789E-16	.22023453E-16	.22023977E-16
99	.114889E+04	.990000E+02	.16484211E-16	.22302826E-16	.22265551E-16	.22265687E-16
100	.116049E+04	.100000E+03	.16633682E-16	.22534093E-16	.22506134E-16	.22506766E-16

SAMPLE PROBLEM CASE 3 HF310.P1ALPHA FUSION REACTION

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KDATA = 1 CROSS SECTIONS INPUT IN ENDF/B FORMAT
KINTE = 3 GENSE TRAP/NOIAL INTEGRATION
KTEUP = 1 KOTM NUCLEI MAXWELLIAN
KSCPN = 5 COMPARISON OF SCREENING TREATMENTS
KPOUT = 1 NO PLOT OUTPUT
KPNCH = 1 NO PUNCHED OUTPUT
KPRNT = 3 SELECTED PRINTED OUTPUT
KCNFL = 1 USE ALL INTERNAL PARAMETERS

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PLASMA MATERIAL          NUMBER OF PARTICLE TYPES = 5
IMAT  7(IMAT)            4(IMAT) NO.DENSITY          IMAT  2  Z(IMAT)  4(IMAT)  NO.DENSITY
      1 .100000E+01 .201355E+01 .500000E+26          2 .200000E+01 .301493E+01 .500000E+26
TARGET IMAT = 2 PROJECTILE IMAT = 1
REDA = .190727E+01 AMU      REDM = .125122E+14 KEV SEC0=2/CM0=2      BGAM = .687640E+02 KEV0=0.5

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CROSS SECTION INPUT          NUMBER OF DATA (NS) = 66
                              NUMBER OF INTERPOLATION REGIONS (NXS) = 3
                              INTERPOLATION SCHEME      (1 = GAMOW FORM)
                                                         (2 = LOG-LOG )
                                                         (3 = CUBIC )
                              ( 1 ) .1669E+03 KEV ( 3 ) .5837E+03 KEV ( 2 )

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ENDF/B CROSS SECTION DATA PAIRS ENERGY(KEV)/SIGMA(HARMS) (IS)/IS=1,NS
.40000E+04 .12374E-13 .10000E+05 .70447E-09 .20000E+05 .13452E-05
.40000E+05 .23703E-03 .60000E+05 .21937E-02 .80000E+05 .81163E-02

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.10000E+06 .19785E-01 .12000E+06 .38309E-01 .14000E+06 .64763F-01
.16000E+06 .99552F-01 .18000E+06 .14324E+00 .20000E+06 .19604F+00
.22000E+06 .25776E+00 .24000E+06 .32756E+00 .26000E+06 .45372F+00
.28000E+06 .48353E+00 .30000E+06 .56375E+00 .32000E+06 .63491E+00
.34000E+06 .70595E+00 .36000E+06 .76003E+00 .38000E+06 .85121F+00
.40000E+06 .87629E+00 .41000E+06 .83324E+00 .42000E+06 .83673F+00
.43000E+06 .83698E+00 .44000E+06 .83471E+00 .45000E+06 .82902F+00
.46000E+06 .82713E+00 .47000E+06 .81107E+00 .48000E+06 .87064F+00
.49000E+06 .78803E+00 .50000E+06 .77472E+00 .52000E+06 .74457F+00
.54000E+06 .71284E+00 .56000E+06 .68041E+00 .58000E+06 .66461F+00
.60000E+06 .61747E+00 .62000E+06 .58759E+00 .64000E+06 .55918F+00
.66000E+06 .53237E+00 .68000E+06 .50718E+00 .70000E+06 .48360F+00
.72000E+06 .46158E+00 .74000E+06 .44103E+00 .76000E+06 .42187F+00
.78000E+06 .40402E+00 .80000E+06 .38718E+00 .85000E+06 .36050F+00
.90000E+06 .31934E+00 .95000E+06 .29297E+00 .10000E+07 .27040F+00
.12000E+07 .20664E+00 .14000E+07 .16832E+00 .16000E+07 .14334F+00
.18000E+07 .12457E+00 .20000E+07 .11651E+00 .22000E+07 .10865F+00
.24000E+07 .10224E+00 .26000E+07 .97202E+01 .28000E+07 .91528E+01
.30000E+07 .86689E+01 .32000E+07 .88547E+01 .34000E+07 .87013F+01
.36000E+07 .85912E+01 .38000E+07 .85176E+01 .40000E+07 .84736F+01

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PLASMA TEMPERATURES (NO. = 100; TMIN = .10000E+01 KEV; TMAX = .10000E+03)

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CENTER OF MASS CROSS SECTION DATA ENERGY(KEV)/SIGMA(CM^2) (IS).IS=1.N5
.79975E+01 .12374F+37 .599571F+01 .704470E-33 .119014E+32 .134520F+29
.239828E+02 .23703E+27 .359743E+02 .219370E-26 .479457E+32 .811610F+25
.599571E+02 .19785E+25 .719445E+02 .383090E-25 .839499F+32 .647630F+25
.995913E+02 .995520E+25 .107923E+03 .143240E-24 .119014E+33 .196040F+24
.131506E+03 .257760F+24 .143870F+03 .127560E-24 .155888F+33 .403720F+24
.167800E+03 .483530F+24 .178871E+03 .563750E-24 .191863F+33 .634910F+24
.203854E+03 .705950E+24 .215846E+03 .760030E-24 .227837E+33 .851210F+24
.239828E+03 .876290F+24 .245824E+03 .833240E-24 .251820F+33 .836730F+24
.257815E+03 .836980E+24 .263811E+03 .811070E-24 .269807F+33 .870640F+24
.275803E+03 .82130F+24 .281798E+03 .811870E-24 .287794E+33 .800640F+24
.293790E+03 .788030E+24 .299785E+03 .774720E-24 .311777E+33 .744570F+24
.323760E+03 .712840E+24 .335760E+03 .680410E-24 .347751E+33 .664610E+24
.359743E+03 .617470E+24 .371734E+03 .587590E-24 .383725F+33 .559180F+24
.395717E+03 .532370E+24 .407708E+03 .507180E-24 .419700F+33 .483600F+24
.431691E+03 .461580E+24 .443642E+03 .441030E-24 .455674F+33 .421870F+24
.447705F+03 .404020E+24 .470457F+03 .387180E-24 .509435F+33 .360500F+24
.539414E+03 .319340E+24 .569502F+03 .292970E-24 .599571F+33 .270400F+24
.719455E+03 .206640E+24 .839399E+03 .168320E-24 .959133F+33 .143340E+24
.107923E+04 .12670E+24 .110914E+04 .116510E-24 .131606F+34 .108650F+24
.143857E+04 .102240E+24 .155888E+04 .972020E-25 .167800E+34 .935280F+25
.178871E+04 .904890E+25 .191863E+04 .885470E-25 .203854E+34 .870130F+25
.215846E+04 .853120E+25 .227837E+04 .851760E-25 .239828E+34 .847360F+25

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INTERPOLATION BREAK ENERGIES IN CENTER OF MASS SYS
.100002E+03 .349993E+03

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CROSS SECTION INTERPOLATION DATA B5(15).IS=1.N5
.698258E+02 .698258E+02 .693391E+02 .702045F+02 .714492F+02 .730926F+02
.751105E+02 .774259E+02 .790327E+02 .824824E+02 .848546E+02 .868327F+02
.881223E+02 .893951E+02 .873516E+02 .847457F+02 .804573E+02 .744151F+02
.640042E+02 .582670F+02 .489516E+02 .417355E+02 .370186F+02 .323300F+02
.279053E+02 .234211E+02 .192093F+02 .152164E+02 .116214F+02 .784661F+01
.452237E+01 .101329F+01 .538382E+01 .94168E+01 .137460F+02 .169746F+02
.196042E+02 .218827F+02 .235572F+02 .250004E+02 .261591F+02 .269975F+02
.277061E+02 .282228F+02 .284866E+02 .287796F+02 .289150E+02 .287015E+02
.298832E+02 .272147F+02 .243382E+02 .184272E+02 .121440E+02 .359649F+01
.144309E+02 .184444F+02 .223574F+02 .294300E+02 .376117F+02 .461872F+02
.545902E+02 .629495E+02 .711905E+02 .791929E+02 .869306E+02

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CROSS SECTION INTERPOLATION DATA S5(15).IS=2.N5
.698597E-20 .716572F-20 .801342F-20 .956216E-20 .117475F-20 .149191F-20
.194404E-19 .254372F-19 .334422F-19 .433062F-19 .545754F-19 .653088F-19
.736598E-19 .747567F-19 .687679E-19 .562309F-19 .407204E-19 .264059F-19
.154012E-19 .866496F-20 .667572F-20 .293393E-20 .217167F-20 .161613F-20
.121955E-20 .930827F-21 .720209E-21 .566356F-21 .451762F-21 .365927E-21
.301416E-21 .231994F-21 .171122E-21 .132830E-21 .107809E-21 .907677F-21
.789955E-22 .705014F-22 .644614E-22 .595902F-22 .566911E-22 .543381F-22
.525163F-22 .512438F-22 .504676E-22 .499314E-22 .496515F-22 .500951F-22
.514444E-22 .533501F-22 .600015F-22 .747466E-22 .928468F-22 .122433F-21
.211943E-21 .241477E-21 .265211E-21 .319602E-21 .393792F-21 .483786F-21
.59998E-21 .715483F-21 .858375E-21 .101972E-20 .119014E-20

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MAXWELLIAN DISTRIBUTION INTERPOLATION CALCULATIONS

IT	T(KEV)	T(KEV)	FGAM(KEV)	VFAM(CM/S)	DEGAM(1/KEV)	VFAM(CM^2)	RATFG(CC/SEC)
1	.116049E+02	.100000E+01	.105736E+02	.1300050E+09	.9386722E-04	.4186986E-30	.3400272E-25
2	.232097E+02	.200000E+01	.167846F+02	.1637961E+09	.3703700E-03	.2136930E-28	.1532934E-22
3	.348148E+02	.300000E+01	.219940F+02	.1874997E+09	.6467469E-03	.1391866E-28	.2871577E-21
4	.464197E+02	.400000E+01	.266439F+02	.2053701E+09	.9318370E-03	.4448220E-27	.1867366E-20
5	.580244F+02	.500000E+01	.309175F+02	.2223055E+09	.1157873E-02	.1016272E-26	.6656014E-20
6	.696296E+02	.600000E+01	.349134F+02	.2362348E+09	.1347751E-02	.1894672E-26	.1768870E-19
7	.812345E+02	.700000E+01	.386422F+02	.2486907E+09	.1668676E-02	.3122913E-26	.3941855E-19
8	.928394F+02	.800000E+01	.422945F+02	.2610101E+09	.1440312E-02	.4710513E-26	.7543417E-19

