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PARTICLE REFLECTION FROM SURFACES - A RECOMMENDED DATA BASE

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Particle Reflection from Surfaces - A Recommended Data Base

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Abstract The previously published data on particle backscattering from surfaces is critically reviewed with the aim to arrive at a single evaluated data set and to establish general scaling relationships for the reflection coefficients related to projectile energy and mass of the colliding species. A simple empirical formula is proposed for analytic representation of the recommended data, which can also be used for interpolation and extrapolation purposes. The evaluated data base includes the number and energy reflection coefficients of H^+, D^+, T^+ and He^+ from monoatomic materials of fusion interest in the energy range from a few tens of eV up to several hundreds of keV under normal incidence collisions. Data for self-ion reflection for several low- and high-Z materials are also provided.

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1. Introduction

We shall consider the available information for light atomic particle reflection from surfaces with the objective of establishing a base of reliable data and developing algebraic representations based on systematics of behaviour. Particle reflection from solid surfaces is an important parameter in the modelling of fusion energy devices with particular relevance to the recycling of fuel (H, D and T), ash (He) and impurities (generally metals, O and C) from machine walls, limiters and divertor plates. The modelling of fusion device operation requires first a reliable data base. Secondly it is desirable if the data can be represented in an analytical form that may be conveniently incorporated into modelling codes. With our particular interest in fusion related applications, we will restrict our discussions to scattering of light ions (H^+, D^+, T^+, He^+) and metallic impurities on candidate plasma facing component materials. Impact energies will range from a few times 10 eV, characteristic of first wall recycling to several hundreds of keV, that might be appropriate to neutral beams used for large tokamak plasma heating.

The particle reflection is characterized by two parameters. First, the number reflection coefficient, R_N, defined as the ratio of all particles backscattered from the surface to the number of particles incident. Secondly, the energy reflection coefficient, R_E, defined as the energy carried away by the reflected particles divided by the energy of the incident particles. Both coefficients are taken as integrated over the half space outside the surface. There is also interest in the energy and angular distribution of back scattered particles, and in the dependence of reflected particle fluxes on the angle of incidence of the bombarding ion. For the present paper we will confine ourselves to total reflection integrated over all angles and energies of the backscattered particles. Most information is available for normal incidence onto the surface and we will confine ourselves to this situation. We shall be interested in how R_N and R_E vary with incident projectile energy and seek systematic behaviours as a function of projectile-target combination.

A significant effort has already been devoted to the collection of data and attempts to describe the reflection coefficients analytically. Eckstein and Verbeek [EC 79] tabulated the results of their own extensive measurements and calculations through 1979; the work of that group continues to be the dominant source of information. Itoh et al [IT 85] in 1985 collected all available information and developed certain useful scaling relations. There are also review papers dealing specifically with the relevance of such information to fusion [EC 84], [EC 91].

Generally speaking, the particle reflection coefficients are high at low energies and decrease monotonically as projectile energy increases. It has been shown [EC 83] that at sufficiently high energies in the MeV region, as inelastic processes begin to dominate the stopping power, the reflection coefficients eventually become constant with energy. There is some uncertainty as to how one should describe reflection at vanishingly low energies. If a projectile can be retained in the target then reflection should tend to zero at some finite threshold. This might be the case for a hydrogen on carbon or a metallic ion incident on a solid of the same type (self-ion). For a projectile that cannot be retained, for example He on Fe, the reflection coefficient should presumably tend to unity. There is very little information for these low energy, near threshold, conditions although we do now have computer simulations for metallic ions on the surface of the parent material where retention is demonstrated [EC 86].

The experiments are small in number and cover only a limited range of collision species; they encompass very limited energy ranges often a decade or less in the low keV energy region. By themselves they represent an inadequate data base both for analysis of general behaviour and for fusion applications. There are, however, a substantial number of computer simulations which extend over a full spectrum of parameters. These simulations are validated by comparison with experiment and do provide an adequate data base from which general trends many be evaluated. We shall first review the available sources of data and then seek systematics in the behaviour.

2. Data Sources

The most sophisticated experimental procedure is to measure the energy distribution of particles reflected into a particular direction, repeat this as a function of exit angle and then integrate the results to arrive at total reflection coefficients R_N and R_E. The majority of reflected particles are neutral. In the early work by Eckstein and coworkers [ME 74] the neutrals were stripped in a cell to form ions and then electrostatically energy analyzed. At low energies stripping is very inefficient so that the lowest energy recoils are not detected. An alternative technique used by the same group is to detect the particles by secondary electron emission and to use a pulsed projectile beam to achieve energy resolution through time of flight analysis [AR 89a]. Again the lowest energy particles are not detected. For both techniques there are dificulties in establishing detection sensitivity. The result is an energy distribution measured at a particular recoil angle. In the work of Eckstein's group the measurements were often performed at only one exit direction and integration over angles achieved by recourse to a theoretical prediction by TRIM or MARLOWE simulations; the simulation was checked against experiment in certain cases [VE 80]. The result is a value for R_N or R_E that is in part dependent on theory, excludes the lowest energy recoils (below 150 eV for H^+ and 800 eV for He^+) with the result that R_N and R_E will be too low. The work of Aratari and Eckstein [AR 89a] demonstrates that 30% of reflected atoms may be undetected in an experiment to study reflection of 40 eV H^+ from C but the loss is negligible at 2 keV.

Within the numerous publications of Eckstein and co-workers there are significant differences between data on a particular case. For example, the original data for H^+ reflection from gold [EC 78] was changed [VE 80] somewhat, then revised upwards by 50% for a later report [EC 79] and review [EC 84] as a result of reassessment. Data for other cases in the same early paper were not reassessed and appear unchanged in the later publications [EC 79] [EC 84]. This is of particular concern for targets such as Mo and W where the original paper is the sole experimental study available to us and where, as we shall later find, the data lie 50% below our scaling curves. Eckstein and Verbeek [EC 79] admit that thin oxide layers were probably present.

We are forced to conclude that the reliability of hydrogen reflection data may be closer to 50% rather than the 10% generally quoted as an error limit by this group. The reliability of He^+ data for which accuracy is claimed to be [EC 78] 30 to 50% may be very poor. In general we have used the last data published for our present work; most of this is detailed in a Summary Report of the Garching Institute for Plasma Physics, [EC 79].

There are quite a number of measurements of energy distributions of backscattered H^+ ions which comprises only 5% or less of the backscattered flux. The ion fraction of the backscattered flux at any recoil energy is related to charge transfer processes occuring as the recoil exits the surface. If this fraction is known, as for example from beam-foil measurements, then one might evaluate the energy distribution of all recoils and hence R_N and R_E. This was done by Overbury et al [OV 80] for H^+ scattering from C and gives a result similar to other measurements. We regard this as an indirect method since the charge state ratio is obtained from subsidiary information.

There are a number of experiments designed to measure directly the fraction of an incident beam that emerges from a surface. Thomas and Braun [TH 80] [BR 82] measured D^+ reflection by the pressure rise of D in the chamber containing a target. Sidenius and Lenskjaer [SI 76] detected recoils in a proportional counter to directly derive R_N and R_E. In experiments that measure the fraction of projectiles T retained or trapped in a target, one may presumably estimate reflection as $R_N = 1-T$. Such trapping will occur for hydrogenic projectiles in reactive targets such as C, Ti and Zr. The technique has been applied by monitoring the retained component by nuclear techniques [ST 79] and by weight gain [BO 76]. Trapping can also be induced in non-reactive situations by keeping targets at low temperature to reduce mobility; the retained component may then be depth profiled as in the work of Amano and Seidman [AM 81]. The rise in temperature of a bombarded target gives a measure of retained energy which, with some calibration, can be used to give a direct measure of retained energy ([AN 76], [SC 78], [CO 91], which can be used to estimate directly the reflected energy fraction R_E. This is, however, a rather indirect approach since the measured energy retention relates not only to reflected

energy carried away by the reflected projectiles, but also to the energy carried away by sputtered particles and secondary electrons. The influence of these other processes on the value of R_E must be estimated by subsidiary experiments or theory. All these various experiments are claimed to have accuracies of 10% or so and in some cases excellent agreement by different techniques has been demonstrated [AN 76], [TH 80]. All these approaches measure a total reflected fluence or a total retained fluence compared with the fluence of the projectile beam. They are effective only when reflection is at least 0.05 to 0.1. Validity of the technique requires some assumptions as to how projectiles are retained. In general, the results are quite compatible with those derived from direct measurements of reflected particle energy distributions.

In any experiment involving surfaces there must be attention to whether the surface is atomically clean, flat and pure. There have been very few systematic studies of how the surface conditions might influence R_N and R_E. Most experiments claimed to have started with pure polycrystalline samples, mechanically (and some times electrically) polished, heated in-situ to remove adsorbates, sputter cleaned to remove oxides and held at elevated temperatures to force migration of implanted species to the surface to avoid changing the sample composition. The ambient pressures in the target chambers are, however, of the order 10^{-7} to 10^{-8} torr so that oxide contaminant layers will form during the period of the experiment. It has been shown [BH 79] that backscattering from bulk oxides is lower than that of the corresponding metals, presumably due to the lower scattering cross section of oxygen. If a surface has an oxide layer, one expects a lower reflection coefficient. No attempts have been made to define the crystalline nature of the targets except for the work of Amano and Seidman on single crystal W [AM 81]). Computer simulations [OE 76] suggest that reflection from polycrystalline materials may be as much as 20% lower than reflection from amorphous forms. Eckstein and Verbeek [EC 79] state that reflection from a polycrystalline tungsten surface covered with dendrites was a factor of 2.5 smaller than that for a polished target. Bandurko et al (BA 90) provide experimental and theoretical comparison of reflection from tungsten targets with a

variety of defined surface irregularities; the tested surfaces included tungsten exposed to erosion in a plasma discharge at parameters close to those of a tokamak edge plasma. Overbury [OV 80] demonstrated that reflection from a carbon film varied by 30% from point to point, indicating the effects of differences in structure.

There has been some systematic study of how the implantation and retention of hydrogenic species will influence backscattering. Hydrogen (as a target) will exhibit lower backscattering cross sections than a metal; so, reflection from a target containing chemically bonded hydrogen will inevitably be below that of the pure material. This has been demonstrated [AR 89a] for H^+ impact on C where retained hydrogen causes a 30% drop in H^+ reflection at 50 eV. It has also been demonstrated for H^+ impact on Ni [AR 89a], where the implanted hydrogen migrates but some remains as an adsorbed layer on the surface; R_N decreases by 60% at 20 eV. Retention effects are also observed for hydrogen impact on Ti, again a chemically reactive situation [EC 78].

Experimental studies are largely confined to energies between 1 and 10 keV where beams are easy to prepare, reflected species are easy to detect and particle reflection coefficients are 10^{-2} to 3×10^{-1}. Their accuracy is quoted as 10 to 30% but this is probably optimistic as changes of up to 50% are seen in successive publications by the same group. The precise nature of the surface is often undefined. Systematic problems of particle detection, oxide layers and light projectile retention in the target will invariably cause a measured reflection coefficient to be too low. The limited range of available data, coupled with the poor statistical accuracy, makes it impossible to elucidate general trends using experimental data alone.

The earliest theoretical calculation on backscattering was a single collision model by McCracken and Freeman [Mc 69] which assumes that the projectile penetrates along a straight trajectory, experiences some large angle collision and returns to the surface again along a straight trajectory. This is a very simplistic approach that can be applied only at energies of a few tens of keV.

More recently Zhengming [ZH 87] has developed a "bipartition model" that treats ions scattered out of the projectile beam by a diffusion approach and evaluates the coefficients of reflection. The data published to date [ZH 87] are restricted to R_N for H^+ on Au; for this one case the predictions are in excellent agreement with the results of simulations and experiments. There is now a report [ZH 91] which greatly extends the data coverage and also gives the detailed energy and angular distributions of the reflected species. In order to evaluate the validity of such a prediction one should compare the detailed prediction of energy distributions with experiment. Such a comparison is shown on Fig. 1 where we reproduce reflected particle energy distributions measured by Aratari and Eckstein [AR 89b] with calculations from the work of Zhengming [ZH 91]. While the two data sets do not correspond in energies, there is a clear and significant discrepancy between theory and experiment. It is particularly important to note the major difference at high recoil energies. Aratari and Eckstein [AR 89b] point out that elastic energy loss for a single scattering through an angle of 135° (the conditions of the experiment) is 44% of incident energy for D^+ or C. The experimental data in Fig. 1 show quite clearly that the highest energy recoils have suffered a single elastic collision at, or close to, the surface. The theory of Zhengming [ZH 91] predicts a significant flux at energies $E/E_o > 0.6$ where none is observed. Similar comparisons have been made with data for scattering of H^+ from Ni using published experimental energy spectra [AR 89a] and again there is no correspondence with Zhengming's calculations. The overestimate of reflection coefficients by the bipartition model is a consequence of the incorporated assumption (on which the partition of distribution function in the Boltzmann equation is based) that forward scattering has a dominant role in the collision. This assumption holds only for low energies and badly fails at high energies. We conclude that the energy distributions predicted by Zhengming bipartition model are quite incorrect. In that case the values of R_N and R_E obtained by integrating such distributions may be quite unreliable. It is interesting to find that the calculations of R_N and R_E for heavy target species do often agree quite well with experiment and with simulations for reasonably high energies (above a few keV); we regard

this as fortuitous. At the present we consider these calculations to be unreliable and should not be a major component in our data base.

There are very extensive sets of Monte Carlo simulations of the backscattering phenomena that give distributions in energy and angle as well as the integrated values R_N and R_E. Most of these are by the TRIM and MARLOWE codes described originally in references [HA 76] and [RO 74] and compared in detail by Eckstein et al [EC 80]. Both codes are based on binary collisions and require the adoption of interaction potentials and expressions for the energy loss. A major difference is that MARLOWE was developed for single crystals; to deal with an amorphous target the lattice cell is randomly rotated between collision events. TRIM works with an inherently random target; as a result it is 20 times faster to execute. It has been shown [EC 80] that these two codes give essentially the same results provided one utilizes the same input information. Both codes use the Lindhard - Scharff model for the energy loss due to electronic stopping. This is adequate up to energies of about 100 keV. A study has been made for H^+ and He^+ on gold for higher energies through the Bethe - Bloch region [EC 83] with a modified stopping cross section; it shows that R_N and R_E eventually become constant at energies of many hundred MeV. A further important parameter is the choice of potential for the scattering process. In the original MARLOWE and TRIM studies this was a Moliére potential [EC 80]. An analysis of different potentials [OC 86] has led Eckstein to use a Kr-C potential in more recent work [EC 86]. In an analysis of these codes it is shown [EC 80] that the calculated value of R_N (specifically for 8 keV H^+ on Au) may vary over a range of 30% as a result of various choices of potentials and stopping powers that are justifiable on the basis of comparisons with other information. TRIM and MARLOWE are the best developed codes and the origin of most of the simulation data. There are other similar Monte Carlo codes that give consistent results such as ACAT [TA 83] and BABOUM [BE 87]. Monte Carlo simulations generally have an inherent statistical accuracy of 10%; the results may, however, be altered by as much as 30% through the choice of potentials and other relevant parameters.

