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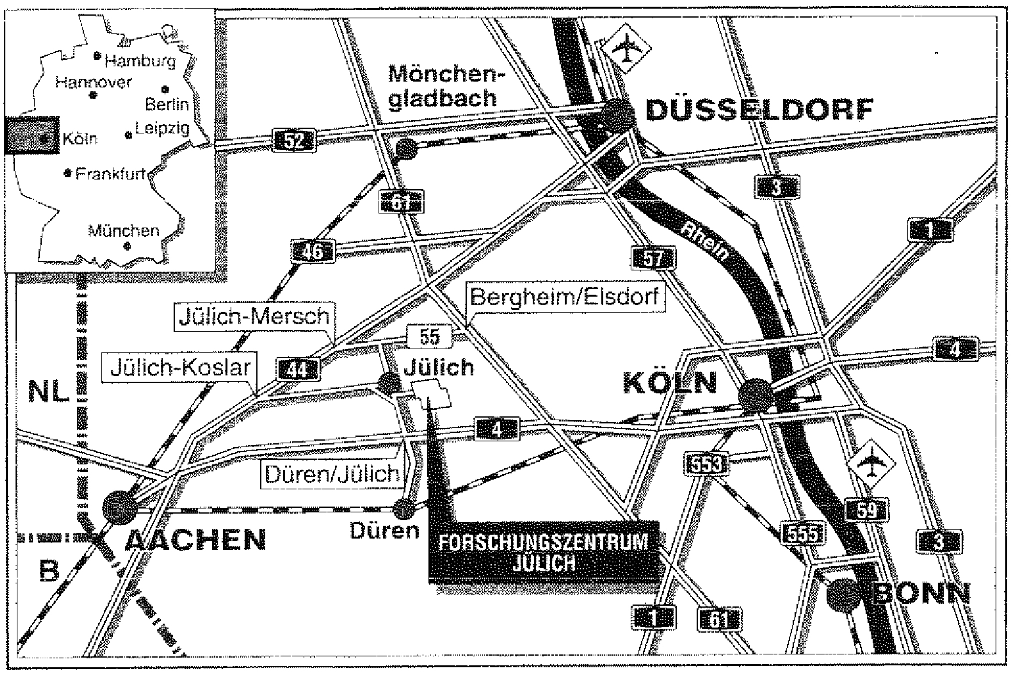

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Database for recycling and penetration of neutral helium atoms in the boundary of a fusion plasma

D. Reiter W. Eckstein* G. Giesen H.J. Belitz

Forschungszentrum Jülich (KFA)
Institut für Plasmaphysik, EURATOM-KFA Association
W-5170 Jülich, P.O.B. 1913, FRG

* Max-Planck-Institut für Plasmaphysik, EURATOM-Association
W-8046 Garching/München, Boltzmannstraße 2, FRG

Abstract

Recently renewed attention has focused on the problem of helium ash accumulation in burning fusion plasmas, originating from both newly derived ignition criteria (e.g. /1/) for point reactor models and from results of elaborate transport code calculations (e.g. /2/). Both approaches identify the repenetration of recycled helium atoms back into the plasma core as one of the critical processes. In order to facilitate numerical analysis of this problem and for reference purposes, we have compiled newly derived relevant atomic and surface data in handy formats, similar to those routinely used in the analysis of the neutral hydrogen recycling process so far /3-6/. In this report we provide a collisional-radiative atomic data package for the interaction of helium atoms with a thermalized electron background, and a surface reflection model for helium atoms or ions incident onto stainless steel, graphite and tungston target surfaces. This model comprises, as function of incident energy and angle, the reflection probability and the fully 3 dimensional distribution in velocity space of the reflected particles.

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1 Introduction

Helium, as the ash of the D-T fusion process, is one of the components necessarily present in a steady burning D-T fusion reactor plasma. A decisive parameter controlling the fuel dilution problem is the ratio τ_{He}^{*}/τ_{E} of the global helium particle confinement time ("life time") over the energy confinement time. This ratio needs to remain sufficiently below 15 for steady burning /1/. Depending on the re-penetration efficiency of unpumped helium particles from first wall components, τ_{He}^{*} may include a contribution originating from recycled helium particles. In the first phase of this recycling process, the helium particles are neutral and interact with the background plasma predominantly via inelastic collisions such as ionisation or charge exchange. Their concentration in the plasma is in most cases small enough to permit to neglect elastic collisions between these particles themselves. Under these circumstances this recycling process can readily be investigated by means of the powerful tools developed in the field of linear transport theory, such as fully three-dimensional Monte Carlo Codes (/7, 8, 9/), provided that the relevant atomic data and surface interaction processes are not only identified and sufficiently well known, but are also put in handy formats for convenient use in these very complex computer codes.

Therefore, in this report, we compile such data and we stick to exactly those data formats, which are already widely used in plasma edge computer transport models.

In the following section 2 we briefly describe the multi-step electron impact ionisation and recombination model for helium atoms, and the format of the data (the latter being identical with the format of the data collections /3/ and /4/).

Section 3 deals with the surface reflection data for helium atoms and ions from carbon, stainless steel and from tungston surfaces. For comparison and completeness we have retained all earlier databases of the same format (refs./5/ and /6/) in the new database presented here. The present database contains the old ones as a subset and extends them to include data for more target projectile combinations. Again we have used a well known format to present the data (see refs. /5/ and /6/), which may look somewhat awkward but happens to be the optimal choice for implementation of these recycling models in Monte Carlo algorithms. This is because, generally, random sampling from multidimensional distributions is carried out in Monte Carlo procedures by resorting to inverted conditional distributions (quantiles). Such data are derived from random samples of test-particle trajectories, which are obtained by computing histories of a beam of particles incident onto the surface, penetrating the solid and being reflected. For the data compiled in the new database we have replaced the 'histogram quantile approach' described by G.Bateman in ref./5/ by the 'consistent conditional quantile estimators' derived by C.J.Stone (ref./11/). This is just a different statistical method for estimating the same parameters of conditional distributions. Thus the meaning of the corresponding numbers is identical in refs./5/, /6/ and in this report.

Section 4 then is a compilation of graphical presentations of the various multistep helium collision rate coefficients obtained from the model described by Fujimoto in ref./10/, as well as the fitting coefficients.

Finally, in section 5, we have plotted and printed examples of a few selected aspects of the full helium surface reflection model, namely particle and energy reflection coefficients in the plots and a table of one complete distribution function of reflected helium particles for a monoenergetic beam of helium atoms or ions normally incident onto a graphite, stainless steel and a tungston target, respectively. Including such distribution functions for all target projectile combinations and incident beam energy and polar angles in this report, which are available in the complete database, or plotting all relations between the five variables E_{in}, ϑ_{in}, E_{out}, ϑ_{out} and Φ_{out} (see section 3) would render this report too voluminous. The full databases are, however, available from the first author of this report, e.g. on file by electronic mail.

2 Collisional-radiative model for helium atoms

The multi-step ionisation and recombination model for helium atoms in a Maxwellian electron background presented here has been developed, originally, by T.Fujimoto (ref./10/). We have used his model to derive the effective rate coefficients needed in helium transport calculations. No changes whatsoever have been made to the physical model, but, as compared to what is described in /10/, we have neglected the inelastic neutral-neutral interactions, ie. we have solved a linear system of rate equations only. Furthermore we have eliminated the transport terms in Fujimoto's equations (particle diffusion). It is, instead, the purpose of this work to provide the effective rate coefficients needed to carry out such transport analyses by existing general neutral gas transport (Monte Carlo) codes. Monte Carlo code allow to study transport effects (including the nonlinear neutral neutral interactions, ref./12/) in much greater detail. Such codes (as e.g. the EIRENE code, ref./7/) communicate with atomic and molecular databases in an automatted procedure. Therefore, data fits like the ones presented here have simply to be added to existing data collections and can then be included in transport studies without need for any modification in the Monte Carlo codes.
Before we proceed to explain the format of the data derived here, we briefly generalise matters for reference purposes and to set the framework for deriving multi-step collision data for other neutral particle - plasma interaction processes:

Let there be m different neutral particle species (e.g. different exited levels of one particular neutral atom, but also different neutral atoms). n_p is the density of the background plasma collision partners (electrons or ions).

The rate equations for these m particle species with regard to a particular set of collision processes "k" then read

$$\frac{d}{dt} n_1 = -<\sigma v>_{k,1} \bullet n_1 \bullet n_p + <\sigma v>_{k,2,1} \bullet n_2 \bullet n_p + \ldots <\sigma v>_{k,m,1} \bullet n_m \bullet n_p + \text{o.c.}$$

$$\vdots$$

$$\frac{d}{dt} n_m = <\sigma v>_{k,1,m} \bullet n_1 \bullet n_p + <\sigma v>_{k,2,m} \bullet n_2 \bullet n_p + \ldots - <\sigma v>_{k,m} \bullet n_m \bullet n_p + \text{o.c.}$$

The term o.c. stands for "other contributions", such as (inhomogeneous) source terms (e.g. volume recombination processes, which are included in this report, see below), or other linear collision terms due to different collision processes (e.g. charge exchange) not considered here. Transport terms (convective) are included in the total time derivatives on the left-hand side of the equations.
In what follows we will omit the collision type index k. The remaining indices i,j in the above rate coefficients indicate a collision process of species i with the backgound par-

ticles, which results in one new neutral particle of species j. Correspondingly, the first rate coefficient in the first equation (for species 1) and the last coefficient in the second equation (for species m), respectively, comprises all processes of the first (or the last, respectively) species with the background particles, which lead to any other of the m distinct neutral species considered here, or to a total loss from the community of these m species.
The key assumption underlying a multi-step collision model is then, that for some of these m particle species, e.g. for those labelled by the species indices $m_j = m_T + 1, m_T + 2, ..., m$, some of the collision frequencies $< \sigma v >_{m_j,i} \cdot n_p, \quad i = 1, m$, are very large compared to $\frac{d}{dt} \ln(n_j)$.

Then, for these particles the total derivative

$$\frac{d}{dt} n_j$$

can be neglected compared to the right hand side of the rate equation.
A multi-step collisional model for the one particular set of processes, e.g. for electron impact ionisation and recombination, is then derived by excluding all other contributions mentioned in the equations above from consideration. What results is a system of $m - m_T$ linear algebraic equations, supplemented by the m_T (transport-) equations for those particle species, for which the total time derivative could not be neglected compared to collision frequencies. Taking these first m_T densities as (known) parameters, one obtains a system of $m - m_T$ inhomogeneous linear algebraic equations for the unknowns $n_{m_T+1}, ..., n_m$, with the coefficients being algebraic functions of the rate coefficients $< \sigma v >_{k, m_T+i, j}$ $i = 1, ..., m - m_T$, $j = 1, ..., m_T$, and of the densities $n_{m_1}, ..., n_{m_T}$. Terms containing these latter T densities are the inhomogeneous part in this system, which may be completed by further inhomogeneous terms independent of these densities (e.g. the volume recombinations terms or other contributions from species not considered here).

One then solves this system of linear equations for n_{m_T+i}, $i = 1, ... , m\text{-}m_T$ and inserts the solutions

$$n_{m_T+i}(< \sigma v >_{m_T+i,j}, n_{m_1}, ..., n_{m_T}, \text{otherinhomog.terms}) \quad , i = 1, 2, ...m - m_T j = 1,2,...,m$$

into the transport equations (i.e. into those m_T equations which still contain the substantive time derivative).
This then finally eliminates the densities n_{m_T+i}, $i = 1, 2, ..., m\text{-}m_T$ from the transport equations for the species m_j, $j = 1, 2, ..., m_T$.

The resulting coefficients $< \sigma v >^*_{i,j}$ in the reduced system

$$\frac{d}{dt} n_i = < \sigma v >^*_{1,i} \cdot n_{m_1} \cdot n_p + ... + < \sigma v >^*_{m_T,i} \cdot n_{m_T} \cdot n_p + \text{other contributions}$$

for $i = 1, 2, ..., m_T$ are then the multi-step collision rates for the set of neutral-plasma interaction processes considered.

For the data in this report, we have considered $m = 59$ electronic levels of the helium atom, and have retained transport equations for $m_T = 3$ distinct neutral helium atom species. These three particle species considered are helium atoms in the ground state

(1 | 1S), and helium atoms in the two metastable states (2 | 1S) and (2 | 3S). This is referred to as "formulation I", as in ref. /10/.
To facilitate neutral gas transport calculations, we also provide the data using the same cross-sections, but with $m_T = 1$ and ground-state atoms as the only remaining species with transport terms.
In this case, only one neutral helium atom species has to be considered in the neutral gas transport equations. Data belonging to this model are refered to as "formulation II", (loc. cit.)

The processes and data included here are rate coefficients for exitation and de-excitation by electron impact between all 59 levels, spontaneous transition probabilities, electron impact ionisation from each level and the invers 3 body recombination coefficients, furthermore radiative and dielectric recombination to each level.

The following levels have been grouped together:
for principal quantum numbers $n \leq 7$ all levels are treated as individual levels, except those with orbital angular momentum $l \geq 3$. These latter levels with the same n are grouped together to form a single level. Thus, since there is a singlet and a triplet system, these are 1 + (2 + 3 + 4 + 4 + 4 + 4)*2 = 43 levels.
For $8 \leq n \leq 10$, all of the S,P,D,... levels are grouped together, ie. adding another (1 + 1 + 1)*2 = 6 levels to the system.
All states with $11 \leq n \leq 20$ are approximated by the hydrogenic levels having statistical weights twice those of hydrogen. This provides the final 10 states for the system of 59 rate equations.
Finally, the levels $21 \leq n \leq 26$ are assumed to be in local thermal equlibrium and are computed from the Saha-Boltzmann relation.

All these collisional-radiative coefficients have been computed over a wide range of electron densities and temperatures, using the cross-sections compiled in ref./10/.

The data have then been fitted to double polynomials of the form:

$$\ln < \sigma v >^{*} = \sum_{j=0}^{8} \sum_{i=0}^{8} b_{i,j} \ln^{i}(T_e) \cdot \ln^{j}(n_e)$$

The fitting coefficients $b_{i,j}$ are given in section 4, for each particular coefficient. n_e is the electron density, in units such that $\tilde{n}_e = n_e \cdot 10^8$ is in units of particles/cm^3. T_e is the electron temperature in eV.
Also included there is information concerning the errors involved, but, to be precise, these absolute and relative errors refer to the data fitting procedure alone, and not to the accuracy of cross-sections or other physical parameters in the model derived by Fujimoto. For a discussion of those the reader is refered to ref./10/.

Note that the format of the fits is identical to that of some of the fits in the data-bases /3/ and /4/, namely to the format used there for rate coefficients (beam - Maxwellian background) for inelastic interaction processes between two heavy particles in a hydrogenic or helium plasma background, e.g. for charge exchange or ion impact ionisation collisions. Such rate coefficients depend on two parameters, the (beam) neutral particle's energy and the (Maxwellian) target plasma ion temperature (loc. cit.).

Here we have chosen exactly the same presentation, but with replacement of the dependence on the beam particle's energy by the plasma (electron) density dependence (this is the origin of the nomenclature used in the tables of fitting coefficients below, in particular of the term E-index, which now should, more suggestively, read n_e-index).

3 The TRIM code surface reflection database

For details concerning the physical assumptions, the format of the database, and the random sampling procedure, which allows one to generate the distribution of reflected particles from the data given here, we refer the reader to the earlier works /5/ and /6/ on the same issue.
Whereas in ref. /5/ the data are based on MARLOWE code calculations, they are obtained using the TRIM Monte Carlo code in ref./6/ and in this report. The TRIM code assumes an amorphous target, while in the earlier MARLOWE code a crystal target structure is retained. In the TRIM code, the "krypton-carbon potential" is used, whereas in MARLOWE usually the "Moliere potential" is employed.
The MARLOWE data (/5/) had been produced on the basis of 20,000 particle histories for each incident energy and angle. The TRIM calculations have been performed with 200,000 cascades for each such incident beam, both in ref./6/ and in this report. Thus the statistical relevance of the more recent TRIM data can be expected to be better, but the trends should be similar as with the MARLOWE code data.

The only difference of this present data compilation to the ones presented in /6/ is the choice of different target-projectile combinations in this report. However, for comparison, we have kept the plots for particle and energy reflection coefficients in section 5 also for the previous data. The complete databases had been set up in refs. /5/ and /6/ for the following target-projectile combinations:

D onto Fe (ref./5/, MARLOWE code, "Histogram quantile estimator")
T onto Fe (dito)
He onto Fe (dito)
H onto Fe and H onto C (ref./6/, TRIM code, "Histogram quantile estimator")
D onto Fe and D onto C (dito)

We have now added the following combinations:

D onto W (this report, TRIM code, "Stone quantile estimator")
T onto Fe and T onto C (dito)
He onto Fe and He onto C and He onto W (dito)

All these databases (including the old ones), are available from the first author, e.g. by electronic mail.

Some of the physical input parameters specified for the TRIM code calculations for these combinations are listed in the table below.

	target density (g/cm³)	displ. energy (eV)	surf. bind. energy (eV)
He → Fe	7.87	30.0	0.0
He → C	2.26	25.0	0.0
T → Fe	7.87	17.0	1.0
T → C	2.26	25.0	1.0
He → W	19.30	35.0	0.0
D → W	19.30	35.0	1.0

Distribution functions for back-scattered particles are available for incident energies of 1, 2, 5, 10, 20, 50, ... 5000 eV, and for incident polar angles of 0, 30, 45, 60, 80 and 85 degrees against the surface normal.

The distribution function for back-scattered particles in velocity space is presented by tables of conditional quantile functions, as explained in /6/ (although not mentioned explicitly there). They comprise a table of 5 numbers for the backscattered energy distribution (corresponding to 5 random numbers 0.1, 0.3, 0.5, 0.7 and 0.9, a table of 25 number for the polar emission angle (5 rows of 5 numbers each, each row corresponding to one energy value sampled from the previously mentioned energy distribution). Finaly there is a block of 125 number for the azimuthal distribution, 5 blocks consisting of 5 rows of 5 numbers each. The choice of a block is made with the same random number as used for the energy, the row number within one block is selected using the second (polar angle) random number, and the column in this row is determined then by a third random number.

Three examples of such tables, for an incident energy of 200 eV and for normal incidence, are shown in section 5, for He onto C, onto Fe and onto W, respectively. The full database for one particular target - projectile combination consists of 84 such tables (12 incident energies and 7 incident polar angles).

Use of these tables has been explained in /5/ and /6/. However, the examples for the one particular triple of random numbers given in refs. /8/ and /6/ are wrong. For the three random numbers $\omega_1 = 0.3$, $\omega_2 = 0.5$ and $\omega_3 = 0.9$ chosen as an example in /6/ and for the incident energy of 200 eV and the incident polar angle of 30 degrees, the energy of the reflected particle should be 91.665 eV (as correctly stated in /6/) but for the polar and azimuthal angles β and Φ one must find $\cos\beta = 0.778114$ and $\cos\Phi = 0.942824$in this case. The same triple of random numbers, for example applied to the table on page 66 (helium onto carbon, 200 ev, normal incidence) would yield: 26.905 eV, $\cos\beta = 0.83113$ and $\cos\Phi = 0.94738$.

The correct interpretation of the data can be checked e.g. using the fact that for the example tables printed in this report, the resulting azimuthal distribution must be isotropic, due to the normal incidence of the particle beam in the particular cases chosen here (and e.g. in the faulty example in ref. /8/, where this would not be the case).

4 Plots and fits of the rate coefficients

This section is taken from a users manual describing an atomic and molecular data file AMEIR (D.Reiter, unpublished) linked to the EIRENE code. The EIRENE neutral gas transport Monte Carlo code automatically reads data from the files described in refs. /3,4/, selected by the user for each run by specifying labelling indices (as described in ref./7/). AMEIR comprises further data, such as collision-radiative models or processes not included in refs. /3,4/ and is set up in an identical format.
In this report we present the multi-step helium ionisation and recombination data contained in the data collection AMEIR. All results in this section are based on the model and data compiled by T.Fujimoto (ref./10/). The resulting multi-step ionisation and recombination data fits have, until now, been distributed to:
Univ. Stuttgart (K.Behringer)
Max Planck Institut Garching (R.Schneider and S.Bosch)
Oak Ridge National Laboratory (J.Hogan)
JET Joint European Torus (E.Deksnis)
Princeton Plasma Physics Laboratory (R.Schneider)
Univ. Düsseldorf (J.Uhlenbusch)

Reaction 2.3.9a

Helium collisional-radiative ionisation rate, ref./10/, formulation II, i.e. metastable levels implicitly included in effective rate coefficents.

$$\frac{d}{dt} n_{He}(1 \mid 1S) = - n_{He}(1 \mid 1S) \bullet n_e \bullet < \sigma v >_{eff} (T_e, n_e) + \text{ other terms}$$

$$\ln < \sigma v >_{eff} (T_e, n_e) = \sum_{i,j=0}^{8} b_{ij} \ln^i(T_e) \ln^j(n_e/10^8)$$

T_e in eV

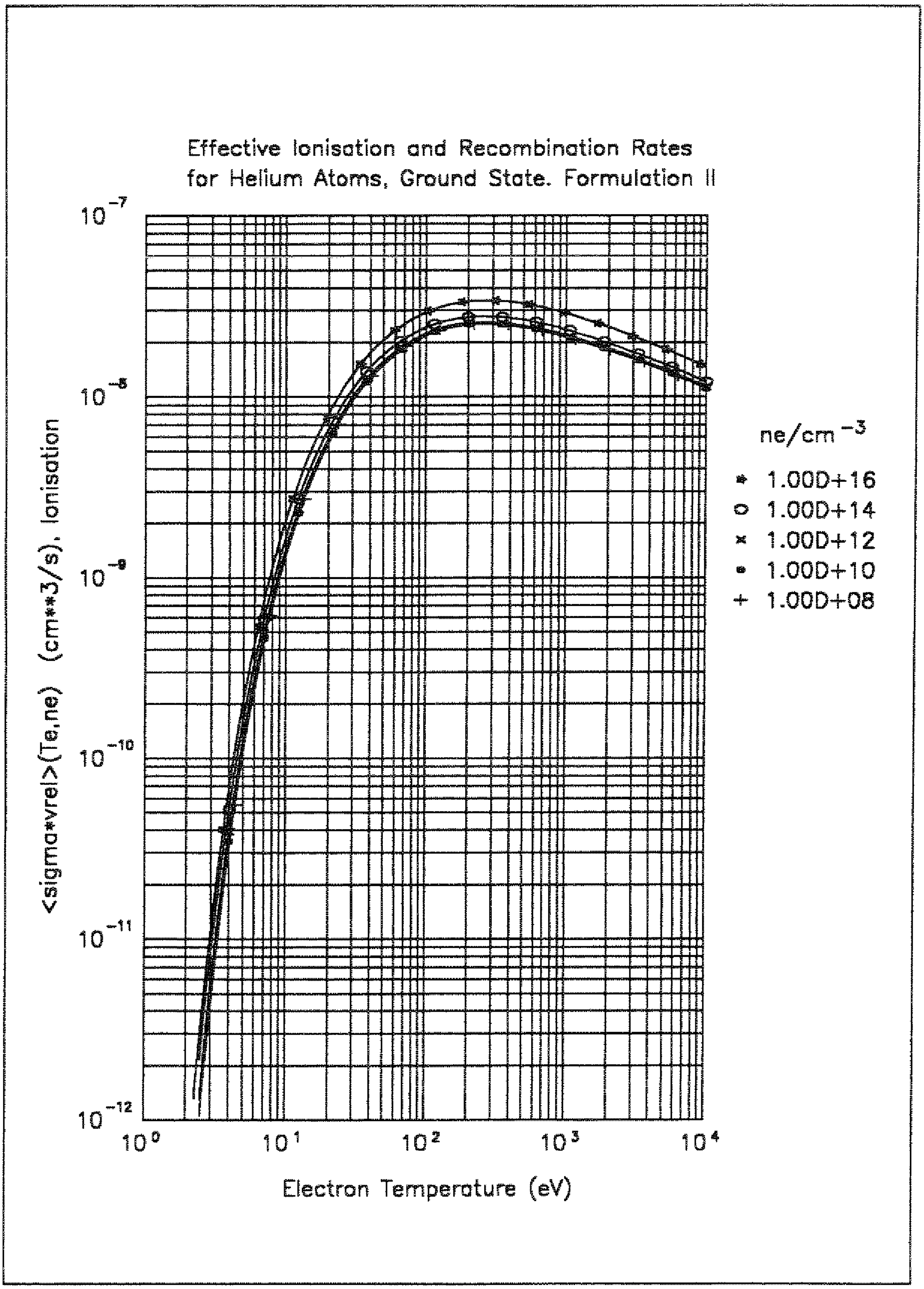
n_e in cm^{-3}

fitted from Fujimotos data in the range

$1 \leq T_e \leq 10^4$

$10^8 \leq n_e \leq 10^{16}$

computed according to formula 12a for S in ref./10/


Effective Ionisation and Recombination Rates
for Helium Atoms, Ground State. Formulation II
<sigma*vrel>(Te,ne) (cm**3/s), Ionisation
Electron Temperature (eV)
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^0
10^1
10^2
10^3
10^4
ne/cm^-3
1.00D+16
1.00D+14
1.00D+12
1.00D+10
1.00D+08