9	.104444E+03	.900000E+01	.457495E+02	.274214E+09	.1752453E-02	.6647614E-26	.1308314E-18
10	.116494E+03	.100000E+02	.490745E+02	.2800874E+09	.1486927E-02	.4946604E-26	.2008413E-18
11	.127454E+03	.110000E+02	.522941E+02	.2891286E+09	.1976682E-02	.1163471E-25	.3181564E-18
12	.139259E+03	.120000E+02	.554215E+02	.2976372E+09	.1994116E-02	.1465748E-25	.4591551E-18
13	.150864E+03	.130000E+02	.584593E+02	.3056856E+09	.2551175E-02	.1799476E-25	.6365849E-18
14	.162469E+03	.140000E+02	.614204E+02	.3133306E+09	.2599454E-02	.2169395E-25	.8644479E-18
15	.174074E+03	.150000E+02	.643110E+02	.3206200E+09	.2710242E-02	.2576281E-25	.1123785E-17
16	.185679E+03	.160000E+02	.671384E+02	.3275922E+09	.2774682E-02	.3012168E-25	.1439455E-17
17	.197284E+03	.170000E+02	.699075E+02	.3342796E+09	.2203615E-02	.3475114E-25	.1806115E-17
18	.208889E+03	.180000E+02	.726228E+02	.3407096E+09	.2227816E-02	.3968271E-25	.2278855E-17
19	.220494E+03	.190000E+02	.752882E+02	.3469057E+09	.2247920E-02	.4502171E-25	.2717688E-17
20	.232099E+03	.200000E+02	.779072E+02	.3528880E+09	.226463E-02	.5061370E-25	.3267520E-17
21	.243703E+03	.210000E+02	.804829E+02	.3586740E+09	.2277903E-02	.5644145E-25	.3800067E-17
22	.255308E+03	.220000E+02	.831811E+02	.3642792E+09	.2288629E-02	.6244885E-25	.4450742E-17
23	.266913E+03	.230000E+02	.855151E+02	.3697170E+09	.2296977E-02	.6891448E-25	.5312117E-17
24	.278518E+03	.240000E+02	.879762E+02	.3749944E+09	.2303236E-02	.7564045E-25	.6145687E-17
25	.290123E+03	.250000E+02	.904034E+02	.3801370E+09	.2307654E-02	.8241715E-25	.7051400E-17
26	.301728E+03	.260000E+02	.927983E+02	.3851394E+09	.231048E-02	.8977161E-25	.8000446E-17
27	.313333E+03	.270000E+02	.951627E+02	.3901515E+09	.2311811E-02	.9710802E-25	.9000434E-17
28	.324938E+03	.280000E+02	.974982E+02	.3947717E+09	.2311902E-02	.1048384E-25	.1023193E-16
29	.336543E+03	.290000E+02	.999059E+02	.3994167E+09	.2310869E-02	.1124621E-24	.1147471E-16
30	.348148E+03	.300000E+02	.102087E+03	.4039559E+09	.2308839E-02	.1230781E-24	.1300162E-16
31	.359753E+03	.310000E+02	.104344E+03	.4083953E+09	.2305923E-02	.1311180E-24	.1437364E-16
32	.371358E+03	.320000E+02	.106576E+03	.4127403E+09	.2302221E-02	.1387689E-24	.1570628E-16
33	.382963E+03	.330000E+02	.108846E+03	.4169956E+09	.2297828E-02	.1473495E-24	.1717229E-16
34	.394568E+03	.340000E+02	.110971E+03	.4211658E+09	.2292798E-02	.1575342E-24	.1892418E-16
35	.406172E+03	.350000E+02	.113137E+03	.4252551E+09	.2287225E-02	.1673282E-24	.2096078E-16
36	.417777E+03	.360000E+02	.115281E+03	.4292672E+09	.2281133E-02	.1767337E-24	.2281806E-16
37	.429382E+03	.370000E+02	.117407E+03	.4332056E+09	.2274665E-02	.1857414E-24	.2469212E-16
38	.440987E+03	.380000E+02	.119513E+03	.4370737E+09	.2267782E-02	.1944219E-24	.2657021E-16
39	.452592E+03	.390000E+02	.121600E+03	.4408746E+09	.2260585E-02	.2052250E-24	.2843350E-16
40	.464197E+03	.400000E+02	.123678E+03	.4446110E+09	.2253382E-02	.2163782E-24	.3119978E-16
41	.475802E+03	.410000E+02	.125723E+03	.4482856E+09	.2245274E-02	.2271023E-24	.3356783E-16
42	.487407E+03	.420000E+02	.127759E+03	.4519017E+09	.2237212E-02	.2374774E-24	.3604475E-16
43	.499012E+03	.430000E+02	.129779E+03	.4554594E+09	.2228909E-02	.2475978E-24	.3841603E-16
44	.510617E+03	.440000E+02	.131793E+03	.4589631E+09	.2220647E-02	.2571771E-24	.4084836E-16
45	.522222E+03	.450000E+02	.133772E+03	.4624140E+09	.2211999E-02	.2669201E-24	.4327448E-16
46	.533827E+03	.460000E+02	.135747E+03	.4658143E+09	.2203295E-02	.2810810E-24	.4565572E-16
47	.545432E+03	.470000E+02	.137707E+03	.4691656E+09	.2194475E-02	.2926447E-24	.4806094E-16
48	.557037E+03	.480000E+02	.139654E+03	.4724697E+09	.2185566E-02	.3038914E-24	.5055828E-16
49	.568641E+03	.490000E+02	.141586E+03	.4757282E+09	.2176553E-02	.314819E-24	.5357039E-16
50	.580246E+03	.500000E+02	.143506E+03	.4789426E+09	.2167482E-02	.3254110E-24	.5658332E-16
51	.591851E+03	.510000E+02	.145413E+03	.4821145E+09	.2158354E-02	.337598E-24	.5961832E-16
52	.603456E+03	.520000E+02	.147308E+03	.4852452E+09	.2149182E-02	.3499899E-24	.6278064E-16
53	.615061E+03	.530000E+02	.149191E+03	.4883361E+09	.2139975E-02	.3621257E-24	.6607156E-16
54	.626666E+03	.540000E+02	.151061E+03	.4913882E+09	.2130744E-02	.3740010E-24	.6938468E-16
55	.638271E+03	.550000E+02	.152921E+03	.4944030E+09	.2121497E-02	.3856118E-24	.7270154E-16
56	.649876E+03	.560000E+02	.154789E+03	.4973814E+09	.2112241E-02	.3969589E-24	.7606009E-16
57	.661481E+03	.570000E+02	.156660E+03	.5003245E+09	.2102905E-02	.4086328E-24	.7937396E-16
58	.673086E+03	.580000E+02	.158432E+03	.5032335E+09	.2093734E-02	.4210772E-24	.8278073E-16
59	.684691E+03	.590000E+02	.160248E+03	.5061091E+09	.2084494E-02	.4333848E-24	.8608809E-16
60	.696296E+03	.600000E+02	.162054E+03	.5089525E+09	.2075271E-02	.4454370E-24	.8940077E-16
61	.707901E+03	.610000E+02	.163849E+03	.5117645E+09	.2066049E-02	.4573360E-24	.9270224E-16
62	.719505E+03	.620000E+02	.165635E+03	.5145458E+09	.2056893E-02	.4690344E-24	.9600572E-16
63	.731110E+03	.630000E+02	.167411E+03	.5172975E+09	.2047747E-02	.4805247E-24	.9930891E-16
64	.742715E+03	.640000E+02	.169178E+03	.5200201E+09	.2038434E-02	.4920495E-24	.1026135E-15
65	.754320E+03	.650000E+02	.170936E+03	.5227145E+09	.2029098E-02	.5034840E-24	.1058350E-15
66	.765925E+03	.660000E+02	.172685E+03	.5253816E+09	.2020021E-02	.5157532E-24	.109073E-15
67	.777530E+03	.670000E+02	.174425E+03	.5280217E+09	.2011152E-02	.5277682E-24	.1123930E-15
68	.789135E+03	.680000E+02	.176156E+03	.5306375E+09	.2002575E-02	.5388767E-24	.1157269E-15
69	.800740E+03	.690000E+02	.177879E+03	.5332242E+09	.1993670E-02	.5496777E-24	.1190638E-15
70	.812345E+03	.700000E+02	.179593E+03	.5357878E+09	.1984814E-02	.561307E-24	.1123703E-15
71	.823950E+03	.710000E+02	.181299E+03	.5383272E+09	.1976008E-02	.5729395E-24	.1157339E-15
72	.835555E+03	.720000E+02	.182998E+03	.5408427E+09	.1967254E-02	.5848133E-24	.1190678E-15
73	.847160E+03	.730000E+02	.184688E+03	.5433351E+09	.1958552E-02	.5963409E-24	.1224071E-15
74	.858765E+03	.740000E+02	.186371E+03	.5458043E+09	.1949904E-02	.6080584E-24	.1257516E-15
75	.870370E+03	.750000E+02	.188046E+03	.5482525E+09	.1941311E-02	.6166604E-24	.1290978E-15
76	.881974E+03	.760000E+02	.189714E+03	.5506784E+09	.1932774E-02	.6257497E-24	.1324537E-15
77	.893579E+03	.770000E+02	.191375E+03	.5530831E+09	.1924293E-02	.6350073E-24	.1358120E-15
78	.905184E+03	.780000E+02	.193028E+03	.5554671E+09	.1915470E-02	.6451107E-24	.1391703E-15
79	.916789E+03	.790000E+02	.194675E+03	.5578309E+09	.1907505E-02	.6539998E-24	.1425274E-15
80	.928394E+03	.800000E+02	.196314E+03	.5601747E+09	.1899197E-02	.6629951E-24	.1458912E-15
81	.939999E+03	.810000E+02	.197946E+03	.5624991E+09	.1890949E-02	.6720861E-24	.1492624E-15
82	.951604E+03	.820000E+02	.199572E+03	.5648045E+09	.1882759E-02	.6812629E-24	.1526745E-15
83	.963209E+03	.830000E+02	.201192E+03	.5670912E+09	.1874629E-02	.6905151E-24	.1560078E-15
84	.974814E+03	.840000E+02	.202804E+03	.5693595E+09	.1866558E-02	.6998335E-24	.1593537E-15
85	.986419E+03	.850000E+02	.204411E+03	.5716100E+09	.1858454E-02	.7092464E-24	.1627044E-15
86	.998024E+03	.860000E+02	.206011E+03	.5738429E+09	.1850303E-02	.7187015E-24	.1660582E-15
87	.100963E+04	.870000E+02	.207615E+03	.5760585E+09	.1842101E-02	.7281983E-24	.1694121E-15
88	.102123E+04	.880000E+02	.209193E+03	.5782572E+09	.1834067E-02	.7290194E-24	.1727647E-15
89	.103284E+04	.890000E+02	.210774E+03	.5804393E+09	.1826763E-02	.7362874E-24	.1761194E-15
90	.104444E+04	.900000E+02	.212350E+03	.582652E+09	.181978E-02	.7437154E-24	.1794747E-15
91	.105605E+04	.910000E+02	.213920E+03	.5847550E+09	.1813722E-02	.7512967E-24	.1828304E-15
92	.106765E+04	.920000E+02	.215485E+03	.5868892E+09	.1807424E-02	.7590273E-24	.1861857E-15
93	.107926E+04	.930000E+02	.217043E+03	.5890080E+09	.1796586E-02	.7642247E-24	.1895422E-15
94	.109086E+04	.940000E+02	.218596E+03	.5911116E+09	.178910E-02	.7688406E-24	.1928987E-15

95	.114247E+04	.950000E+02	.220144F+03	.593200E+09	.178163E+02	.773679E-24	.262020E-15
96	.111407E+04	.960000E+02	.221686F+03	.595274E+09	.177431E-02	.778736E-24	.245577E-15
97	.112568E+04	.970000E+02	.223223F+03	.597334E+09	.176710E-02	.784007E-24	.240216E-15
98	.113729E+04	.980000E+02	.224755E+03	.599379E+09	.175976E-02	.789490E-24	.252937E-15
99	.114890E+04	.990000E+02	.226281F+03	.601411E+09	.175256E-02	.795179E-24	.256742E-15
100	.116049E+04	.100000E+03	.227802F+03	.603429E+09	.174542E-02	.801072E-24	.260029E-15