In general, we regard TRIM and MARLOWE simulations as the most reliable data concerning particle reflection. They are inherently accurate, extend over broad energy ranges, cover broad classes of collision combinations and therefore may demonstrate general trends in the behaviour of R_N and R_E. We shall use this type of data as the main component of our data base. Experimental information, where available, should be examined to determine whether it confirms the simulation, we must however bear in mind that experiments are generally of poor accuracy, often underestimate the reflection coefficient, and do not cover a sufficient range of energies to display general trends. It is generally found that experiments both on energy distributions and on particle reflection coefficients, agree with simulations to within the accuracy of the measurements lending confirmantion to the simulation procedure. The accuracy of experiments are not sufficient to permit a detailed evaluation of which potentials and other parameters are the most appropriate choices in simulations. The extensive calculations of Zhengming [ZH 91] often agree with Monte Carlo simulations and with experiment for energies above a few keV and when targets are moderately heavy (e.g. atomic mass of 12 or above). For lower masses and energies there is significant disagreement with the TRIM and MARLOWE simulations and with the few experiments available for comparison. Since the calculations of Zhengming [ZH 91] fail rather badly to reproduce experimentaly measured energy distributions, we feel that they should be treated with caution and not form the basis for an evaluated data base.

The results of TRIM and MARLOWE simulations should also be taken with caution at energies below 10-15 eV. The local collision dynamics in these codes is described in terms of the classical binary encounter approximation which accounts only for elastic particle energy losses. The inelastic energy losses (due to bound electron excitations, for instance) may be in this region of the order of the collision energy itself, and they are not included in the collision dynamics.

3. Scaling Relations

It has long been recognised that values of R_N (and R_E) for different collision combinations can be scaled together. Two parameters are of importance in the collision of a projectile of atomic mass and charge M_1 and Z_1 on a target of mass and charge M_2 and Z_2 at a collision energy E_0 (keV). These are the mass ratio

$$\mu = M_2 / M_1 \tag{1}$$

and the reduced energy

$$\varepsilon = 32.55 \frac{\mu}{1+\mu} \frac{1}{Z_1 Z_2 (Z_1^{2/3} + Z_2^{2/3})^{1/2}} E_0 \tag{2}$$

$$\varepsilon = \varepsilon_L E_0 \quad .$$

This particular reduced energy is based on a Thomas-Fermi screening length; for a Firsov screening length the expression becomes [EC 84]

$$\varepsilon = 32.55 \frac{\mu}{1+\mu} \frac{1}{Z_1 Z_2 (Z_1^{1/2} + Z_2^{1/2})^{2/3}} E_0 \tag{3}$$

$$\varepsilon = \varepsilon_F E_0 \quad .$$

The values of ε_L and ε_F agree to within 10% and the precise choice has no significant impact on the scaling procedure; we shall use the formulation of Eq. (2) and for convenience we tabulate the values of ε_L for selected cases in Table 1.

Eckstein and Verbeek [EC 84] showed that by plotting R_N (and R_E) as a function of ε all available data agreed to within a factor of 2 to 3. It was further noted that cases for similar mass ratio cluster together. This allows the generation of a whole family of curves as demonstrated by Eckstein and Biersack [EC 86]. In an attempt to further refine the situation Itoh et al [IT 84] have also introduced a rather complex scaling of R_N (and R_E) based on theoretical grounds.

Scaling rules are a potentially valuable tool for systematising, extending and checking data. By scaling together a number of data sets one increases the density of information available, facilitates the establishing of algebraic relationships and lends some confidence to extrapolation and interpolation. As a particular example one might use data for H, D and He as a basis for establishing the behaviour for T where there is little information and which is of importance in fusion applications. Failure of a data set to agree with a scaling relation may indicate that the data is incorrect; it may of course also indicate the failure of the scaling procedure.

In a study of rare gas atom reflection from U it has been shown [EC 86] that for high mass ratios ($\mu \geqq 20$) the functional dependence of R_N (and R_E) on ε is likely to be the same for all particle - solid combinations; as μ is reduced, the functional dependence changes in a systematic manner. The corresponding behaviour for light ions will be examined to elucidate the functional dependence of R_N (and R_E) on ε by considering five mass ratio cases; $\mu \gtrsim 20$, $\mu \simeq 12$, $\mu \simeq 6$ $\mu \simeq 3$ and $\mu = 1$. In each case we show that the available data is consistent with the expression

$$R_N \text{ (or } R_E) = \frac{A_1 \ln (A_2 \varepsilon + e)}{1 + A_3 \varepsilon^{A_4} + A_5 \varepsilon^{A_6}} \quad , \qquad (4)$$

where e=2.7183 ... is the base of natural logarithm.
The parameters A_1 through A_6 are likely to be different for each mass ratio group; they differ also between R_N and R_E. The chosen function has no particular theoretical basis; in that respect it has been constructed in the same spirit as similar functions used by others [EC 79], [IT 84]. It would clearly be best to evaluate Eq. (4) for individual mass ratios but there is insufficient data to support this. Rather we shall group together data sets for approximately the same mass and treat them as one; for example a mass ratio of about 12 will be covered by a composite of He^+ + Ni (μ = 14.7), He^+ + Fe (μ = 14), D^+ + Si (μ = 14) and H^+ + C (μ = 12).

The proposed function is fitted to the data using the ALESQ non-linear least squares fitting program of Itoh and Tabata [IT 84]. It will be tested for the energy region $10^{-3} \lesssim \varepsilon \lesssim 40$, and for non-reactive projectile-target combinations. At somewhat higher energies, R_N (and R_E) tends eventually to a constant and a further term is required; this will be examined in Section 5.1. At low energies there is no data on which a study may be performed. For reactive species, such as self-ion reflection ($X^+ + X$) or H on Ti (or C), the particle reflection decreases towards zero at some finite energy related to binding energy; this will also be treated separately in Section 5.2.

3.1. High mass ratio case: $\mu \gtrsim 20$

First we shall consider the high mass ratio case ($\mu \gtrsim 20$). As our principal data source we use the extensive simulations of Eckstein, Oen and co-workers using TRIM and MARLOWE codes. For gold we use Eckstein's MARLOWE and TRIM codes [EC 79] [EC 83], excluding those data points available for H^+ above 400 keV and He^+ above 900 keV (i.e. above $\varepsilon \simeq 40$). For tungsten and iron we use the MARLOWE results of Eckstein [EC 79], while for nickel we use his TRIM results [EC 84]. For each case we have information for H^+, D^+ and He^+; the data for He^+ on Ni and Fe are excluded as being outside the chosen mass range.

The composite plots of the R_N and R_E data against reduced energy are shown in Fig. 2a and 2b, respectively. The fitted curves are also shown, while the values of fitting parameters A_1-A_6 are listed in Table 2. The curves fit the data with a relative RMS deviation of 12%. We note that the exponents of the ε-terms in the denominators are almost equal for R_N and R_E.

The fitted equations have been checked against each individual data source and against less extensive simulations for Mo and Cu, [EC 79]. The only systematic deviations from the source data are for H^+ + Au (in both R_N and R_E), for which the fitted curves exceed the source

data by 25%, for D^+ + W (R_E only) where they lie below the source data by 15%, and for He^+ + Cu, for which the source data are below the general curve by 15% for R_N and 30% for R_E.

We conclude that the fitted curve represent essentially all the available reliable data to within ± 25% and propose that they be used for prediction of cases for which no data is available.

3.2. Case: $15 \gtrsim \mu \gtrsim 12$

Data for this mass group are obtained for He^+ on Fe and Ni [EC 84] He^+ + Ti [EC 79] (experimental data), D^+ + Si [EC 79] and H^+ + C [EC 79], [EC 90]. The data show the same functional dependence on energy as the higher masses but shifted lower in absolute magnitude. Plots of the data with the lines of their best fit are shown in Fig. 3. The relative deviation is 9% for R_N and 13% for R_E, essentially the same as for the case of $\mu \gtrsim 20$. We adopt Eq. (4) with the parameters A_1-A_6 reproduced in Table 2 as representing this group of data.

3.3. Case: $7 \gtrsim \mu \gtrsim 6$

Data for this case are drawn from D^+ + C [EC 79], He^+ + Al [OE 76] and H^+ + Li [OE 84], all being TRIM or MARLOWE simulations. In this case the functional dependence of R_E and R_N on ε differs from higher mass data. We have fitted Eq. (4) with all parameters A_1-A_6 free, resulting in the curves shown in Fig. 4 and with values of the coefficients given in Table 2. The relative RMS deviation of the data from the line is about 15%, again comparable with the results at higher mass ratios.

3.4. Case: $\mu \simeq 3$

Here the available data is quite inadequate to reliably perform our fitting procedure. As reliable simulation data for R_N we have an

unpublished TRIM simulation by Eckstein [EC 90] for He^+ + C, where μ = 3.0, and the MARLOWE simulations for D^+ on Li, (μ = 3.5) by Oen and Robinson [OE 84] and by Hiskes and Schneider [HI 81]. When plotted on the basis of reduced energy ε these data are in excellent agreement. As reliable simulation data for R_E we have only unpublished TRIM simulations by Eckstein [EC 90]. Equation (4) can be fitted to these data and will reliably represent them. The result, however, gives an equation which has an asymptotic behaviour at low energies that is quite inconsistent with the fits for the higher μ cases; in essence the use of such an equation for extrapolation could be totally misleading. To avoid this, we have fixed the coefficient A_1 so that the ratios of R_N for μ = 6 and μ = 3 are the same at $\varepsilon = 10^{-3}$ (where there is no data) as they are at $\varepsilon = 10^{-2}$ (approximately where data ends). We have also fixed A_1 for R_E so that the ratio R_E/R_N at $\varepsilon = 10^{-3}$ is the same for μ = 3 as it is for μ = 12 and 6. The remainder of the parameters are then obtained by fitting to the simulation data in the same manner as previously. The result is shown in Fig. 5 along with the simulation data, and the fitting coefficients are tabulated in Table 2. The relative RMS deviation from the simulation data is about 4%.

While this procedure is somewhat arbitrary it will have little practical effect on our use of the fitting equation for extrapolation. A reduced energy ε of 10^{-2} corresponds to 10 eV He^+ on C or 2.5 eV H^+ on Be. At these energies the simulations on which all this is based are invalid. We will not be using the equations for any purpose at such energies.

3.5. Self-ion reflection: μ = 1

This is a rather special case where projectile and target are identical. There are in fact no data for light ion (H^+, D^+, T^+, He^+) reflection from a solid of the same chemical species. Self reflection may however be important in fusion devices where one has impurity ions of wall material incident on the wall. There is available extensive

data on self-reflection of candidate plasma facing materials from the TRIM simulations of Eckstein and Biersack [EC 86]. It is of interest to examine whether these data can be represented by the same formulation as the light ion reflection.

The self-reflection situation differs inherently from the previously considered cases in that the projectile is likely to be retained and the reflection coefficients must tend to zero as energy is decreased with some finite threshold related to the binding energy of the atom in its matrix. As a result one does not anticipate that data will scale with ε at low energies and this is indeed demonstrated by Eckstein and Biersack. The threshold behaviour appears to be confined to a region up to an energy equal to about 50 times the apparent threshold; at higher energies all data again scales with ε.

We have taken the data of Eckstein and Biersack for self-reflection, removed all data at reduced energies below 50 times apparent threshold, and performed a fit of the data to Eq. (4) with all parameters free. The values obtained for the coefficients A_1-A_6 are given in Table 2 (RMS deviation being 3%). The expression (4) for R_N (or R_E), thus, provide an adequate representation of the available data for $\mu = 1$ for energies generally in excess of $\varepsilon = 10^{-3}$. The question of near threshold behaviour will be addressed in Section 5.2.

3.6. The predictive power of analytic fits

The overall result is that Eq. (4) may be used to represent light ion (H^+, D^+, T^+, He^+) reflection from a broad range of materials provided one makes some adjustments to the coefficients as shown in Table 2. For high mass ratios $\mu \geqq 20$ a single set of coefficients appears adequate; to accomodate cases with $15 > \mu > 12$ the only significant change is that of the normalizing coefficient A_1. As the mass ratio is further reduced, the functional dependence of reflection on reduced energy changes so that all coefficients must be altered to accomodate the data. It is interesting to note that the powers of ε in

the denominator of Eq. (4) (the parameters A_4 and A_6) change with μ by only relatively small amounts; this reflects the similarity of all the data sets. We show in Figs. 6 and 7 plots of R_N and R_E for all the mass ratios considered.

In order to evaluate the predictive power of the above discussed analytic fits, we examine a number of specific cases. In Fig. 8 we show a compendium of data for R_E in the case of H^+ on Cu. The value of R_E predicted by Eq. (4) using the coefficients in Table 2 for $\mu \geqq 20$ case (the solid line) is in excellent agreement with a MARLOWE simulation by Oen and Robinson [OE 84]. Note that this simulation was not used in the derivation of the fitting coefficients; thus the agreement demonstrates the ability of our equation to predict the R_E reflection coefficients. The only significant discrepancy (25-30%), between simulation and prediction is for $E \lesssim 25$ eV. It should be noted that the 5 eV energy is used in the simulations as a cut-off from which the recoiling atom is no longer followed. It is not clear whether the simulation, or indeed our equations, should satisfactorily represent the true behaviour at such low energies. We note also that the calculations of Zhengming [ZH 91] are in excellent agreement with the present formula and with MARLOWE simulations at energies above 200 eV; at lower energies the results diverge, a behavior that is typical for these calculations. The reader is cautioned that Zhengming's calculated values do not demonstrate such good agreement in all cases and each should be examined individually. Experimental measurements by Sidenius and Lenskjaer [SI 76] are 30% low at 5 keV and agree well above 20 keV; the discrepancy is probably within limits of experimental reliability. Experimental data by Tanaka et al [TA 78] are also in fair agreement with the fit. In this figure we also show (dashed line) the semi-empirical prediction of Itoh [IT 85] which dissagrees with all the predictions but is a better representation of experiment over the limited range where data exist. The overall picture is quite satisfactory. Our predicted behaviour is consistent with all other information at energies above 200 eV; at lower energies the various predictions diverge.