Reaction 2.3.9b

Helium collisional-radiative ionisation rate, ref./10/, formulation I, i.e. ground level (1 | 1S) and metastable levels (2 | 1S) and (2 | 3S) must be accounted for explicitly in separate transport equations.

$$\frac{d}{dt} n_{He}(1 \mid 1S) = -n_{He}(1 \mid 1S) \bullet n_e \bullet < \sigma v >_{eff} (T_e, n_e) + \text{other terms}$$

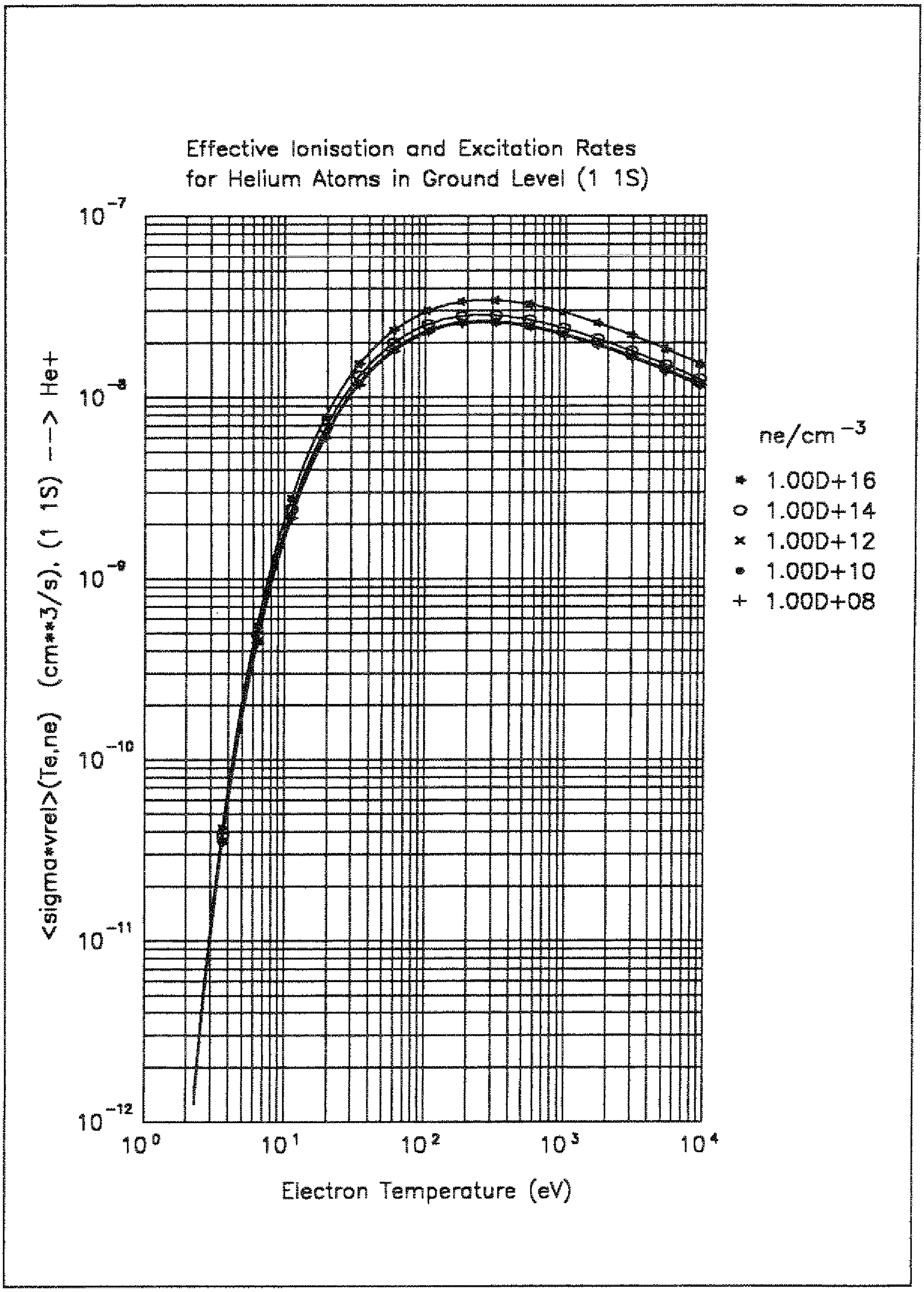
$$\ln < \sigma v >_{eff} (T_e, n_e) = \sum_{i,j=0}^{8} b_{ij} \ln^i(T_e) \ln^j(n_e/10^8)$$

T_e in eV
n_e in cm^{-3}

fitted from Fujimotos data in the range

$1 \leq T_e \leq 10^4$
$10^8 \leq n_e \leq 10^{16}$

computed according to formula 7 for k_1 in ref./10/


Effective Ionisation and Excitation Rates
for Helium Atoms in Ground Level (1 1S)
<sigma*vrel>(Te,ne) (cm**3/s), (1 1S) ---> He+
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^0
10^1
10^2
10^3
10^4
Electron Temperature (eV)
ne/cm^-3
* 1.00D+16
o 1.00D+14
x 1.00D+12
• 1.00D+10
+ 1.00D+08

Reaction 2.3.9c

Helium collisional-radiative ionisation rate, ref./10/, formulation I, i.e. ground level (1 | 1S) and metastable levels (2 | 1S) and (2 | 3S) must be accounted for explicitly in separate transport equations.

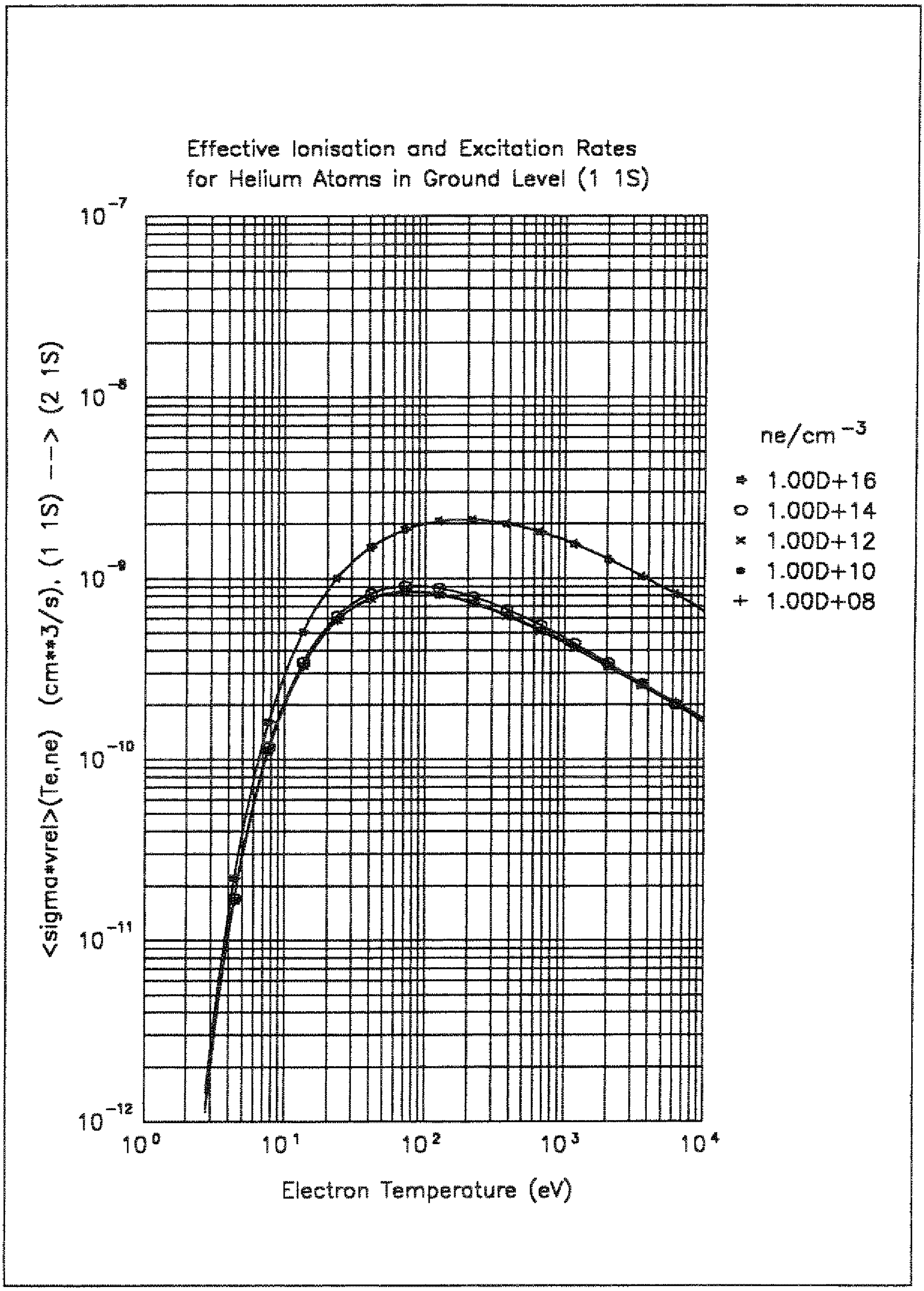
$$\frac{d}{dt}\, n_{He}(2 \mid 1S) = n_{He}(1 \mid 1S) \bullet n_e \bullet < \sigma v >_{eff} (T_e, n_e) + \text{ other terms}$$

$$\ln < \sigma v >_{eff} (T_e, n_e) = \sum_{i,j=0}^{8} b_{ij} \ \ln^i(T_e) \ln^j(n_e/10^8)$$

T_e in eV
n_e in cm^{-3}

fitted from Fujimotos data in the range
$1 \leq T_e \leq 10^4$
$10^8 \leq n_e \leq 10^{16}$

computed according to formula 7 for k_{12} in ref./10/


Effective Ionisation and Excitation Rates
for Helium Atoms in Ground Level (1 1S)
<sigma*vrel>(Te,ne) (cm**3/s), (1 1S) --> (2 1S)
Electron Temperature (eV)
ne/cm-3
1.00D+16
1.00D+14
1.00D+12
1.00D+10
1.00D+08

Reaction 2.3.9d

Helium collisional-radiative ionisation rate, ref./10/, formulation I, i.e. ground level (1 | 1S) and metastable levels (2 | 1S) and (2 | 3S) must be accounted for explicitly in separate transport equations.

$$\frac{d}{dt} n_{He}(2 \mid 3S) = n_{He}(1 \mid 1S) \bullet n_e \bullet < \sigma v >_{eff} (T_e, n_e) + \text{ other terms}$$

$$\ln < \sigma v >_{eff} (T_e, n_e) = \sum_{i,j=0}^{8} b_{ij} \ \ln^i(T_e) \ln^j(n_e/10^8)$$

T_e in eV

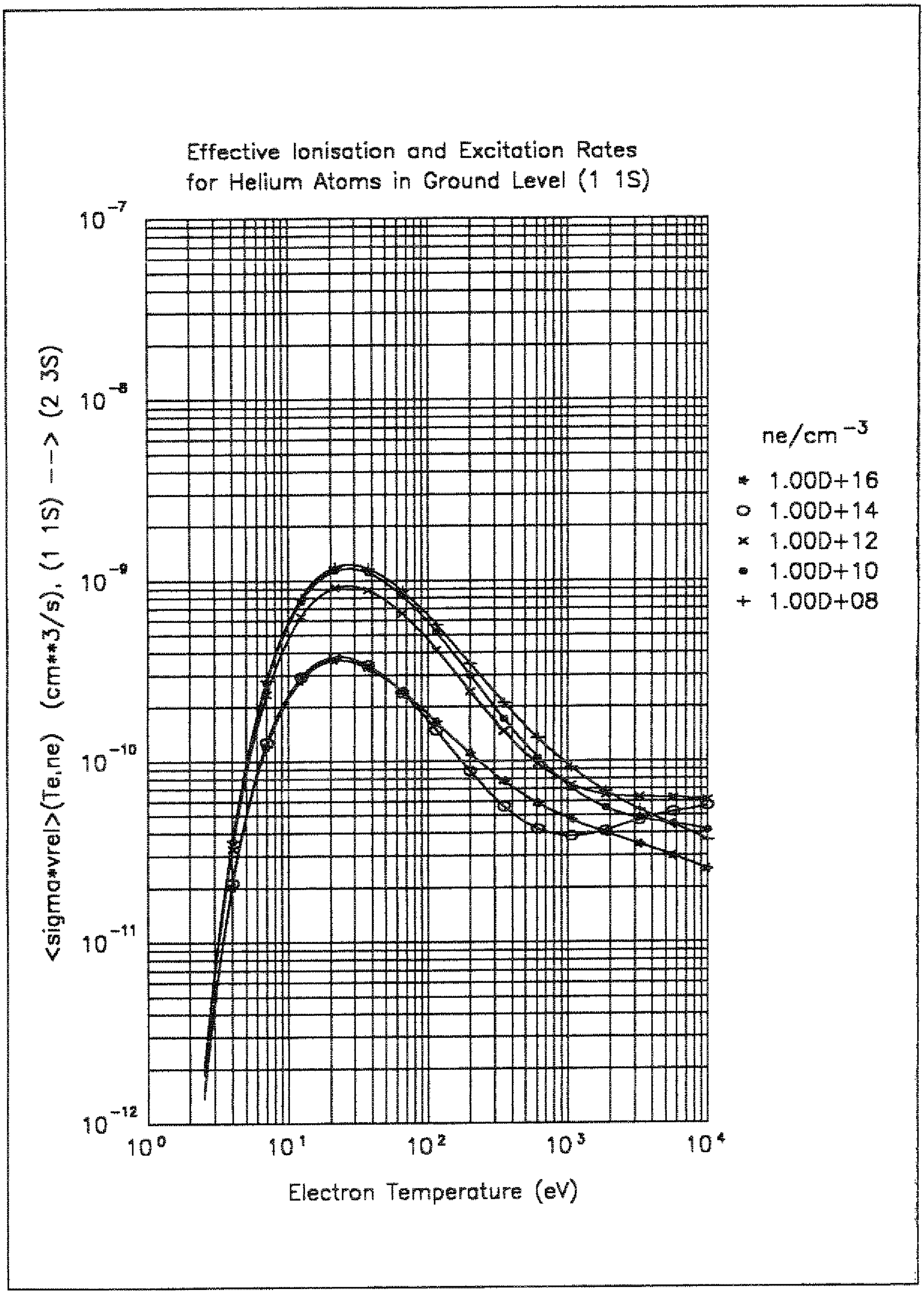
n_e in cm^{-3}

fitted from Fujimotos data in the range

$1 \leq T_e \leq 10^4$

$10^8 \leq n_e \leq 10^{16}$

computed according to formula 7 for k_{13} in ref./10/



Effective Ionisation and Excitation Rates
for Helium Atoms in Ground Level (1 1S)
<sigma*vrel>(Te,ne) (cm**3/s), (1 1S) --> (2 3S)
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^0
10^1
10^2
10^3
10^4
Electron Temperature (eV)
ne/cm^-3
1.00D+16
1.00D+14
1.00D+12
1.00D+10
1.00D+08

Reaction 2.3.9e

Helium collisional-radiative ionisation rate, ref./10/, formulation I, i.e. ground level (1 | 1S) and metastable levels (2 | 1S) and (2 | 3S) must be accounted for explicitly in separate transport equations.

$$\frac{d}{dt} n_{He}(1 \mid 1S) = n_{He}(2 \mid 1S) \bullet n_e \bullet < \sigma v >_{eff} (T_e, n_e) + \text{ other terms}$$

$$\ln < \sigma v >_{eff} (T_e, n_e) = \sum_{i,j=0}^{8} b_{ij} \ln^i(T_e) \ln^j(n_e/10^8)$$

T_e in eV

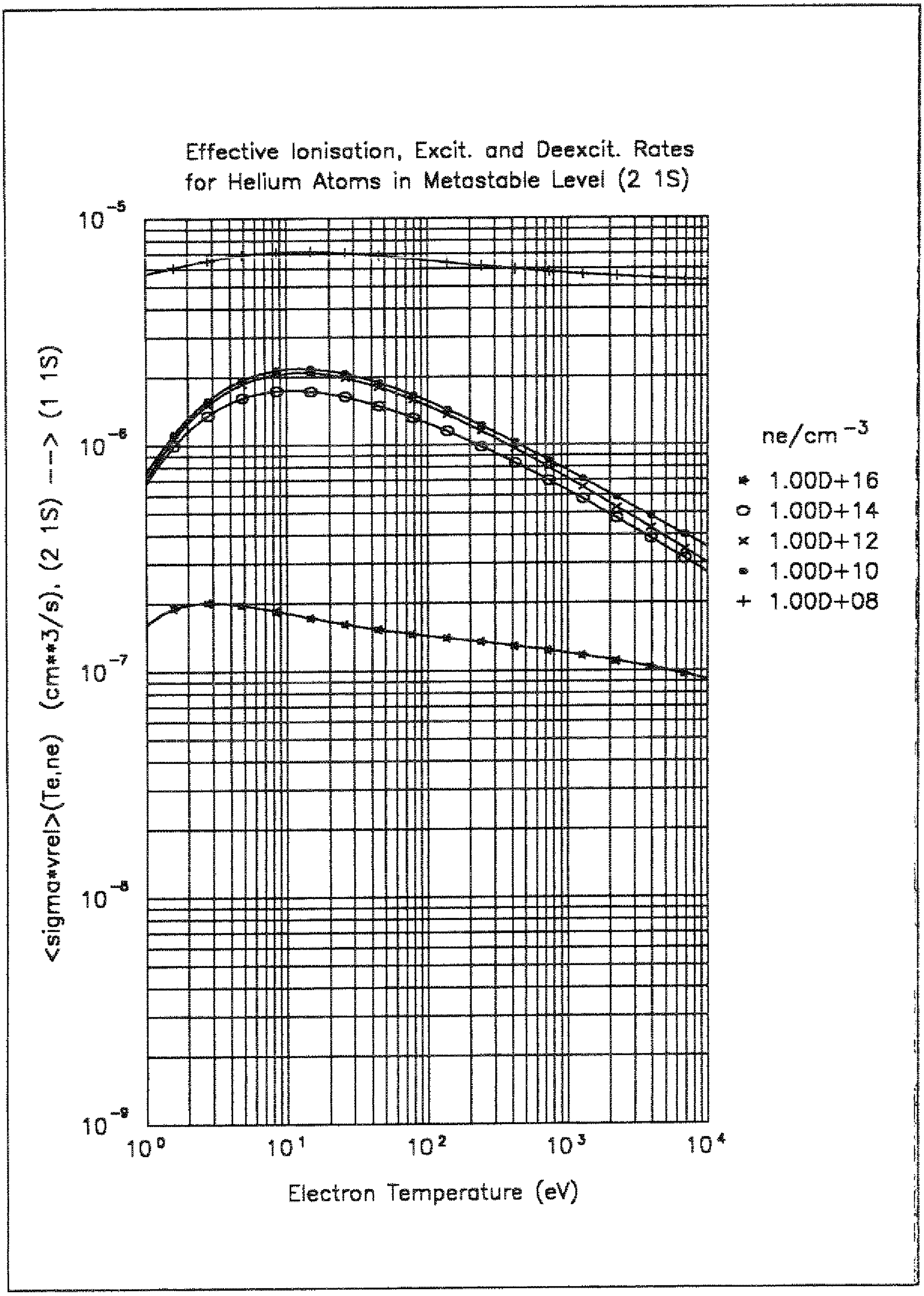
n_e in cm^{-3}

fitted from Fujimotos data in the range

$1 \leq T_e \leq 10^4$

$10^8 \leq n_e \leq 10^{16}$

computed according to formula 7 for k_{21} in ref./10/



Effective Ionisation, Excit. and Deexcit. Rates
for Helium Atoms in Metastable Level (2 1S)
<sigma*vrel>(Te,ne) (cm**3/s), (2 1S) ---> (1 1S)
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁰
10¹
10²
10³
10⁴
Electron Temperature (eV)
ne/cm⁻³
* 1.00D+16
o 1.00D+14
x 1.00D+12
• 1.00D+10
+ 1.00D+08

Reaction 2.3.9f

Helium collisional-radiative ionisation rate, ref./10/, formulation I, i.e. ground level (1 | 1S) and metastable levels (2 | 1S) and (2 | 3S) must be accounted for explicitly in separate transport equations.

$$\frac{d}{dt} n_{He}(2 \mid 1S) = -n_{He}(2 \mid 1S) \bullet n_e \bullet < \sigma v >_{eff} (T_e, n_e) + \text{other terms}$$

$$\ln < \sigma v >_{eff} (T_e, n_e) = \sum_{i,j=0}^{8} b_{ij} \ln^i(T_e) \ln^j(n_e/10^8)$$