COMPARISON OF SCREENING FACTORS

IT	T(DFG K)	T(KEV)	WFEAK	SALPETER	GRANDSKE
1	.116049E+02	.100000E+01	.126491E+01	.121709E+01	.113843E+01
2	.232099E+02	.200000E+01	.108891E+01	.107989E+01	.108891E+01
3	.348148E+02	.300000E+01	.104781E+01	.104435E+01	.104781E+01
4	.464197E+02	.400000E+01	.103090E+01	.103090E+01	.103090E+01
5	.580246E+02	.500000E+01	.102206E+01	.102206E+01	.102206E+01
6	.696296E+02	.600000E+01	.101675E+01	.101675E+01	.101675E+01
7	.812345E+02	.700000E+01	.101328E+01	.101328E+01	.101328E+01
8	.928394E+02	.800000E+01	.101086E+01	.101086E+01	.101086E+01
9	.104444E+03	.900000E+01	.100910E+01	.100910E+01	.100910E+01
10	.116049E+03	.100000E+02	.100777E+01	.100777E+01	.100777E+01
11	.127654E+03	.110000E+02	.100673E+01	.100673E+01	.100673E+01
12	.139259E+03	.120000E+02	.100590E+01	.100590E+01	.100590E+01
13	.150864E+03	.130000E+02	.100524E+01	.100524E+01	.100524E+01
14	.162469E+03	.140000E+02	.100468E+01	.100468E+01	.100468E+01
15	.174074E+03	.150000E+02	.100422E+01	.100422E+01	.100422E+01
16	.185679E+03	.160000E+02	.100383E+01	.100383E+01	.100383E+01
17	.197284E+03	.170000E+02	.100350E+01	.100350E+01	.100350E+01
18	.208889E+03	.180000E+02	.100321E+01	.100321E+01	.100321E+01
19	.220494E+03	.190000E+02	.100296E+01	.100296E+01	.100296E+01
20	.232099E+03	.200000E+02	.100274E+01	.100274E+01	.100274E+01
21	.243703E+03	.210000E+02	.100255E+01	.100255E+01	.100255E+01
22	.255308E+03	.220000E+02	.100238E+01	.100238E+01	.100238E+01
23	.266913E+03	.230000E+02	.100222E+01	.100222E+01	.100222E+01
24	.278518E+03	.240000E+02	.100209E+01	.100209E+01	.100209E+01
25	.290123E+03	.250000E+02	.100196E+01	.100196E+01	.100196E+01
26	.301728E+03	.260000E+02	.100185E+01	.100185E+01	.100185E+01
27	.313333E+03	.270000E+02	.100175E+01	.100175E+01	.100175E+01
28	.324938E+03	.280000E+02	.100165E+01	.100165E+01	.100165E+01
29	.336543E+03	.290000E+02	.100157E+01	.100157E+01	.100157E+01
30	.348148E+03	.300000E+02	.100149E+01	.100149E+01	.100149E+01
31	.359753E+03	.310000E+02	.100142E+01	.100142E+01	.100142E+01
32	.371358E+03	.320000E+02	.100135E+01	.100135E+01	.100135E+01
33	.382963E+03	.330000E+02	.100129E+01	.100129E+01	.100129E+01
34	.394568E+03	.340000E+02	.100124E+01	.100124E+01	.100124E+01
35	.406172E+03	.350000E+02	.100118E+01	.100118E+01	.100118E+01
36	.417777E+03	.360000E+02	.100113E+01	.100113E+01	.100113E+01
37	.429382E+03	.370000E+02	.100109E+01	.100109E+01	.100109E+01
38	.440987E+03	.380000E+02	.100105E+01	.100105E+01	.100105E+01
39	.452592E+03	.390000E+02	.100101E+01	.100101E+01	.100101E+01
40	.464197E+03	.400000E+02	.100097E+01	.100097E+01	.100097E+01
41	.475802E+03	.410000E+02	.100093E+01	.100093E+01	.100093E+01
42	.487407E+03	.420000E+02	.100090E+01	.100090E+01	.100090E+01
43	.499012E+03	.430000E+02	.100087E+01	.100087E+01	.100087E+01
44	.510617E+03	.440000E+02	.100084E+01	.100084E+01	.100084E+01
45	.522222E+03	.450000E+02	.100081E+01	.100081E+01	.100081E+01
46	.533827E+03	.460000E+02	.100079E+01	.100079E+01	.100079E+01
47	.545432E+03	.470000E+02	.100076E+01	.100076E+01	.100076E+01
48	.557037E+03	.480000E+02	.100074E+01	.100074E+01	.100074E+01
49	.568642E+03	.490000E+02	.100071E+01	.100071E+01	.100071E+01
50	.580246E+03	.500000E+02	.100069E+01	.100069E+01	.100069E+01
51	.591851E+03	.510000E+02	.100067E+01	.100067E+01	.100067E+01
52	.603456E+03	.520000E+02	.100065E+01	.100065E+01	.100065E+01
53	.615061E+03	.530000E+02	.100064E+01	.100064E+01	.100064E+01
54	.626666E+03	.540000E+02	.100062E+01	.100062E+01	.100062E+01
55	.638271E+03	.550000E+02	.100060E+01	.100060E+01	.100060E+01
56	.649876E+03	.560000E+02	.100058E+01	.100058E+01	.100058E+01
57	.661481E+03	.570000E+02	.100057E+01	.100057E+01	.100057E+01
58	.673086E+03	.580000E+02	.100055E+01	.100055E+01	.100055E+01
59	.684691E+03	.590000E+02	.100054E+01	.100054E+01	.100054E+01
60	.696296E+03	.600000E+02	.100053E+01	.100053E+01	.100053E+01
61	.707901E+03	.610000E+02	.100051E+01	.100051E+01	.100051E+01
62	.719506E+03	.620000E+02	.100050E+01	.100050E+01	.100050E+01
63	.731111E+03	.630000E+02	.100049E+01	.100049E+01	.100049E+01
64	.742716E+03	.640000E+02	.100048E+01	.100048E+01	.100048E+01
65	.754321E+03	.650000E+02	.100047E+01	.100047E+01	.100047E+01
66	.765926E+03	.660000E+02	.100046E+01	.100046E+01	.100046E+01
67	.777531E+03	.670000E+02	.100045E+01	.100045E+01	.100045E+01
68	.789136E+03	.680000E+02	.100044E+01	.100044E+01	.100044E+01
69	.800741E+03	.690000E+02	.100043E+01	.100043E+01	.100043E+01
70	.812346E+03	.700000E+02	.100042E+01	.100042E+01	.100042E+01
71	.823951E+03	.710000E+02	.100041E+01	.100041E+01	.100041E+01
72	.835556E+03	.720000E+02	.100040E+01	.100040E+01	.100040E+01
73	.847161E+03	.730000E+02	.100039E+01	.100039E+01	.100039E+01
74	.858766E+03	.740000E+02	.100038E+01	.100038E+01	.100038E+01
75	.870371E+03	.750000E+02	.100038E+01	.100038E+01	.100038E+01
76	.881976E+03	.760000E+02	.100037E+01	.100037E+01	.100037E+01
77	.893581E+03	.770000E+02	.100036E+01	.100036E+01	.100036E+01
78	.905186E+03	.780000E+02	.100036E+01	.100036E+01	.100036E+01

79	.914799E+03	.790000E+02	.100035E+01	.100035E+01	.100035E+01
80	.924394E+03	.800000E+02	.100034E+01	.100034E+01	.100034E+01
81	.939999E+03	.810000E+02	.100034E+01	.100034E+01	.100034E+01
82	.951604E+03	.820000E+02	.100033E+01	.100033E+01	.100033E+01
83	.964709E+03	.830000E+02	.100032E+01	.100032E+01	.100032E+01
84	.974414E+03	.840000E+02	.100032E+01	.100032E+01	.100032E+01
85	.984417E+03	.850000E+02	.100031E+01	.100031E+01	.100031E+01
86	.994424E+03	.860000E+02	.100031E+01	.100031E+01	.100031E+01
87	.100956E+04	.870000E+02	.100030E+01	.100030E+01	.100030E+01
88	.102123E+04	.880000E+02	.100030E+01	.100030E+01	.100030E+01
89	.103294E+04	.890000E+02	.100029E+01	.100029E+01	.100029E+01
90	.104444E+04	.900000E+02	.100029E+01	.100029E+01	.100029E+01
91	.105595E+04	.910000E+02	.100028E+01	.100028E+01	.100028E+01
92	.106765E+04	.920000E+02	.100028E+01	.100028E+01	.100028E+01
93	.107924E+04	.930000E+02	.100027E+01	.100027E+01	.100027E+01
94	.109094E+04	.940000E+02	.100027E+01	.100027E+01	.100027E+01
95	.110247E+04	.950000E+02	.100026E+01	.100026E+01	.100026E+01
96	.111407E+04	.960000E+02	.100026E+01	.100026E+01	.100026E+01
97	.112568E+04	.970000E+02	.100026E+01	.100026E+01	.100026E+01
98	.113729E+04	.980000E+02	.100025E+01	.100025E+01	.100025E+01
99	.114889E+04	.990000E+02	.100025E+01	.100025E+01	.100025E+01
100	.116049E+04	.100000E+03	.100025E+01	.100025E+01	.100025E+01

***** FINAL RESULTS FOR SIGMA-VBAR *****

ION DISTRIBUTION-----BOTH IONS MAXWELLIAN
MAXWELLIAN INTEGRATION-----DENSE TRAPEZOIDAL
SCREENING FACTOR-----COMPARISON OF TREATMENTS

IT	TEMP (100+6 DEG K)	TEMP (KEV)	SIGMA-VBAR COMPONENTS		TOTAL SIGMA-VBAR (CM ² /SEC)			
			SLOWING DOWN	MAXWELLIAN	NO SCREENING	WITH SCREENING WEAK SALPETER	WITH SCREENING SALPETER (FULL RANGE)	GRUBBS NEWITT
1	.114049E+02	.100000E+01		.345921E-24	.345921E-25	.437557E-25	.421010E-25	.393808E-25
2	.212939E+02	.200000E+01		.156588E-25	.156588E-22	.170509E-22	.164097E-22	.170509E-22
3	.348197E+02	.300000E+01		.296584E-21	.296584E-21	.310450E-21	.305423E-21	.310450E-21
4	.464197E+02	.400000E+01		.187666E-20	.187666E-20	.193465E-20	.191465E-20	.193465E-20
5	.580245E+02	.500000E+01		.695435E-20	.695435E-20	.716773E-20	.714773E-20	.716773E-20
6	.694294E+02	.600000E+01		.188732E-19	.188732E-19	.191893E-19	.191893E-19	.191893E-19
7	.812345E+02	.700000E+01		.419067E-19	.419067E-19	.424633E-19	.424633E-19	.424633E-19
8	.928394E+02	.800000E+01		.810999E-19	.810999E-19	.818899E-19	.818899E-19	.818899E-19
9	.104444E+03	.900000E+01		.141604E-18	.142893E-18	.142893E-18	.142893E-18	.142893E-18
10	.114049E+03	.100000E+02		.229407E-18	.229407E-18	.231188E-18	.231188E-18	.231188E-18
11	.127654E+03	.110000E+02		.353022E-18	.353022E-18	.352659E-18	.352659E-18	.352659E-18
12	.139259E+03	.120000E+02		.512306E-18	.512306E-18	.512306E-18	.512306E-18	.512306E-18
13	.150864E+03	.130000E+02		.715071E-18	.715071E-18	.718815E-18	.718815E-18	.718815E-18
14	.162469E+03	.140000E+02		.976202E-18	.976202E-18	.976202E-18	.976202E-18	.976202E-18
15	.174074E+03	.150000E+02		.129237E-17	.129237E-17	.129237E-17	.129237E-17	.129237E-17
16	.185679E+03	.160000E+02		.165568E-17	.165568E-17	.166203E-17	.166203E-17	.166203E-17
17	.197284E+03	.170000E+02		.209537E-17	.209537E-17	.210270E-17	.210270E-17	.210270E-17
18	.208889E+03	.180000E+02		.267601E-17	.267601E-17	.267601E-17	.267601E-17	.267601E-17
19	.220494E+03	.190000E+02		.319106E-17	.319106E-17	.320105E-17	.320105E-17	.320105E-17
20	.232099E+03	.200000E+02		.385565E-17	.385565E-17	.386622E-17	.386622E-17	.386622E-17
21	.243703E+03	.210000E+02		.461108E-17	.461108E-17	.461280E-17	.461280E-17	.461280E-17
22	.255308E+03	.220000E+02		.543065E-17	.543065E-17	.544356E-17	.544356E-17	.544356E-17
23	.266913E+03	.230000E+02		.634583E-17	.634583E-17	.635993E-17	.635993E-17	.635993E-17
24	.278518E+03	.240000E+02		.734839E-17	.734839E-17	.736371E-17	.736371E-17	.736371E-17
25	.290123E+03	.250000E+02		.843851E-17	.843851E-17	.845506E-17	.845506E-17	.845506E-17
26	.301728E+03	.260000E+02		.961700E-17	.961700E-17	.963478E-17	.963478E-17	.963478E-17
27	.313333E+03	.270000E+02		.108829E-16	.108829E-16	.109019E-16	.109019E-16	.109019E-16
28	.324938E+03	.280000E+02		.122361E-16	.122361E-16	.122563E-16	.122563E-16	.122563E-16
29	.336543E+03	.290000E+02		.136755E-16	.136755E-16	.136970E-16	.136970E-16	.136970E-16
30	.348148E+03	.300000E+02		.151998E-16	.151998E-16	.152224E-16	.152224E-16	.152224E-16
31	.359753E+03	.310000E+02		.168057E-16	.168057E-16	.168296E-16	.168296E-16	.168296E-16
32	.371358E+03	.320000E+02		.184921E-16	.184921E-16	.185172E-16	.185172E-16	.185172E-16
33	.382963E+03	.330000E+02		.202567E-16	.202567E-16	.202829E-16	.202829E-16	.202829E-16
34	.394568E+03	.340000E+02		.222968E-16	.222968E-16	.222124E-16	.222124E-16	.222124E-16
35	.406173E+03	.350000E+02		.240933E-16	.240933E-16	.240377E-16	.240377E-16	.240377E-16
36	.417777E+03	.360000E+02		.259896E-16	.259896E-16	.260191E-16	.260191E-16	.260191E-16
37	.429382E+03	.370000E+02		.281359E-16	.281359E-16	.280665E-16	.280665E-16	.280665E-16
38	.440987E+03	.380000E+02		.301470E-16	.301470E-16	.301786E-16	.301786E-16	.301786E-16
39	.452592E+03	.390000E+02		.323156E-16	.323156E-16	.323481E-16	.323481E-16	.323481E-16
40	.464197E+03	.400000E+02		.345406E-16	.345406E-16	.345741E-16	.345741E-16	.345741E-16
41	.475802E+03	.410000E+02		.368179E-16	.368179E-16	.368523E-16	.368523E-16	.368523E-16
42	.487407E+03	.420000E+02		.391421E-16	.391421E-16	.391774E-16	.391774E-16	.391774E-16
43	.499012E+03	.430000E+02		.415145E-16	.415145E-16	.415505E-16	.415505E-16	.415505E-16
44	.510617E+03	.440000E+02		.439288E-16	.439288E-16	.439657E-16	.439657E-16	.439657E-16
45	.522222E+03	.450000E+02		.463797E-16	.463797E-16	.464174E-16	.464174E-16	.464174E-16
46	.533827E+03	.460000E+02		.488689E-16	.488689E-16	.489073E-16	.489073E-16	.489073E-16
47	.545432E+03	.470000E+02		.513077E-16	.513077E-16	.512688E-16	.512688E-16	.512688E-16
48	.557037E+03	.480000E+02		.539358E-16	.539358E-16	.539755E-16	.539755E-16	.539755E-16
49	.568642E+03	.490000E+02		.565126E-16	.565126E-16	.565530E-16	.565530E-16	.565530E-16
50	.580247E+03	.500000E+02		.591102E-16	.591102E-16	.591512E-16	.591512E-16	.591512E-16
51	.591852E+03	.510000E+02		.617281E-16	.617281E-16	.617696E-16	.617696E-16	.617696E-16