Figure 9 shows a comparison of energy reflection coefficients R_E for He^+ on Al, a case where $\mu = 6.75$. The predicted line by Eq. (4) is in adequate agreement with the MARLOWE simulations [OE 84]; this is not surprising since the simulation was part of the data set used to establish the fitting parameters. There is good agreement with the very limited experimental data of Hildebrandt and Manns [HI 76]. The semi-empirical prediction of Itoh et al [IT 85] agrees adequately with the present work except at very high energies. The calculations of Zhengming [ZH 91] are three-to-four times higher than the experiment and the present predictions and exhibit a rather different functional dependence on energy.

Figure 10 gives R_N for H^+ on Be, a case where there are no detailed simulations and no experiment. The mass ratio here is 9, a case for which we have no fitted curve. This is a situation where we can do no more than give an estimate. We recommend that this case be estimated using the coefficients from Table 2 applicable to mass ratios in the range $15 \gtrsim \mu \gtrsim 12$; since this is a rather free estimate we ascribe a reliability of 30% and regard the prediction as an upper estimate. The present estimate has a similarity to the semi-empirical prediction of Itoh et al [IT 85] and to the calculations of Zhengming [ZH 91]. An isolated simulation by the BABOUM code [BE 87] has a functional dependence on energy that is quite different from any other case published to date; we suggest that this be disregarded. This is a situation where more information is needed before any reliable estimates can be proposed.

In general terms, the predictions of Eq. (4) with coefficients evaluated in the quoted mass ratio bands are in good agreement with detailed simulations. They are generally consistent also with the limited experiments. Within the constraints of the mass ratio bands we believe R_N and R_E can be predicted with reliability. The present procedure is much easier to use than the semi-empirical procedure of Itoh and may be more reliable. The calculations of Zhengming [ZH 91]

generally agree with other predictions and with experiment at intermediate energies and for high mass targets; however, they may be quite misleading under other circumstances.

Equation (4), with coefficients evaluated for specific bands of the projectile-target mass ratio, provides a simple and accurate representation of all published simulation data and is compatible with the few experimental results that are available. We suggest that it may be used for extrapolation over a broad energy range and for interpolation to collision combinations for which there have not yet been detailed simulations nor experiments.

4. Evaluated Particle Reflection Data Base

In this Section we shall establish a set of best available particle reflection data for a variety of projectile-target combinations relevant to fusion. Our study of scaling relationships suggests that Eq. (4), with the appropriate coefficients from Table 2, should provide an adequate algebraic representation of the data.

For each particular case we have taken Eq. (4), with the appropriate A_1-A_6 coefficients, and matched it against the available data. In many cases there is agreement with TRIM or MARLOWE simulations to within 10% or better, agreement with Zhengming's calculations above a few keV, and agreement with experiment. In such cases Eq. (4) can be used directly to generate the reflection data in the reduced energy region $\varepsilon=10^{-3}$ to $\varepsilon=40$ with the appropriate coefficients from Table 2. We regard these as accurate to 10%. The fitted line is also used for cases where there are no other supporting information, as for example is almost always the case for T^+ projectiles. In a few cases, namely H^+ + Au, D^+ + W and He^+ + Cu, the fitted line was systematically different from the simulations by more than 10%. For these cases, we have altered the parameter A_1 to reach agreement with the simulations to within 10% in the entire reduced energy range considered. The values of the corresponding A_1 coefficients for these combinations are given in the Note under Table 3.

In a few cases, particularly for light targets, the mass ratio does not fall into the mass-ratio ranges for which the coefficients in Eq. (4) were determined and there is no reliable data from simulation or experiment. In such cases we have used the information for the closest mass ratio and assigned a reliability of 50%. It can be noted that the differences between the curves on Figs. 9 and 10 are never larger than 50% and therefore, it is quite unlikely that the estimate based on the closest mass-ratio group will be incorrect by a larger amount.

The results of our evaluation procedure are also presented in the Appendix in form of tables, and figures of the R_N and R_E coefficients. All this information in presented in terms of the

laboratory (not reduced) collision energy, E_o, expressed in keV. The values of the coefficients A_2, A_3 and A_5 given in the Appendix accordingly, differ from those in Table 2. The data information in the Appendix is supplemented by additional comments on the data accuracy, and the sources used to derive the recommended data.

All recommended data have been stored in the ALADDIN Data Base of the Atomic and Molecular Data Unit of International Atomic Energy Agency, Vienna. For retrieval of the data from this data base, the necessary searching labels are given, as well as the name of the ALADDIN data generating function (e.g. REFL1).

5. Special Situations

We shall discuss here a number of situations that fall outside the framework of our previous considerations, both in the sense of underlying physics and applicability of the scaling relation (4).

5.1. High Energies

We have set an upper limit of $\varepsilon = 40$ for application of our scaling laws; for most cases this represents a limit of 40 keV or more. In a practical sense it represents the limit for use of a stopping power formula related to the square root of projectile energy; this is employed in almost all of the published simulations. At very high energies where this law is inappropriate the reflection coefficients eventually become constant; the transition region has been studied by Eckstein and Biersack [EC 83] only for the case of H^+ and He^+ on Au. In this region the data no larger scales with ε. The available data can be fitted by an equation of the form,

$$R_N \text{ (or } R_E) = \frac{A_1 \ln (A_2\varepsilon + e)}{1+A_3\varepsilon^{A_4}+A_5\varepsilon^{A_6}} + A_7 \ln\left(\frac{A_8}{\varepsilon} + e\right) \qquad (5)$$

This equation contains our previous expression, Eq. (4), for R_N (or R_E), that has been verified for energies below ε=40, and an additional logarithmic term to describe the high energy behaviour. For the coefficients A_2 through A_6 we retain the values determined for high mass ratio data at energies below 100 keV, as quoted in Table 2. The value of A_1 for H^+ has been adjusted from the composite value to better represent the TRIM data at moderate energies; no adjustment was needed for He^+. With this input information Eq. (5) was fitted to the data of Ref. [EC 83] and the coefficients A_7 and A_8 established to represent the data at high energies. The values of the coefficients A_1-A_8 for the H^+, He^+ + Au reflection are given in Table 4.

In Figures 11 and 12, we show R_N and R_E for H^+ and He^+ on gold up to energies of 100 MeV. Our fitted line from equation (5) is in good agreement with the TRIM simulations of Eckstein and Biersack [EC 83]. It should be noted that the values of R_N (and R_E) for H^+ and He^+, at high energies, do not scale together with reduced energy ε. It is expected that the analytic expression (5) should be appropriate to fit hight energy data also for other projectile-target combinations, when such data become available.

5.2. Self-Ion Reflection

Self-ion reflection ($X^+ + X$) for a variety of metals has been covered by a TRIM simulation [EC 86]. The projectiles will chemically bond to the target leading to zero reflection at some energy related to the binding energy. In Figs. 13 and 14, we show the available data as a function of reduced energy ε. At energies about 50 times (apparent) threshold all the data scale together and this was the basis of establishing our fitted curve for $\mu = 1$. Below 50 times threshold the coefficients decrease and clearly there is no simple scaling as a function of ε. All curves, nevertheless, show similar shapes and we are again tempted to seek a single analytic expression to describe them.

The equation

$$R_N \text{ (or } R_E) = \frac{A_1 \ln(A_2\varepsilon + e)}{1+A_3\varepsilon^{A_4}+A_5\varepsilon^{A_6}} \left[1 - \left(\frac{A_7}{\varepsilon}\right)^{A_8} \right]^{A_9} \qquad (6)$$

is proposed as a representation of these special cases. The first factor is recognized as our standard fitting expression [Eq. (4)] and the coefficients are established by the procedure discussed in Section 3 for the case $\mu = 1$. The second factor (in square brackets) represents the threshold behaviour.

The coefficient A_7 was taken to be five times the sublimation energy of target material (expressed in units of keV), which approximately corresponds to the apparent threshold, and the coefficients A_8 and A_9 have been determined for each of the considered cases by fitting Eq. (6) to the TRIM data. All coefficients are listed in Table 5. The fitting curves are also shown in Figs. 13 and 14.

5.3. Projectile Retention

For certain targets the projectile will be chemically retained so changing composition. Particular examples are hydrogen into C and Ti where chemical bonding is possible [EC 78] [AR 89a]. We should also include H (as well as D and T) on Ni where the projectiles migrate to form a surface layer [AR 89a]; a similar effect may occur for other metals but there has as yet been no systematic test. Reflection of projectiles from the hydrogen component of the target is smaller than that from the heavier target atoms; the reflection coefficient from the composite is, therefore, smaller than that of the pure target as has been demonstrated by simulations and experiment [AR 89a], [AR 89b]. It is possible to modify simulations to take into account any target composition or the presence of layers. There is no obvious way in which the scaling relations can be modified to accomodate this.

The data we present in the tables and as represented by Eq. (4) and the parameters of Table 2, are representative of a pure target. During a practical experiment the target may be initially pure, but as dose and retention increase the reflection coefficients will fall. We have made no attempt to model this situation and refer the reader to the original papers on specific cases.

5.4. Composite Targets

Eckstein suggests [EC 84] that a composite target $A_x B_y$ should again scale to the some rules as pure materials provided that we use in the scaling an average target mass

$$M^c = \frac{X M_A + Y M_B}{X + Y} \tag{7}$$

and target atomic number

$$Z^c = \frac{X Z_A + Y Z_B}{X + Y} \quad . \tag{8}$$

The limited available data [EC 84] show that this is only a very general approximation and is quite inappropriate for hydrides and for other compounds of elements of greatly different atomic numbers. There is insufficient information to develop a data base for composite targets.

6. Conclusions

We have shown that particle reflection coefficients scale with reduced energy ε and mass ratio μ. Available data for limited mass ratio ranges have been grouped together as a function of ε, and Eq. (4) fitted to represent them. The resulting formulation is found to reliably represent the available data and is used with some confidence to interpolate for collision combinations of interest to fusion where there are no experiments nor simulations.

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Table 1: Values of the energy scaling parameter ε_L for some ion-target combinations [EC 84]

Target atom			ε_L				
Element	Z_2	M_2	H	D	T	^3He	^4He
Be	4	9.01	3.900	3.545	3.249	1.504	1.390
B	5	10.81	3.008	2.773	2.572	1.200	1.117
C	6	12.0	2.414	2.242	2.092	0.9814	0.9200
Al	13	26.98	0.9449	0.9123	0.8819	0.4223	0.4087
Si	14	28.09	0.8604	0.8318	0.8050	0.3862	0.3742
Ti	22	47.90	0.4871	0.4774	0.4680	0.2266	0.2222
Fe	26	55.85	0.3934	0.3866	0.3800	0.1845	0.1814
Ni	28	58.69	0.3575	0.3516	0.3459	0.1682	0.1655
Cu	29	63.54	0.3420	0.3368	0.3317	0.1614	0.1590
Nb	41	92.91	0.2188	0.2165	0.2142	0.1047	0.1037
Mo	42	95.95	0.2121	0.2099	0.2078	0.1016	0.1006
Ag	47	107.87	0.1832	0.1816	0.1799	0.08814	0.08735
Ta	73	180.95	0.1032	0.1026	0.1021	0.05024	0.04997
W	74	183.92	0.1014	0.1008	0.1003	0.04937	0.04911
Au	79	197.0	0.09305	0.09258	0.09212	0.04538	0.04515

Table 2: Values of fitting parameters in Eq. (4) for various mass ratio ranges

Mass Range	Reflection Parameters	A_1	A_2	A_3	A_4	A_5	A_6	Note
$\mu > 20$	R_N	0.8250	21.41	8.606	0.6425	1.907	1.927	1
	R_E	0.6831	27.16	15.66	0.6598	7.967	1.822	1
$15 \geq \mu \geq 12$	R_N	0.6192	20.01	8.922	0.6669	1.864	1.899	1
	R_E	0.4484	27.16	15.66	0.6598	7.967	1.822	1
$7 \geq \mu \geq 6$	R_N	0.5173	2.549	5.325	0.5719	1.094	1.933	1
	R_E	0.4222	3.092	13.17	0.5393	4.464	1.877	1
$\mu \simeq 3$	R_N	0.3680	2.985	7.122	0.5802	4.211	1.597	1, 2
	R_E	0.2058	3.848	19.07	0.4872	15.13	1.638	1, 2
$\mu = 1$	R_N	0.02129	16.39	26.39	0.9131	6.249	2.550	3
	R_E	0.001445	404.7	73.73	0.6519	34.66	1.971	3

Notes:

1. The fits are limited to the reduced energy range $10^{-3} \leq \varepsilon \leq 40$. For presentation of data above ε=40, when available, see Section 5.1.

2. The available data base for this case is very poor (see Section 3.4.).

3. This is based on the special case of self reflection. Below $\varepsilon = 10^{-3}$ a threshold term must be added (see Section 5.2.).

Table 3: Projectile-target combinations included in the present reflection data base

Mass ratio range	Projectile-target combinations
$\mu \geq 20$	H^+, D^+, T^+, $^4He^+$ + Mo H^+ + AL, Si, Ti, Fe, Ni, Cu, W, Au* D^+ + Ti, Fe, Ni, Cu, W*, Au T^+ + Fe, Ni, Cu, W, Au $^4He^{2+}$ + Cu*, W, Au
$15 \geq \mu \geq 12$	H^+ + B, Be, C D^+, T^+ + AL, Si T^+ + Ti $^4He^+$ + Ti, Fe, Ni
$7 \geq \mu \geq 6$	D^+ + B, Be, C $^4He^+$ + AL, Si
$\mu \simeq 3$	T^+, $^4He^+$ + B, Be, C

* Note:

The values of parameters $A_1(R_N)$ and $A_1(R_E)$ for these combinations are different than those given in Table 2: H^+ + Au: $A_1(R_N) = 0.6188$, $A_1(R_E) = 0.5123$; D^+ + W: $A_1(R_E) = 0.8197$; He^+ + Cu: $A_1(R_N) = 0.7013$, $A_1(R_E) = 0.4782$.

Table 4: Values of the fitting parameters in Eq. (5) for H^+ and He^+ on Au

	R_N		R_E	
	H^+	He^+	H^+	He^+
A_1	0.6180	0.8250	0.5123	0.6831
A_2	21.41	21.41	27.16	27.16
A_3	8.606	8.606	15.66	15.66
A_4	0.6425	0.6425	0.6598	0.6598
A_5	1.907	1.907	7.967	7.967
A_6	1.927	1.927	1.822	1.822
A_7	6.286 E-05	5.309 E-05	4.766 E-05	1.602 E-05
A_8	1.558 E+05	4.955 E+03	2.131 E+05	2.964 E+04

Note: The coefficients A_2 through A_6 are the same as on Table 2 (for $\mu > 20$). The coefficient A_1 for H^+ is an adjusted value as described in the text.