T_e in eV

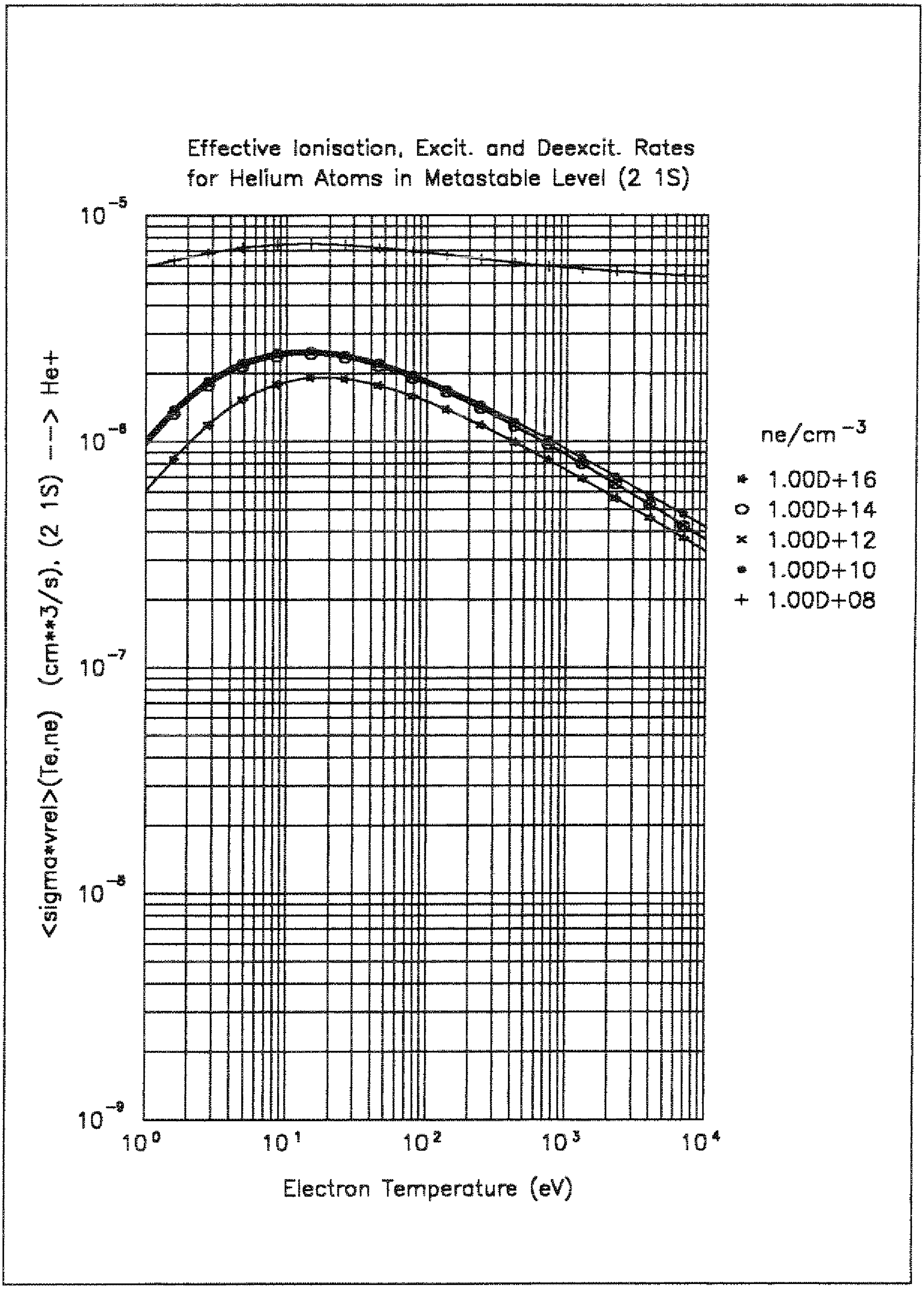
n_e in cm^{-3}

fitted from Fujimotos data in the range

$1 \leq T_e \leq 10^4$

$10^8 \leq n_e \leq 10^{16}$

computed according to formula 7 for k_2 in ref./10/



Effective Ionisation, Excit. and Deexcit. Rates
for Helium Atoms in Metastable Level (2 1S)
<sigma*vrel>(Te,ne) (cm**3/s), (2 1S) ---> He+
Electron Temperature (eV)
ne/cm -3
* 1.00D+16
o 1.00D+14
x 1.00D+12
• 1.00D+10
+ 1.00D+08

Reaction 2.3.9g

Helium collisional-radiative ionisation rate, ref./10/, formulation I, i.e. ground level (1 | 1S) and metastable levels (2 | 1S) and (2 | 3S) must be accounted for explicitly in separate transport equations.

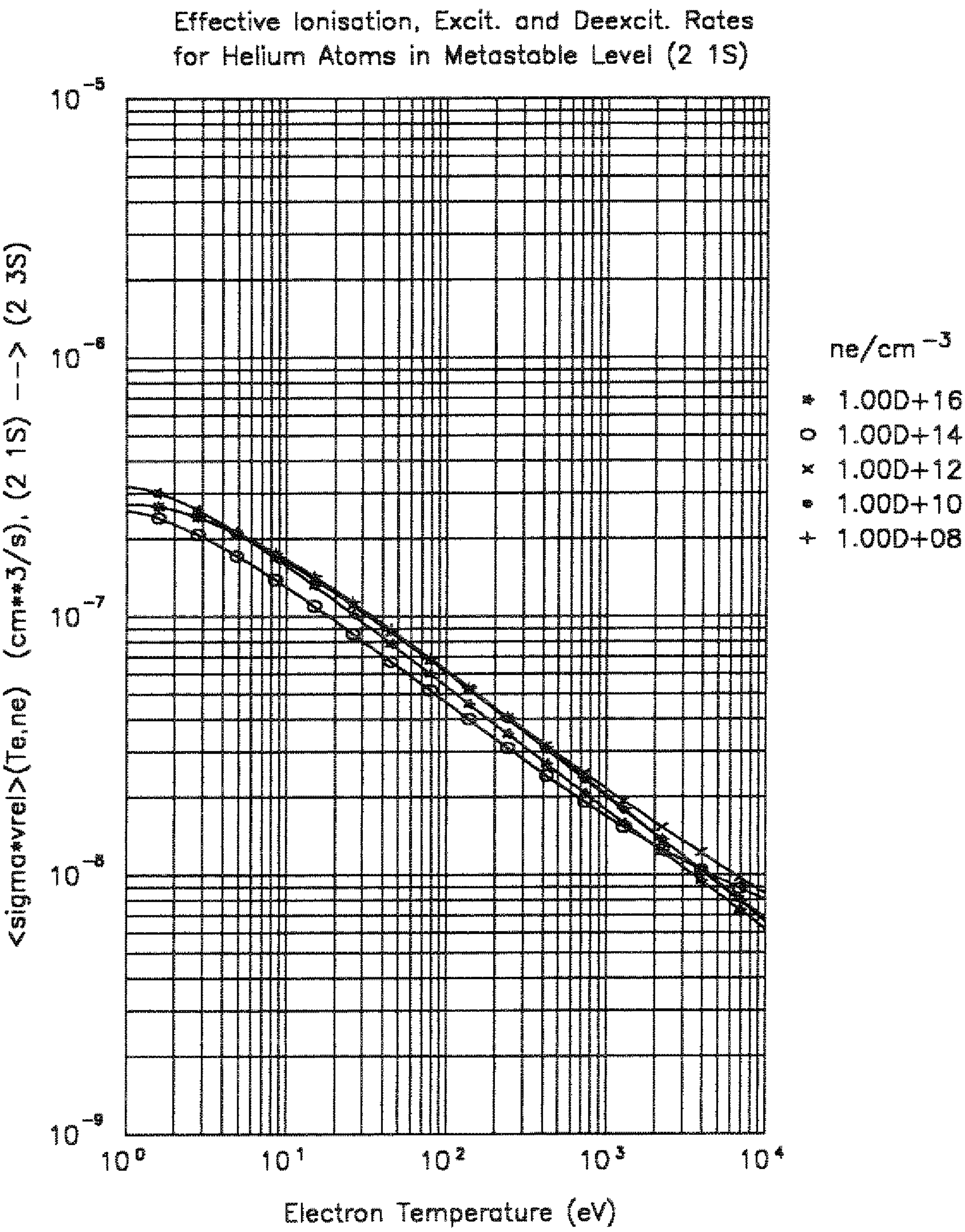
$$\frac{d}{dt} n_{He}(2 \mid 3S) = n_{He}(2 \mid 1S) \bullet n_e \bullet < \sigma v >_{eff} (T_e, n_e) + \text{other terms}$$

$$\ln < \sigma v >_{eff} (T_e, n_e) = \sum_{i,j=0}^{8} b_{ij} \ln^i(T_e) \ln^j(n_e/10^8)$$

T_e in eV
n_e in cm^{-3}

fitted from Fujimotos data in the range
$1 \leq T_e \leq 10^4$
$10^8 \leq n_e \leq 10^{16}$

computed according to formula 7 for k_{23} in ref./10/


Effective Ionisation, Excit. and Deexcit. Rates
for Helium Atoms in Metastable Level (2 1S)
<sigma*vrel>(Te,ne) (cm**3/s), (2 1S) --> (2 3S)
Electron Temperature (eV)
ne/cm^-3
1.00D+16
1.00D+14
1.00D+12
1.00D+10
1.00D+08

Reaction 2.3.9h

Helium collisional-radiative ionisation rate, ref./10/, formulation I, i.e. ground level (1 | 1S) and metastable levels (2 | 1S) and (2 | 3S) must be accounted for explicitly in separate transport equations.

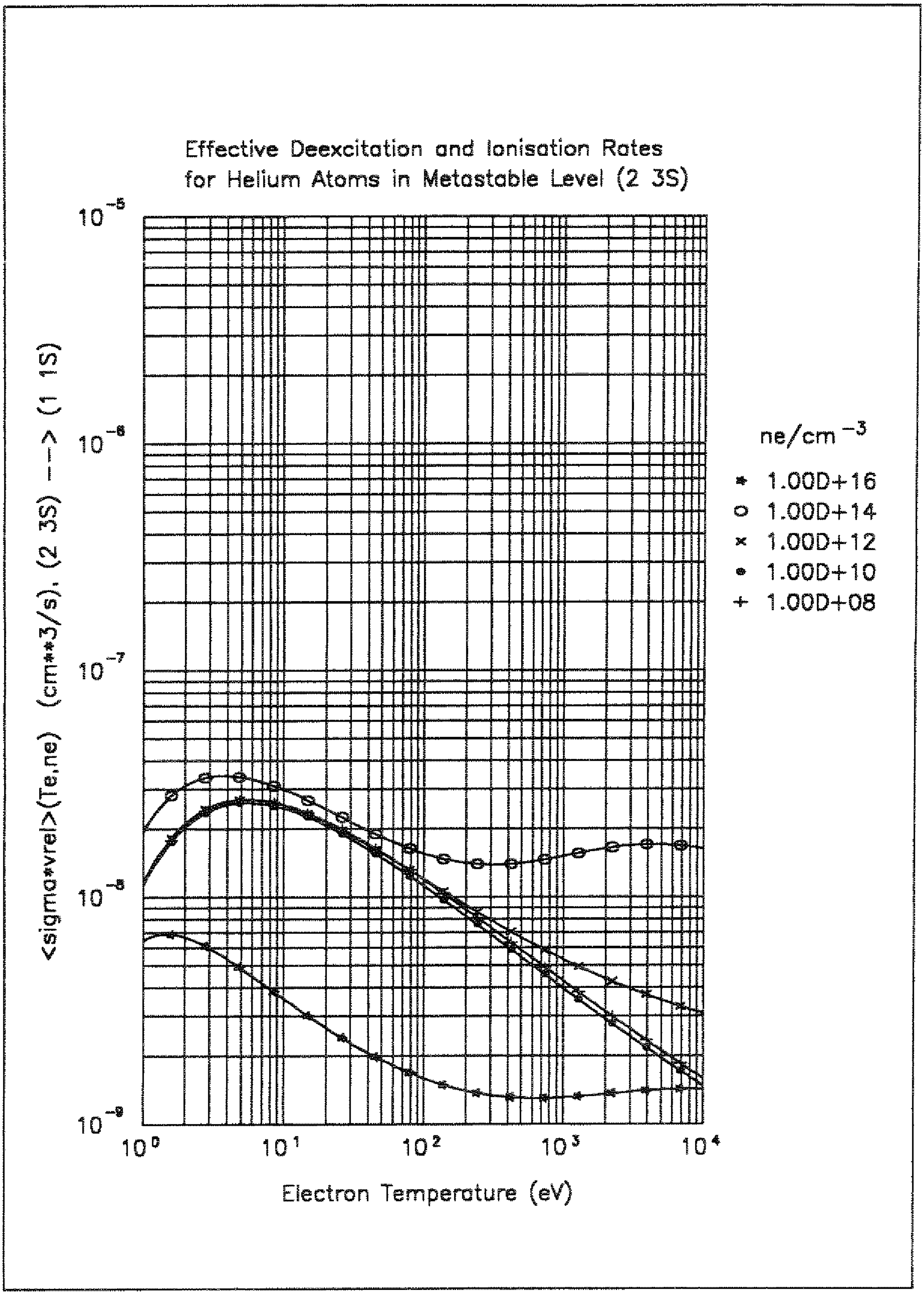
$$\frac{d}{dt} n_{He}(1 \mid 1S) = n_{He}(2 \mid 3S) \bullet n_e \bullet < \sigma v >_{eff} (T_e, n_e) + \text{other terms}$$

$$\ln < \sigma v >_{eff} (T_e, n_e) = \sum_{i,j=0}^{8} b_{ij} \ \ln^i(T_e) \ln^j(n_e/10^8)$$

T_e in eV
n_e in cm^{-3}

fitted from Fujimotos data in the range
$1 \leq T_e \leq 10^4$
$10^8 \leq n_e \leq 10^{16}$

computed according to formula 7 for k_{31} in ref./10/


Effective Deexcitation and Ionisation Rates
for Helium Atoms in Metastable Level (2 3S)
<sigma*vrel>(Te,ne) (cm**3/s), (2 3S) ---> (1 1S)
10^-5
10^-6
10^-7
10^-8
10^-9
10^0
10^1
10^2
10^3
10^4
Electron Temperature (eV)
ne/cm^-3
* 1.00D+16
o 1.00D+14
× 1.00D+12
• 1.00D+10
+ 1.00D+08

Reaction 2.3.9i

Helium collisional-radiative ionisation rate, ref./10/, formulation I, i.e. ground level (1 | 1S) and metastable levels (2 | 3S) and (2 | 1S) must be accounted for explicitly in separate transport equations.

$$\frac{d}{dt} n_{He}(2 \mid 1S) = n_{He}(2 \mid 3S) \bullet n_e \bullet < \sigma v >_{eff} (T_e, n_e) + \text{other terms}$$

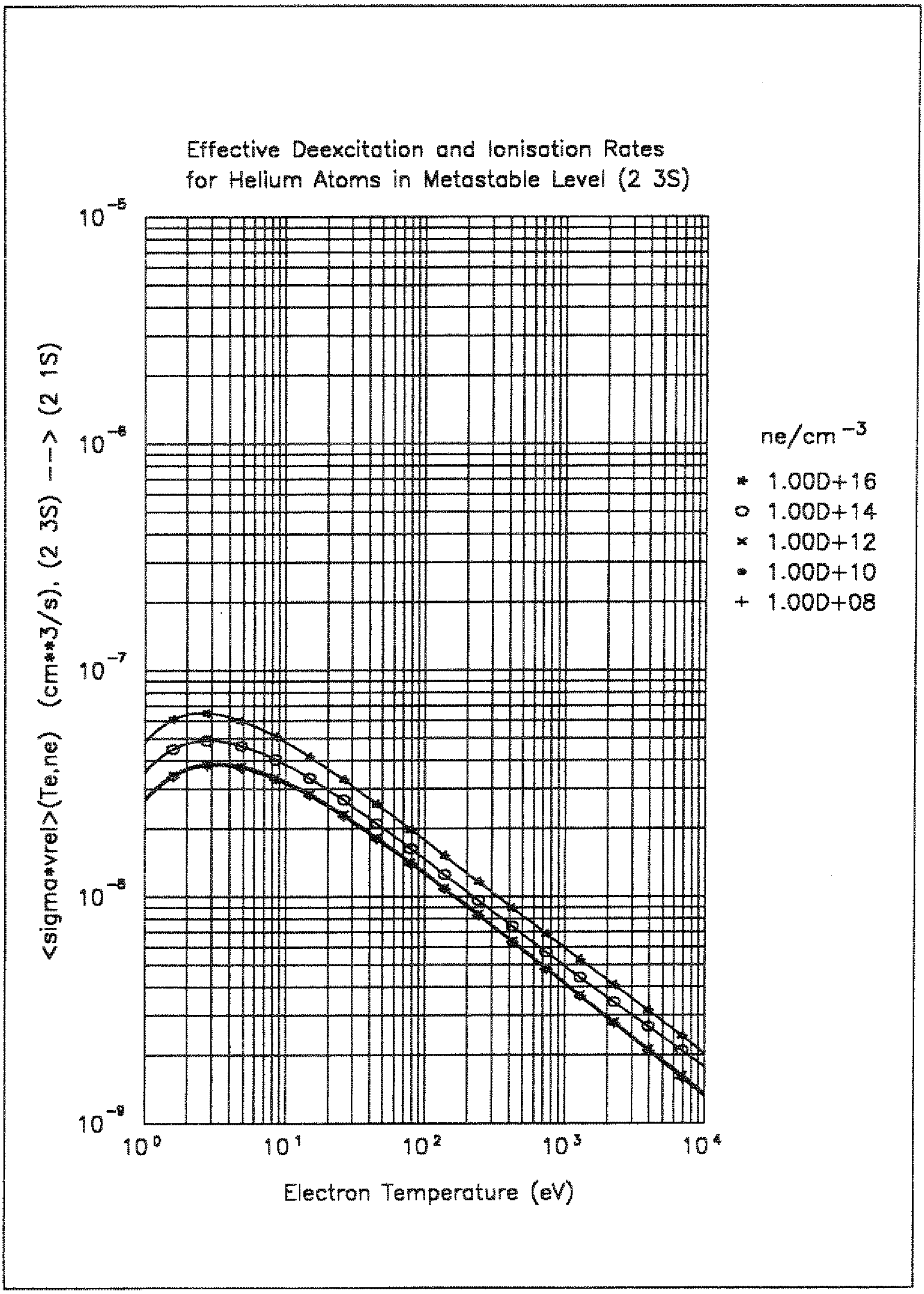
$$\ln < \sigma v >_{eff} (T_e, n_e) = \sum_{i,j=0}^{8} b_{ij} \ln^i(T_e) \ln^j(n_e/10^8)$$

T_e in eV
n_e in cm^{-3}

fitted from Fujimotos data in the range

$1 \leq T_e \leq 10^4$
$10^8 \leq n_e \leq 10^{16}$

computed according to formula 7 for k_{32} in ref./10/



Effective Deexcitation and Ionisation Rates
for Helium Atoms in Metastable Level (2 3S)
<sigma*vrel>(Te,ne) (cm**3/s), (2 3S) ---> (2 1S)
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
Electron Temperature (eV)
ne/cm $^{-3}$
* 1.00D+16
o 1.00D+14
× 1.00D+12
• 1.00D+10
+ 1.00D+08

Reaction 2.3.9j

Helium collisional-radiative ionisation rate ref./10/, formulation I, i.e. ground level (1 | 1S) and metastable levels (2 | 1S) and (2 | 3S) must be accounted for explicitly in separate transport equations.

$$\frac{d}{dt}\, n_{He}(2\,|\,3S) = -\, n_{He}(2\,|\,3S) \bullet n_e \bullet <\sigma v>_{eff}(T_e, n_e) + \text{other terms}$$

$$\ln <\sigma v>_{eff}(T_e, n_e) = \sum_{i,j=0}^{8} b_{ij} \ \ln^i(T_e) \ln^j(n_e/10^8)$$

T_e in eV

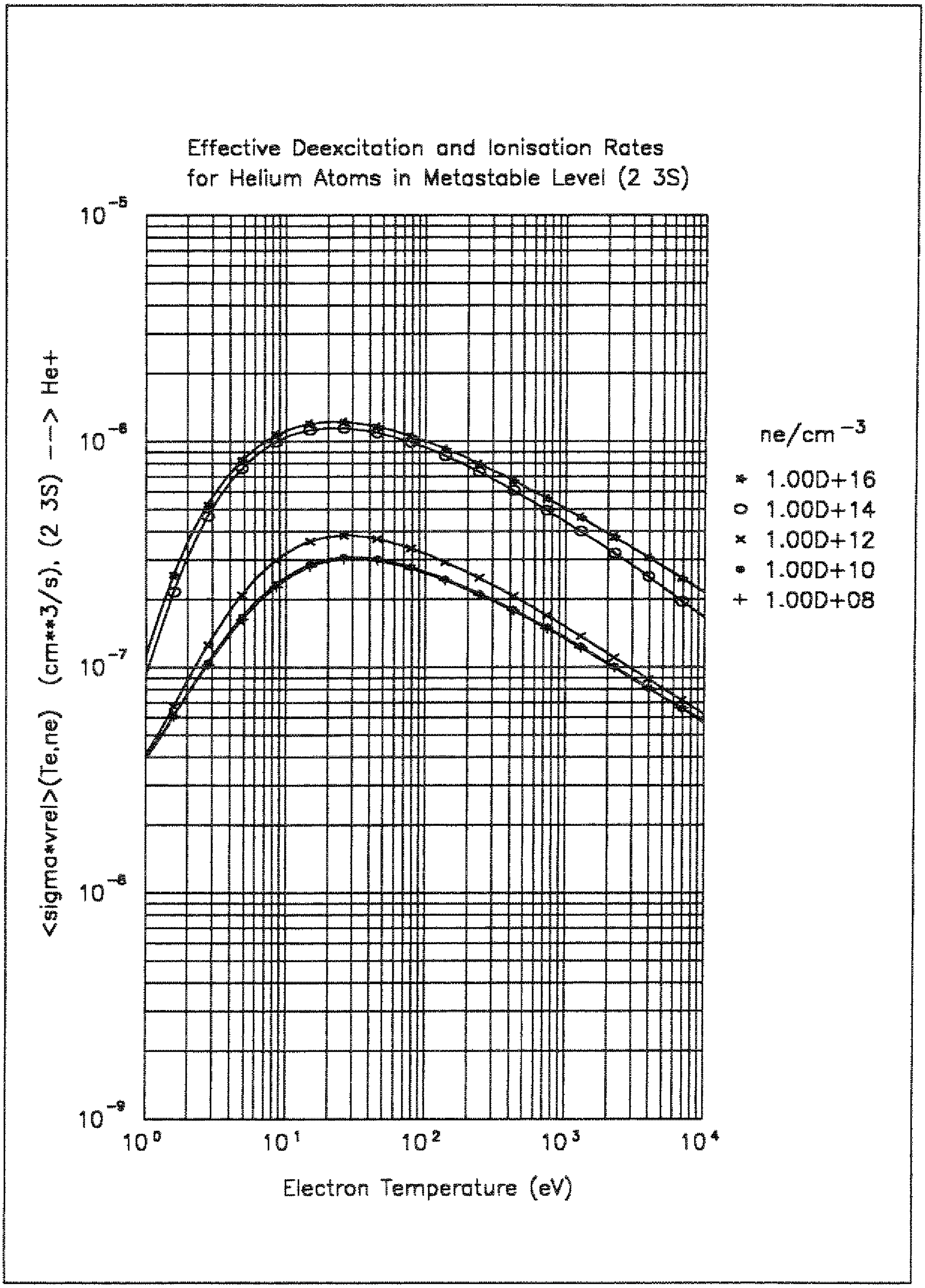
n_e in cm^{-3}

fitted from Fujimotos data in the range

$1 \leq T_e \leq 10^4$

$10^8 \leq n_e \leq 10^{16}$

computed according to formula 7 for k_3 in ref./10/


Effective Deexcitation and Ionisation Rates
for Helium Atoms in Metastable Level (2 3S)
<sigma*vrel>(Te,ne) (cm**3/s), (2 3S) ---> He+
Electron Temperature (eV)
ne/cm^{-3}
1.00D+16
1.00D+14
1.00D+12
1.00D+10
1.00D+08
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}