52	.603455F+03	.520000E+02	.643627E-1A	.647A27E-1A	.444A02E-16	.644A04E-16	.644004E-16
53	.615061F+03	.530000E+02	.670124E-1A	.670124E-1A	.470554E-16	.670554E-16	.670554E-16
54	.624A65F+03	.540000E+02	.696750E-1A	.696750E-1A	.497180E-16	.697180E-16	.697180E-16
55	.630271F+03	.550000E+02	.723A70E-1A	.723A70E-1A	.723005E-16	.723005E-16	.723005E-16
56	.640874F+03	.560000E+02	.750265E-1A	.750265E-1A	.750703E-16	.750703E-16	.750703E-16
57	.661481E+03	.570000E+02	.777111E-1A	.777111E-1A	.777554E-16	.777554E-16	.777554E-16
58	.673085F+03	.580000E+02	.803984E-1A	.803984E-1A	.804430E-16	.804430E-16	.804430E-16
59	.684A91E+03	.590000E+02	.830870E-1A	.830870E-1A	.831320E-16	.831320E-16	.831320E-16
60	.696296E+03	.600000E+02	.857744E-1A	.857744E-1A	.858197E-16	.858197E-16	.858197E-16
61	.707901E+03	.610000E+02	.884594E-1A	.884594E-1A	.885049E-16	.885049E-16	.885049E-16
62	.719505F+03	.620000E+02	.911394E-1A	.911394E-1A	.911851E-16	.911851E-16	.911851E-16
63	.731100E+03	.630000E+02	.938091E-1A	.938091E-1A	.938550E-16	.938550E-16	.938550E-16
64	.742715E+03	.640000E+02	.964744E-1A	.964744E-1A	.965206E-16	.965206E-16	.965206E-16
65	.754320E+03	.650000E+02	.991321E-1A	.991321E-1A	.991784E-16	.991784E-16	.991784E-16
66	.765925E+03	.660000E+02	.101774E-1A	.101774E-1A	.101821E-15	.101821E-15	.101821E-15
67	.777530E+03	.670000E+02	.104400E-1A	.104400E-1A	.104455E-15	.104455E-15	.104455E-15
68	.789135E+03	.680000E+02	.107028E-1A	.107028E-1A	.107075E-15	.107075E-15	.107075E-15
69	.800740E+03	.690000E+02	.109631E-1A	.109631E-1A	.109678E-15	.109678E-15	.109678E-15
70	.812345E+03	.700000E+02	.112222E-1A	.112222E-1A	.112269E-15	.112269E-15	.112269E-15
71	.823950E+03	.710000E+02	.114796E-1A	.114796E-1A	.114843E-15	.114843E-15	.114843E-15
72	.835555E+03	.720000E+02	.117349E-1A	.117349E-1A	.117397E-15	.117397E-15	.117397E-15
73	.847160E+03	.730000E+02	.119888E-1A	.119888E-1A	.119935E-15	.119935E-15	.119935E-15
74	.858765E+03	.740000E+02	.122402E-1A	.122402E-1A	.122449E-15	.122449E-15	.122449E-15
75	.870369E+03	.750000E+02	.124903E-1A	.124903E-1A	.124950E-15	.124950E-15	.124950E-15
76	.881974E+03	.760000E+02	.127377E-1A	.127377E-1A	.127424E-15	.127424E-15	.127424E-15
77	.893579E+03	.770000E+02	.129835E-1A	.129835E-1A	.129883E-15	.129883E-15	.129883E-15
78	.905184E+03	.780000E+02	.132267E-1A	.132267E-1A	.132314E-15	.132314E-15	.132314E-15
79	.916789E+03	.790000E+02	.134681E-1A	.134681E-1A	.134728E-15	.134728E-15	.134728E-15
80	.928394E+03	.800000E+02	.137069E-1A	.137069E-1A	.137115E-15	.137115E-15	.137115E-15
81	.940000E+03	.810000E+02	.139432E-1A	.139432E-1A	.139478E-15	.139478E-15	.139478E-15
82	.951604E+03	.820000E+02	.141776E-1A	.141776E-1A	.141823E-15	.141823E-15	.141823E-15
83	.963209E+03	.830000E+02	.144094E-1A	.144094E-1A	.144141E-15	.144141E-15	.144141E-15
84	.974814E+03	.840000E+02	.146386E-1A	.146386E-1A	.146433E-15	.146433E-15	.146433E-15
85	.986419E+03	.850000E+02	.148656E-1A	.148656E-1A	.148702E-15	.148702E-15	.148702E-15
86	.998024E+03	.860000E+02	.150898E-1A	.150898E-1A	.150944E-15	.150944E-15	.150944E-15
87	.100000E+03	.870000E+02	.153120E-1A	.153120E-1A	.153167E-15	.153167E-15	.153167E-15
88	.102121E+04	.880000E+02	.155312E-1A	.155312E-1A	.155358E-15	.155358E-15	.155358E-15
89	.104244E+04	.890000E+02	.157484E-1A	.157484E-1A	.157530E-15	.157530E-15	.157530E-15
90	.106367E+04	.900000E+02	.159626E-1A	.159626E-1A	.159672E-15	.159672E-15	.159672E-15
91	.108490E+04	.910000E+02	.161741E-1A	.161741E-1A	.161787E-15	.161787E-15	.161787E-15
92	.110613E+04	.920000E+02	.163837E-1A	.163837E-1A	.163882E-15	.163882E-15	.163882E-15
93	.112736E+04	.930000E+02	.165902E-1A	.165902E-1A	.165947E-15	.165947E-15	.165947E-15
94	.114859E+04	.940000E+02	.167941E-1A	.167941E-1A	.167986E-15	.167986E-15	.167986E-15
95	.116982E+04	.950000E+02	.169953E-1A	.169953E-1A	.169998E-15	.169998E-15	.169998E-15
96	.119105E+04	.960000E+02	.171946E-1A	.171946E-1A	.171991E-15	.171991E-15	.171991E-15
97	.121228E+04	.970000E+02	.173908E-1A	.173908E-1A	.173953E-15	.173953E-15	.173953E-15
98	.123351E+04	.980000E+02	.175845E-1A	.175845E-1A	.175890E-15	.175890E-15	.175890E-15
99	.125474E+04	.990000E+02	.177764E-1A	.177764E-1A	.177809E-15	.177809E-15	.177809E-15
100	.127597E+04	.100000E+03	.179647E-1A	.179647E-1A	.179691E-15	.179691E-15	.179691E-15

SAMPLE PROBLEM CASE 4 T(D,N)ALPHA FUSION REACTION

KDATA = 1 CROSS SECTIONS INPUT IN ENDF/B FORMAT
 KTYPE = 3 DENSE TRAPEZOIDAL INTEGRATION
 KTEMP = -1 RCTM NUCLEI MAXWELLIAN
 (LOGARITHMIC PLASMA TEMP INCREMENTS)
 KSCRM = 1 NO SCREENING CALCULATION
 KPL0T = 1 NO PLOT OUTPUT
 KPNCH = 2 PUNCHED OUTPUT
 KPRNT = 2 FULL PRINTED OUTPUT
 KCNTL = 1 USE ALL INTERNAL PARAMETERS

PLASMA MATERIAL NUMBER OF PARTICLE TYPES = 5
 IMAT 2(IMAT) A1(IMAT) NO.DENSITY IMAT 2(IMAT) A1(IMAT) NO.DENSITY
 1 .100000E+01 .201355E+01 .500000E+14 2 .100000E+01 .301550E+01 .500000E+14
 TARGET IMAT = 2 PROJECTILE IMAT = 1
 REOA = .120736E+01 AMU REUM = .125132E+14 KEV SFC=2/CM=2 BGAM = .343837E+02 KEV=0.5

CROSS SECTION INPUT NUMBER OF DATA (NS) = 69
 NUMBER OF INTERPOLATION REGIONS (NXS) = 3
 INTERPOLATION SCHEME (1 = GAMMA FORM)
 (2 = LOG-LOG)
 (3 = CURTC)
 (1) .1167E+03 KEV (3) .5003E+03 KEV (2)

ENDF/B CROSS SECTION DATA PAIRS ENERGY(EV)/SIGMA(BARNS) (IS) IS=1,NS
 .10000E+04 .99063E-15 .20000E+04 .22278E-09 .30000E+04 .47548E-07
 .40000E+04 .11170E-05 .50000E+04 .94049E-05 .10000E+05 .1A024E-02
 .15000E+05 .15416E-01 .20000E+05 .57040E-01 .25000E+05 .1A074E-00
 .30000E+05 .26795E+00 .35000E+05 .44079E+00 .40000E+05 .60014E+00
 .45000E+05 .97090E+00 .50000E+05 .13006E+01 .55000E+05 .1A040E+01
 .60000E+05 .21149E+01 .65000E+05 .25004E+01 .70000E+05 .30109E+01
 .80000E+05 .38581E+01 .90000E+05 .45115E+01 .10000E+06 .4A049E+01
 .10500E+06 .49443E+01 .10900E+06 .49018E+01 .11500E+06 .49420E+01
 .12000E+06 .49423E+01 .14000E+06 .42949E+01 .16000E+06 .36391E+01
 .18000E+06 .30604E+01 .20000E+06 .25014E+01 .22000E+06 .22192E+01

```

.24000E+06 .19235E+01 .26000E+06 .15845E+01 .28000E+06 .14941E+01
.30000E+06 .13360E+01 .32000E+06 .12044E+01 .34000E+06 .11937E+01
.36000E+06 .99967E+00 .38000E+06 .91826E+00 .40000E+06 .84912E+00
.42000E+06 .79823E+00 .44000E+06 .73477E+00 .46000E+06 .68754E+00
.48000E+06 .64556E+00 .50000E+06 .60807E+00 .55000E+06 .52998E+00
.60000E+06 .46844E+00 .65000E+06 .41991E+00 .70000E+06 .38005E+00
.75000E+06 .34708E+00 .80000E+06 .31946E+00 .85000E+06 .29604E+00
.90000E+06 .27604E+00 .95000E+06 .25875E+00 .10000E+07 .24370E+00
.12000E+07 .19911E+00 .14000E+07 .17314E+00 .16000E+07 .15931E+00
.18000E+07 .14387E+00 .20000E+07 .13206E+00 .22000E+07 .12350E+00
.24000E+07 .11718E+00 .26000E+07 .11244E+00 .28000E+07 .10866E+00
.30000E+07 .10616E+00 .32000E+07 .10415E+00 .34000E+07 .10267E+00
.36000E+07 .10162E+00 .38000E+07 .10093E+00 .40000E+07 .10052E+00

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PLASMA TEMPERATURES (NO. = 100. TMIN = .10000E+01 KEV. Tmax = .10000E+03)

CENTER OF MASS CROSS SECTION DATA ENERGY(KEV)/SIGMA(CM²) (IS)=1.5 NS

```

.59946E+00 .99063E+39 .119923E+01 .22228E+33 .17985E+31 .47548E+31
.239846E+01 .11170E+02 .299808E+01 .94049E+29 .599416E+01 .16625E+26
.499424E+01 .15416E+25 .119923E+02 .57040E+25 .149004E+02 .13874E+24
.17985E+02 .26795E+24 .299808E+02 .44879E+24 .239846E+02 .68314E+24
.269827E+02 .97090E+24 .299808E+02 .13096E+23 .329789E+02 .16940E+23
.359770E+02 .21149E+23 .389751E+02 .25594E+23 .419731E+02 .30109E+23
.479652E+02 .38581E+23 .539655E+02 .45115E+23 .599416E+02 .48849E+23
.629957E+02 .49643E+23 .65358E+02 .49818E+23 .689459E+02 .49420E+23
.719539E+02 .48623E+23 .839463E+02 .42969E+23 .959486E+02 .36391E+23
.107931E+03 .30604E+23 .119923E+03 .25914E+23 .131916E+03 .22192E+23
.14390E+03 .19235E+23 .15590E+03 .16865E+23 .16789E+03 .14941E+23
.17985E+03 .13360E+23 .191877E+03 .12044E+23 .20387E+03 .10937E+23
.21584E+03 .99967E+24 .227854E+03 .91826E+24 .239846E+03 .84912E+24
.25183E+03 .79823E+24 .263831E+03 .73477E+24 .275823E+03 .68754E+24
.287814E+03 .64556E+24 .299808E+03 .60807E+24 .329789E+03 .52998E+24
.359770E+03 .46844E+24 .389751E+03 .41991E+24 .419731E+03 .38005E+24
.449712E+03 .34708E+24 .479652E+03 .31946E+24 .509474E+03 .29604E+24
.539655E+03 .27604E+24 .569435E+03 .25875E+24 .599416E+03 .24370E+24
.719539E+03 .19911E+24 .839463E+03 .17314E+24 .959486E+03 .15931E+24
.107931E+04 .14387E+24 .119923E+04 .13206E+24 .131916E+04 .12350E+24
.14390E+04 .11718E+24 .15590E+04 .11244E+24 .16789E+04 .10866E+24
.17985E+04 .10616E+24 .191877E+04 .10415E+24 .20387E+04 .10267E+24
.21584E+04 .10162E+24 .227854E+04 .10093E+24 .239846E+04 .10052E+24