Table 5: Values of the fitting parameters A_7-A_9 Eq. (6) for self-ion reflection*

Species	Reflection Coefficient	A_7	A_8	A_9
Li + Li	R_N	7.444	1.314	10.53
	R_E	7.444	1.859	14.82
Be + Be	R_N	7.518	0.7136	3.367
	R_E	7.518	1.101	4.388
C + C	R_N	6.479	0.6467	2.577
	R_E	6.479	0.9572	3.213
Si + Si	R_N	5.637×10^{-1}	0.7965	4.082
	R_E	5.637×10^{-1}	0.9764	3.473
Ni + Ni	R_N	1.073×10^{-1}	1.283	4.916
	R_E	1.073×10^{-1}	1.315	4.533
Mo + Mo	R_N	6.397×10^{-2}	1.048	5.318
	R_E	6.397×10^{-2}	1.269	6.368
W + W	R_N	2.226×10^{-2}	1.003	5.258
	R_E	2.226×10^{-2}	1.021	4.749

* Note:

The values of parameter A_1-A_6 in Eq. (6) are given in Table 2 for the case $\mu = 1$.

Figure Captions

Fig. 1. Measured energy distributions for deuterium reflection from C [AR 89b] compared with the calculated spectrum by Zhengming [ZH 91] (shown as crosses with a line drawn to guide the eye).

Fig. 2. Number reflection coefficients R_N and R_E as a function of reduced energy ε for high mass ratio cases ($\mu > 20$). For convenience the individual data points for R_N are shown in (a) and the individual data points for R_E in (b). The solid line is the fit of Eq. (4) to the R_N data with the coefficients shown in table 2; the dashed line is the corresponding fit for R_E. Data sources are as follows: Gold target: ● H^+ [EC 83], O H^+ [EC 79], ∇ D^+ [EC 79], ▼ He^+ [EC 83]; Tungsten target: Δ H^+ [EC 79], ▲ D^+ [EC 79]; ◇ He^+ [EC 79]; Iron target: □ H^+ [EC 79]; ■ D^+ [EC 79]; Nickel ◆ H^+ [EC 84]; * D^+ [EC 84].

Fig. 3. R_N and R_E as a function of reduced energy ε for $15 > \mu \geq 12$. The lines are a fit of Eq. (4) to the data with the coefficients shown in Table 2. Data sources are as follows: Iron target: ■ He^+ [EC 79]; Nickel target: Δ He^+ [EC 84], Titanium target: □ He^+ [EC 79]; Silicon target: ▼ D^+ [EC 79]; Carbon target: O, ●, ∇, H^+ [EC 79]. The solid line is the fit of Eq. (4) for R_N; the dashed line is the fit for R_E. Coefficients are given in Table 2.

Fig. 4. R_N and R_E as a function of reduced energy ε for $7 \geq \mu \geq 6$. The lines are a fit of Eq. (4) to the data. Data sources are as follows: Aluminum target: ∇ He^+ [OE 76]; Carbon target: ●, O D^+ [OE 79]; Lithium target: ▼ H^+ [OE 84]. The solid line is the fit for R_N; the dashed line the fit for R_E. Coefficients are given in Table 2.

Fig. 5. R_N and R_E as a function of reduced energy ε for $\mu \simeq 3$. The lines are a fit of Eq. (4) to the data. Data sources are as follows: Carbon target: O He^+ [EC 79]; Lithium, ∇ D^+ [OE 84], ● D^+ [HI 81]. The solid line is the fit for R_N; the dashed line the fit for R_E. Coefficients are given in Table 2.

Fig. 6. Analytic fits of particle reflection coefficients as a function of reduced energy ε for the mass ratios $\mu \geq 20$, $15 > \mu \geq 12$, $7 \geq \mu \geq 6$, $\mu \simeq 3$ and $\mu = 1$.

Fig. 7. Analytic fits of energy reflection coefficients as a function of reduced energy ε for the mass ratios $\mu \geq 20$, $15 > \mu \geq 12$, $7 \geq \mu \geq 6$, $\mu \simeq 3$ and $\mu = 1$.

Fig. 8. Energy reflection coefficient R_E for H^+ + Cu shown as a function of projectile energy. The solid line is the prediction of Eq. (4) with the parameters listed in Table 2 for the case of $\mu > 20$. The dashed line is the prediction of the semi-empirical formula by Itoh et al. [IT 85]. Solid circles are the MARLOWE simulations of Oen and Robinson [OE 84]; solid triangles are the calculations of Zhenming et al. [ZH 91]. The open triangles are the experimental data of Sidenius and Lenskjaer [SI 76] and the open circles are the experimental data of Tanaka et al [TA 78].

Fig. 9. Energy reflection coefficient R_E for He^+ + Al shown as a function of projectile energy. The solid line is the prediction of Eq. (4) with the parameters listed in Table 2 for the case of $7 \geq \mu \geq 6$. The dashed line is the prediction of the semi-empirical formula by Itoh et al [IT 85]. The solid circles are the MARLOWE simulations of Oen and Robinson [OE 84]; the triangles are calculations by Zhengming et al. [ZH 91]. The open circles are the experimental measurements by Hildebrand and Manns [HI 76].

Fig. 10. Particle reflection coefficient R_N for H^+ + Be shown as a function of projectile energy. The solid line is the prediction of Eq. (4) with the parameters listed in Table 2 for the case of $7 \geq \mu \geq 6$. The dashed line is the prediction of the semi-empirical fitting procedure by Itoh et al [IT 85]. The triangles are calculations by Zhengming et al. [ZH 91]. The open squares are Monte Carlo simulations by the BABOUM code [BE 87].

Fig. 11. Particle reflection coefficients for H^+ and He^+ on gold, including high energies. The lines (solid for H^+ and dashed for He^+) are the fit of Eq. (5) as described in the text. Circles are TRIM simulations [EC 83] (solid for H^+ and open for He^+).

Fig. 12. Energy reflection coefficients for H^+ and He^+ on gold, including high energies. The lines (solid for H^+ and dashed for He^+) are the fit of Eq. (5) as described in the text. Circles are TRIM simulations [EC 83] (solid for H^+ and open for He^+).

Fig. 13. Self-ion particle reflection coefficients (a) for Li^+ + Li(o), Be^+ + Be(●), C^+ + C(▽), Si^+ + Si(▼), Ni^+ + Ni(□), Mo^+ + Mo(■) and W^+ + W(Δ). Symbols are the TRIM simulation results [EC 86]; the lines represent the fits of the data with Eq. (6). Coefficients A_7-A_8 are given in Table 4.

Fig. 14. Self-ion energy reflection coefficients for Li^+ + Li, Be^+ + Be, C^+ + C, Si^+ + Si, Ni^+ + Ni, Mo^+ + Mo and W^+ + W. Symbols, as on Fig. 12, are the TRIM simulation results [EC 86]; the lines represent the fits of the data with Eq. (6). Coefficients A_7-A_8 are given in Table 5.

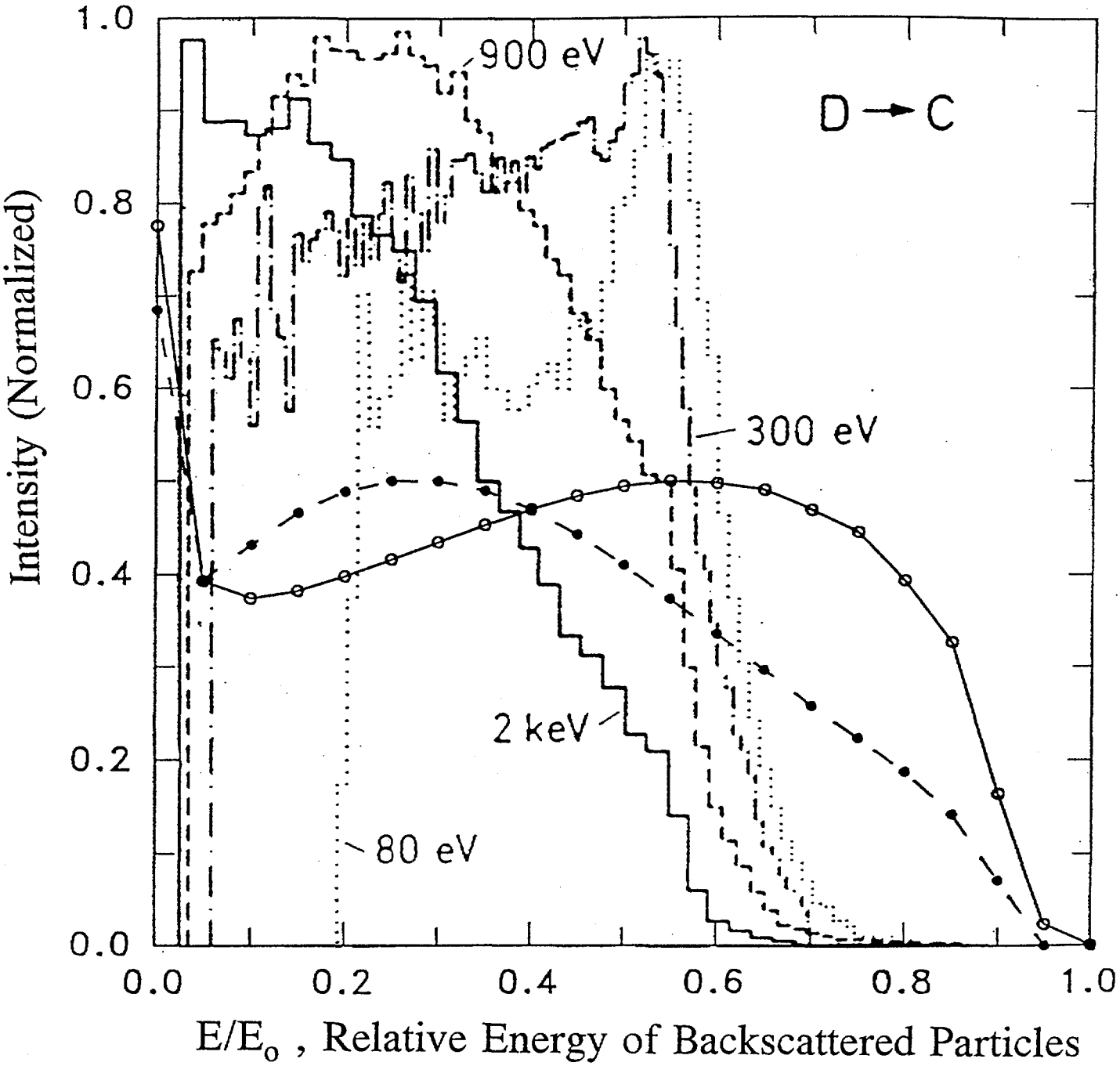

1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Intensity (Normalized)
E/E$_o$, Relative Energy of Backscattered Particles
900 eV
D → C
300 eV
2 keV
80 eV

Fig. 1

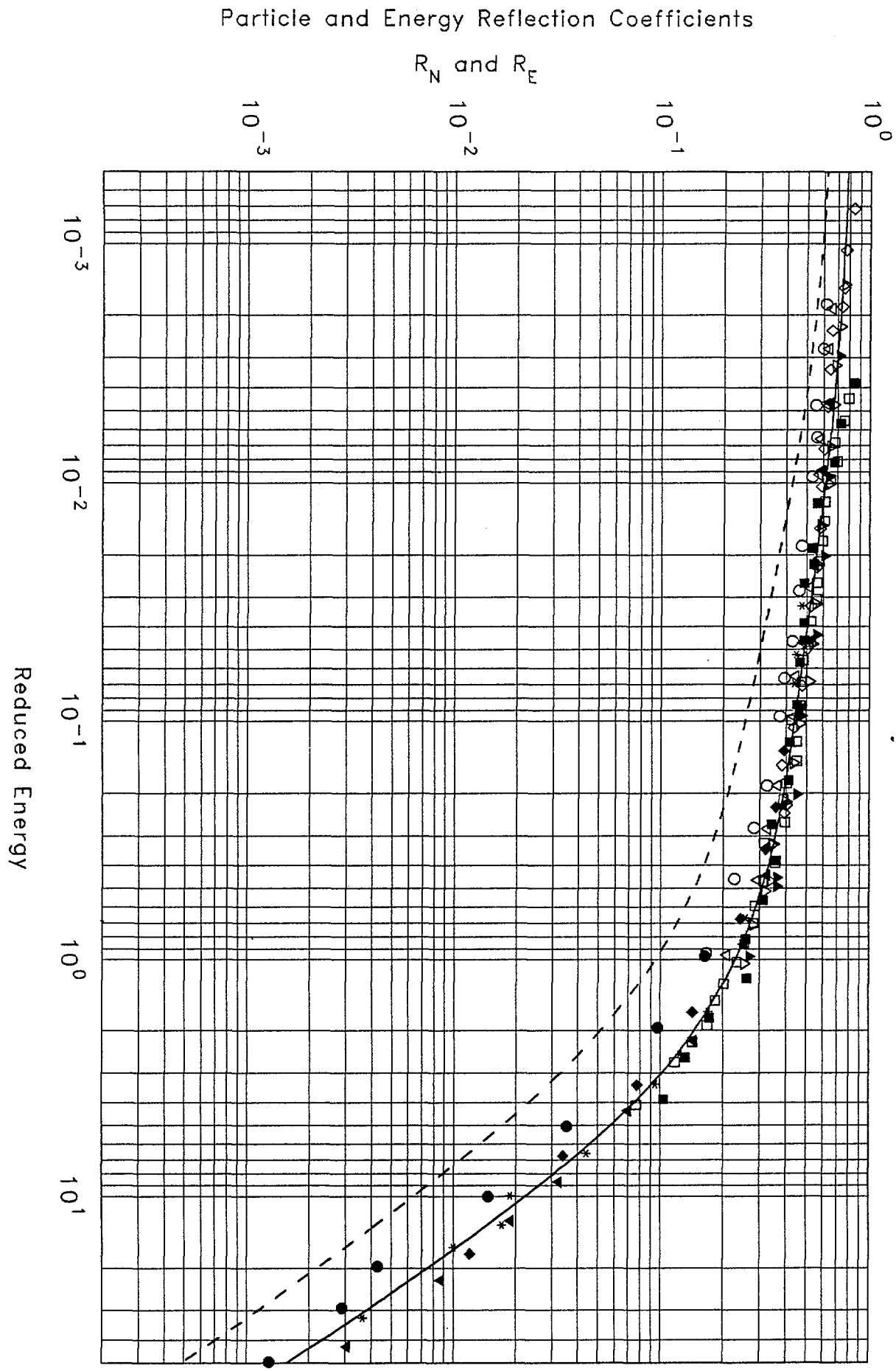

Particle and Energy Reflection Coefficients
R_N and R_E
10^{-3}
10^{-2}
10^{-1}
10^{0}
Reduced Energy
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}