Reaction 2.3.13a

Helium collisional-radiative recombination rate, ref./10/, formulation II, i.e. metastable levels implicitly included in effective rate coefficents.

$$\frac{d}{dt}\, n_{He}(1 \mid 1S) \;=\; n_{He^+} \bullet n_e \bullet < \sigma v >_{eff} (T_e, n_e) \;+\; \text{other terms}$$

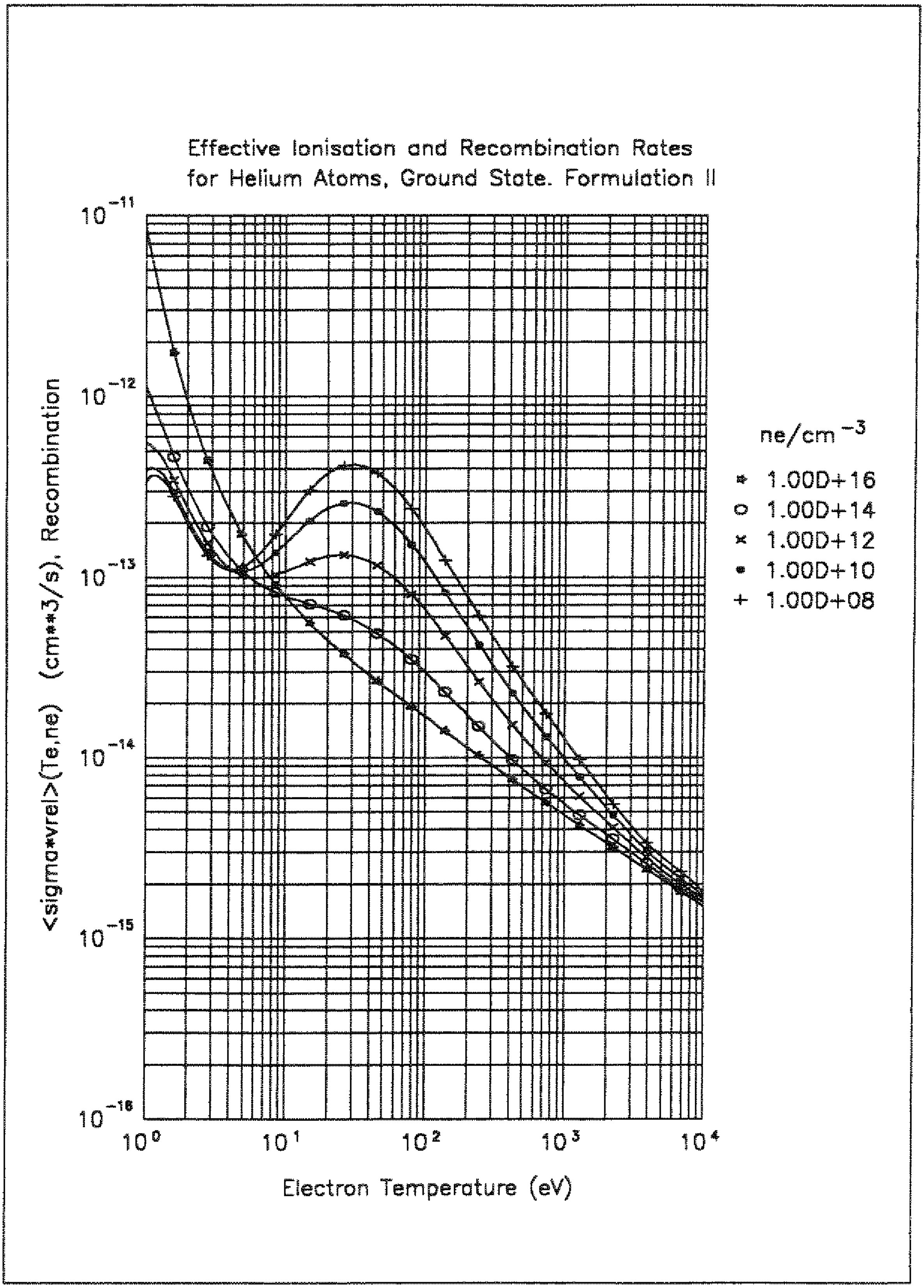
$$\ln < \sigma v >_{eff} (T_e, n_e) \;=\; \sum_{i,j=0}^{8} b_{ij}\; \ln^i(T_e)\, \ln^j(n_e/10^8)$$

T_e in eV
n_e in cm^{-3}

fitted from Fujimotos data in the range

$1 \leq T_e \leq 10^4$
$10^8 \leq n_e \leq 10^{16}$

computed according to formula 12b for α in ref./10/


Effective Ionisation and Recombination Rates
for Helium Atoms, Ground State. Formulation II
<sigma*vrel>(Te,ne)   (cm**3/s), Recombination
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
10^0
10^1
10^2
10^3
10^4
Electron Temperature (eV)
ne/cm^-3
1.00D+16
1.00D+14
1.00D+12
1.00D+10
1.00D+08

Reaction 2.3.13b

Helium collisional-radiative recombination rate, ref./10/, formulation I, i.e. ground level (1 | 1S) and metastable levels (2 | 1S) and (2 | 3S) must be accounted for explicitly in separate transport equations.

$$\frac{d}{dt} n_{He}(1 \mid 1S) = n_{He^+} \bullet n_e \bullet < \sigma v >_{eff} (T_e, n_e) + \text{ other terms}$$

$$\ln < \sigma v >_{eff} (T_e, n_e) = \sum_{i,j=0}^{8} b_{ij} \ \ln^i(T_e) \ln^j(n_e/10^8)$$

T_e in eV

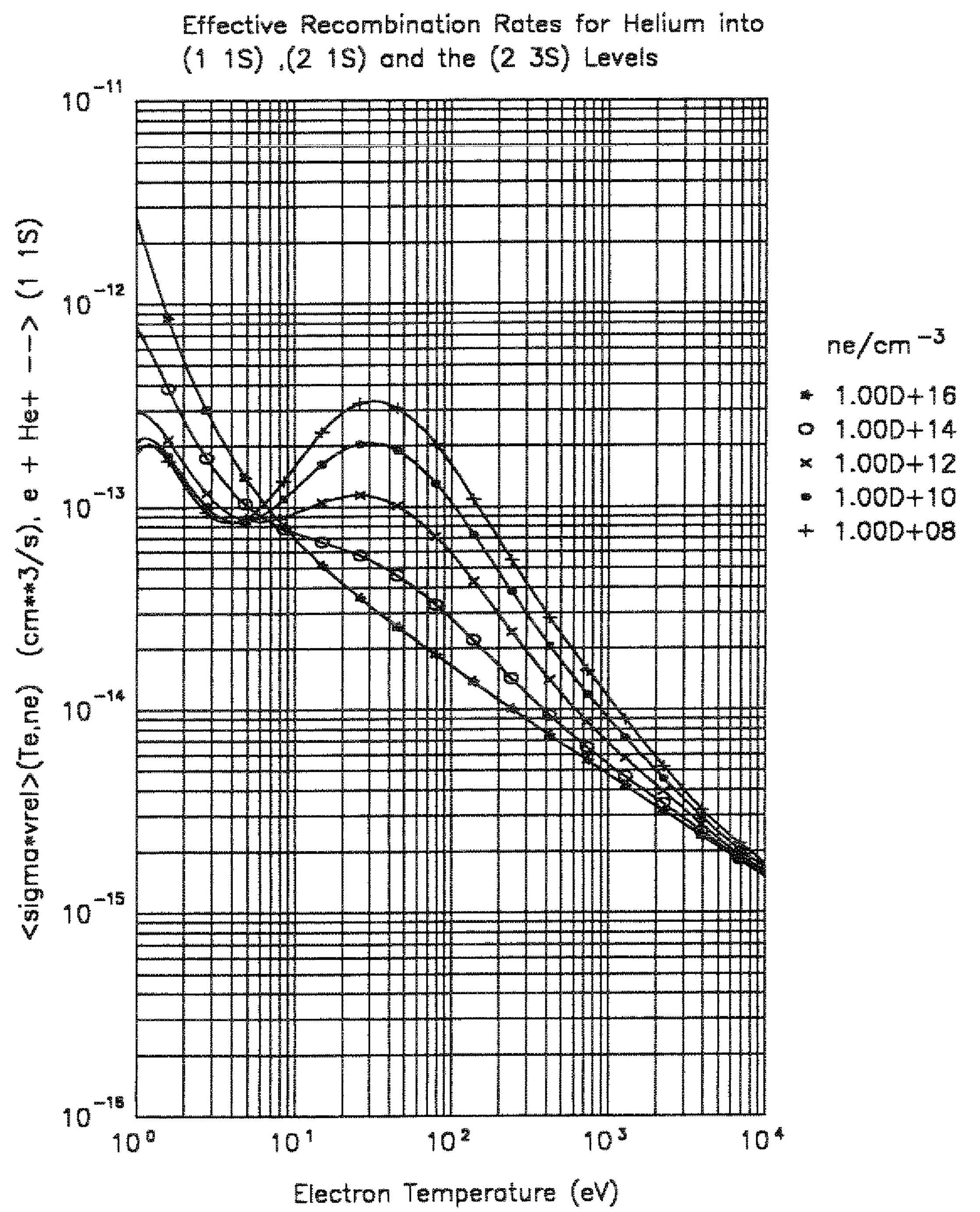
n_e in cm^{-3}

fitted from Fujimotos data in the range

$1 \leq T_e \leq 10^4$

$10^8 \leq n_e \leq 10^{16}$

computed according to formula 7 for k_{01} in ref./10/


Effective Recombination Rates for Helium into
(1 1S) ,(2 1S) and the (2 3S) Levels
<sigma*vrel>(Te,ne) (cm**3/s), e + He+ --> (1 1S)
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁻¹⁵
10⁻¹⁶
10⁰
10¹
10²
10³
10⁴
Electron Temperature (eV)
ne/cm⁻³
* 1.00D+16
o 1.00D+14
x 1.00D+12
• 1.00D+10
+ 1.00D+08

Reaction 2.3.13c

Helium collisional-radiative recombination rate, ref./10/, formulation I, i.e. ground level (1 | 1S) and metastable levels (2 | 1S) and (2 | 3S) must be accounted for explicitly in separate transport equations.

$$\frac{d}{dt} n_{He}(2 \mid 1S) = n_{He^+} \bullet n_e \bullet < \sigma v >_{eff} (T_e, n_e) + \text{ other terms}$$

$$\ln < \sigma v >_{eff} (T_e, n_e) = \sum_{i,j=0}^{8} b_{ij} \ln^i(T_e) \ln^j(n_e/10^8)$$

T_e in eV

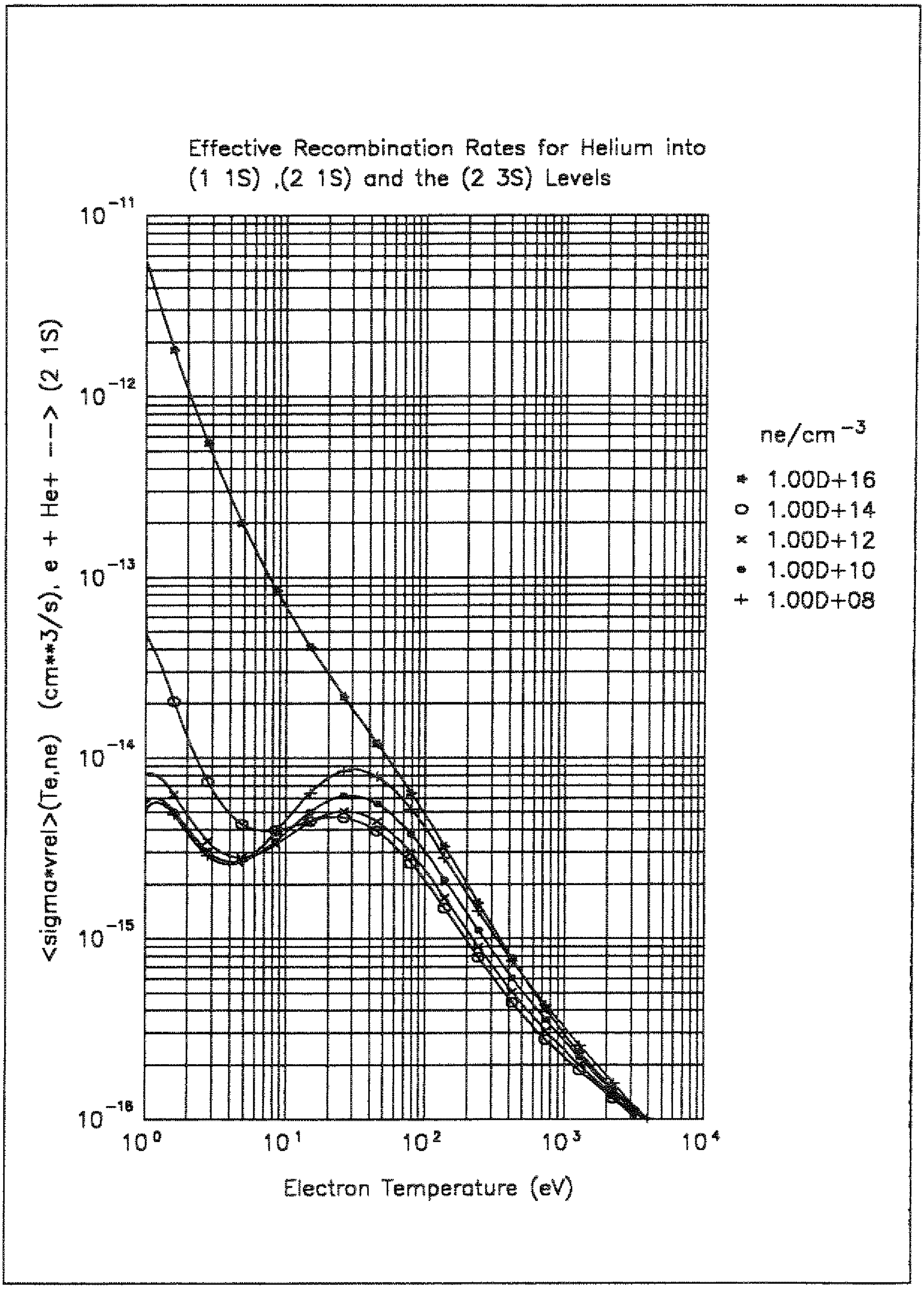
n_e in cm^{-3}

fitted from Fujimotos data in the range

$1 \leq T_e \leq 10^4$

$10^8 \leq n_e \leq 10^{16}$

computed according to formula 7 for k_{02} in ref./10/


Effective Recombination Rates for Helium into
(1 1S) ,(2 1S) and the (2 3S) Levels
<sigma*vrel>(Te,ne) (cm**3/s), e + He+ ---> (2 1S)
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
Electron Temperature (eV)
ne/cm^{-3}
* 1.00D+16
o 1.00D+14
x 1.00D+12
• 1.00D+10
+ 1.00D+08

Reaction 2.3.13d

Helium collisional-radiative recombination rate, ref./10/, formulation I, i.e. ground level (1 | 1S) and metastable levels (2 | 1S) and (2 | 3S) must be accounted for explicitly in separate transport equations.

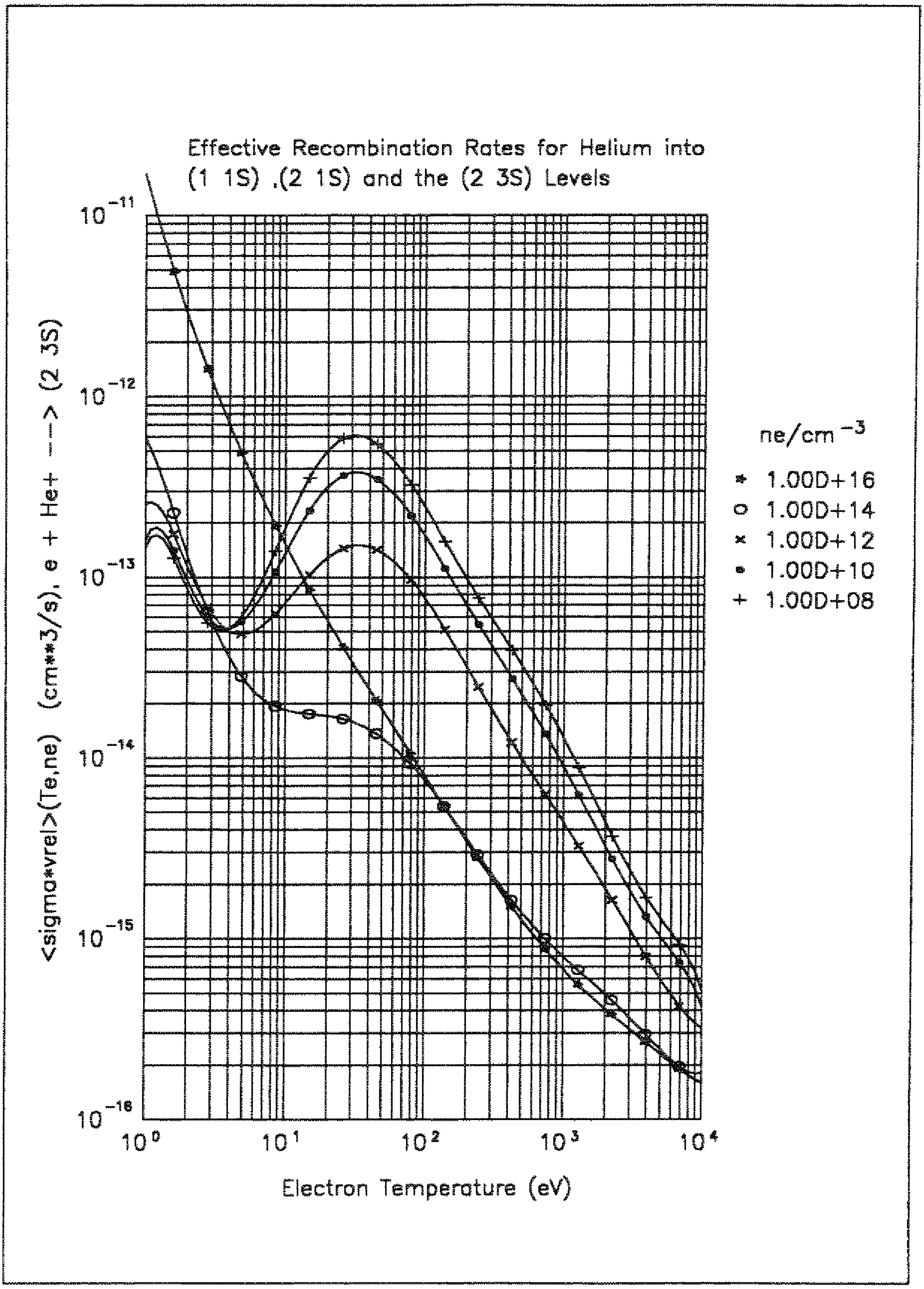
$$\frac{d}{dt} n_{He}(2 \mid 3S) = n_{He^+} \bullet n_e \bullet < \sigma v >_{eff} (T_e, n_e) + \text{ other terms}$$

$$\ln < \sigma v >_{eff} (T_e, n_e) = \sum_{i,j=0}^{8} b_{ij} \ln^i(T_e) \ln^j(n_e/10^8)$$

T_e in eV
n_e in cm^{-3}

fitted from Fujimotos data in the range
$1 \leq T_e \leq 10^4$
$10^8 \leq n_e \leq 10^{16}$

computed according to formula 7 for k_{03} in ref./10/


Effective Recombination Rates for Helium into
(1 1S) ,(2 1S) and the (2 3S) Levels
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
10^0
10^1
10^2
10^3
10^4
Electron Temperature (eV)
<sigma*vrel>(Te,ne) (cm**3/s), e + He+ ---> (2 3S)
ne/cm^-3
1.00D+16
1.00D+14
1.00D+12
1.00D+10
1.00D+08

Reaction 2.3.9a   e + He(1|1S) T e + He+ + e

T-Index \ E-Index:	0	1	2
0	-4.217997777548D+01	5.308536269042D-01	-5.163843759221D-01
1	2.390126229236D+01	-1.442302296011D-01	1.340706380316D-01
2	-1.183992855878D+01	-6.856861237956D-02	6.709472555483D-02
3	3.746697037397D+00	2.974643959266D-02	-3.111630914777D-02
4	-7.761864343928D-01	-2.274921798849D-03	5.844300220507D-03
5	1.034547765269D-01	-1.093457655764D-03	-4.589914103386D-04
6	-8.519306375832D-03	3.535235205836D-04	-6.970371667345D-05
7	3.940560712077D-04	-4.084681400268D-05	1.696603852592D-05
8	-7.830408444828D-06	1.663310015710D-06	-9.005920982810D-07

T-Index \ E-Index:	3	4	5
0	2.249204355960D-01	-4.933605410913D-02	5.888442185200D-03
1	-7.922244520712D-02	1.999797994644D-02	-2.448772168825D-03
2	-8.698993813677D-03	-5.517098220715D-04	9.736680866748D-05
3	5.326819190097D-03	-1.195233864863D-04	1.165198358115D-06
4	-1.053095130748D-03	-1.820875228904D-05	8.021211665253D-06
5	1.684856854619D-04	-1.037566912144D-05	2.568259348736D-07
6	-2.768839885532D-08	4.603341649760D-07	-7.371970231973D-08
7	-3.167271723394D-06	3.866703336741D-07	-2.962644283520D-08
8	2.189887422486D-07	-3.158217019174D-08	2.796286749443D-09

T-Index \ E-Index:	6	7	8
0	-3.845848804577D-04	1.290157551072D-05	-1.738938663602D-07
1	1.506589284939D-04	-4.438433590211D-06	4.886256046456D-08
2	4.398842891057D-06	-7.780926660129D-07	2.114689227402D-08
3	-4.349539318953D-06	3.860667252354D-07	-9.106312305315D-09
4	1.783666353262D-07	-4.749670477829D-08	1.290755321282D-09
5	-6.498995724954D-08	5.259126836712D-09	-1.127903123194D-10
6	7.811237594817D-09	-3.130240133956D-10	3.200841194466D-12
7	1.468494639868D-09	-5.091819124346D-11	9.288123525032D-13
8	-1.546349651813D-10	5.095422137830D-12	-7.640022458018D-14

Max. rel. Error: 0.7827 %
Mean rel. Error: 0.1953 %

P = 1.000E+08,   Err-max = 0.2965
P = 1.000E+10,   Err-max = 0.3947
P = 1.000E+12,   Err-max = 0.7827
P = 1.000E+14,   Err-max = 0.7270
P = 1.000E+16,   Err-max = 0.5267