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INTERPOLATION BREAK ENERGIES IN CENTER OF MASS SYS

.699952E+02 .30000E+03

CROSS SECTION INTERPOLATION DATA BS(1S),IS=1.5 NS

```

.344077E+02 .344398E+02 .344811E+02 .345280E+02 .346898E+02 .351293E+02
.357273E+02 .364755E+02 .373501E+02 .383023E+02 .392727E+02 .401888E+02
.409567E+02 .414955E+02 .416716E+02 .418441E+02 .406720E+02 .382655E+02
.332110E+02 .264469E+02 .208572E+02 .15259E+02 .139822E+02 .103612E+02
.34918E+01 .46283E+01 .94842E+01 .123467E+02 .14068E+02 .151049E+02
.161232E+02 .161447E+02 .163747E+02 .165402E+02 .166445E+02 .165909E+02
.165844E+02 .165244E+02 .164641E+02 .163670E+02 .162466E+02 .161244E+02
.159592E+02 .156791E+02 .151713E+02 .145908E+02 .139798E+02 .131442E+02
.122779E+02 .113299E+02 .103029E+02 .924657E+01 .81362E+01 .555313E+01
.52044E+01 .225572E+02 .857939E+01 .126162E+02 .210452E+02 .294171E+02
.374712E+02 .453185E+02 .530217E+02 .606702E+02 .67947E+02 .751266E+02
.823152E+02 .890239E+02

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CROSS SECTION INTERPOLATION DATA SS(1S),IS=2.5 NS

```

.117756E-19 .121335E-19 .125134E-19 .128976E-19 .141414E-19 .169451E-19
.246849E-19 .256733E-19 .321799E-19 .402795E-19 .497828E-19 .600131E-19
.69585E-19 .767816E-19 .791713E-19 .757188E-19 .665889E-19 .464274E-19
.223787E-19 .893465E-20 .433022E-20 .284559E-20 .183731E-20 .117442E-20
.528025E-21 .217455E-21 .132506E-21 .100645E-21 .860840E-22 .785847E-22
.745822E-22 .721811E-22 .708887E-22 .700194E-22 .696959E-22 .697617E-22
.697666E-22 .699859E-22 .703409E-22 .707727E-22 .712090E-22 .718247E-22
.725222E-22 .737114E-22 .758812E-22 .781572E-22 .809001E-22 .839888E-22
.874824E-22 .913522E-22 .956038E-22 .100051E-21 .104819E-21 .116477E-21
.173947E-21 .316646E-21 .201619E-21 .227979E-21 .290889E-21 .366197E-21
.452815E-21 .552376E-21 .666625E-21 .798362E-21 .942491E-21 .110518E-20
.129082E-20 .148469E-20

```

CROSS SECTION INTERPOLATION DATA CS(1S),IS=2.5 NS

```

.177756E+02 .132331E+02 .109727E+02 .854804E+01 .746673E+01 .549266E+01
.454769E+01 .398331E+01 .361010E+01 .334578E+01 .314641E+01 .298450E+01
.284028E+01 .270035E+01 .255041E+01 .238329E+01 .219529E+01 .185676E+01
.132823E+01 .754734E+00 .330466E+00 .041215E+01 .146594E+00 .386296E+00
.801928E+00 .124433E+01 .147042E+01 .157884E+01 .162681E+01 .164347E+01
.164276E+01 .163453E+01 .162109E+01 .160677E+01 .159336E+01 .157276E+01
.155700E+01 .154098E+01 .152511E+01 .150972E+01 .149460E+01 .148032E+01
.146559E+01 .144214E+01 .140875E+01 .137703E+01 .134844E+01 .131573E+01
.129466E+01 .125477E+01 .122495E+01 .119635E+01 .116827E+01 .110837E+01
.906625E+00 .623438E+00 .865506E+00 .812959E+00 .703728E+00 .603713E+00
.515868E+00 .436621E+00 .364927E+00 .296183E+00 .23679E+00 .179844E+00
.126013E+00 .793572E+01

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CROSS SECTION INTERPOLATION DATA AS(1S),1S=2,NS

.079722E-35 .200800E-34 .757079E-34 .263289E-33 .259543E-32 .087493F-31
 .707040E-30 .267460F-29 .789587E-29 .169478E-28 .310236E-28 .520111E-28
 .836541E-28 .134631E-27 .227397E-27 .413833E-27 .833552E-27 .291895F-26
 .225662E-25 .222349E-24 .124278E-23 .336146E-23 .918536E-23 .253639F-22
 .149951E-21 .106475E-20 .298786E-20 .496352E-20 .624474E-20 .67731E-20
 .675010E-20 .647515E-20 .604457F-20 .561131E-20 .514759F-20 .468766F-20
 .430652E-20 .398425F-20 .361943E-20 .332419E-20 .305435F-20 .281977F-20
 .257477E-20 .224240F-20 .184998F-20 .155140F-20 .128808F-20 .107127F-20
 .849386E-21 .738598F-21 .613317E-21 .512324E-21 .428706E-21 .292266F-21
 .77514E-22 .115169F-22 .606981E-22 .420526E-22 .193834F-22 .945000E-23
 .498844E-23 .278657F-23 .162505F-23 .977317E-24 .620458E-24 .404213E-24
 .247379E-24 .186412E-24

CROSS SECTION INTERPOLATION DATA NS(1S),1S=3,NSM1

.121076E-29 .340789E-28 .533756E-27 .775317E-26 .779158F-25 .325551F-24
 .744860E-24 .130236E-23 .196712E-23 .268434E-23 .333422F-23 .374690F-23
 .352950E-23 .250490E-23 .312300E-24 .304170E-24 .705607F-23 .128484F-22
 .144341E-22 .107423F-22 .444770E-23 .892896F-24 .404109F-23 .512700F-24
 .188471E-23 .285070E-23 .389294F-23 .433890F-23 .433890F-23 .422150F-23
 .387820E-23 .365534E-23 .326400E-23 .300900E-23 .287530F-23 .254878F-23
 .275492E-23 .220927F-23 .202545F-23 .193322E-23 .174532F-23 .160320F-23
 .134576E-23 .112662F-23 .101166E-23 .906240F-24 .818808F-24 .752180F-24
 .691140E-24 .649644E-24 .595240E-24 .506130E-24 .293583E-24 .190710F-24
 .700020E-24 .993700E-25 .132410E-24 .205560F-24 .190380E-24 .170940E-24
 .155340E-24 .140710E-24 .143110E-24 .123750E-24 .111850E-24 .130000E-24

CROSS SECTION INTERPOLATION DATA HS(1S),1S=3,NSM1

.325546E-29 .525296E-28 .629138E-27 .503540E-26 .243210F-25 .640614F-25
 .106827E-24 .147244E-24 .183438E-24 .211216E-24 .221180E-24 .203892F-24
 .135348E-24 .207966F-25 .151074F-24 .357962E-24 .563590E-24 .623388E-24
 .430851E-24 .755463E-25 .254033E-24 .424461E-24 .456647E-24 .383356F-24
 .235348E-24 .890361E-25 .440699E-25 .306377E-25 .408497E-25 .430359F-25
 .38249E-25 .353434E-25 .291784F-25 .255651E-25 .238137F-25 .197441F-25
 .170265E-25 .151065E-25 .131847E-25 .120120E-25 .996457E-26 .861468F-26
 .644371E-26 .507641F-26 .406446E-26 .337755E-26 .279573F-26 .238925F-26
 .203964E-26 .182456F-26 .153709E-26 .108713E-26 .195888E-27 .170943F-27
 .214667E-26 .114888F-26 .612753F-26 .206521E-27 .169042E-27 .126414F-27
 .961776E-28 .711149E-28 .774523F-28 .460155E-28 .302555E-28 .581761E-26

CROSS SECTION INTERPOLATION DATA FS(1S),1S=3,NSM1

.277737E-29 .272725E-28 .248974E-27 .105397E-26 .242758E-26 .358720F-26
 .388341E-26 .378873E-26 .349948E-26 .293765F-26 .187784F-26 .210269F-27
 .257552E-26 .586355E-26 .976885E-26 .134950E-25 .153146F-25 .122852F-25
 .431505E-26 .259918F-26 .765238F-26 .977690E-26 .960515E-26 .723564F-26
 .385250E-26 .112649F-26 .222577E-26 .369222E-27 .414767F-27 .384172F-27
 .310466E-27 .260402F-27 .199908E-27 .162639F-27 .140840F-27 .107012F-27
 .890375F-28 .745745F-28 .617804E-28 .532973F-28 .425197F-28 .353597F-28
 .257770E-28 .195750F-28 .141681E-28 .107193E-28 .816244E-29 .645270E-29
 .512978E-29 .426657F-29 .338767E-29 .234216F-29 .678507E-30 .704373E-30
 .292423E-29 .140144E-29 .738100F-32 .238152F-30 .174529E-30 .120293F-30
 .862214E-31 .618847E-31 .594510E-31 .372004E-31 .264527F-31 .375480F-31

CROSS SECTION INTERPOLATION DATA GS(1S),1S=3,NSM1

.753778E-30 .479030E-29 .332074E-28 .793973E-28 .975333F-28 .754873F-28
 .459771E-28 .254810E-28 .116427E-28 .618470E-30 .152762F-28 .234678F-28
 .568952E-28 .797824F-28 .107666E-27 .118746E-27 .110768F-27 .666401F-28
 .568952E-28 .371899F-28 .595277E-28 .648691E-28 .583447E-28 .381905F-28
 .145731E-28 .295746F-29 .124660E-29 .196171E-29 .172812F-29 .136257F-29
 .995350E-30 .753760F-30 .541141E-30 .408770E-30 .323730E-30 .236758F-30
 .185541E-30 .146887F-30 .115963E-30 .947032E-31 .734433E-31 .590307F-31
 .416363E-31 .293155F-31 .194200E-31 .134826E-31 .952444F-32 .698871F-32
 .519515E-32 .402055F-32 .303050E-32 .209971E-32 .818057F-33 .626281F-33
 .132814E-32 .56372E-33 .367217E-34 .976233E-34 .637977E-34 .405871F-34
 .270581E-34 .183688E-34 .154617E-34 .966359E-35 .67652E-35 .773887E-35

MAXWELLIAN DISTRIBUTION INTEGRATION CALCULATIONS

IT	T(NEG K)	T(KEV)	E(4M(KEV)	VEGAM(CM/S)	DE(4M(1/KEV)	VEGAM(CM/S)	EPL/EPH	EPS	RATE(C/SEC)
	DE(KEV)	TOL/100	EPL/EPH(KEV)	APL/100(CM/S)		EPL/EPH			RATE
	DE MIN/MAX(KEV)								
1	.116049E+02	100000E+01	.466114F+01	.1031825F+09	.3726749F-02	.7120692E-26	.6338812E-20		
	.298E-01	169 517	.1427E+01	.221E+02	.138F-31	.528E-24	.892F-04	.998E-06	.100E-05
2	.121575E+02	.104762E+01	.807095E+01	.104794E+02	.3910872E-02	.3730211E-26	.8394612E-20		
	.318E-01	168 520	.167E+01	.233F+02	.108F-31	.600E-24	.957F-06	.984E-06	.100E-05
3	.127364E+02	.109750E+01	.709736F+01	.1064324F+09	.4097604E-02	.4444434E-26	.1106392E-19		
	.322E-01	168 522	.168E+01	.239F+02	.264F-31	.676E-24	.815F-06	.993E-06	.100E-05
4	.133424E+02	.114976E+01	.731052F+01	.1080958E+09	.4280520F-02	.5278640E-26	.1451378E-19		
	.339F-01	167 525	.172E+01	.249F+02	.278F-31	.765E-24	.867E-06	.982E-06	.100E-05
5	.139782E+02	.120458E+01	.754086F+01	.1097847E+09	.4477443E-02	.6249866E-26	.1804966E-19		
	.348E-01	166 527	.176E+01	.259E+02	.377F-31	.860E-24	.923E-06	.994F-06	.100E-05
6	.144434E+02	.126186E+01	.777837F+01	.1115003E+09	.4669760E-02	.7377066E-26	.2442906E-19		
	.362E-01	165 530	.181E+01	.270F+02	.509F-31	.948E-24	.983F-06	.983E-06	.100E-05
7	.151414E+02	.132194E+01	.802337F+01	.1132426E+09	.4863123E-02	.8681274E-26	.3186658E-19		
	.376E-01	165 532	.182E+01	.280F+02	.540E-31	.108E-23	.831E-06	.998E-06	.100E-05
8	.160715E+02	.138489E+01	.827608F+01	.1150122E+09	.5057109E-02	.1018554E-25	.4184821E-19		
	.391E-01	164 535	.186E+01	.292F+02	.725E-31	.122E-23	.885F-06	.998E-06	.100E-05