Fig. 2a

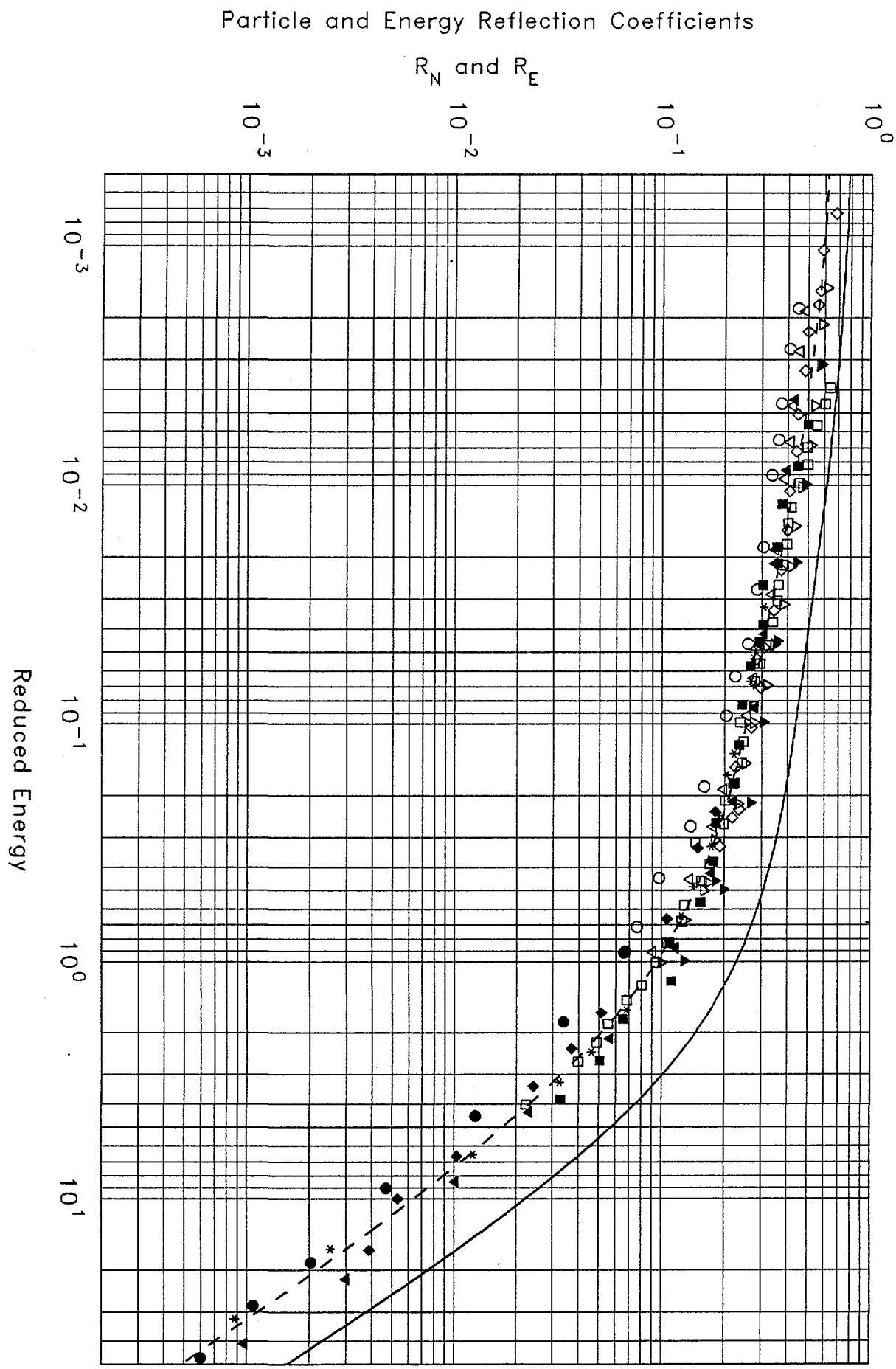

Particle and Energy Reflection Coefficients
R_N and R_E
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
Reduced Energy

Fig. 2b

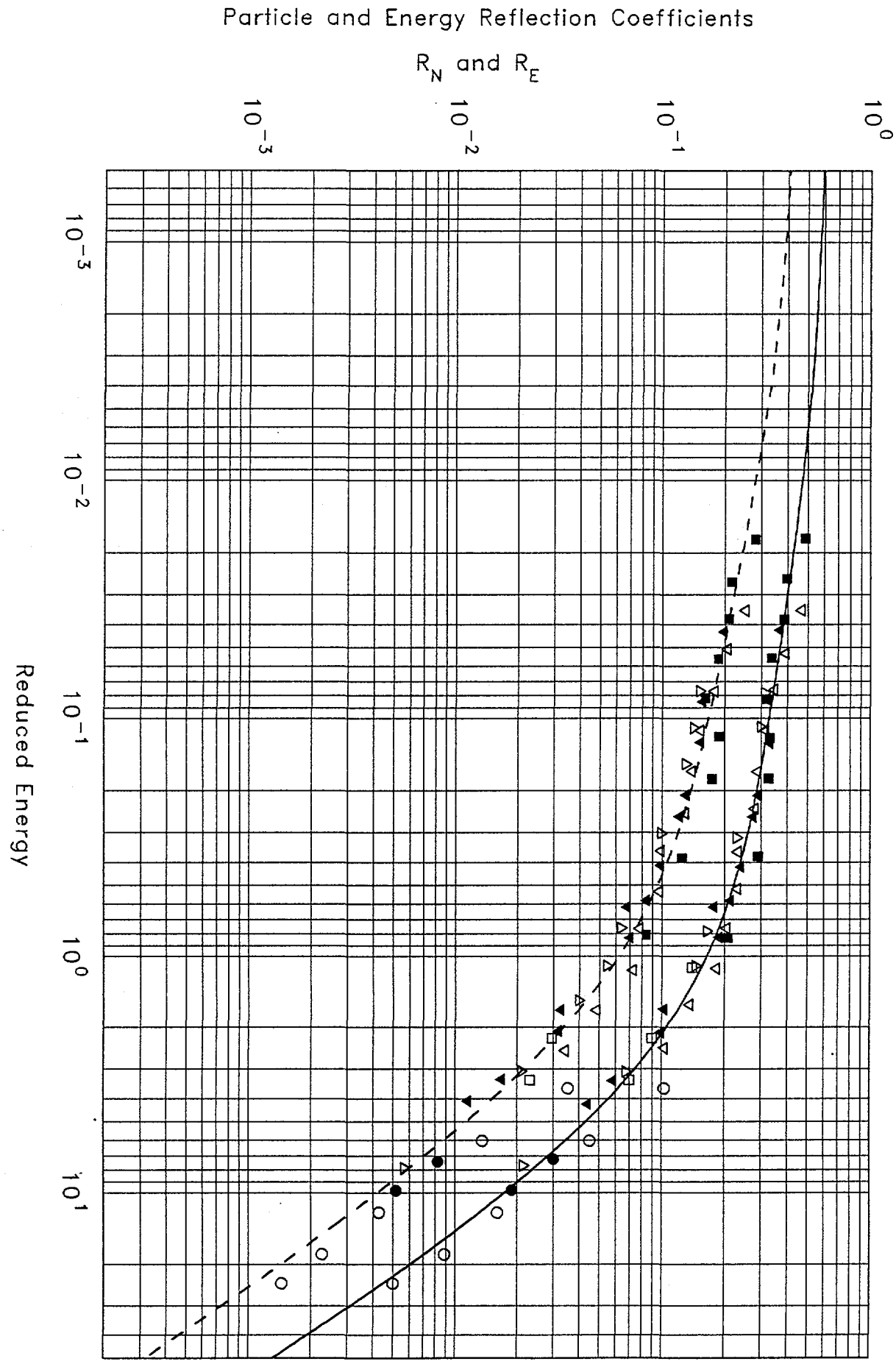

Particle and Energy Reflection Coefficients
R_N and R_E
10^0
10^{-1}
10^{-2}
10^{-3}
Reduced Energy
10^{-3}
10^{-2}
10^{-1}
10^0
10^1

Fig. 3

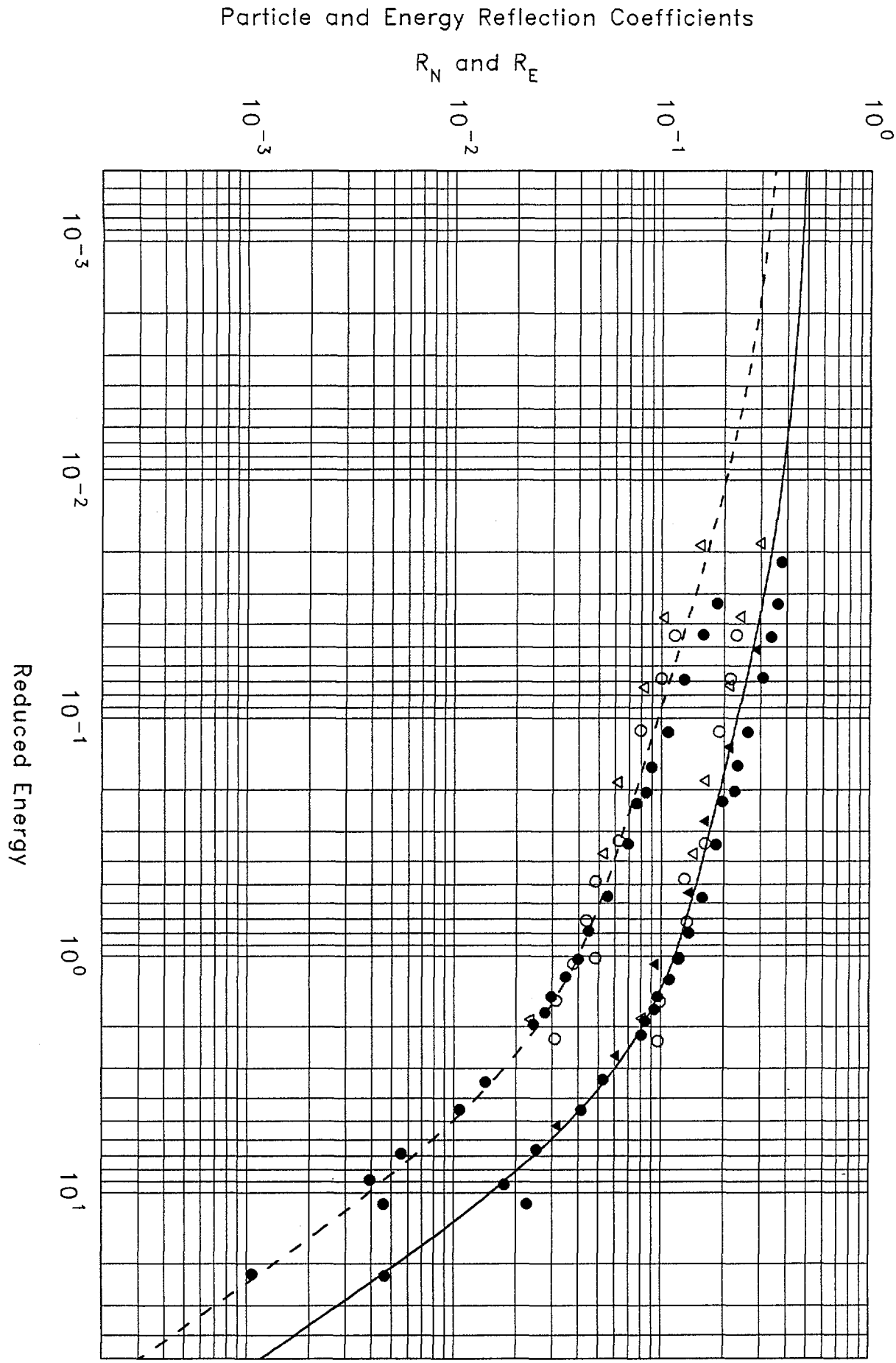

Particle and Energy Reflection Coefficients
R_N and R_E
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
Reduced Energy

Fig. 4

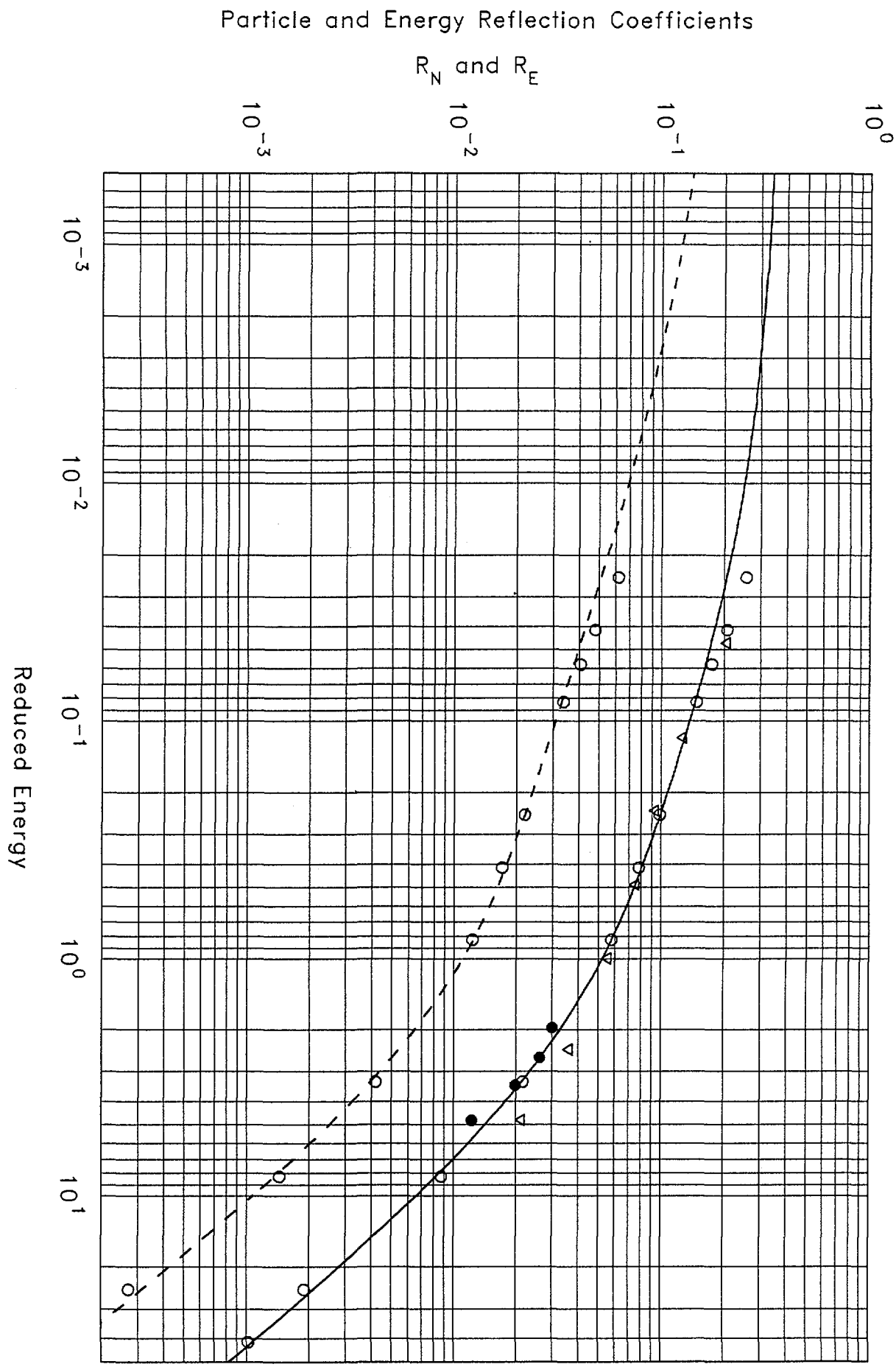

Particle and Energy Reflection Coefficients
R_N and R_E
10^{-3}
10^{-2}
10^{-1}
10^{0}
Reduced Energy
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}