Reaction 2.3.9b   e + He(1|1S) T e + He+ + e

T-Index \ E-Index:	0	1	2
0	-3.868216800270D+01	-9.805338495836D-03	1.018992805057D-02
1	1.951908329517D+01	2.874645308936D-02	-2.292429982772D-02
2	-9.237751759241D+00	-3.410077731304D-02	1.996672948434D-02
3	2.832316073767D+00	2.176348836222D-02	-9.565021983101D-03
4	-5.734428474501D-01	-7.750954383577D-03	2.663823918982D-03
5	7.481498131493D-02	1.586653961599D-03	-4.426803787425D-04
6	-6.019923854504D-03	-1.853905088040D-04	4.330775989448D-05
7	2.712351398665D-04	1.148878748432D-05	-2.309358145590D-06
8	-5.231172845546D-06	-2.929955418126D-07	5.208195223514D-08

T-Index \ E-Index:	3	4	5
0	-4.128036074381D-03	8.476717658308D-04	-9.613614248908D-05
1	8.266239669020D-03	-1.638557590102D-03	1.853357970573D-04
2	-5.651974184461D-03	9.935349892875D-04	-1.055562472278D-04
3	1.949226022459D-03	-2.753492869743D-04	2.615773524440D-05
4	-3.433939008290D-04	2.857440734441D-05	-2.002367248450D-06
5	2.783807716045D-05	1.202188053796D-06	-1.736683049046D-07
6	-3.959750524385D-07	-4.452889799376D-07	2.177363372184D-08
7	-6.653682603358D-08	2.528382779373D-08	1.280663547662D-09
8	2.451654723868D-09	-2.054658174477D-10	-1.478794916776D-10

T-Index \ E-Index:	6	7	8
0	6.090391104839D-06	-2.017055693776D-07	2.720783199537D-09
1	-1.186348201144D-05	3.989126304292D-07	-5.460795495803D-09
2	6.440307404100D-06	-2.039792976274D-07	2.564068422545D-09
3	-1.438878579504D-06	3.766293473513D-08	-3.096137288656D-10
4	7.101983750743D-08	1.136180319984D-09	-9.214311558113D-11
5	1.177911056379D-08	-8.728206983311D-10	2.569821779029D-11
6	2.653503079459D-10	3.393883388923D-12	-1.223045236175D-12
7	-3.103448536767D-10	1.294750726471D-11	-1.390080204675D-13
8	1.876781391364D-11	-7.876195431393D-13	1.081405428921D-14

Max. rel. Error: 0.4789 %
Mean rel. Error: 0.1276 %

P = 1.000E+08,   Err-max = 0.4521
P = 1.000E+10,   Err-max = 0.4566
P = 1.000E+12,   Err-max = 0.4569
P = 1.000E+14,   Err-max = 0.4762
P = 1.000E+16,   Err-max = 0.4597

Reaction 2.3.9c   e + He(1|1S) T e + He(2|1S)

T-Index \ E-Index:	0	1	2
0	-4.045934106183D+01	1.897748701790D-02	-2.018557671772D-02
1	2.020178553245D+01	-1.604827521421D-02	1.838297235860D-02
2	-9.959758069051D+00	4.936385922325D-04	-6.363462021662D-03
3	3.114010425084D+00	9.231476371297D-03	-4.993073776888D-03
4	-6.581797570145D-01	-3.772270379715D-03	2.143339196071D-03
5	9.259978456780D-02	6.549569060506D-04	-3.018332624476D-04
6	-8.248551199952D-03	-6.398429580978D-05	2.078106783503D-05
7	4.186352139437D-04	4.043306359226D-06	-1.269824404134D-06
8	-9.186648649581D-06	-1.350567572811D-07	6.268985808577D-08

T-Index \ E-Index:	3	4	5
0	8.126937214373D-03	-1.644452798934D-03	1.839756014609D-04
1	-7.443809617021D-03	1.416480678197D-03	-1.412832755892D-04
2	4.200242132318D-03	-1.031796603229D-03	1.261940593216D-04
3	6.518933399831D-04	1.575864400101D-05	-9.492697344398D-06
4	-3.588153289421D-04	2.399712143608D-05	-1.029001778375D-06
5	2.123895295956D-05	3.608884909283D-06	-3.957010271719D-07
6	2.930602478394D-06	-1.268449450975D-06	9.938776178258D-08
7	-1.772758786445D-07	6.542253283235D-08	-2.441433837883D-09
8	-7.480568781185D-09	9.713464809450D-10	-2.790244190175D-10

T-Index \ E-Index:	6	7	8
0	-1.154629989357D-05	3.810164923796D-07	-5.140206740778D-09
1	7.583144415205D-06	-2.066347697234D-07	2.236730413069D-09
2	-8.432456081284D-06	2.989433130580D-07	-4.414325935867D-09
3	8.627961879177D-07	-3.744074960086D-08	6.707183091869D-10
4	6.410297955765D-08	-2.482906874399D-09	2.521072929552D-11
5	-1.789086357767D-09	1.112712155072D-09	-2.710635660661D-11
6	1.072528292601D-10	-2.474738876383D-10	6.489706891150D-12
7	-4.215983455846D-10	3.599785261962D-11	-7.832597058288D-13
8	3.612595105210D-11	-1.911578017747D-12	3.571817781693D-14

Max. rel. Error: 0.5595 %
Mean rel. Error: 0.2120 %

P = 1.000E+08, Err-max = 0.3783
P = 1.000E+10, Err-max = 0.4121
P = 1.000E+12, Err-max = 0.4213
P = 1.000E+14, Err-max = 0.4436
P = 1.000E+16, Err-max = 0.5595

Reaction 2.3.9d e + He(1|1S) T e + He(2|3S)

T-Index \ E-Index:	0	1	2
0	-3.887045587045D+01	1.320693157991D-01	-1.389950792688D-01
1	1.934769221717D+01	-2.663397522050D-01	2.412268070743D-01
2	-9.126303474854D+00	1.110393587351D-01	-1.902661950413D-02
3	2.715842941185D+00	-8.946944967316D-02	5.682165234135D-03
4	-5.649558263963D-01	4.196989442372D-02	-5.248141641461D-03
5	7.868195637176D-02	-9.510261396794D-03	8.491716947007D-04
6	-6.831171492071D-03	1.163264194916D-03	-5.469961679037D-05
7	3.321871125553D-04	-7.737603075484D-05	4.950649352289D-06
8	-6.916350370080D-06	2.225875635061D-06	-3.311205920312D-07

T-Index \ E-Index:	3	4	5
0	5.630452656393D-02	-1.153937428749D-02	1.312801217552D-03
1	-9.455116049141D-02	1.893841211186D-02	-2.088005930167D-03
2	2.053372165053D-03	-2.647092765496D-04	1.566206708250D-05
3	2.223829649496D-03	-4.183979589622D-04	3.544567889853D-05
4	1.051784981559D-04	-3.849164026420D-05	1.083322485290D-05
5	1.356635823502D-04	-2.203481398962D-05	5.910379302138D-07
6	-3.657641719683D-05	5.433804031439D-06	-1.869975935885D-07
7	1.535102028895D-06	-3.223361061477D-08	-4.490318888818D-08
8	5.043235502459D-08	-2.266106853493D-08	4.540876095623D-09

T-Index \ E-Index:	6	7	8
0	-8.397622188808D-05	2.823441604873D-06	-3.877800886269D-08
1	1.281691245688D-04	-4.106246895538D-06	5.353854830965D-08
2	5.976597074615D-07	-9.741685073732D-08	2.640420907301D-09
3	-2.522030643003D-06	1.380749262472D-07	-3.145423155796D-09
4	-5.338646893695D-07	-1.322231044792D-08	9.119513297024D-10
5	-7.319917600855D-08	1.095763675735D-08	-3.536685513513D-10
6	7.735758137915D-09	-1.230202317121D-09	4.362831935856D-11
7	4.244101798295D-09	-1.031053681115D-10	-1.838891947916D-13
8	-3.654216273657D-10	1.219947356760D-11	-1.335219758265D-13

Max. rel. Error: 1.5416 %
Mean rel. Error: 0.5496 %

P = 1.000E+08, Err-max = 0.9268
P = 1.000E+10, Err-max = 1.2753
P = 1.000E+12, Err-max = 1.5416
P = 1.000E+14, Err-max = 1.5365
P = 1.000E+16, Err-max = 0.2034

Reaction 2.3.9e   e + He(2|1S) T e + He(1|1S)

E-Index:	0	1	2
T-Index:			
0	-1.207424672727D+01	-9.994639248939D-01	1.429837802275D-01
1	1.163836430631D-01	2.776514252871D-02	2.018763208501D-01
2	5.669255962960D-02	7.452739655873D-02	-1.125478594445D-01
3	-5.297570717798D-02	-3.941740747595D-02	3.192310600602D-02
4	1.485991336024D-02	4.904897829382D-03	-3.214602936437D-03
5	-2.195960385057D-03	6.248188202923D-04	-4.759139430314D-04
6	1.869889237493D-04	-2.176544687989D-04	1.495047658139D-04
7	-8.748413171936D-06	2.049723696248D-05	-1.370848936448D-05
8	1.754983816834D-07	-6.694445206791D-07	4.424631396107D-07

E-Index:	3	4	5
T-Index:			
0	5.565008759495D-03	-3.940190373146D-03	4.913049997067D-04
1	-7.402071952065D-02	1.223659870603D-02	-1.116926465296D-03
2	3.222240517662D-02	-4.208373161535D-03	2.664678638003D-04
3	-7.944119987385D-03	8.913468684927D-04	-3.410265193659D-05
4	8.946871169908D-04	-1.251071485760D-04	6.487744454150D-06
5	7.242430624465D-05	4.523834386431D-07	-5.248314781573D-07
6	-3.013655820437D-05	2.343771250086D-06	-6.477057246291D-08
7	2.935543595930D-06	-2.778062471938D-07	1.330536218273D-08
8	-9.817948248616D-08	1.026143294413D-08	-6.007706781648D-10

E-Index:	6	7	8
T-Index:			
0	-2.968517684755D-05	9.173744513982D-07	-1.186216922096D-08
1	5.811685159463D-05	-1.617817154792D-06	1.869361935569D-08
2	-6.230439805111D-06	-8.925883775427D-08	4.675608679106D-09
3	-1.531509608405D-06	1.617778263960D-07	-3.557354884034D-09
4	1.525258476657D-07	-2.479845848678D-08	5.961186832680D-10
5	1.023683043496D-08	1.323524123113D-09	-4.446972167897D-11
6	6.061074460715D-10	-6.429452967638D-11	2.370140204161D-12
7	-4.035416242774D-10	1.127215729116D-11	-1.991967037261D-13
8	2.346954503200D-11	-6.635933965469D-13	9.727886292274D-15

Max. rel. Error: 0.1171 %
Mean rel. Error: 0.0261 %

P = 1.000E+08,   Err-max = 0.1067
P = 1.000E+10,   Err-max = 0.0904
P = 1.000E+12,   Err-max = 0.0928
P = 1.000E+14,   Err-max = 0.1098
P = 1.000E+16,   Err-max = 0.0641

Reaction 2.3.9f e + He(2|1S) T e + He+ + e

T-Index	E-Index: 0	1	2
0	-1.202741972924D+01	-9.920958704112D-01	2.083851177308D-01
1	1.158628327919D-01	1.183164058464D-01	7.206462010314D-02
2	3.989415757835D-02	1.682271876089D-02	-3.745675105724D-02
3	-3.432838025282D-02	-2.581406098103D-02	1.157399266293D-02
4	6.989474750355D-03	7.158667514435D-03	-2.578453090364D-03
5	-5.166283800973D-04	-1.011889738021D-03	3.715555743353D-04
6	-8.581628432270D-06	7.427999576700D-05	-2.682971542421D-05
7	3.156588398285D-06	-1.891647873905D-06	1.867231354869D-07
8	-1.217087648166D-07	-2.648797940556D-08	4.676925061589D-08

T-Index	E-Index: 3	4	5
0	-1.896460727903D-02	2.494406432018D-04	9.056015624054D-05
1	-3.192009139768D-02	5.627551527403D-03	-5.488795672076D-04
2	9.537878511914D-03	-1.097349562953D-03	6.934816319253D-05
3	-1.357239370719D-03	-5.334178827141D-05	2.335939650806D-05
4	3.216930136825D-04	-2.878075950746D-06	-2.681077679108D-06
5	-7.007491811239D-05	7.548046383090D-06	-5.085723633572D-07
6	6.076731387298D-06	-7.622803270229D-07	5.170683445447D-08
7	4.495006430686D-08	-3.108517827283D-08	5.961737786705D-09
8	-1.893751278414D-08	4.352113527464D-09	-5.680957590846D-10

T-Index	E-Index: 6	7	8
0	-7.341754903377D-06	2.286441582484D-07	-2.616593463127D-09
1	3.128356640531D-05	-9.801802478296D-07	1.303662342433D-08
2	-2.657384142377D-06	6.366064054308D-08	-7.474947571659D-10
3	-1.949969529203D-06	7.157331249974D-08	-1.040701423464D-09
4	2.472178617519D-07	-9.704502513665D-09	1.590102350721D-10
5	2.107367554795D-08	-3.649201514278D-10	-1.963724537786D-12
6	-1.606790119708D-09	-5.524601070496D-12	1.141848849941D-12
7	-5.259446965106D-10	2.273028241962D-11	-3.932425436990D-13
8	4.105293255809D-11	-1.540566297887D-12	2.355148085757D-14

Max. rel. Error: 0.0981 %
Mean rel. Error: 0.0210 %

P = 1.000E+08, Err-max = 0.0796
P = 1.000E+10, Err-max = 0.0686
P = 1.000E+12, Err-max = 0.0850
P = 1.000E+14, Err-max = 0.0480
P = 1.000E+16, Err-max = 0.0487

Reaction 2.3.9g e + He(2|1S) T e + He(2|3S)

T-Index \ E-Index	0	1	2
0	-1.511448746198D+01	7.531890904535D-02	-8.456399819203D-02
1	1.070969389454D-02	-6.062478554254D-02	6.874103935543D-02
2	-1.395461591699D-01	2.635286259824D-03	-7.036122920828D-03
3	2.359638321232D-02	-2.657667176845D-03	2.385933368832D-03
4	-3.142792726605D-03	2.630709926327D-03	-1.178159030423D-03
5	4.142948865832D-04	-8.809577686607D-04	2.902302538549D-04
6	-4.664485317036D-05	1.636294024362D-04	-6.334426647840D-05
7	3.198619021089D-06	-1.489865595361D-05	6.969883363416D-06
8	-9.210534486066D-08	5.052050348793D-07	-2.634983416661D-07

T-Index \ E-Index	3	4	5
0	3.607444969385D-02	-7.781388002831D-03	9.322888906762D-04
1	-2.689744763925D-02	4.926113953913D-03	-4.653197168352D-04
2	2.179083661270D-03	-1.767017126588D-05	-6.157257347008D-05
3	-5.577476974525D-04	-1.275353360967D-05	1.608284415353D-05
4	1.620197365696D-04	-1.083865193294D-06	-6.606722574035D-07
5	1.326447203889D-07	-8.829417070073D-06	8.755989519740D-07
6	5.408654475545D-06	3.408674881752D-07	-1.308182363778D-08
7	-1.185588689804D-06	1.264938670224D-07	-1.635278412832D-08
8	5.586727779480D-08	-7.835167394489D-09	9.499823812554D-10

T-Index \ E-Index	6	7	8
0	-6.274151754506D-05	2.211957635565D-06	-3.168537919889D-08
1	2.268442769216D-05	-5.138707719867D-07	3.708293773713D-09
2	8.127814220725D-06	-4.039575123512D-07	7.122582514900D-09
3	-1.784315125421D-06	7.776171411468D-08	-1.215339657978D-09
4	-4.568378562096D-08	7.464244861341D-09	-2.065294632996D-10
5	-4.154160628408D-09	-2.355134345715D-09	7.060833386493D-11
6	-7.678444932462D-09	6.538113952770D-10	-1.490366531592D-11
7	1.706033175906D-09	-8.782303548590D-11	1.659449706462D-12
8	-8.087144213439D-11	3.646748870809D-12	-6.388330667751D-14

Max. rel. Error: 0.2564 %
Mean rel. Error: 0.0438 %

P = 1.000E+08, Err-max = 0.0359
P = 1.000E+10, Err-max = 0.0655
P = 1.000E+12, Err-max = 0.2564
P = 1.000E+14, Err-max = 0.1417
P = 1.000E+16, Err-max = 0.0911

Reaction 2.3.9h e + He(2|3S) T e + He(1|1S)

T-Index \ E-Index:	0	1	2
0	-1.828030576392D+01	6.433818828786D-02	-7.758306566276D-02
1	1.156310348191D+00	5.121810596974D-02	-1.857415421411D-02
2	-5.011218555982D-01	-7.782750526554D-02	2.505399654721D-03
3	6.695452624604D-02	8.510208598474D-02	-2.946382648843D-02
4	3.407177022782D-03	-3.248956012406D-02	1.160067496520D-02
5	-2.695290239110D-03	6.216953653412D-03	-1.905801137986D-03
6	4.155088902340D-04	-6.087292712653D-04	1.087495375701D-04
7	-2.893943877939D-05	2.597583206102D-05	4.799508472029D-06
8	7.869605930906D-07	-2.626120201773D-07	-5.227352569820D-07

T-Index \ E-Index:	3	4	5
0	2.925420787733D-02	-5.009957809565D-03	4.117062711576D-04
1	6.793500637976D-03	-2.339030051553D-03	4.209865018948D-04
2	9.337798585020D-03	-2.391857648400D-03	2.604628848663D-04
3	3.010233024141D-03	2.867677906795D-05	-3.099973245667D-05
4	-1.445379275028D-03	7.883283990752D-05	-3.545660069518D-07
5	1.764320509600D-04	-1.032222101838D-05	1.380370413270D-06
6	1.274244332981D-05	-2.527809560138D-06	-7.435614649216D-08
7	-4.585387999800D-06	7.238087533625D-07	-3.638679181237D-08
8	2.571206291023D-07	-4.189232810777D-08	2.991557498656D-09

T-Index \ E-Index:	6	7	8
0	-1.395725558912D-05	2.391903225558D-08	5.538611494891D-09
1	-3.718037428874D-05	1.563013215133D-06	-2.517301761932D-08
2	-1.516443382061D-05	4.746055519269D-07	-6.337647726099D-09
3	3.318711269217D-06	-1.684731786109D-07	3.304517033736D-09
4	-4.685571189862D-07	4.045289843261D-08	-1.017369763840D-09
5	-8.611285754029D-08	5.378854611142D-11	7.731806986192D-11
6	2.314524715113D-08	-9.495199222319D-10	9.171678010026D-12
7	-1.751387100970D-10	5.588984505646D-11	-9.762800515610D-13
8	-9.157822128575D-11	7.258982651300D-13	8.148833848929D-15

Max. rel. Error: 0.5138 %
Mean rel. Error: 0.1116 %

P = 1.000E+08, Err-max = 0.1198
P = 1.000E+10, Err-max = 0.2034
P = 1.000E+12, Err-max = 0.4686
P = 1.000E+14, Err-max = 0.3503
P = 1.000E+16, Err-max = 0.0901

Reaction 2.3.9i   e + He(2|3S) T e + He(2|1S)

E-Index:	0	1	2
T-Index:			
0	-1.744598847882D+01	-1.720302176607D-02	2.229780833121D-02
1	7.317132528135D-01	1.599943300178D-01	-1.889891428397D-01
2	-4.815656678592D-01	-9.399466605934D-03	3.033316260334D-02
3	1.284746216145D-01	-2.356165638651D-02	1.306742586676D-02
4	-2.525585319524D-02	7.696802401640D-03	-4.129163532088D-03
5	3.556217870120D-03	-1.085606386640D-03	3.410885750382D-04
6	-3.305955246108D-04	9.908097401109D-05	-9.464037595364D-06
7	1.781252774813D-05	-7.435807656553D-06	1.775770262402D-06
8	-4.164467227076D-07	3.000214626857D-07	-1.554044504076D-07

E-Index:	3	4	5
T-Index:			
0	-1.125920749352D-02	2.894091789735D-03	-4.108050736757D-04
1	8.440836898223D-02	-1.888564591534D-02	2.318423586451D-03
2	-1.895410388385D-02	5.021758526704D-03	-6.737553318652D-04
3	-2.186544273533D-03	3.557911182485D-06	3.273360441799D-05
4	8.455840523042D-04	-8.063763979720D-05	4.378700616716D-06
5	-8.416314946482D-06	-7.685621738978D-06	8.405976654964D-07
6	-8.291124408627D-06	2.005012342528D-06	-1.374986977562D-07
7	-8.368477366919D-08	3.307024597323D-08	-1.338637152225D-08
8	4.834260851866D-08	-1.093743271037D-08	1.567320267437D-09

E-Index:	6	7	8
T-Index:			
0	3.225187402546D-05	-1.293813248731D-06	2.058283547037D-08
1	-1.579961918513D-04	5.593989478657D-06	-8.012778221595D-08
2	4.800073613091D-05	-1.732879345729D-06	2.495119943897D-08
3	-3.337985122124D-06	1.330737043089D-07	-1.920066873770D-09
4	-2.186754332833D-07	1.034506155719D-08	-2.224364848370D-10
5	-1.139397118112D-08	-1.720999937475D-09	5.622937513560D-11
6	-9.285680330303D-10	4.087362153532D-10	-1.087263058672D-11
7	1.687025214434D-09	-8.659173099247D-11	1.588604131435D-12
8	-1.260626482077D-10	5.136346980720D-12	-8.232634921993D-14

Max. rel. Error: 0.2065 %
Mean rel. Error: 0.0362 %

P = 1.000E+08,   Err-max = 0.0429
P = 1.000E+10,   Err-max = 0.0847
P = 1.000E+12,   Err-max = 0.0889
P = 1.000E+14,   Err-max = 0.1900
P = 1.000E+16,   Err-max = 0.1099

Reaction 2.3.9j   e + He(2|3S) T e + He + + e

T-Index \ E-Index:	0	1	2
0	-1.704924041544D+01	-1.266316103695D-01	1.433449004291D-01
1	8.685982121684D-01	1.260487614425D+00	-1.322191350637D+00
2	1.850943855695D-01	-7.646641175203D-01	7.305566429011D-01
3	-1.250502139825D-01	2.974864530179D-01	-2.485562205285D-01
4	7.084740479405D-03	-7.514417977585D-02	5.238518561474D-02
5	4.623288484133D-03	1.283135333880D-02	-7.288566622195D-03
6	-1.021819251963D-03	-1.549600599854D-03	8.090570536783D-04
7	8.350946387174D-05	1.169455427644D-04	-6.579336838766D-05
8	-2.487258471895D-06	-3.875212326003D-06	2.448484319988D-06

T-Index \ E-Index:	3	4	5
0	-6.620256680502D-02	1.591865497661D-02	-2.138652914428D-03
1	5.314009025388D-01	-1.083908671711D-01	1.225064409296D-02
2	-2.626937437958D-01	4.810409373038D-02	-4.877671356316D-03
3	7.590588281033D-02	-1.187591210543D-02	1.026240986577D-03
4	-1.236409212893D-02	1.453999356331D-03	-9.263734939861D-05
5	1.120316703087D-03	-4.701420030433D-05	-2.345587448080D-06
6	-1.044360397565D-04	2.576327904650D-06	2.984937469210D-08
7	1.183327773107D-05	-1.304161779171D-06	1.501346239692D-07
8	-5.807805142323D-07	8.940137114526D-08	-1.049433252219D-08