9 148362E-02 145083E-01 153675F-01 1164094E-02 521272F-02 1191549E-25 524442E-1V
10 174384E-02 151991E-01 148564F-01 1186349E-02 545291E-02 1389902E-25 564204E-19
11 144793E-02 159272F-01 140829F-01 124886E-02 563847E-02 161824E-25 866699E-19
12 193592E-02 146610E-01 193600F-01 127371E-02 563847E-02 161824E-25 866699E-19
13 287179E-02 174753E-01 1966418E-01 1242830E-02 620901F-02 218431E-25 1374789E-18
14 124564F-02 183074F-01 196857F-01 124259E-02 620947E-02 275721E-25 1731871E-18
15 227572E-02 191791F-01 102826F-02 1281982E-02 639538E-02 2915997E-25 2172925E-18
16 233174E-02 200923E-01 104064F-02 1304015E-02 657843E-02 335558E-25 2715507E-18
17 244277E-02 210490E-01 109405F-02 1322361E-02 675814F-02 3951273E-25 3380040E-18
18 245904E-02 220513E-01 112851F-02 1343025E-02 693483E-02 408717E-25 4101788E-18
19 246887E-02 231013E-01 114405F-02 136411E-02 715858E-02 5033961E-25 5178373E-18
20 248854F-02 242013F-01 120812F-02 138532E-02 7273071F-02 573418E-25 617422E-18
21 294272E-02 253536E-01 121854F-02 1406974E-02 7435144E-02 653645E-25 7042189E-18
22 312437E-02 265609E-01 12775F-02 1428960E-02 7592315E-02 7432422E-25 9613436E-18
23 322914E-02 278256E-01 131779F-02 1451289E-02 7743641E-02 84181E-25 1174197E-17
24 32929F-02 291505E-01 135097F-02 1473968E-02 7888994E-02 9539512E-25 1429375E-17
25 354399E-02 305386E-01 140211F-02 1497001E-02 8128070E-02 1076878E-24 1733740E-17
26 371273E-02 319927E-01 144627F-02 1520394E-02 8160585E-02 1212801E-24 2094889E-17
27 388951E-02 335160E-01 149182F-02 1544152E-02 8286776E-02 1362734E-24 2523471E-17
28 40471E-02 351119E-01 153881F-02 1568282E-02 8444903E-02 1512226E-24 3283931E-17
29 426873E-02 367838E-01 158728F-02 1592788E-02 8516291E-02 1719797E-24 3640234E-17
30 447199E-02 385353E-01 163727E-02 1617678E-02 8620125E-02 1925984E-24 4636087E-17
31 468493E-02 403702E-01 168894F-02 1642957E-02 8716335E-02 2132146E-24 5268283E-17
32 490801E-02 422924E-01 174204F-02 168663E-02 884485E-02 2399574E-24 589555E-17
33 51417E-02 443062E-01 179490F-02 1694705E-02 895534E-02 268696E-24 6103141E-17
34 539653E-02 464159E-01 185350F-02 1721187E-02 895784E-02 2977380E-24 7341179E-17
35 554701F-02 486260F-01 191188F-02 1748083E-02 902234E-02 3035917E-24 8740411E-17
36 591171E-02 509414F-01 197218F-02 1775480E-02 9178408E-02 3766739E-24 8931634E-17
37 619320E-02 533670E-01 203422F-02 183143E-02 917684F-02 4059964E-24 1010054E-17
38 648809E-02 559081E-01 209829F-02 1831320E-02 9166929E-02 4485394E-24 1634916E-16
39 679703E-02 585702E-01 216438F-02 1859937E-02 9198846E-02 4719615E-24 1919092E-16
40 712069E-02 613591E-01 223255F-02 18849001E-02 9226676E-02 5417712E-24 2285734E-16
41 745973F-02 642807E-01 230287F-02 1918513F-02 9258482E-02 6034255E-24 2683237E-16
42 781447E-02 673415F-01 237548F-02 1948499E-02 934634E-02 66164903E-24 3094370E-16
43 818705E-02 705480E-01 245022F-02 1978947E-02 9246375E-02 7295881E-24 3543297E-16
44 857680E-02 739072E-01 252748F-02 2049871E-02 9238685F-02 8014202E-24 4162584E-16
45 894527E-02 774264F-01 260700F-02 2041278E-02 9273414E-02 8786347E-24 4745051E-16
46 94311E-02 811131E-01 269911F-02 2073176E-02 9300717E-02 9614665E-24 5429637E-16
47 984133E-02 849753E-01 277381F-02 215572E-02 9370763E-02 1052722E-24 6186653E-16
48 107709E-03 892125E-01 286118F-02 2138475E-02 9373376E-02 1149814E-24 7097789E-16
49 108222E-03 932603F-01 295130F-02 2171892E-02 9389831E-02 1254075E-24 8462353E-16
50 113381E-03 977010E-01 304426F-02 2205831E-02 939257E-02 1366336E-24 9149024E-16
51 118784E-03 102353F-02 314014F-02 2240300E-02 9392733F-02 1447112E-24 1037335E-15
52 124436E-03 107227E-02 323995F-02 2275308E-02 9391897E-02 1615684E-23 1250595E-15
215E-00 131 529 420F-01 146F-03 150E-27 188E-23 904F-06 990E-06 100E-05 1303543E-15

53 .13n361E+03 .112332E+02 .3341n7E+02 .231n863E+09 .8n49757E-02 .1752647E-23 .1421149E-15
 .224E+00 131 52n .411E+01 .152E+03 .127E-27 .178E-23 .664E+0n .982E+06 .1nE-05 .1450152E-15
 54 .174558E+03 .117681E+02 .34463nF+02 .2344974E+09 .8774787E-02 .189n453E-23 .1411459E-15
 .233E+00 130 52n .423E+01 .157E+03 .129E-27 .167E-23 .754E+0n .988E+06 .1nE-05 .1420637E-15
 55 .143071E+03 .123285E+02 .35545E+02 .2333649E+09 .849479E-02 .2052887E-23 .1422954E-15
 .242E+00 129 52n .437E+01 .162E+03 .200E-27 .159E-23 .857E+0n .988E+06 .1nE-05 .1701055E-15
 56 .140883E+03 .129155E+02 .366682F+02 .2420897E+09 .8n08438E-02 .2215211E-23 .2456224E-15
 .251E+00 128 52n .450E+01 .168E+03 .250E-27 .149E-23 .978E+0n .999E+06 .1nE-05 .1985325E-15
 57 .15702nE+03 .135305E+02 .37831F+02 .2458727E+09 .8617975E-02 .238511E-23 .2213461E-15
 .261E+00 128 52n .439E+01 .174E+03 .207E-27 .141E-23 .712E+0n .985E+06 .1nE-05 .2195238E-15
 58 .144497E+03 .141747E+02 .390144E+02 .2497148E+09 .8422405E-02 .2565224E-23 .2496755E-15
 .272E+00 127 52n .453E+01 .181E+03 .240E-27 .133E-23 .820E+0n .985E+06 .1nE-05 .2396451E-15
 59 .172329E+03 .148497E+02 .402433F+02 .2536170E+09 .832792E-02 .274444E-23 .249260E-15
 .282E+00 126 52n .468E+01 .187E+03 .327E-27 .126E-23 .948E+0n .997E+06 .1nE-05 .2618458E-15
 60 .18n535E+03 .155568E+02 .415108F+02 .2575801E+09 .8218065E-02 .2940305E-23 .3237413E-15
 .293E+00 126 52n .465E+01 .194E+03 .246E-27 .118E-23 .678E+0n .986E+06 .1nE-05 .250669E-15
 61 .184131E+03 .162975E+02 .428183F+02 .2616n52E+09 .8110094E-02 .3129537E-23 .3500177E-15
 .305E+00 125 52n .469E+01 .202E+03 .333E-27 .112E-23 .793E+0n .982E+06 .1nE-05 .3529296E-15
 62 .198137E+03 .170735E+02 .441670F+02 .2659931E+09 .7999343E-02 .3319613E-23 .3965324E-15
 .317E+00 124 52n .485E+01 .209E+03 .420E-27 .105E-23 .93nE+0n .982E+06 .1nE-05 .3742460E-15
 63 .207571E+03 .178865E+02 .455581F+02 .2698450E+09 .7884481E-02 .3516342E-23 .4770498E-15
 .330E+00 124 52n .467E+01 .217E+03 .331E-27 .091F-24 .652E+0n .983E+06 .1nE-05 .3600143E-15
 64 .217455E+03 .187382F+02 .46903nF+02 .274n617E+09 .7746471E-02 .7119694E-23 .4884446E-15
 .343E+00 123 52n .485E+01 .226E+03 .419E-27 .036E-24 .774E+0n .991E+06 .1nE-05 .3844216E-15
 65 .273909E+03 .196304E+02 .484732F+02 .2783443E+09 .7445417E-02 .7914401E-23 .5259471E-15
 .364E+00 122 52n .507E+01 .234E+03 .531E-27 .182F-24 .927E+0n .984E+06 .1nE-05 .4133449E-15
 66 .278657E+03 .205651E+02 .499993F+02 .2820338E+09 .7522176E-02 .4084076E-23 .5694522E-15
 .374E+00 122 52n .483F+01 .243F+03 .488E-27 .833E-24 .637E+0n .999E+06 .1nE-05 .4486571E-15
 67 .25021E+03 .215443E+02 .515748F+02 .2871113E+09 .7396403F-02 .4254080E-23 .616098E-15
 .385E+00 121 52n .500E+01 .253E+03 .519E-27 .784E-24 .763E+0n .998E+06 .1nE-05 .4482152E-15
 68 .261925E+03 .225702E+02 .531993F+02 .2915973E+09 .7268548E-02 .4430199E-23 .6659470E-15
 .400E+00 120 52n .518F+01 .263E+03 .644E-27 .737E-24 .924E+0n .984E+06 .1nE-05 .4958811E-15
 69 .274797E+03 .236449E+02 .548749F+02 .2941545E+09 .7138857E-02 .4571750E-23 .7125729E-15
 .414E+00 120 52n .496E+01 .274E+03 .463E-27 .497E-24 .818E+0n .993E+06 .1nE-05 .525308E-15
 70 .287463E+03 .247708E+02 .566033F+02 .3007824E+09 .7407548E-02 .4682608E-23 .7563839E-15
 .432E+00 119 52n .515E+01 .285E+03 .632E-27 .456E-24 .760E+0n .988E+06 .1nE-05 .5569470E-15
 71 .301151E+03 .259502E+02 .583861F+02 .3054825E+09 .6874916F-02 .4792099E-23 .8017691E-15
 .449E+00 118 530 .535F+01 .297E+03 .811E-27 .419E-24 .937E+0n .987E+06 .1nE-05 .5784029E-15
 72 .31549nE+03 .271859F+02 .602251F+02 .31n2561E+09 .6741127F-02 .4892301E-23 .8473658E-15
 .467E+00 118 532 .509E+01 .309E+03 .506E-27 .454E-24 .408E+0n .988E+06 .1nE-05 .6046652E-15
 73 .37n512E+03 .284804E+02 .621220F+02 .3151043E+09 .6604422E-02 .4844E+00 117 534 .519E+01 .321E+03 .739E-27 .550E-24 .763E+0n .995E+06 .1nE-05 .8458590E-15
 74 .36625nE+03 .298365E+02 .640787F+02 .3221283E+09 .671115E-02 .4973017E-23 .9216270E-15
 .505E+00 116 537 .551E+01 .335E+03 .922E-27 .518E-24 .059E+0n .987E+06 .1nE-05 .6859121E-15
 75 .362737E+03 .312572F+02 .660970F+02 .3250292E+09 .6335111E-02 .4974171E-23 .9528024E-15
 .525E+00 116 540 .521F+01 .350E+03 .606E-27 .488E-24 .603E+0n .984E+06 .1nE-05 .682732E-15
 76 .38n009E+03 .327455E+02 .681784F+02 .3341083E+09 .6798908E-02 .4951604E-23 .9798568E-15
 .546E+00 115 543 .545E+01 .364E+03 .809E-27 .461E-24 .773E+0n .984E+06 .1nE-05 .7826297E-15
 77 .39n103E+03 .343047E+02 .703263F+02 .3352667E+09 .6162590E-02 .4899974E-23 .10n1205E-14
 .567E+00 114 546 .567E+01 .380E+03 .118E-26 .435E-24 .992E+0n .987E+06 .1nE-05 .705869E-15
 78 .417n59E+03 .359381E+02 .725441F+02 .3455057E+09 .5926364E-02 .4824637E-23 .107740E-14
 .590E+00 114 549 .533E+01 .396E+03 .702E-27 .411E-24 .601E+0n .993E+06 .1nE-05 .748n720E-15
 79 .414918E+03 .376494F+02 .748267F+02 .3458266E+09 .579031E-02 .485601E-23 .1079250E-14
 .613E+00 113 553 .557E+01 .414E+03 .145E-24 .307E-24 .789E+0n .985E+06 .1nE-05 .7645818E-15
 80 .457722F+03 .394421E+02 .77183nF+02 .3512307E+09 .5454815E-02 .455685E-23 .1n2723E-14
 .617E+00 113 556 .519E+01 .431E+03 .665F-27 .347E-24 .448E+0n .996E+06 .1nE-05 .7848695E-15
 81 .479517E+03 .413201E+02 .796141E+02 .3567192E+09 .5519825E-02 .4442785E-23 .1n28897E-14
 .647E+00 112 540 .544E+01 .450E+03 .927E-27 .346E-24 .603E+0n .993E+06 .1nE-05 .8017582E-15
 82 .502353E+03 .432876E+02 .821217F+02 .3622934E+09 .5385562E-02 .4348519E-23 .1073552E-14
 .688E+00 111 544 .570E+01 .476E+03 .122E-26 .328E-24 .813E+0n .993E+06 .1nE-05 .8171187E-15
 83 .524209E+03 .453488E+02 .847083F+02 .3679548F+09 .5525149E-02 .4255044E-23 .1042200E-14
 .718E+00 111 548 .527E+01 .491E+03 .734E-27 .31nE-24 .438F+0n .996E+06 .1nE-05 .83n9274E-15
 84 .551328E+03 .475081E+02 .873763F+02 .3737045E+09 .511978nE-02 .4091814E-23 .1032335E-14
 .744E+00 110 573 .554E+01 .514E+03 .1n2E-26 .293E-24 .609E+0n .986E+06 .1nE-05 .8431478E-15
 85 .57758nE+03 .497702E+02 .901284F+02 .3795443F+09 .4988521E-02 .793544nE-23 .1n2138E-14
 .774E+00 109 577 .593E+01 .536F+03 .140E-26 .278E-24 .844E+0n .993E+06 .1nE-05 .8537651E-15
 86 .5n5082E+03 .521401E+02 .929672F+02 .385752E+09 .4858512E-02 .78414nF+23 .1n8982E-14
 .8n4E+00 109 582 .534E+01 .561E+03 .8n0E-27 .244E-24 .431E+0n .988E+06 .1nE-05 .8627858E-15
 87 .613873E+03 .546222E+02 .958954F+02 .3914989E+09 .477983E-02 .764109E-23 .90n7150E-15
 .836E+00 108 586 .564E+01 .586F+03 .174E-24 .751E-24 .620E+0n .100E-05 .1nE-05 .87n19n7E-15
 88 .644n77E+03 .572237E+02 .989158F+02 .3976166E+09 .44n2678E-02 .3501624E-23 .9867557E-15
 .8n2E+00 107 591 .596E+01 .612E+03 .1n6E-26 .238E-24 .899E+0n .999E+06 .1nE-05 .8740021E-15
 89 .695697E+03 .599484E+02 .102031E+03 .4038299E+09 .4477051E-02 .3353049E-23 .973549E-15
 .9n7E+00 107 597 .54nE+01 .641E+03 .844E-27 .226E-24 .425E+0n .986E+06 .1nE-05 .88n2515E-15
 90 .728n23E+03 .628029E+02 .105245F+03 .411403E+09 .4753n71F-02 .3195307E-23 .9492399E-15
 .939E+00 106 602 .574E+01 .670E+03 .126E-26 .215E-24 .638E+0n .989E+06 .1nE-05 .8n29593E-15
 91 .763527E+03 .657933E+02 .108560F+03 .4165494E+09 .4230820F-02 .303836E-23 .9262751E-15
 .974E+00 105 607 .609E+01 .701E+03 .163E-26 .205E-24 .05nE+0n .993E+06 .1nE-05 .88n1777E-15
 92 .799883E+03 .689261E+02 .111979F+03 .4238586E+09 .4110371E-02 .29149n2E-23 .9714286E-15
 .1n1E+00 105 613 .545E+01 .734E+03 .928E-27 .196E-24 .423E+0n .987E+06 .1nE-05 .8839329E-15
 93 .837970E+03 .722081E+02 .115506E+03 .4296695E+09 .3991792E-02 .2777715E-23 .806n925E-15
 .1n5E+01 104 619 .583E+01 .768E+03 .140E-26 .108E-24 .664E+0n .987E+06 .1nE-05 .8822967E-15