Fig. 5

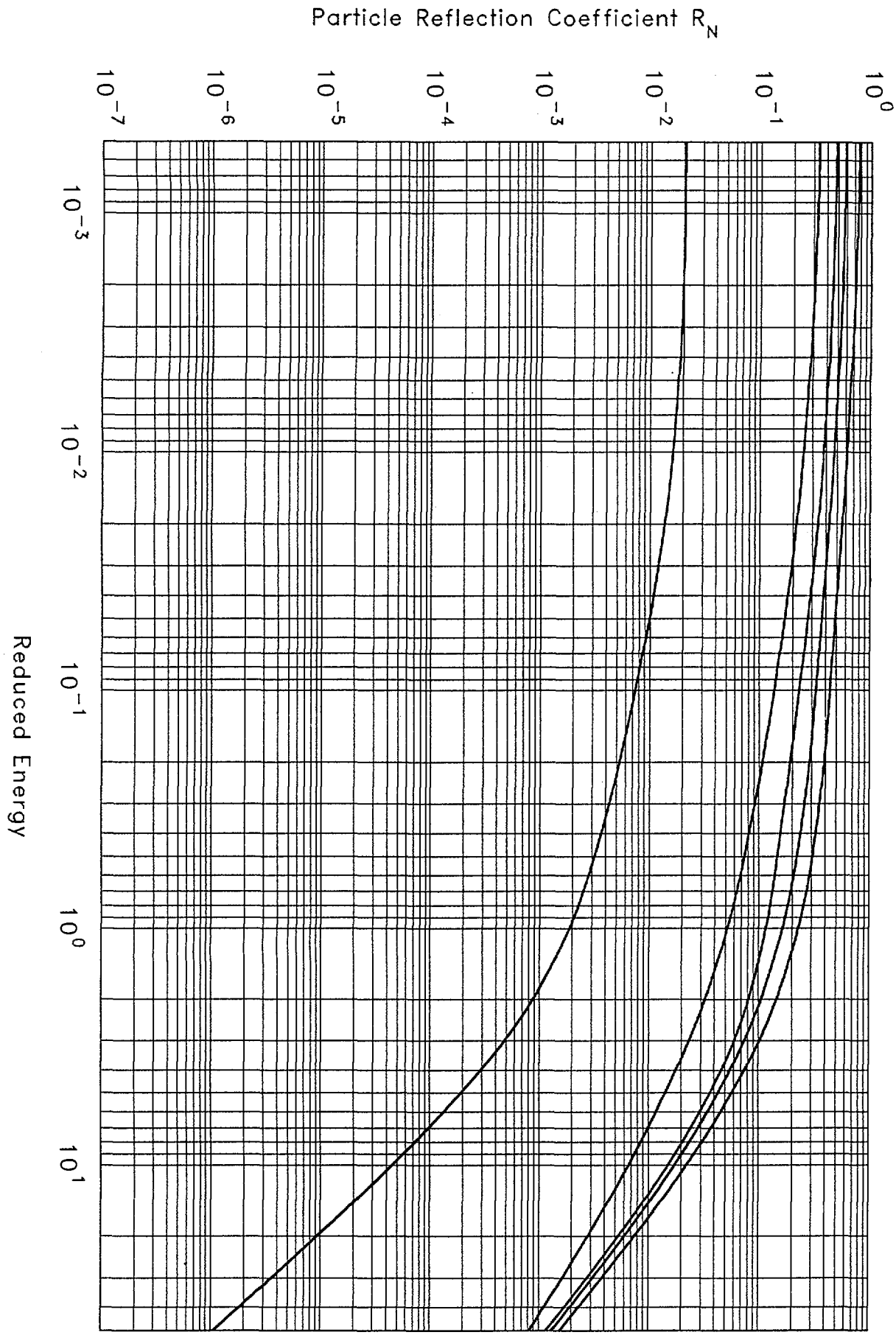

Particle Reflection Coefficient R_N
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Reduced Energy
10^{-3}
10^{-2}
10^{-1}
10^0
10^1

Fig. 6

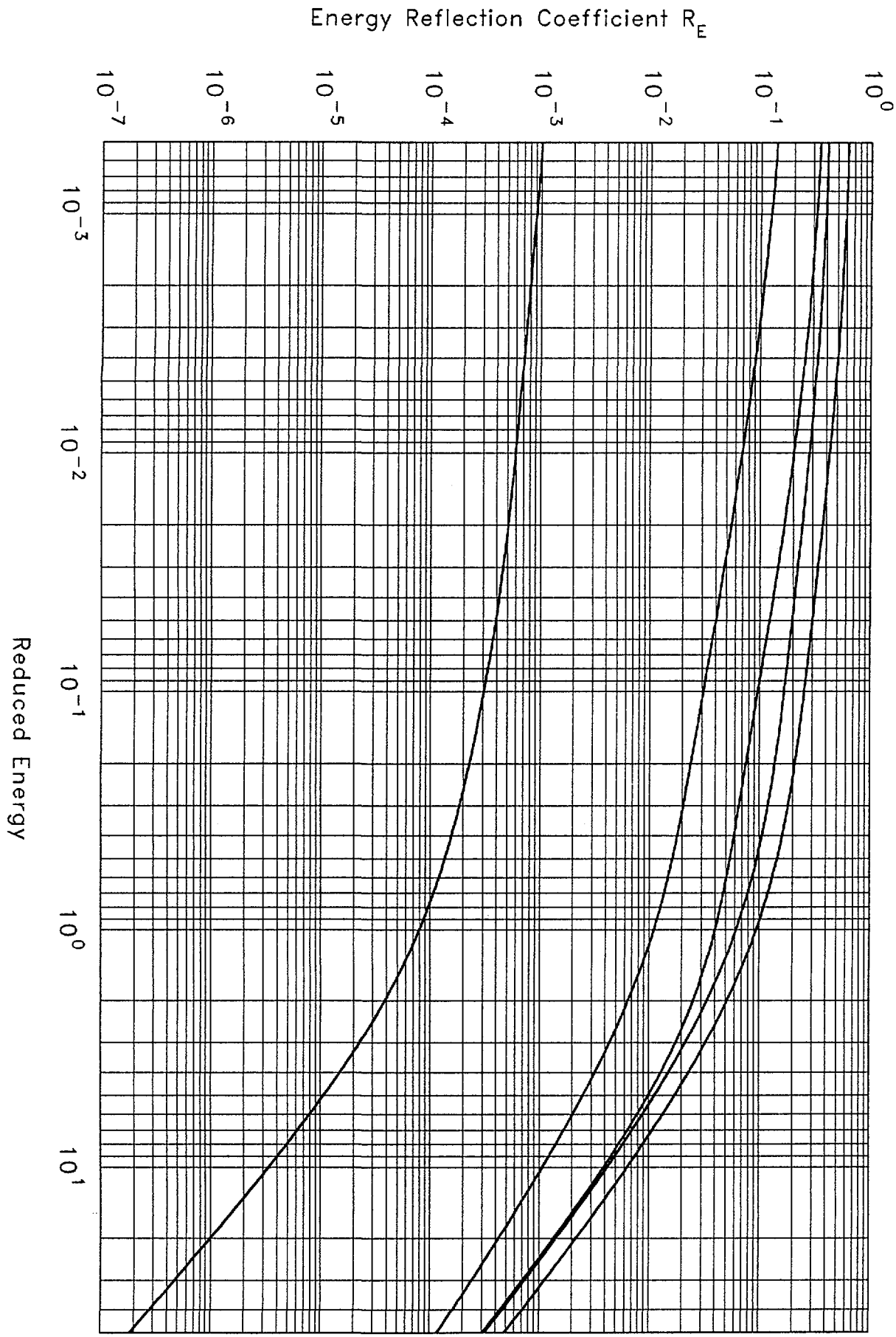

Energy Reflection Coefficient R_E
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Reduced Energy
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}

Fig. 7

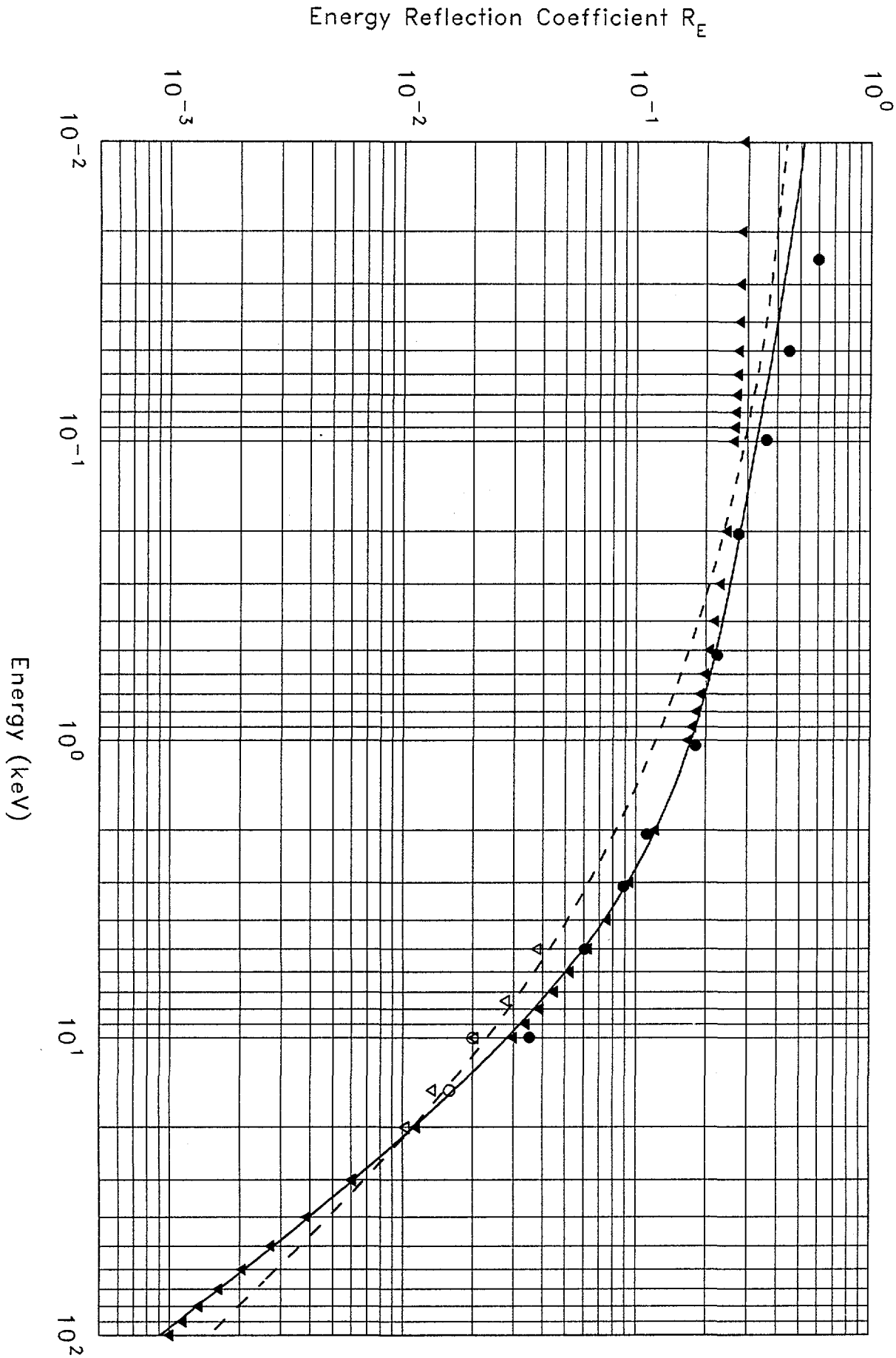

Energy Reflection Coefficient R_E
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
Energy (keV)