T-Index \ E-Index:	6	7	8
0	1.603068297141D-04	-6.200471476734D-06	9.586808742395D-08
1	-7.739313086389D-04	2.555715396676D-05	-3.435073538242D-07
2	2.759881653893D-04	-8.156336120594D-06	9.815775708103D-08
3	-4.904223397647D-05	1.209618564822D-06	-1.200317236575D-08
4	3.372947621275D-06	-7.818983418767D-08	1.090351742981D-09
5	1.202526920573D-07	8.236631810429D-09	-3.780930043029D-10
6	4.756851601509D-08	-4.674347156739D-09	1.172200668053D-10
7	-1.459459608788D-08	7.523213023632D-10	-1.458930131881D-11
8	8.295694541734D-10	-3.578861641969D-11	6.173469408897D-13

Max. rel. Error: 1.4571 %
Mean rel. Error: 0.2971 %

P = 1.000E+08,   Err-max = 0.8346
P = 1.000E+10,   Err-max = 1.4571
P = 1.000E+12,   Err-max = 1.3178
P = 1.000E+14,   Err-max = 0.7926
P = 1.000E+16,   Err-max = 0.2980

Reaction 2.3.13a e + He+(1s) T He(1S) + hn

E-Index:	0	1	2
T-Index:			
0	-2.871983344245D+01	-9.914131034370D-02	1.084243975141D-01
1	1.362129666751D+00	2.738297541831D-02	-3.524151102144D-02
2	-5.790390660356D+00	3.172178715881D-02	9.095572872849D-02
3	5.162039454979D+00	-9.617954586845D-02	-6.866258801766D-02
4	-2.013633096160D+00	6.218605169131D-02	1.738102798689D-02
5	4.128641032784D-01	-1.748752518305D-02	-1.489847587575D-03
6	-4.676477974032D-02	2.417776012543D-03	5.481280403141D-06
7	2.778979909772D-03	-1.599754429937D-04	9.227390184513D-07
8	-6.779276041243D-05	4.001368464975D-06	2.211004859498D-07

E-Index:	3	4	5
T-Index:			
0	-3.523991395855D-02	5.628945235626D-03	-4.530138064810D-04
1	-1.827058558362D-02	8.985569569740D-03	-1.520051737561D-03
2	-4.185502630748D-03	-3.658764067573D-03	7.932486325355D-04
3	1.307834384986D-02	-9.270266183559D-04	-2.998990511798D-05
4	-3.758769311356D-03	4.501944391337D-04	-2.767755199217D-05
5	2.283701292675D-04	-2.164815607608D-05	5.696315103986D-07
6	1.958530370608D-05	-4.500334405522D-06	5.980256286680D-07
7	-1.028775844416D-06	2.042740225574D-07	-3.063616637462D-08
8	-7.693775181811D-08	1.454031124718D-08	-1.201079264759D-09

E-Index:	6	7	8
T-Index:			
0	1.715437114625D-05	-1.918314963260D-07	-2.330152088030D-09
1	1.220371641647D-04	-4.725637327483D-06	7.110879708760D-08
2	-6.606710369871D-05	2.487923231744D-06	-3.535357380982D-08
3	6.356304448582D-06	-2.400779919531D-07	2.467534801122D-09
4	1.221237893224D-06	-5.304233209262D-08	1.192626498964D-09
5	-2.002897590266D-08	4.209692339178D-09	-1.489729888394D-10
6	-3.920678176108D-08	1.044853502930D-09	-6.983684188387D-12
7	2.467688274686D-09	-8.753939337119D-11	1.081530126869D-12
8	4.211655052209D-11	-4.918839768958D-13	-1.374276392718D-15

Max. rel. Error: 15.0091 %
Mean rel. Error: 3.2387 %

P = 1.000E+08,   Err-max = 15.0091
P = 1.000E+10,   Err-max = 13.9342
P = 1.000E+12,   Err-max = 9.9548
P = 1.000E+14,   Err-max = 6.1937
P = 1.000E+16,   Err-max = 0.7118

Reaction 2.3.13b e + He+(1s) T He(1|1S) + hn

T-Index \ E-Index:	0	1	2
0	-2.932450239883D+01	-1.725214936087D-02	4.209507397331D-02
1	1.368459463821D+00	-7.548584212824D-02	-3.321889449021D-02
2	-5.057940093488D+00	2.531332526084D-01	-1.925988688740D-02
3	4.437755591817D+00	-2.369773678428D-01	2.411850401784D-02
4	-1.704236205062D+00	9.630485149239D-02	-6.971157814419D-03
5	3.430644471030D-01	-2.061167258227D-02	7.487855629993D-04
6	-3.809452269361D-02	2.434745940239D-03	-1.722706965522D-06
7	2.218026788496D-03	-1.502211895379D-04	-5.165559630643D-06
8	-5.301589276464D-05	3.780661493099D-06	2.647213620732D-07

T-Index \ E-Index:	3	4	5
0	-1.843883199649D-02	4.330069861940D-03	-5.571398183907D-04
1	2.246769961570D-02	-6.920109284335D-03	1.034704067336D-03
2	-1.562041938975D-03	2.844891620769D-03	-5.840417169956D-04
3	-6.245247150004D-03	1.707788608782D-04	8.828047075521D-05
4	2.150122229030D-03	-1.997306644340D-04	2.987453868437D-06
5	-2.352870835454D-04	2.321396939441D-05	-1.669051074965D-06
6	-1.929788529702D-06	1.001774243168D-06	7.435769683477D-08
7	1.999043007214D-06	-3.211502011021D-07	8.114609805127D-09
8	-9.897241177277D-08	1.504658532546D-08	-5.883462440247D-10

T-Index \ E-Index:	6	7	8
0	4.006413547865D-05	-1.488766590351D-06	2.211904689519D-08
1	-8.066726007499D-05	3.137222500010D-06	-4.796687278784D-08
2	5.166332348737D-05	-2.133727041895D-06	3.362146796114D-08
3	-1.099721749926D-05	5.014979395019D-07	-8.105197770220D-09
4	4.904814231191D-07	-2.358575243153D-08	2.498171028400D-10
5	1.745034668357D-07	-1.128396994326D-08	2.586295673609D-10
6	-3.342032519922D-08	2.451263340785D-09	-5.477602284810D-11
7	2.414625764231D-09	-2.022906627308D-10	4.590099192405D-12
8	-6.465233005227D-11	6.181507714121D-12	-1.430061439345D-13

Max. rel. Error: 15.0191 %
Mean rel. Error: 3.1731 %

P = 1.000E+08, Err-max = 15.0191
P = 1.000E+10, Err-max = 13.2500
P = 1.000E+12, Err-max = 9.1496
P = 1.000E+14, Err-max = 5.9654
P = 1.000E+16, Err-max = 0.4782

Reaction 2.3.13c e + He+(1s) T He(2|1S) + hn

T-Index \ E-Index:	0	1	2
0	-3.290594969157D+01	5.936377204270D-01	-5.786568026984D-01
1	1.289118555318D+00	-7.322821510173D-01	5.216313908016D-01
2	-4.581116130605D+00	4.359234826400D-01	-1.879684009591D-01
3	3.975023080430D+00	-1.135607337249D-01	-2.093787195291D-02
4	-1.511744296191D+00	9.273954721890D-03	3.091151170807D-02
5	3.006694544045D-01	-7.098672020828D-04	-6.524345786670D-03
6	-3.291282273842D-02	4.674323034046D-04	3.252758528411D-04
7	1.885862263038D-03	-7.894912660673D-05	3.023350709086D-05
8	-4.430501809351D-05	3.801909601518D-06	-2.522313594898D-06

T-Index \ E-Index:	3	4	5
0	2.219812747147D-01	-4.301992587218D-02	4.645717376756D-03
1	-1.469524854136D-01	1.758178948996D-02	-6.553480315101D-04
2	4.156489474989D-02	-1.653580474529D-03	-5.740235177360D-04
3	4.449510483711D-03	-7.099391762833D-04	1.140482945563D-04
4	-6.447934562370D-03	5.521339815402D-04	-1.215385049113D-05
5	1.190208632381D-03	-8.535844740287D-05	1.100343069640D-06
6	7.662178711899D-06	-1.003394753061D-05	9.133676744341D-07
7	-1.693836511335D-05	2.998300023499D-06	-2.134268520285D-07
8	1.008933043477D-06	-1.637662372864D-07	1.194860574397D-08

T-Index \ E-Index:	6	7	8
0	-2.827549938027D-04	9.098967864743D-06	-1.204212130817D-07
1	-3.911503234413D-05	3.838699392781D-06	-8.432388008514D-08
2	8.252435318894D-05	-4.174329959264D-06	7.461274593602D-08
3	-1.015903498277D-05	4.067368927608D-07	-5.956193776494D-09
4	-1.743597814483D-06	1.504881645494D-07	-3.516856295239D-09
5	3.283228084253D-07	-2.777357769656D-08	6.855090395029D-10
6	-3.246510016651D-08	1.021166636920D-09	-2.826061022812D-11
7	5.448904749550D-09	1.026064555133D-11	-1.372295711583D-12
8	-3.572199625876D-10	1.353028569150D-12	7.810473188768D-14

Max. rel. Error: 12.8697 %
Mean rel. Error: 4.3370 %

P = 1.000E+08, Err-max = 12.8697
P = 1.000E+10, Err-max = 11.9497
P = 1.000E+12, Err-max = 11.0229
P = 1.000E+14, Err-max = 9.4995
P = 1.000E+16, Err-max = 3.0136

Reaction 2.3.13d e + He+(1s) T He(2|3S) + hn

T-Index \ E-Index:	0	1	2
0	-2.956247006586D+01	4.857379877013D-01	-4.698385090723D-01
1	2.226655583858D+00	-5.008925977592D-01	4.409072277517D-01
2	-8.386271074322D+00	-6.680555751755D-02	1.358293373473D-01
3	7.802551872732D+00	1.513454163302D-01	-2.382523353494D-01
4	-3.176066118073D+00	-2.915513853670D-02	8.389442053277D-02
5	6.790403187679D-01	-8.583336134054D-03	-8.339355078342D-03
6	-8.005018693268D-02	3.501616009283D-03	-8.108811483383D-04
7	4.936833057738D-03	-4.038202701566D-04	1.917972012272D-04
8	-1.245931475232D-04	1.550754095349D-05	-8.944775549284D-06

T-Index \ E-Index:	3	4	5
0	1.816491812551D-01	-3.584007722558D-02	4.008582628581D-03
1	-1.490076771833D-01	2.428208422290D-02	-2.197248681202D-03
2	-4.192264845130D-02	6.681287810863D-03	-3.474715517406D-04
3	7.034251548002D-02	-9.653541471324D-03	3.950052472624D-04
4	-2.594911934917D-02	3.785834072023D-03	-1.721024156646D-04
5	3.100772841149D-03	-5.641898835295D-04	3.146400786804D-05
6	1.226453809803D-04	9.772361084934D-06	-1.220791337288D-06
7	-4.737671071626D-05	4.334084847132D-06	-1.862385782715D-07
8	2.364380548912D-06	-2.583267263336D-07	1.313403535033D-08

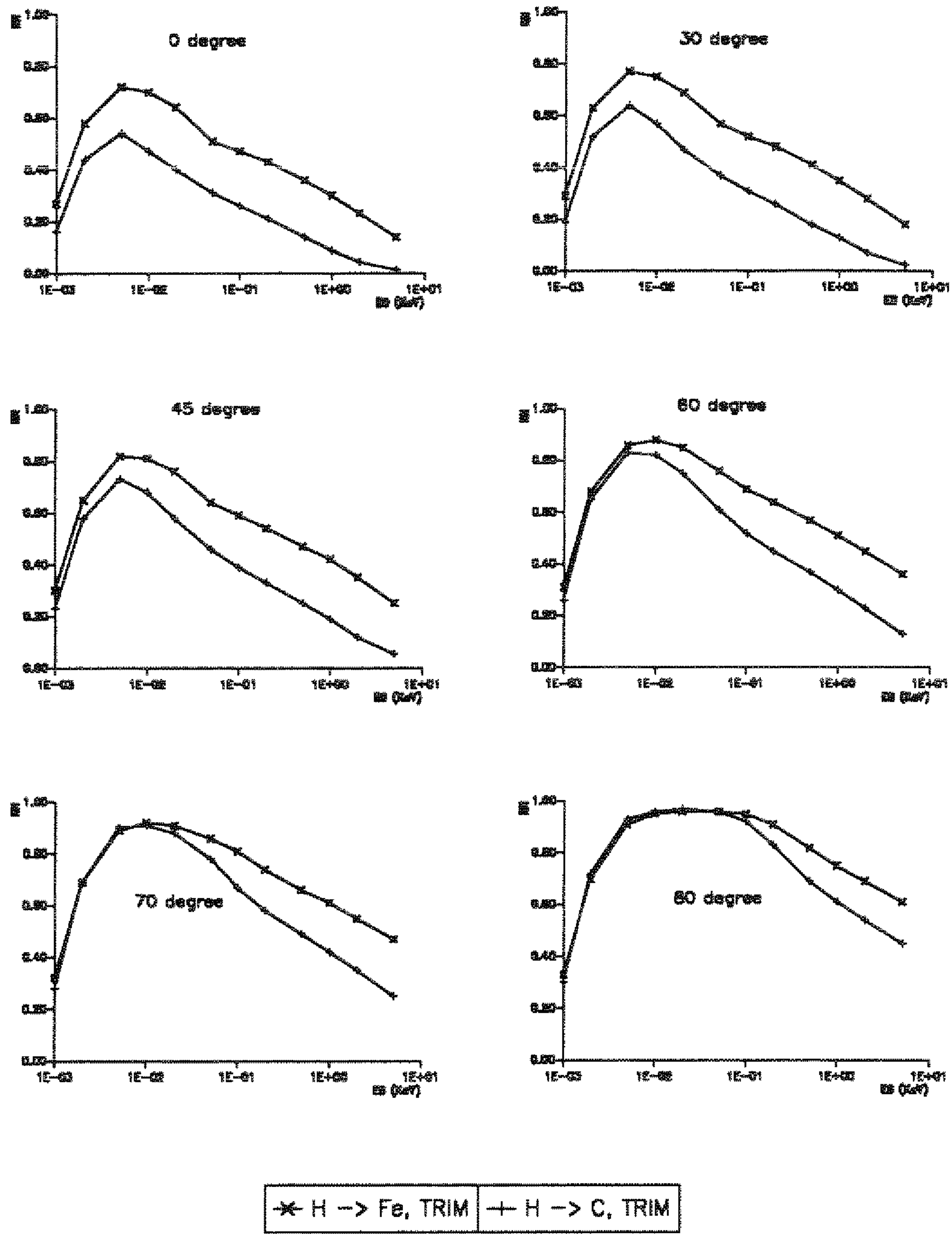
T-Index \ E-Index:	6	7	8
0	-2.562289391561D-04	8.707904177549D-06	-1.215806872260D-07
1	1.109906018249D-04	-2.900632901582D-06	3.027934182965D-08
2	-1.076950834118D-05	1.529234802310D-06	-3.663757563702D-08
3	2.408158683211D-05	-2.450750101163D-06	5.482201735529D-08
4	-8.229247133546D-06	9.351454862581D-07	-2.147970339341D-08
5	1.022459855218D-06	-1.480508733520D-07	3.599099499020D-09
6	-8.112983260770D-08	1.090170350156D-08	-2.777349026055D-10
7	6.415033848685D-09	-3.093185955060D-10	7.625408371264D-12
8	-2.624838999683D-10	-6.850467836445D-13	5.598594440202D-14

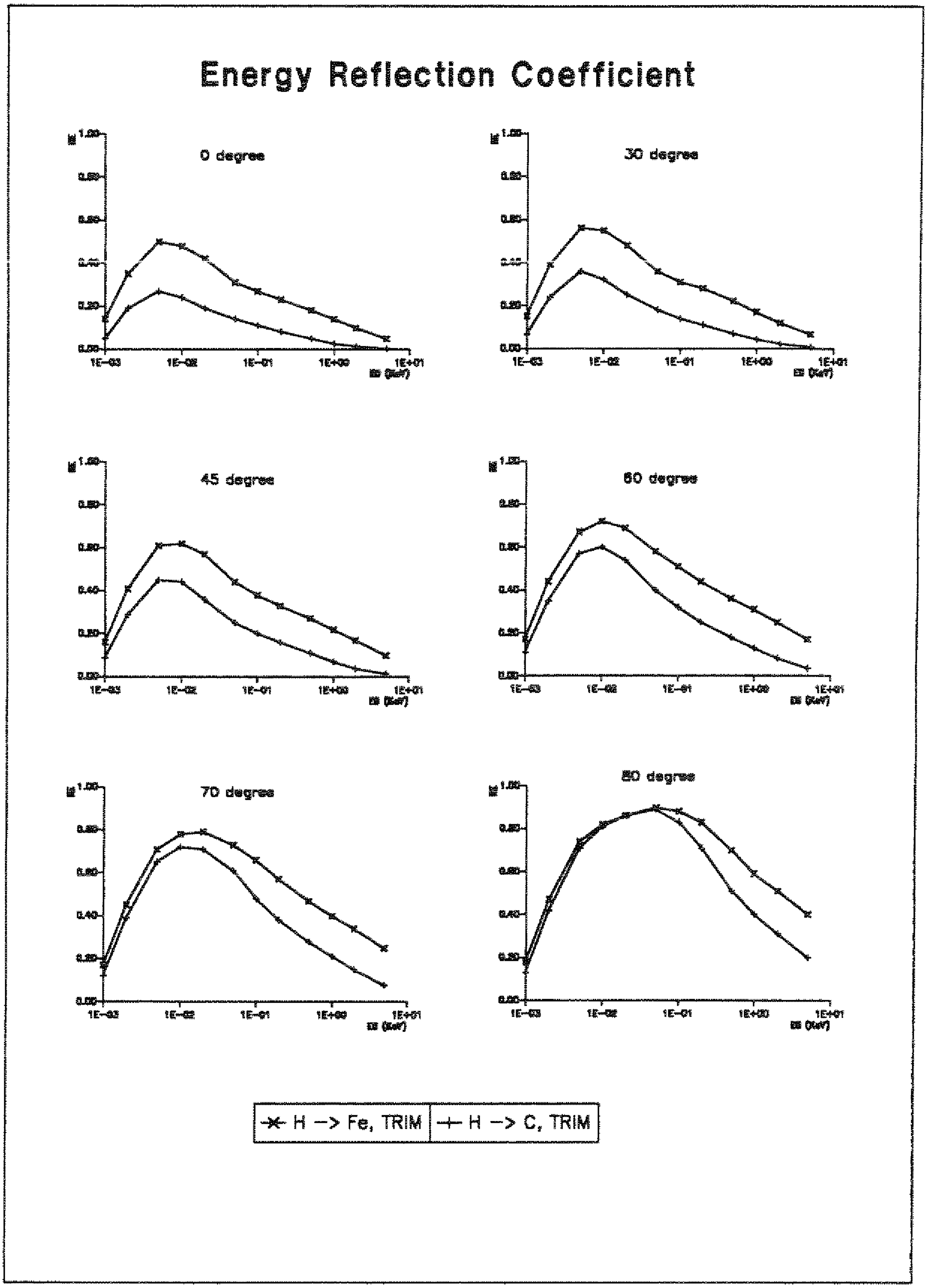
Max. rel. Error: 21.5948 %
Mean rel. Error: 5.8841 %

P = 1.000E+08, Err-max = 21.5948
P = 1.000E+10, Err-max = 19.9186
P = 1.000E+12, Err-max = 19.0835
P = 1.000E+14, Err-max = 9.1815
P = 1.000E+16, Err-max = 1.4432