94	.8777474E+03	.756443E+02	.119144F+03	.4347817E+02	.3n73147E-02	.2625449E-23	.8426674E-19
	.118F+01	1A4	.425	.514E+01	.804E+03	.621F-27	.180E-24
95	.919671E+03	.792483E+02	.122877F+03	.4432023E+02	.3760479E-02	.2508913E-23	.8425813E-15
	.114E+01	1n3	.631	.557F+01	.842E+03	.946E-27	.173E-24
96	.947461E+03	.836218E+02	.124768F+03	.4501285E+02	.3447847E-02	.2392129E-23	.8247899E-15
	.114E+01	1n2	.638	.594E+01	.883F+03	.147E-24	.168E-24
97	.100934E+04	.869749E+02	.130761F+03	.4571624E+02	.3437289E-02	.2259808E-23	.7976144E-15
	.123F+01	1n2	.645	.516E+01	.925E+03	.637E-27	.163F-24
98	.105740E+04	.911163E+02	.134880F+03	.4643063E+02	.3428843E-02	.2153923E-23	.8629935E-15
	.128E+01	1n1	.652	.559E+01	.969E+03	.148E-24	.158E-24
99	.110775E+04	.954548E+02	.139128E+03	.4715617E+02	.3322538E-02	.2051673E-23	.7581706E-15
	.133E+01	100	.648	.606E+01	.101E+04	.177E-26	.152E-24
100	.116049E+04	.100000E+03	.143516E+03	.4789306E+02	.3218402E-02	.1934727E-23	.7311691E-15
	.138E+01	100	.665	.518E+01	.106E+04	.058E-27	.146E-24
						.241E-06	.990E-06
							.100E-05
							.0370298E-15

***** FINAL RESULTS FOR SIGMA-VBAR *****

ION DISTRIBUTION-----BOTH IONS MAXWELLIAN
MAXWELLIAN INTEGRATION-----DENSE TRAPEZOIDAL
SCREENING FACTOR-----NO CALCULATION

IT	TEMP (10**6 DEG K)	TEMP (KEV)	SIGMA-VBAR COMPONENTS	TOTAL SIGMA-VBAR (CM**3/SEC)		
			SLOWING DOWN	MAXWELLIAN	SCREENING FACTOR	
1	.114049E+02	.100000E+01		.658283E-24		.658283E-28
2	.121575E+02	.104762E+01		.872344E-20		.872344E-20
3	.127764E+02	.107759E+01		.115800E-18		.115800E-19
4	.133428E+02	.114974E+01		.151143E-19		.151143E-19
5	.139782E+02	.128456E+01		.197645E-19		.197645E-19
6	.144438E+02	.126188E+01		.257752E-19		.257752E-19
7	.157410E+02	.132194E+01		.333694E-19		.333694E-19
8	.167151E+02	.138489E+01		.437908E-19		.437908E-19
9	.184369E+02	.145084F+01		.554205E-19		.554205E-19
10	.174386F+02	.151991E+01		.709968E-19		.709968E-19
11	.184783E+02	.159228F+01		.905991E-19		.905991E-19
12	.197582E+02	.166810F+01		.115175E-18		.115175E-18
13	.207792E+02	.174751E+01		.145875E-18		.145875E-18
14	.212454E+02	.183074E+01		.184084E-18		.184084E-18
15	.222572F+02	.191791E+01		.231474E-18		.231474E-18
16	.233170F+02	.200923F+01		.290048E-18		.290048E-18
17	.244273E+02	.210490E+01		.362201E-18		.362201E-18
18	.255904F+02	.220513F+01		.457788E-18		.457788E-18
19	.268089E+02	.231013E+01		.559202E-18		.559202E-18
20	.280954F+02	.242013F+01		.691460E-18		.691460E-18
21	.294227E+02	.253536E+01		.852307E-18		.852307E-18
22	.308237E+02	.265609F+01		.104733E-17		.104733E-17
23	.322914E+02	.278254F+01		.128307E-17		.128307E-17
24	.338290E+02	.291505F+01		.156721E-17		.156721E-17
25	.354398E+02	.305386E+01		.190868E-17		.190868E-17
26	.371273E+02	.319927E+01		.231786E-17		.231786E-17
27	.388951E+02	.335166E+01		.280677E-17		.280677E-17
28	.407471E+02	.351119E+01		.338929E-17		.338929E-17
29	.426877E+02	.367838E+01		.407134E-17		.407134E-17
30	.447199E+02	.385357E+01		.490118E-17		.490118E-17
31	.468493E+02	.403702E+01		.586957E-17		.586957E-17
32	.490801E+02	.422924E+01		.701005E-17		.701005E-17
33	.514170E+02	.443062F+01		.834921E-17		.834921E-17
34	.538453F+02	.464159F+01		.991683E-17		.991683E-17
35	.564301E+02	.486266F+01		.117462E-16		.117462E-16
36	.591171E+02	.509414F+01		.138740E-16		.138740E-16
37	.619324E+02	.533670E+01		.163409E-16		.163409E-16
38	.648809E+02	.559061F+01		.191909E-16		.191909E-16
39	.679707E+02	.585702E+01		.224721E-16		.224721E-16
40	.712806E+02	.613591E+01		.262359E-16		.262359E-16
41	.748073E+02	.642807E+01		.305737E-16		.305737E-16
42	.784991E+02	.673415F+01		.354329E-16		.354329E-16
43	.814705E+02	.705486E+01		.409835E-16		.409835E-16
44	.847688E+02	.739072E+01		.472505E-16		.472505E-16
45	.884527E+02	.774264E+01		.542964E-16		.542964E-16
46	.941311E+02	.811131E+01		.621835E-16		.621835E-16
47	.988133E+02	.849753F+01		.709729E-16		.709729E-16
48	.103309E+03	.890215E+01		.807235E-16		.807235E-16
49	.108728E+03	.932603E+01		.914982E-16		.914982E-16
50	.113381E+03	.977010E+01		.103323E-15		.103323E-15
51	.118780E+03	.102353E+02		.116566E-15		.116566E-15
52	.124436E+03	.107227E+02		.132354E-15		.132354E-15
53	.130161E+03	.112332F+02		.145415E-15		.145415E-15
54	.136566E+03	.117641E+02		.162064E-15		.162064E-15
55	.143671F+03	.123225F+02		.172765E-15		.172765E-15
56	.149883E+03	.129155E+02		.194532E-15		.194532E-15
57	.157020E+03	.135305E+02		.214524E-15		.214524E-15
58	.164497F+03	.141747F+02		.239645E-15		.239645E-15

59	.172329F+03	.148447F+02	.261846E-15	.261846E-15
60	.180533E+03	.155568F+02	.285067E-15	.285067E-15
61	.189131F+03	.162975F+02	.309230E-15	.309230E-15
62	.198137E+03	.170735E+02	.334246E-15	.334246E-15
63	.207571F+03	.178865F+02	.360114E-15	.360114E-15
64	.217455E+03	.187382E+02	.386422E-15	.386422E-15
65	.227804E+03	.196304F+02	.413345E-15	.413345E-15
66	.238657E+03	.205651E+02	.440657E-15	.440657E-15
67	.250021E+03	.215443E+02	.468215E-15	.468215E-15
68	.261925E+03	.225702E+02	.495881E-15	.495881E-15
69	.274397E+03	.236449E+02	.523507E-15	.523507E-15
70	.287463E+03	.247708F+02	.551942E-15	.551942E-15
71	.301151F+03	.259502E+02	.578043E-15	.578043E-15
72	.315490E+03	.271859F+02	.604665E-15	.604665E-15
73	.330512E+03	.284804E+02	.631669E-15	.631669E-15
74	.346250F+03	.298365F+02	.659912E-15	.659912E-15
75	.362737E+03	.312572E+02	.688273E-15	.688273E-15
76	.380009F+03	.327455F+02	.707630E-15	.707630E-15
77	.398103E+03	.343047F+02	.725861E-15	.725861E-15
78	.417059E+03	.359381F+02	.744872E-15	.744872E-15
79	.436918E+03	.376494F+02	.764582E-15	.764582E-15
80	.457722E+03	.394421E+02	.784896E-15	.784896E-15
81	.479517E+03	.413201E+02	.801758E-15	.801758E-15
82	.502150F+03	.432874F+02	.817110E-15	.817110E-15
83	.526263E+03	.453488E+02	.831928E-15	.831928E-15
84	.551328E+03	.475081E+02	.847114E-15	.847114E-15
85	.577580E+03	.497702F+02	.853765E-15	.853765E-15
86	.605082E+03	.521401F+02	.862786E-15	.862786E-15
87	.633893F+03	.546228E+02	.87191E-15	.87191E-15
88	.664077E+03	.572237E+02	.878002E-15	.878002E-15
89	.695497E+03	.599484F+02	.881252E-15	.881252E-15
90	.728823E+03	.628029E+02	.882959E-15	.882959E-15
91	.763527E+03	.657933E+02	.884178E-15	.884178E-15
92	.799883E+03	.689261F+02	.883933E-15	.883933E-15
93	.837970F+03	.722081F+02	.882297E-15	.882297E-15
94	.877870E+03	.756463F+02	.879345E-15	.879345E-15
95	.919671E+03	.792483E+02	.875056E-15	.875056E-15
96	.963461E+03	.830218E+02	.869597E-15	.869597E-15
97	.100934E+04	.869749E+02	.862993E-15	.862993E-15
98	.105740E+04	.911163E+02	.855309E-15	.855309E-15
99	.110775E+04	.954548E+02	.846639E-15	.846639E-15
100	.116049E+04	.100000E+03	.837030E-15	.837030E-15

SAMPLE PROBLEM CASE 5 T(D,N)ALPHA FUSION REACTION WITH D SLOWING DOWN

KDATA = 2 CROSS SECTIONS FROM PREVIOUS CASE
 KINTE = 3 DENSE TRAPEZOIDAL INTEGRATION
 KTEMP = 2 PROJECTILE NUCLEI SLOWING IN
 KSCRN = 1 NO SCREENING CALCULATION
 KPLOT = 1 NO PLOT OUTPUT
 KPNCH = 1 NO PUNCHED OUTPUT
 KPRINT = 1 REDUCED PRINTED OUTPUT
 KCNTL = 2 SELECTED INTERNAL PARAMETERS INPUT