Fig. 8

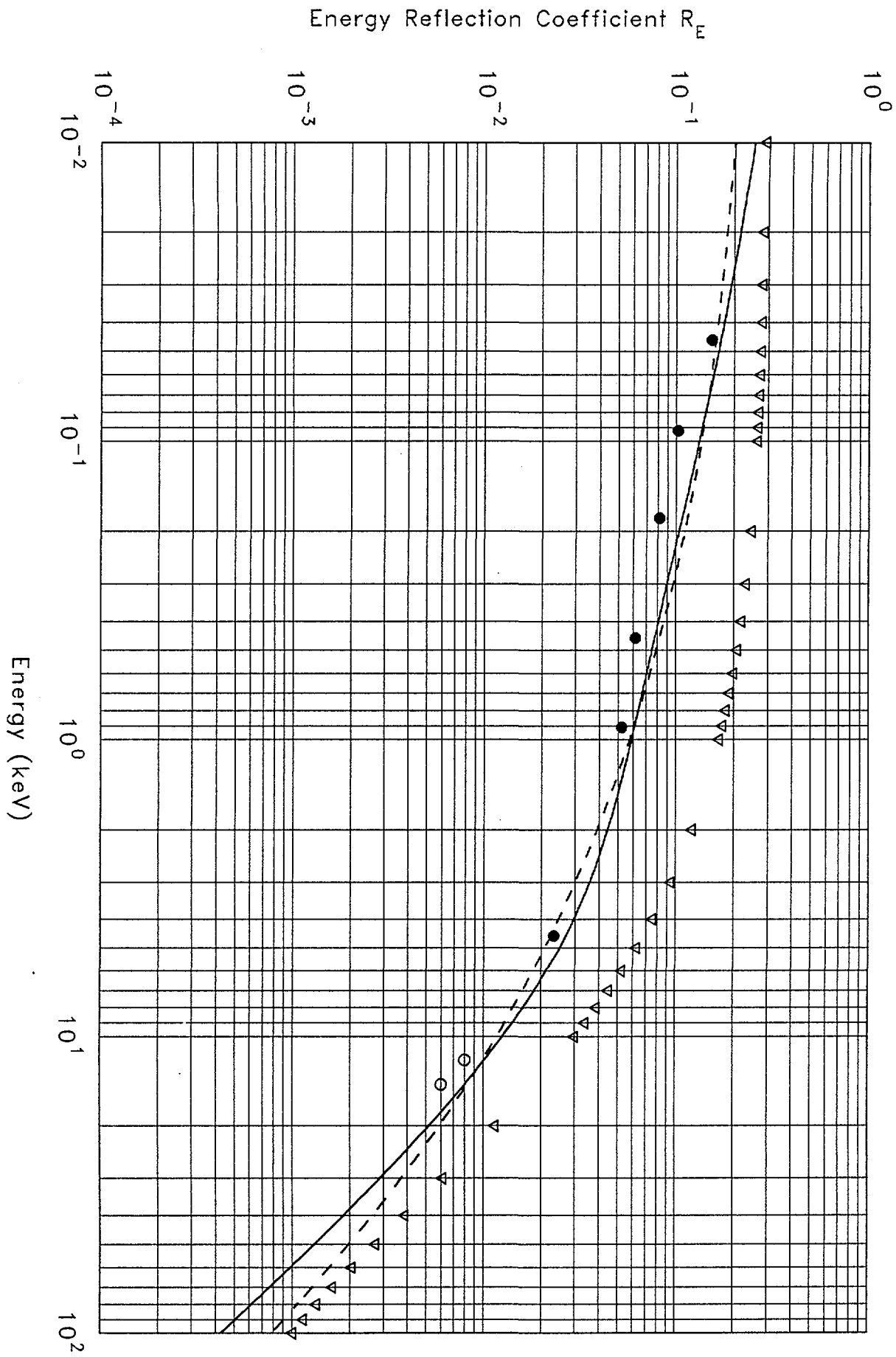

Energy Reflection Coefficient R_E
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
Energy (keV)
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

Fig. 9

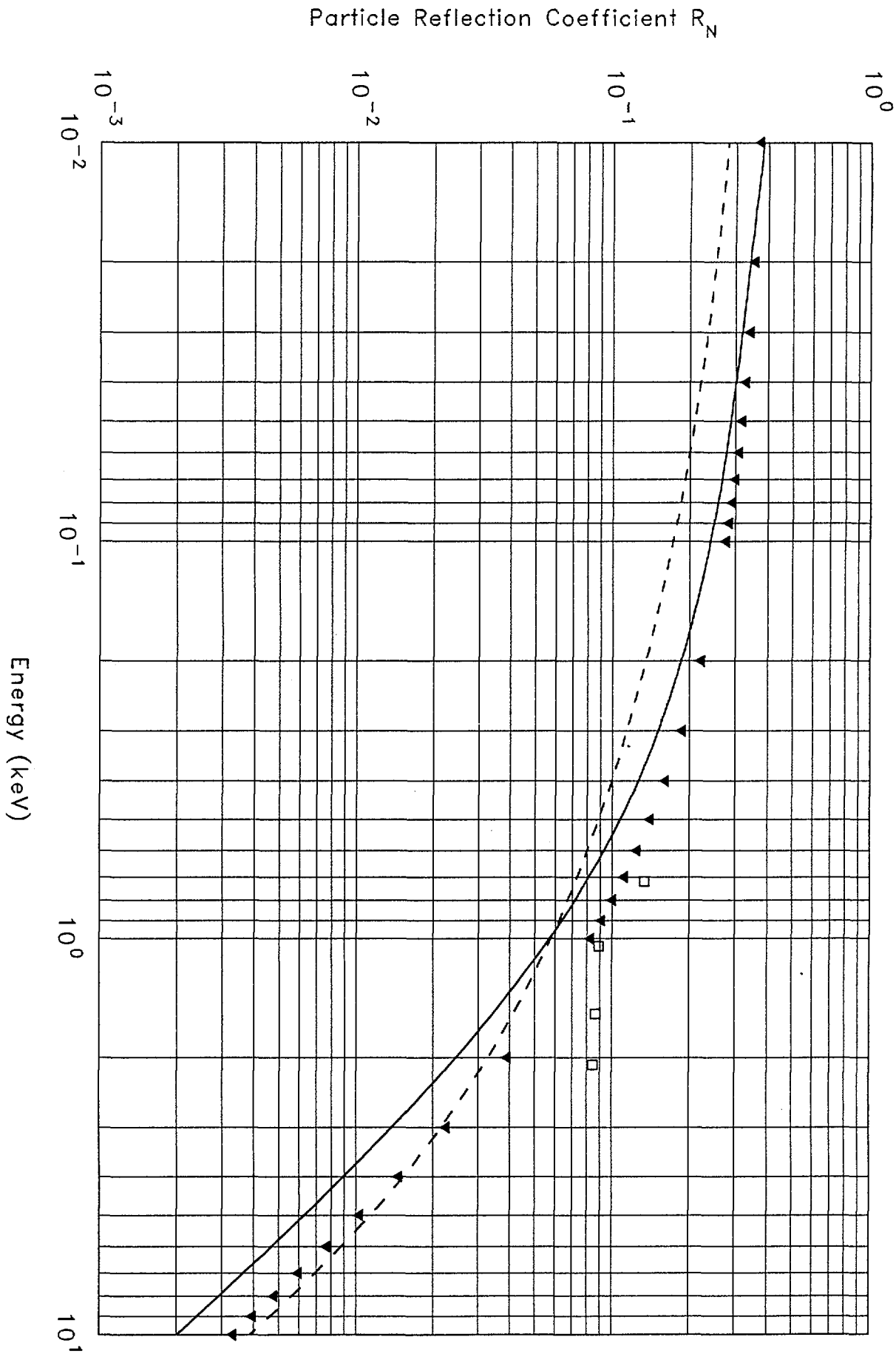

Particle Reflection Coefficient R_N
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
Energy (keV)

Fig. 10

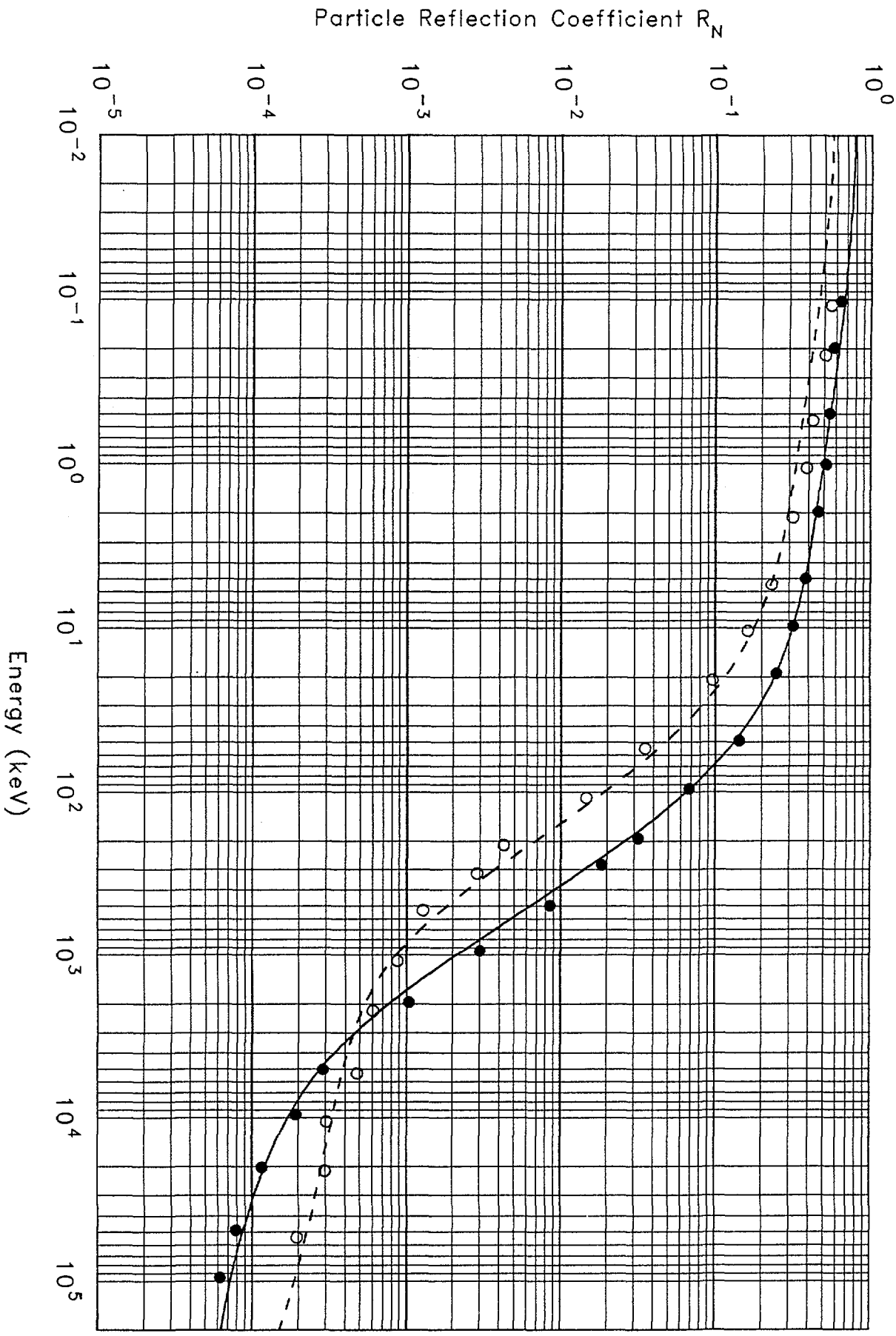

Particle Reflection Coefficient R_N
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4
10^5
Energy (keV)

Fig. 11

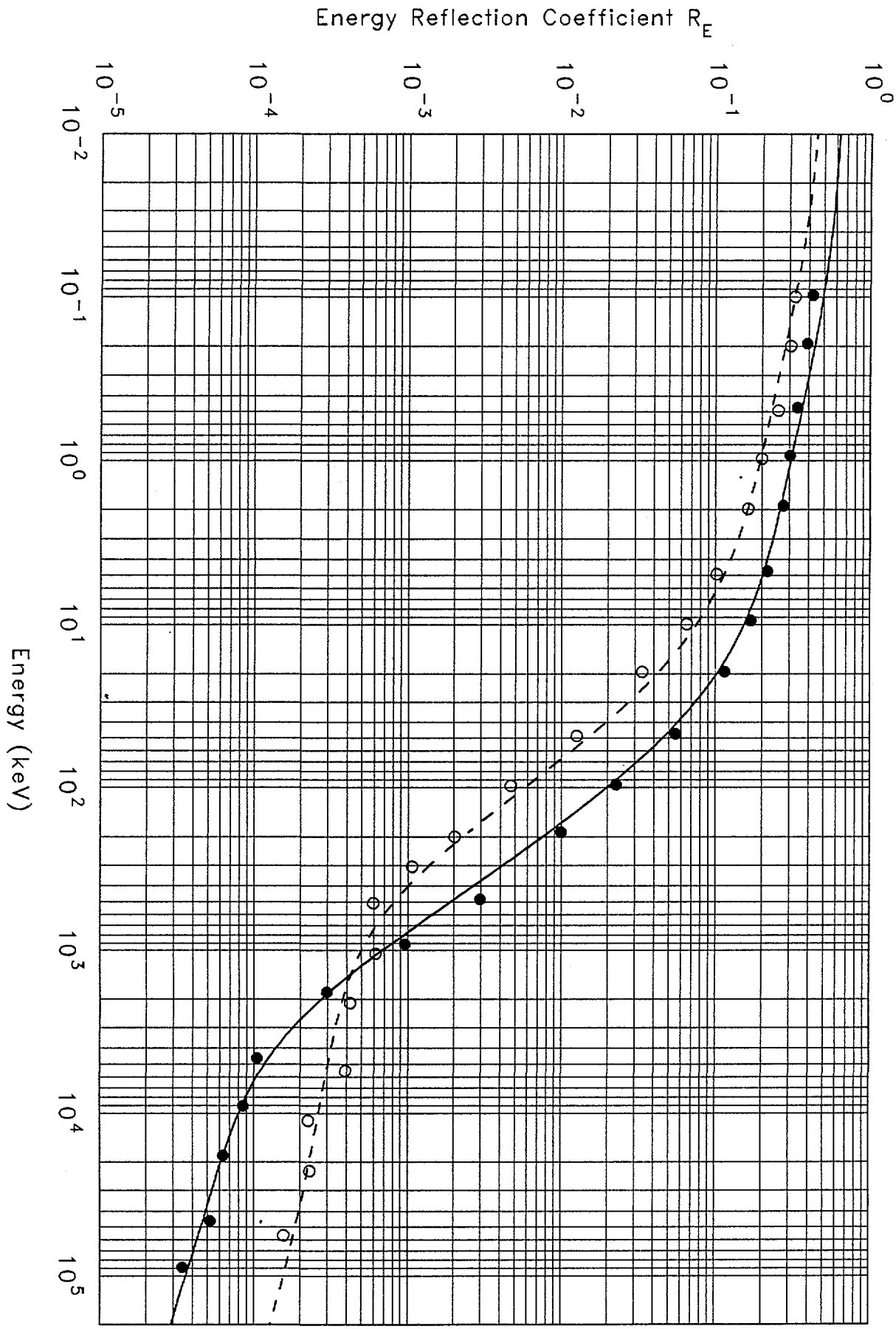

Energy Reflection Coefficient R_E
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Energy (keV)
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4
10^5