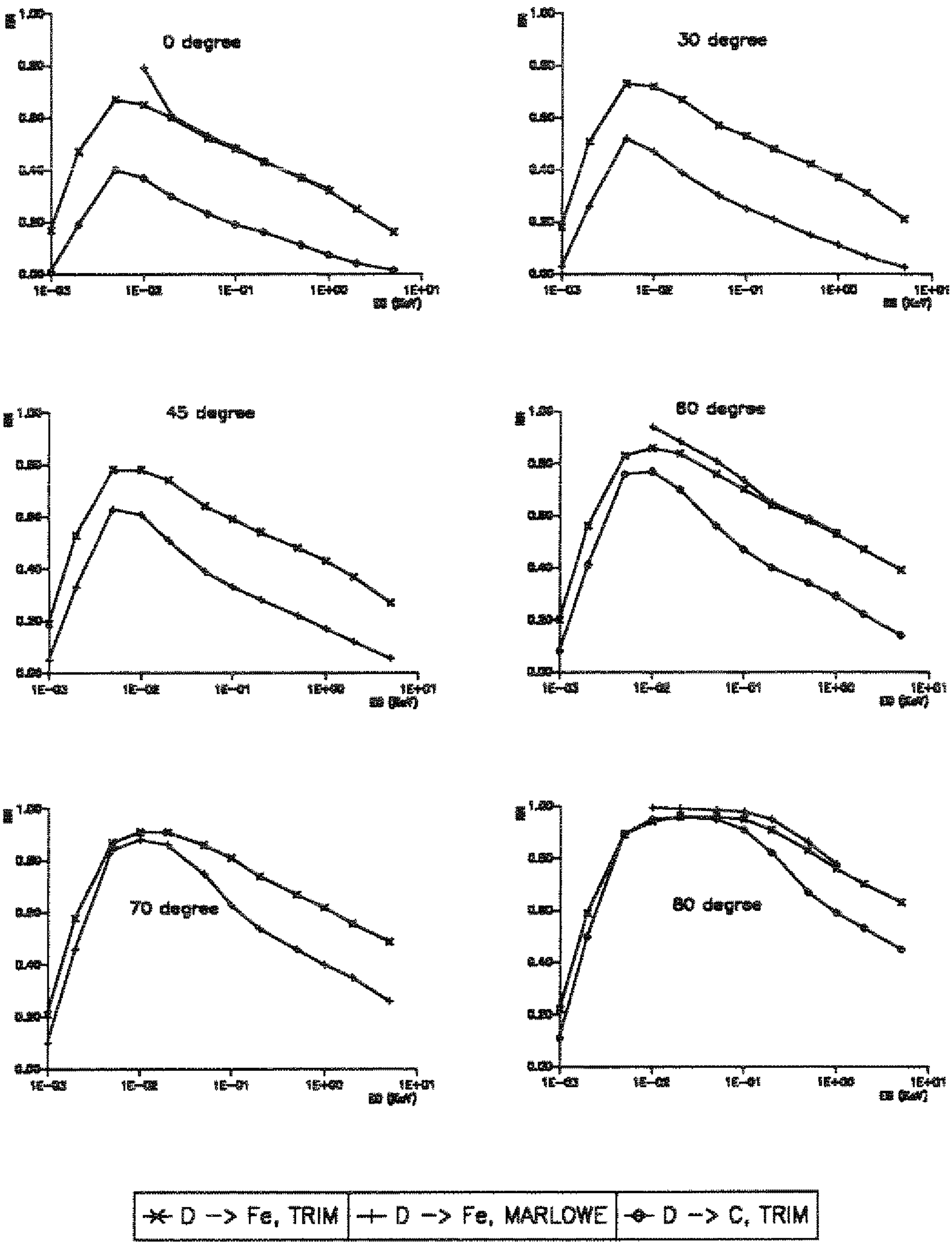
5 TRIM: Database for surface reflection

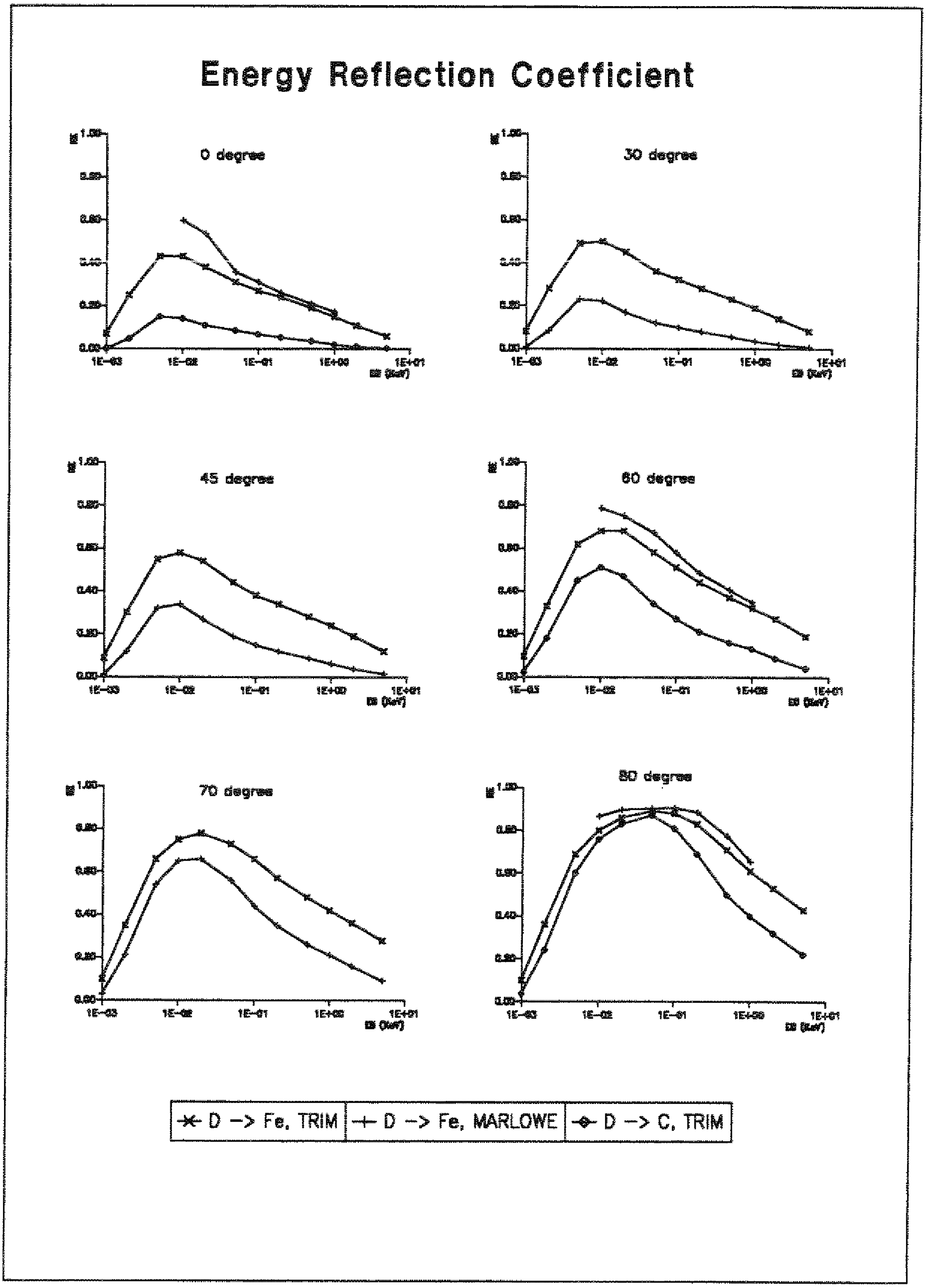
Particle Reflection Coefficient



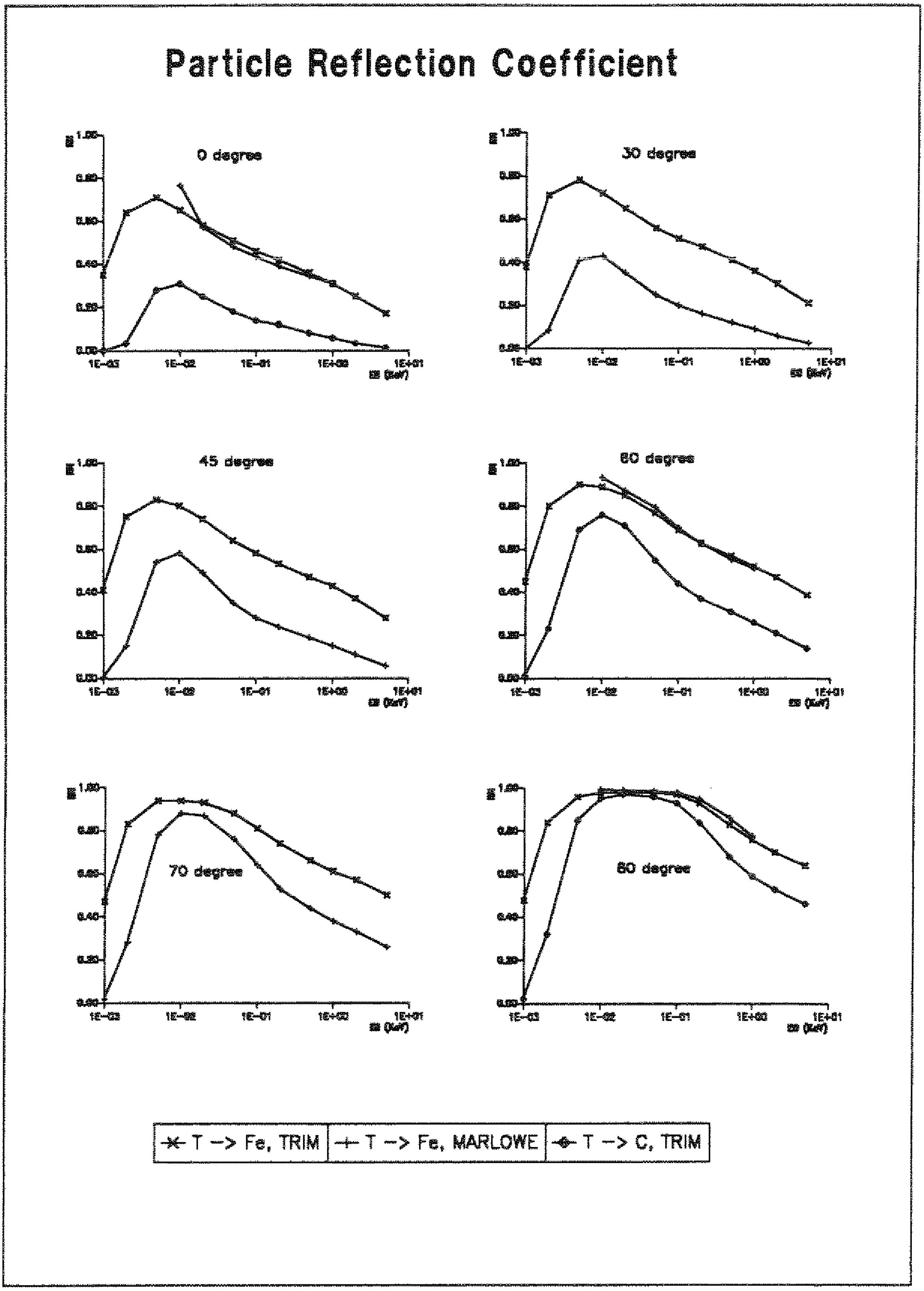

Energy Reflection Coefficient
0 degree
30 degree
45 degree
60 degree
70 degree
80 degree
1E-03
1E-02
1E-01
1E+00
1E+01
H -> Fe, TRIM
H -> C, TRIM

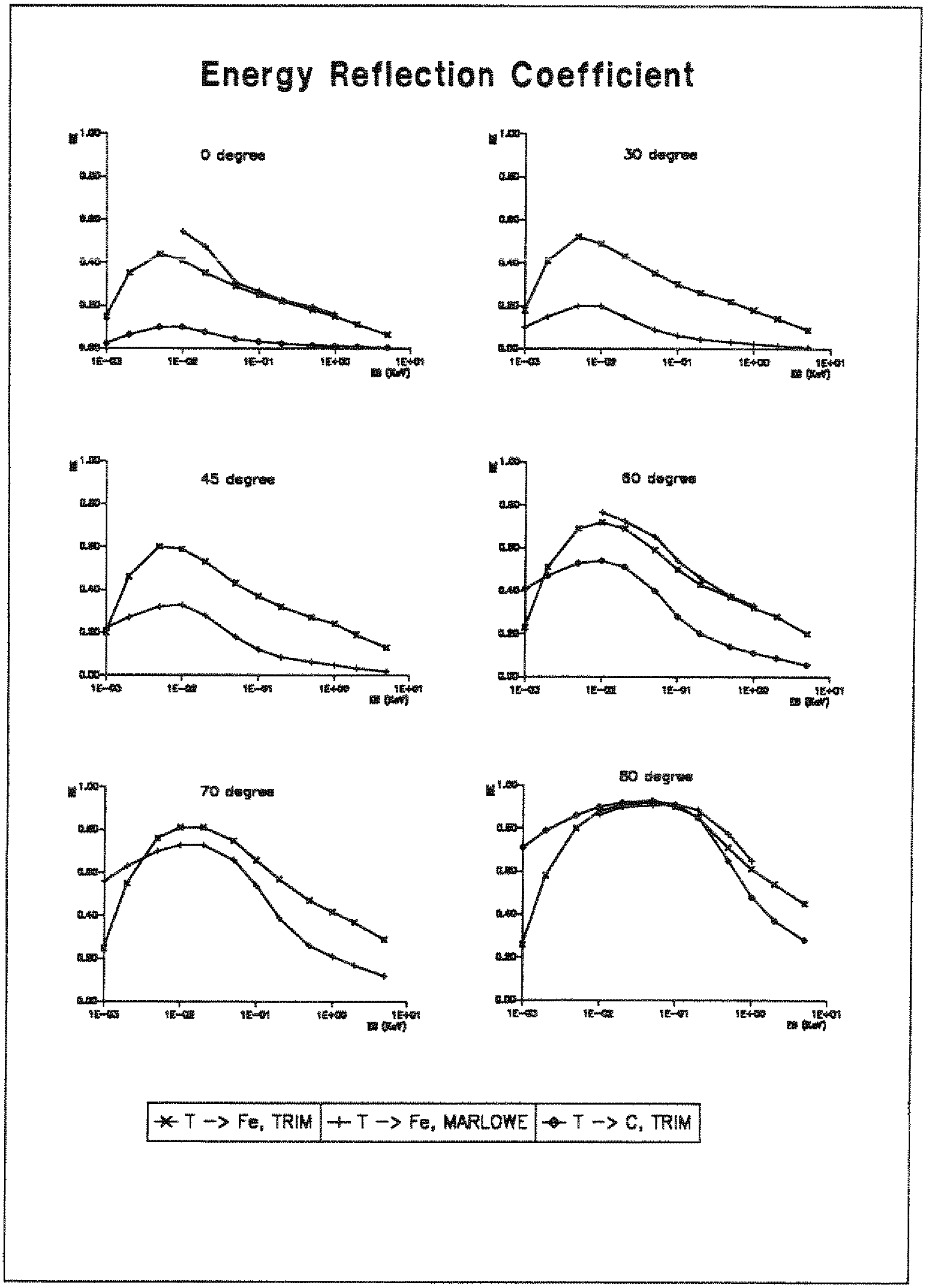
Particle Reflection Coefficient



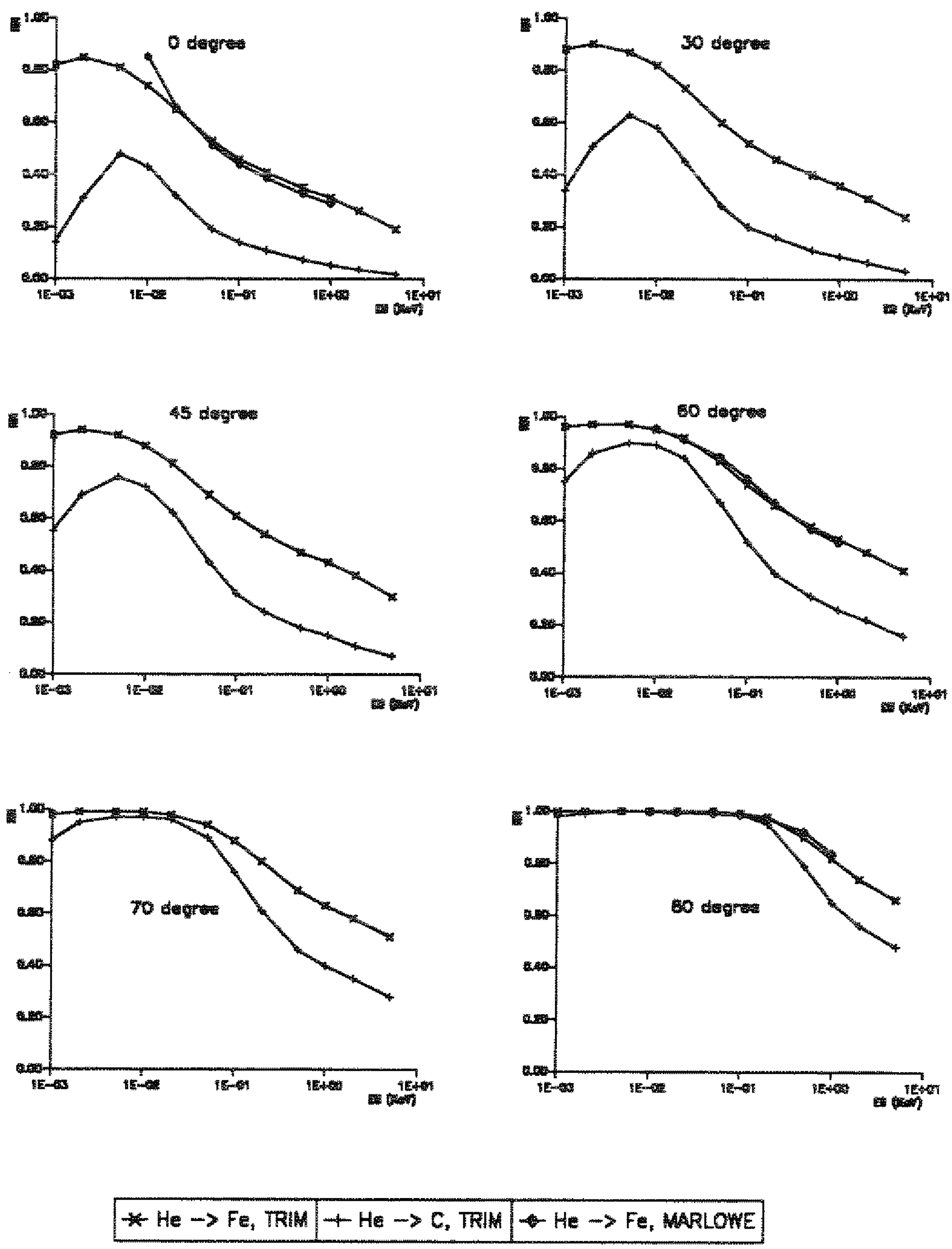


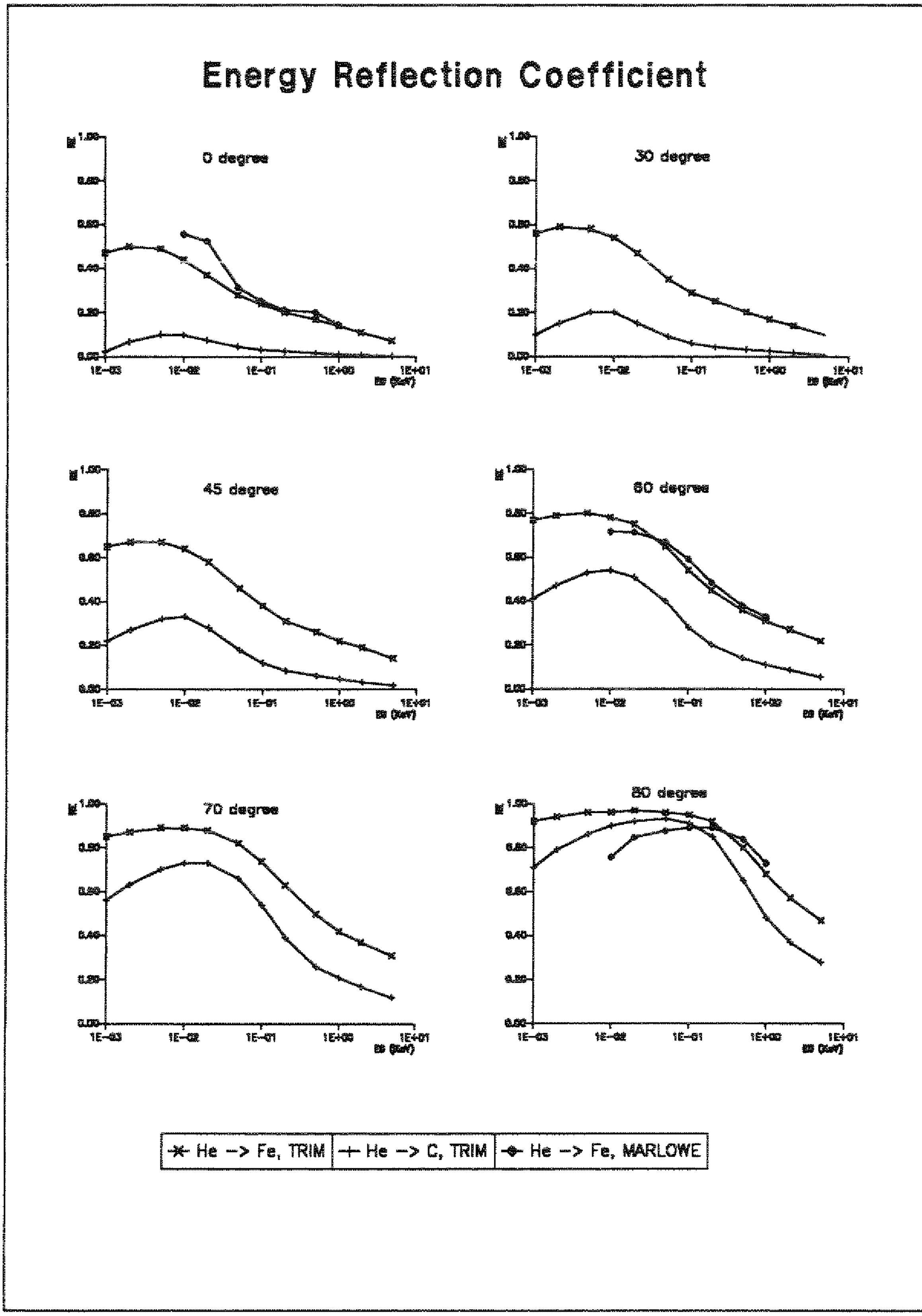
Energy Reflection Coefficient
0 degree
30 degree
45 degree
60 degree
70 degree
80 degree
D -> Fe, TRIM
D -> Fe, MARLOWE
D -> C, TRIM

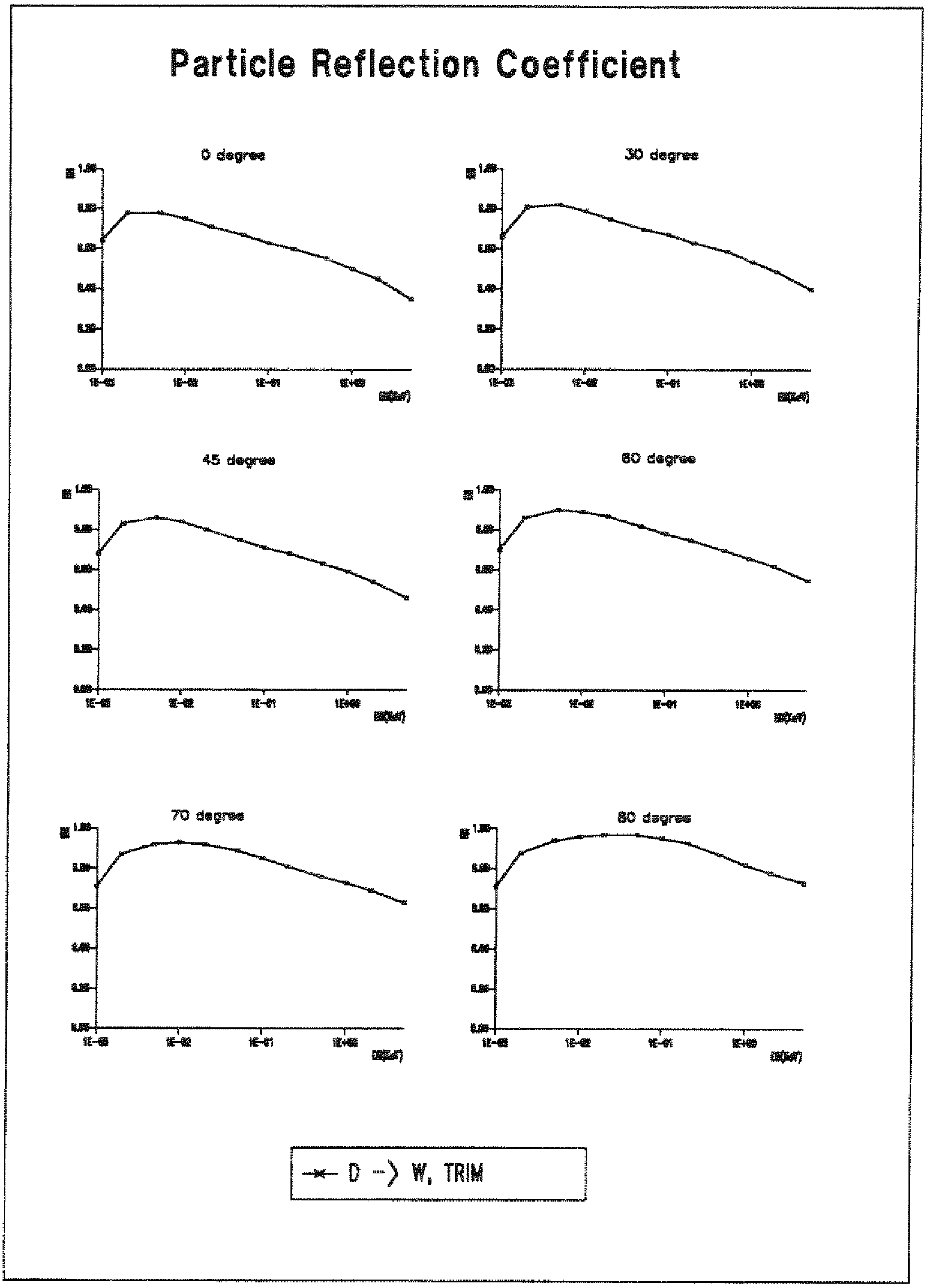

Particle Reflection Coefficient
0 degree
30 degree
45 degree
60 degree
70 degree
80 degree
T --> Fe, TRIM
T --> Fe, MARLOWE
T --> C, TRIM