PLASMA MATERIAL NUMBER OF PARTICLE TYPES = 5
 IMAT Z(IMAT) A(IMAT) NO.DENSITY IMAT Z(IMAT) A(IMAT) NO.DENSITY
 1 .100000E+01 .201355E+01 .500000E+14 2 .107000E+01 .301550E+01 .500000E+14
 TARGET IMAT = 2 PROJECTILE IMAT = 1
 REDA = .120736E+01 AMU REDM = .125132E-14 KEV SEC**2/CM**2 BGAM = .343037E+02 KEV**0.5

CROSS SECTION INPUT NUMBER OF DATA (NS) = 69
 NUMBER OF INTERPOLATION REGIONS (NXS) = 3
 INTERPOLATION SCHEME (1 = GAMOW FORM)
 (2 = LOG-LOG)
 (3 = CURRIC)
 (1) .1167E+03 KEV (3) .5003E+03 KEV (2)

PLASMA TEMPERATURES (NO. = 9. TMIN = .200000E+01 KEV. TMAX = .100000E+02)
 PROJECTILE SOURCE = .100000E+13 PARTICLES/SEC-CM**3 WITH ENERGY OF .120000E+03 KEV

SLOWING DOWN RESULTS

IT	T(DFG K)	T(KEV)	A(1)	RATES(1)	A(2)	RATES(2)	RATES(TOT)
1	.232099E+02	.200000E+01	.301895E-02	.255555E-15			.771506E-18
2	.349148E+02	.300000E+01	.477001F-02	.289961E-15			.133132E-17
3	.466197E+02	.400000E+01	.652945F-02	.321678E-15			.210038E-17
4	.580246E+02	.500000F+01	.826767F-02	.351882E-15			.290924E-17
5	.696296E+02	.600000E+01	.996795F-02	.381802E-15			.375582E-17
6	.812345E+02	.700000E+01	.116198E-01	.400378E-15			.474412E-17
7	.928394E+02	.800000E+01	.132164F-01	.433972E-15			.572553E-17
8	.104444E+03	.900000E+01	.147526F-01	.457499E-15			.674933E-17
9	.116049E+03	.100000E+02	.162253E-01	.175729E-15			.285125E-17

ADJUSTMENT OF MAXWELLIAN SIGMA-VBAR

IT	T (KEV)	RATE (S)	AMXW1	AMXW2	PRE-ADJUSTED RATE (M)	ADJUSTED RATE (M)
1	.200000E+01	.771506E-18	.301895F-02		.287693E-18	.267836E-18
2	.300000E+01	.138312F-17	.477001F-02		.177072F-17	.176278E-17
3	.400000E+01	.210038E-17	.652945E-02		.566507E-17	.562808E-17
4	.500000E+01	.290924E-17	.826767F-02		.120828E-16	.128754E-16
5	.600000E+01	.379582E-17	.996795F-02		.247607E-16	.241179E-16
6	.700000E+01	.474412E-17	.116198F-01		.408059E-16	.395410E-16
7	.800000E+01	.573553E-17	.132164E-01		.597509E-16	.589612E-16
8	.900000E+01	.674933E-17	.147526F-01		.831629E-16	.819361E-16
9	.100000E+02	.285125E-17	.162253F-01		.109657E-15	.107878E-15

***** FINAL RESULTS FOR SIGMA-VBAR *****

ION DISTRIBUTION-----PROJECTILE ION SLOWING IN
 MAXWELLIAN INTEGRATION--DENSE TRAPEZOIDAL
 SCREENING FACTOR-----NO CALCULATION

IT	SIGMA-VBAR COMPONENTS					TOTAL SIGMA-VBAR (CM**3/SEC)
	TFMP (10**6 DEG K)	TEMP (KEV)	SLOWING DOWN	MAXWELLIAN	SCREENING FACTOR	
1	.272099E+02	.200000E+01	.771506F-18	.282836E-18		.165434E-17
2	.340148E+02	.300000E+01	.138312F-17	.176278E-17		.314539E-17
3	.464197E+02	.400000E+01	.210038F-17	.562808E-17		.772846E-17
4	.580246E+02	.500000E+01	.290924F-17	.128754E-16		.157847E-16
5	.696296E+02	.600000E+01	.379582E-17	.241179E-16		.270137E-16
6	.812345E+02	.700000E+01	.474412F-17	.395410E-16		.442851E-16
7	.928394E+02	.800000E+01	.573553F-17	.589612E-16		.646968E-16
8	.104444E+03	.900000E+01	.674933F-17	.819361E-16		.886854E-16
9	.116049E+03	.100000E+02	.285125F-17	.107878E-15		.110729E-15

II. PLOT OUTPUT FROM CASE 2

Figure C-1. First Plot from Case 2.

Figure C-2. Second Plot from Case 2.

Figure C-3. Third Plot from Case 2.

Figure C-4. Fourth Plot from Case 2.

SAMPLE PROBLEM CASE 2 D(O,P)T FUSION REACTION

Figure C-5. Fifth Plot from Case 2.

Figure C-6. Sixth Plot from Case 2.

III. PUNCHED CARD OUTPUT FROM CASE 4

***** TEMP=KEV *****

.100000E+01	.104762E+01	.109750E+01	.114976E+01	.120450E+01	.126186E+01
.132194E+01	.138489E+01	.145083E+01	.151991E+01	.159228E+01	.166810E+01
.174753E+01	.183074E+01	.191791E+01	.200923E+01	.210490E+01	.220513E+01
.231013E+01	.242013E+01	.253536E+01	.265689E+01	.278256E+01	.291205E+01
.305386E+01	.319927E+01	.335160E+01	.351119E+01	.367838E+01	.385353E+01
.403702E+01	.422924E+01	.443062E+01	.464159E+01	.486260E+01	.509414E+01
.533670E+01	.559081E+01	.585702E+01	.613591E+01	.642807E+01	.673415E+01
.705480E+01	.739372E+01	.774264E+01	.811131E+01	.849753E+01	.890215E+01
.932603E+01	.977100E+01	.102353E+02	.107227E+02	.112332E+02	.117681E+02
.123285E+02	.129155E+02	.135305E+02	.141747E+02	.148497E+02	.155568E+02
.162975E+02	.170735E+02	.178865E+02	.187382E+02	.196304E+02	.205651E+02
.215443E+02	.225702E+02	.236409E+02	.247708E+02	.259522E+02	.271859E+02
.284804E+02	.298365E+02	.312572E+02	.327455E+02	.343047E+02	.359381E+02
.376494E+02	.394421E+02	.413201E+02	.432876E+02	.453486E+02	.475081E+02
.497702E+02	.521401E+02	.546228E+02	.572237E+02	.599404E+02	.628029E+02
.667933E+02	.699261E+02	.722081E+02	.756463E+02	.792483E+02	.830218E+02
.889709E+02	.911163E+02	.954500E+02	.100000E+03		

***** RATEG *****

.633881E-20	.839461E-20	.110639E-19	.145133E-19	.189497E-19	.246201E-19
.318666E-19	.410482E-19	.526446E-19	.672274E-19	.855691E-19	.108687E-18
.137479E-18	.173187E-18	.217293E-18	.271551E-18	.338034E-18	.419179E-18
.517837E-18	.637420E-18	.780239E-18	.961304E-18	.117420E-17	.142909E-17
.173324E-17	.200489E-17	.252342E-17	.303839E-17	.364823E-17	.436609E-17
.520828E-17	.619314E-17	.734113E-17	.870401E-17	.102892E-16	.121261E-16
.142480E-16	.166918E-16	.195611E-16	.228573E-16	.266324E-16	.309432E-16
.359230E-16	.416258E-16	.481018E-16	.550353E-16	.634845E-16	.733575E-16
.840653E-16	.961605E-16	.109800E-15	.125060E-15	.142115E-15	.161146E-15
.182285E-15	.205622E-15	.231346E-15	.259675E-15	.290262E-15	.323741E-15
.359018E-15	.396533E-15	.437000E-15	.480844E-15	.525947E-15	.569965E-15
.616610E-15	.665947E-15	.712573E-15	.756384E-15	.801769E-15	.847366E-15
.885859E-15	.921627E-15	.952802E-15	.979857E-15	.100121E-14	.101740E-14
.101925E-14	.102202E-14	.102690E-14	.103535E-14	.104200E-14	.103234E-14
.102138E-14	.100986E-14	.998715E-15	.986756E-15	.970355E-15	.949240E-15
.926275E-15	.911429E-15	.890493E-15	.862608E-15	.844581E-15	.824710E-15
.797614E-15	.774032E-15	.758171E-15	.731169E-15		

***** RATEH *****

.658283E-20	.872344E-20	.115080E-19	.151183E-19	.197605E-19	.257352E-19
.333694E-19	.430908E-19	.554205E-19	.709968E-19	.905991E-19	.115175E-18
.145875E-18	.180084E-18	.231474E-18	.290048E-18	.362201E-18	.450788E-18
.559202E-18	.691460E-18	.852307E-18	.104733E-17	.128307E-17	.156721E-17
.190368E-17	.231786E-17	.280677E-17	.338929E-17	.408134E-17	.490118E-17
.586957E-17	.701005E-17	.834921E-17	.991683E-17	.117462E-16	.138740E-16
.163409E-16	.191909E-16	.224721E-16	.262359E-16	.305370E-16	.354329E-16
.409835E-16	.472505E-16	.542964E-16	.621835E-16	.709729E-16	.807235E-16
.914902E-16	.103323E-15	.116266E-15	.130354E-15	.145615E-15	.162064E-15
.179705E-15	.198532E-15	.218524E-15	.239645E-15	.261846E-15	.285067E-15
.309238E-15	.334246E-15	.360014E-15	.386422E-15	.413345E-15	.440657E-15
.468215E-15	.495881E-15	.523507E-15	.550942E-15	.578043E-15	.604665E-15
.630669E-15	.655912E-15	.680273E-15	.703630E-15	.725861E-15	.746872E-15
.766582E-15	.784896E-15	.801758E-15	.817119E-15	.830928E-15	.843148E-15
.853765E-15	.862786E-15	.870191E-15	.876002E-15	.880252E-15	.882959E-15
.884178E-15	.883933E-15	.882247E-15	.879305E-15	.875056E-15	.869597E-15
.862993E-15	.855309E-15	.846639E-15	.837030E-15		

APPENDIX D

PROGRAM ABSTRACT

1. Name of program: STEEP4.
2. Names of computers for which program is designed: CDC-6600 and CDC-7600.
Programming language: FORTRAN-IV.
3. Nature of the problem solved: STEEP4 calculates fusion reaction rates in terms of the specific reactivity $\langle\sigma v\rangle$ which is the product of cross section and relative velocity averaged over the actual ion distributions of the interacting particles in the plasma. Maxwellian ion distributions are modified to include slowing-down contributions which are characterized in terms of plasma parameters. Rapid and accurate algorithms are used for integrating $\langle\sigma v\rangle$ from spectra and input cross sections. Options are also provided for rapid calculation of screening effects on specific reaction rates.
4. Method of solution: The main program solves for $\langle\sigma v\rangle$ by the method of steepest descent. However, options are provided to use Gauss-Hermite and dense trapezoidal quadrature integration techniques. Gamow penetration form, log-log interpolation, and cubic interpolation routines are used to provide interpolated values of cross sections for the integration routines. Slowing-down contributions are included by joining a $\frac{1}{E}$ ion slowing-down distribution smoothly to a background Maxwellian distribution for the total ion distribution. Multiplicative screening factors are calculated from plasma parameters using weak, intermediate, and strong-screening formulations.

5. Restrictions on the complexity of the problem: The form of the slowing-down distribution used neglects absorption and leakage of plasma particles during the slowing-down process and is based on the assumption that the slowing-down ion is faster than the background ions but slower than the plasma electrons. Spatial and angular dependences of the ion distributions are not treated in this version of the code.
6. Related and auxiliary programs: STEEP4 uses the LASL program library subroutine PLOTM of Ref. 1 to generate SC 4020 Film Plot output.
7. Typical running times: The program requires about 0.1 seconds for $\langle\sigma v\rangle$ evaluation without slowing-down or screening corrections for each set of plasma parameters when run on the CDC-7600. The additional time for screening factor calculation is negligible; however, each slowing-down evaluation requires 10 to 20 seconds.
8. Description: Equations, calculational methods, input and output are described in this report.
9. Unusual features: STEEP4 is modularly structured so that selected sections may be removed for incorporation in thermonuclear burn codes to provide rapid and yet relatively accurate on-line computation of $\langle\sigma v\rangle$. The options to include slowing-down and screening effects provide a great deal of flexibility and increase the range of applicability of the code. Also a subroutine is provided to read input cross-section data from an assumed library of charged-particle cross sections.
10. Status: The program is currently in use and can be obtained from the Argonne Code Center.
11. Machine requirements: None.

12. Operating system: Present version generates plot output via SC 4020 film plotter. Otherwise machine independent.

13. Other programming information: None.

14. Reference:

- 1 R. Frank, "PLOTM - Standardized Plot on Film with Tic Marks",
in Los Alamos Scientific Laboratory Programmer's Information
Manual LA-5525-M, Vol. 2 (1974).

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