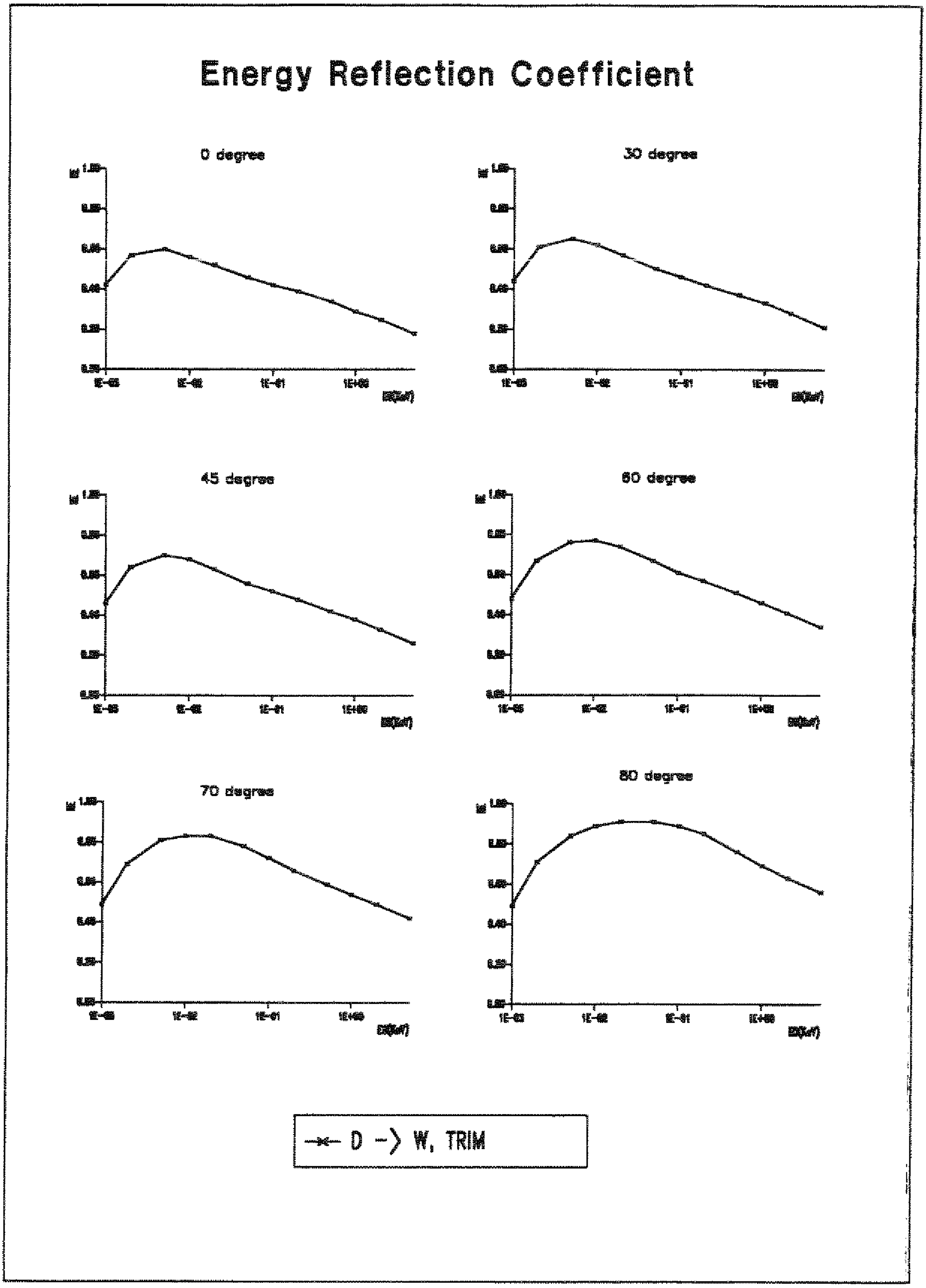

Energy Reflection Coefficient
0 degree
30 degree
45 degree
60 degree
70 degree
80 degree
T -> Fe, TRIM
T -> Fe, MARLOWE
T -> C, TRIM

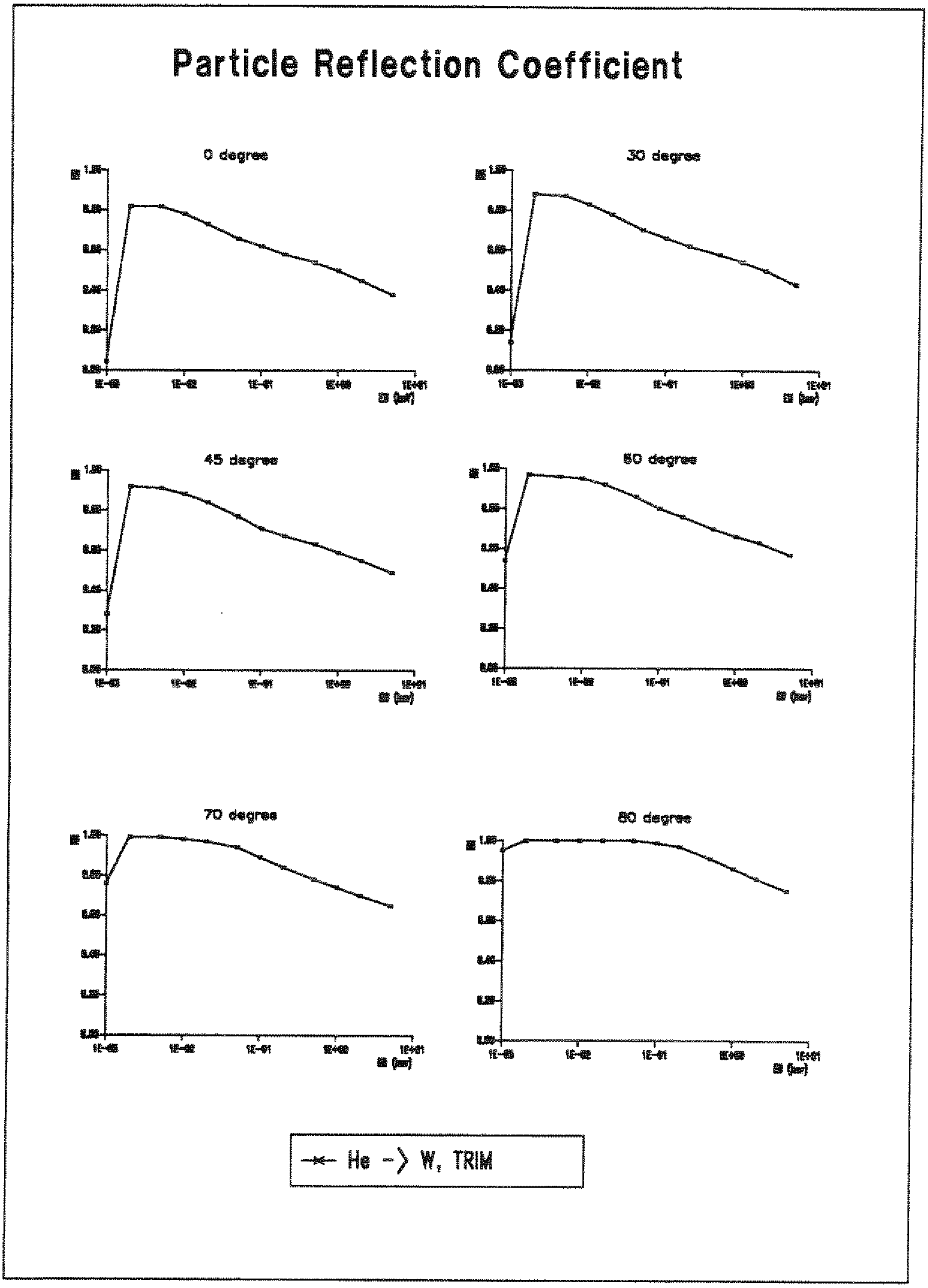
Particle Reflection Coefficient

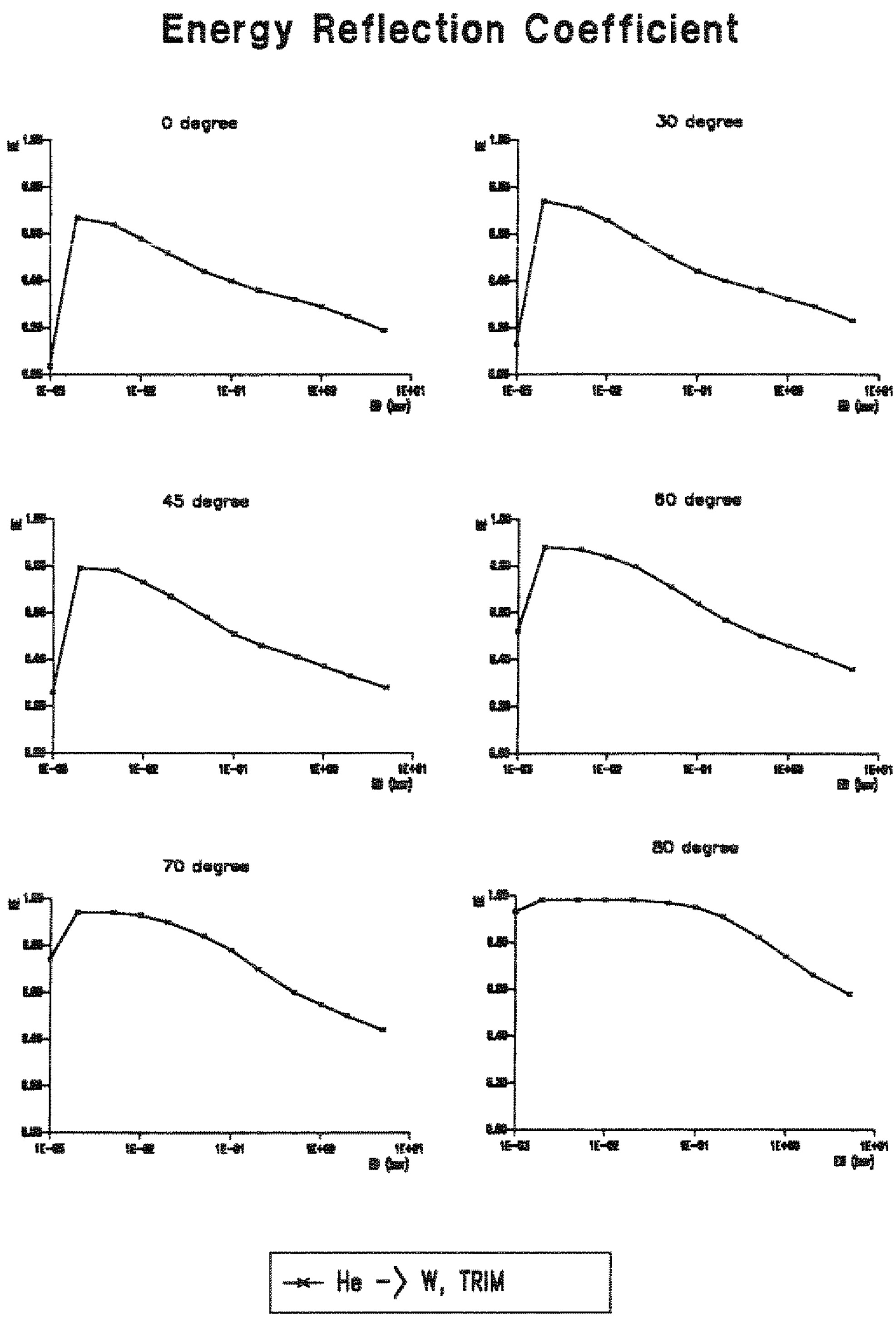



Energy Reflection Coefficient
0 degree
30 degree
45 degree
60 degree
70 degree
80 degree
He --> Fe, TRIM
He --> C, TRIM
He --> Fe, MARLOWE


Particle Reflection Coefficient
0 degree
30 degree
45 degree
60 degree
70 degree
80 degree
D -> W, TRIM


Energy Reflection Coefficient
0 degree
30 degree
45 degree
60 degree
70 degree
80 degree
D -> W, TRIM


Particle Reflection Coefficient
0 degree
30 degree
45 degree
60 degree
70 degree
80 degree
He -> W, TRIM


Energy Reflection Coefficient
0 degree
30 degree
45 degree
60 degree
70 degree
80 degree
He -> W, TRIM

```
Helium onto carbon target, E0=200 eV, ANG= 0 degrees

  2  4.00  6 12.01 0.20E+03  0.0 0.11E+00 0.24E-01  10.0 200000

C Inverted energy distribution
C (quantile function tabled for 0.1, 0.3, 0.5, 0.7 and 0.9 quantiles)
  0.86414E+01  0.26905E+02  0.43856E+02  0.59996E+02  0.82007E+02

C Inverted polar angle distribution, given energy
C (ie. conditional quantile function, same quantiles as above)
  0.61352E+00  0.75826E+00  0.84999E+00  0.92188E+00  0.97674E+00
  0.57659E+00  0.73506E+00  0.83113E+00  0.90403E+00  0.97086E+00
  0.57714E+00  0.73299E+00  0.84048E+00  0.91348E+00  0.97378E+00
  0.52994E+00  0.66439E+00  0.75469E+00  0.84715E+00  0.94346E+00
  0.33700E+00  0.47723E+00  0.60191E+00  0.72579E+00  0.88494E+00

C Inverted azimuthal angle distribution, given energy and polar angle
C (ie. conditional quantile function, same quantiles as above)
 -0.94324E+00 -0.62802E+00 -0.82661E-01  0.50682E+00  0.95462E+00
 -0.92445E+00 -0.52295E+00  0.94094E-01  0.64643E+00  0.95988E+00
 -0.92733E+00 -0.46665E+00  0.12289E+00  0.58376E+00  0.96444E+00
 -0.93250E+00 -0.58820E+00  0.19434E-01  0.60021E+00  0.95166E+00
 -0.95800E+00 -0.64451E+00 -0.45557E-01  0.51675E+00  0.95085E+00
 -0.94829E+00 -0.61805E+00  0.19761E-01  0.59977E+00  0.93774E+00
 -0.93764E+00 -0.53840E+00  0.33347E-01  0.61223E+00  0.95474E+00
 -0.93399E+00 -0.51122E+00  0.16679E-02  0.55914E+00  0.94738E+00
 -0.94354E+00 -0.58778E+00  0.12855E-01  0.62943E+00  0.96353E+00
 -0.91705E+00 -0.54982E+00  0.62269E-01  0.61494E+00  0.95915E+00
 -0.94385E+00 -0.63014E+00  0.34900E-01  0.60136E+00  0.94134E+00
 -0.93611E+00 -0.50737E+00  0.12150E+00  0.66963E+00  0.96225E+00
 -0.96130E+00 -0.56080E+00  0.56574E-01  0.62074E+00  0.95313E+00
 -0.93865E+00 -0.61092E+00 -0.40448E-01  0.53153E+00  0.94804E+00
 -0.94713E+00 -0.58003E+00 -0.27125E-01  0.54711E+00  0.93807E+00
 -0.95549E+00 -0.58220E+00 -0.15810E-01  0.57924E+00  0.96813E+00
 -0.95513E+00 -0.60101E+00 -0.89646E-02  0.53945E+00  0.93961E+00
 -0.94982E+00 -0.55167E+00  0.13471E+00  0.66427E+00  0.96975E+00
 -0.94337E+00 -0.58065E+00  0.25216E-01  0.58432E+00  0.95075E+00
 -0.94550E+00 -0.63559E+00 -0.12697E+00  0.53197E+00  0.92356E+00
 -0.93143E+00 -0.50348E+00  0.19768E-01  0.60767E+00  0.95874E+00
 -0.92693E+00 -0.54340E+00  0.36631E-01  0.61340E+00  0.93977E+00
 -0.95998E+00 -0.57459E+00  0.34936E-01  0.60228E+00  0.95475E+00
 -0.93356E+00 -0.53523E+00 -0.30616E-01  0.57869E+00  0.93628E+00
 -0.95022E+00 -0.63709E+00 -0.71986E-01  0.59146E+00  0.93093E+00
```

Helium onto iron target, E0=200 eV, ANG= 0 degrees

2 4.00 26 55.85 0.20E+03 0.0 0.41E+00 0.20E+00 3.0 200000

0.29280E+02	0.74713E+02	0.10820E+03	0.13337E+03	0.15360E+03

0.57109E+00	0.72830E+00	0.82973E+00	0.90847E+00	0.97159E+00
0.51966E+00	0.69501E+00	0.80434E+00	0.89115E+00	0.96758E+00
0.49051E+00	0.66744E+00	0.78444E+00	0.88004E+00	0.96317E+00
0.49402E+00	0.67248E+00	0.78891E+00	0.88461E+00	0.96628E+00
0.37892E+00	0.53755E+00	0.63741E+00	0.72912E+00	0.84610E+00

-0.95055E+00	-0.60755E+00	-0.29623E-01	0.56422E+00	0.94575E+00
-0.94833E+00	-0.57921E+00	0.27192E-01	0.58679E+00	0.95183E+00
-0.95434E+00	-0.57193E+00	0.72011E-02	0.59732E+00	0.95735E+00
-0.95303E+00	-0.55111E+00	0.36184E-01	0.59242E+00	0.94528E+00
-0.94519E+00	-0.60680E+00	-0.11571E-01	0.58290E+00	0.94539E+00
-0.94538E+00	-0.56985E+00	-0.64138E-02	0.59048E+00	0.94449E+00
-0.93903E+00	-0.56379E+00	0.13820E-01	0.57552E+00	0.96393E+00
-0.95462E+00	-0.58806E+00	-0.82367E-02	0.58042E+00	0.95545E+00
-0.94968E+00	-0.57790E+00	0.32441E-02	0.59225E+00	0.94291E+00
-0.94615E+00	-0.57092E+00	0.45833E-01	0.60324E+00	0.94420E+00
-0.95467E+00	-0.60720E+00	-0.19548E-01	0.55152E+00	0.95043E+00
-0.94427E+00	-0.56198E+00	-0.20832E-02	0.57027E+00	0.95116E+00
-0.94961E+00	-0.59604E+00	-0.20978E-02	0.57460E+00	0.94732E+00
-0.94765E+00	-0.58538E+00	-0.81930E-03	0.60238E+00	0.95318E+00
-0.94783E+00	-0.55878E+00	0.34058E-01	0.61148E+00	0.95388E+00
-0.94638E+00	-0.57687E+00	-0.93667E-02	0.56545E+00	0.94439E+00
-0.94993E+00	-0.60076E+00	0.22940E-02	0.58825E+00	0.95014E+00
-0.94637E+00	-0.57961E+00	0.35661E-01	0.60703E+00	0.95832E+00
-0.94902E+00	-0.58853E+00	-0.23349E-01	0.57767E+00	0.94663E+00
-0.95238E+00	-0.58536E+00	-0.14723E-01	0.57677E+00	0.94241E+00
-0.94485E+00	-0.59745E+00	-0.27317E-01	0.56327E+00	0.94872E+00
-0.95666E+00	-0.61211E+00	0.36352E-02	0.58355E+00	0.95284E+00
-0.94786E+00	-0.58319E+00	0.54993E-02	0.59385E+00	0.95561E+00
-0.94137E+00	-0.59946E+00	0.31979E-02	0.58852E+00	0.95262E+00
-0.93971E+00	-0.58582E+00	-0.12678E-01	0.60170E+00	0.95100E+00

```
Helium onto tungston target, E0=200 eV, ANG= 0 degrees

  2  4.00 74183.85 0.20E+03  0.0 0.58E+00 0.36E+00   3.0 200000


  0.43973E+02  0.10190E+03  0.13730E+03  0.16100E+03  0.17854E+03

  0.53080E+00  0.70324E+00  0.81162E+00  0.89613E+00  0.96890E+00
  0.48303E+00  0.66616E+00  0.78628E+00  0.88288E+00  0.96364E+00
  0.46212E+00  0.64745E+00  0.77302E+00  0.87363E+00  0.96011E+00
  0.45067E+00  0.63464E+00  0.76441E+00  0.86651E+00  0.95874E+00
  0.34568E+00  0.51152E+00  0.64541E+00  0.77458E+00  0.91378E+00

 -0.95050E+00 -0.56841E+00  0.14149E-01  0.58921E+00  0.94449E+00
 -0.95488E+00 -0.59122E+00 -0.22324E-01  0.59076E+00  0.95185E+00
 -0.94698E+00 -0.58082E+00 -0.13563E-02  0.57193E+00  0.93962E+00
 -0.95122E+00 -0.59128E+00  0.33591E-01  0.59735E+00  0.94955E+00
 -0.94857E+00 -0.58588E+00  0.24137E-01  0.60840E+00  0.94931E+00
 -0.95077E+00 -0.56454E+00  0.73217E-02  0.58843E+00  0.95028E+00
 -0.95343E+00 -0.58543E+00 -0.31713E-03  0.57346E+00  0.94998E+00
 -0.95036E+00 -0.59379E+00 -0.19266E-01  0.57702E+00  0.95444E+00
 -0.95189E+00 -0.57847E+00  0.18880E-01  0.59287E+00  0.95393E+00
 -0.95062E+00 -0.58377E+00  0.21074E-01  0.59435E+00  0.96101E+00
 -0.95112E+00 -0.60508E+00 -0.33430E-01  0.57233E+00  0.94606E+00
 -0.94612E+00 -0.57800E+00  0.67463E-02  0.58379E+00  0.95066E+00
 -0.95422E+00 -0.60156E+00 -0.15950E-01  0.60125E+00  0.95246E+00
 -0.94528E+00 -0.58429E+00  0.28716E-01  0.61003E+00  0.95375E+00
 -0.94456E+00 -0.58349E+00  0.91998E-02  0.57783E+00  0.94462E+00
 -0.95268E+00 -0.62499E+00 -0.67304E-01  0.55825E+00  0.94892E+00
 -0.95258E+00 -0.57805E+00 -0.24066E-01  0.59901E+00  0.95005E+00
 -0.95403E+00 -0.58690E+00  0.31209E-02  0.58977E+00  0.95801E+00
 -0.95192E+00 -0.59407E+00 -0.52821E-02  0.57739E+00  0.94775E+00
 -0.95300E+00 -0.58533E+00  0.19852E-01  0.59794E+00  0.95376E+00
 -0.95293E+00 -0.60204E+00 -0.26899E-01  0.58785E+00  0.94388E+00
 -0.95996E+00 -0.58294E+00  0.18827E-01  0.61464E+00  0.95665E+00
 -0.94066E+00 -0.59033E+00 -0.71149E-02  0.59032E+00  0.95070E+00
 -0.95213E+00 -0.57357E+00  0.10825E-01  0.59172E+00  0.95163E+00
 -0.94484E+00 -0.57545E+00 -0.21530E-01  0.58932E+00  0.94792E+00
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