Fig. 12

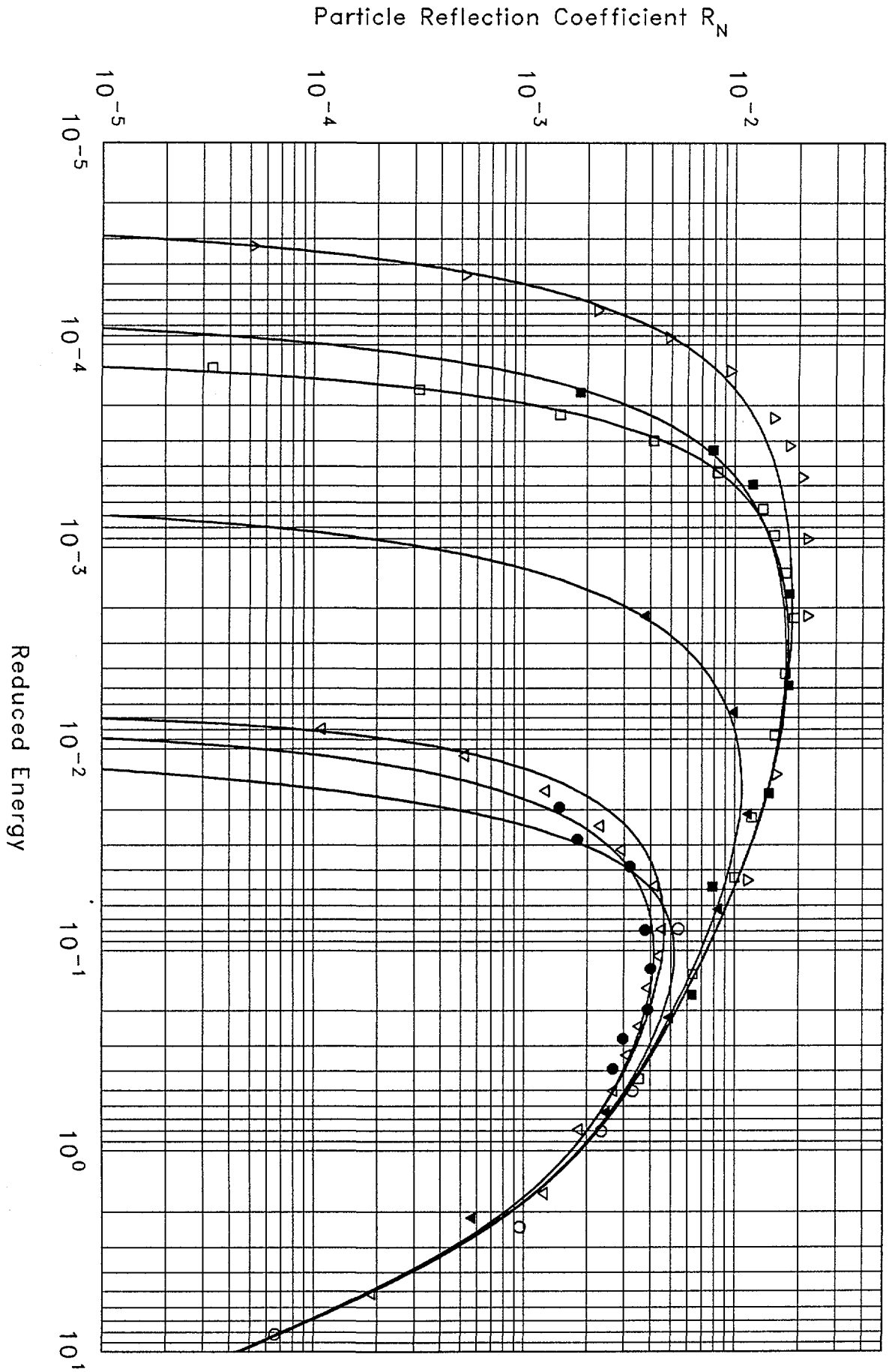

Particle Reflection Coefficient R_N
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
Reduced Energy

Fig. 13

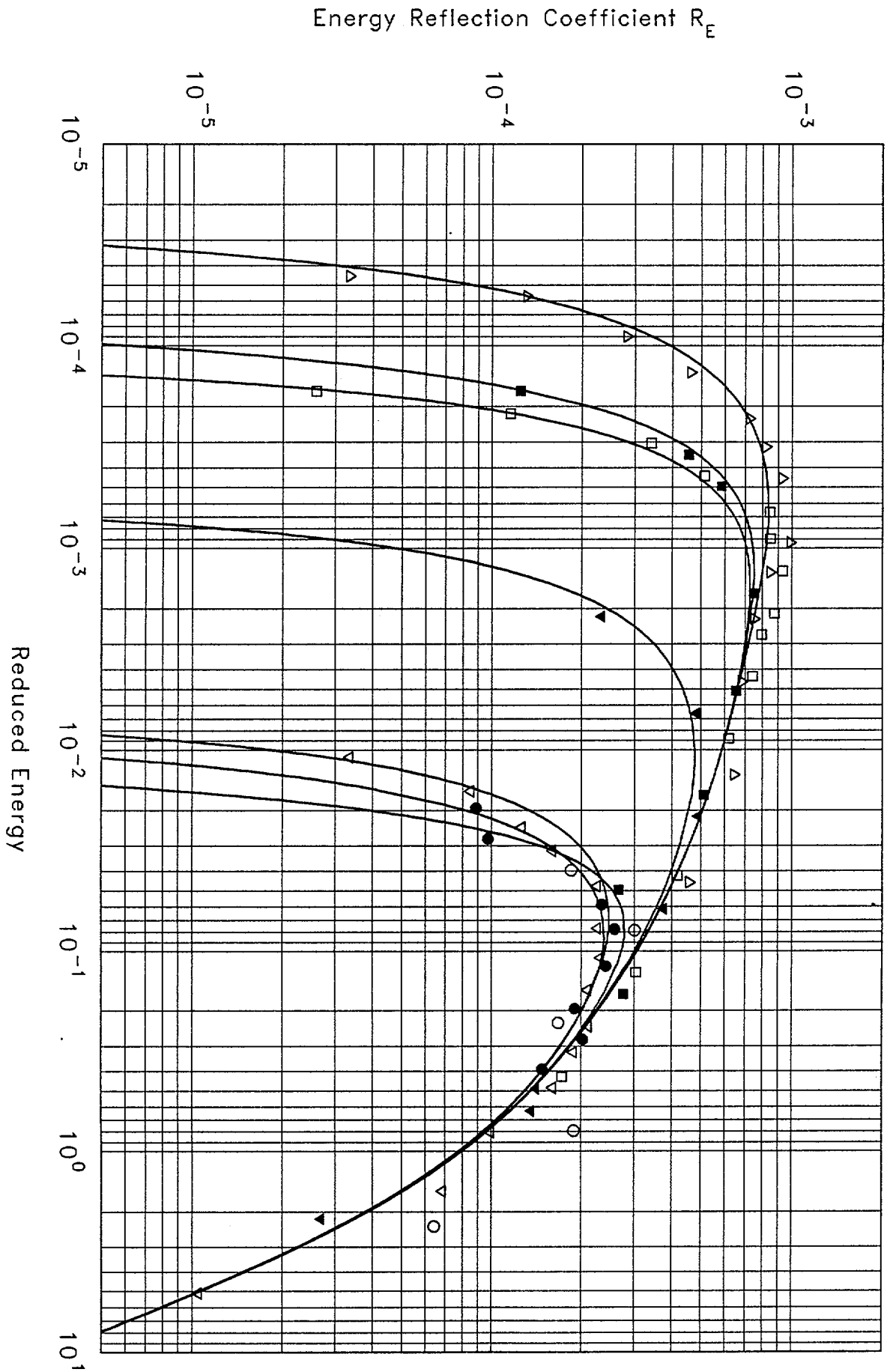

Energy Reflection Coefficient R_E
10^{-3}
10^{-4}
10^{-5}
Reduced Energy
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}

Fig. 14

APPENDIX

RECOMMENDED PARTICLE AND ENERGY REFLECTION DATA FOR H^+, D^+, T^+ AND $^4He^+$ COLLIDING WITH Be, B, C, Al, Si, Ti, Fe, Ni, Cu, Mo, W AND Au SURFACES AT NORMAL INCIDENCE

H^+, D^+, T^+, $^4He^+$ + Be – Particle Reflection R_N

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	3.82E−01	2.98E−01	1.91E−01	2.33E−01
2.00E−02	3.41E−01	2.53E−01	1.57E−01	1.99E−01
5.00E−02	2.87E−01	1.98E−01	1.15E−01	1.53E−01
1.00E−01	2.40E−01	1.63E−01	8.88E−02	1.22E−01
2.00E−01	1.85E−01	1.32E−01	6.54E−02	9.45E−02
5.00E−01	1.07E−01	8.75E−02	3.81E−02	6.32E−02
1.00E+00	5.69E−02	5.18E−02	2.17E−02	4.23E−02
2.00E+00	2.45E−02	2.39E−02	1.08E−02	2.49E−02
5.00E+00	6.27E−03	6.42E−03	3.64E−03	1.00E−02
1.00E+01	2.01E−03	2.09E−03	1.47E−03	4.42E−03
2.00E+01	–	–	–	1.81E−03
5.00E+01	–	–	–	5.22E−04

Accuracy: H^+ : 30 %, D^+ : 30 %, T^+ : 30 %, $^4He^+$: 30 %

Comments: (1) There are no satisfactory simulations (or experiments) for this case. More over the mass ratios do not correspond to the bands we have analyzed. To provide an estimate of behaviour we recommended data based on our six parameter formula (see text) with coefficients taken as follows. For H^+, $15 \geq \mu \geq 12$; for D^+, $\mu \approx 6$; for T^+ $\mu \approx 3$; and for $^4He^+$ $\mu \approx 3$. The accuracy limits reflect the resulting uncertainty.

(2) Calculations by Zhengming et al [ZH91] lie considerably above the recommended data and exhibit a different functional dependence on energy.

(3) There is a single simulation for H^+ + Be [BE87] based on a code that differs from TRIM and MARLOWE. The data (0.7 - 2.0 keV only) lie 2 to 20 times above the recommended data and exhibit a functional dependence on energy quite different from any other case considered here. We suggest they should be disregarded.

(4) No data is provided above 10 keV for H^+, D^+ and T^+ and for $^4He^+$ above 50 keV. The formulae should not be used for extrapolation.

Analytic fitting function data

$$R_N = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.6192	78.00	22.11	0.6669	24.67	1.899
D^+	0.5173	9.037	10.98	0.5719	12.63	1.933
T^+	0.3680	9.692	14.10	0.5802	27.63	1.597
$^4He^+$	0.3680	4.148	8.620	0.5802	7.123	1.597

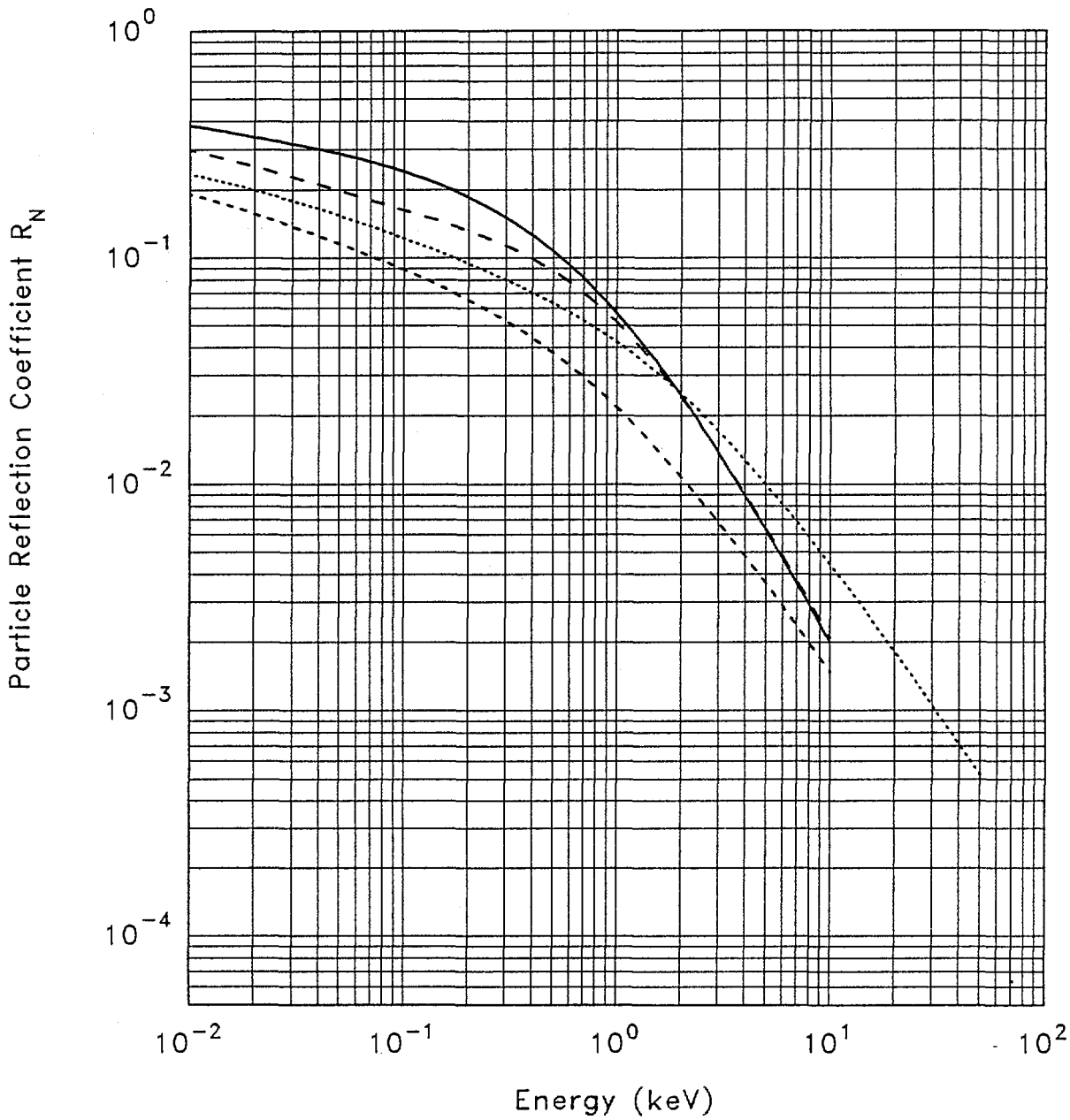
ALADDIN evaluation function for R_N: REFL1

ALADDIN hierarchical labelling:

RN H [+1] Be , for H^+; RN D [+1] Be , for D^+.

RN T [+1] Be , for T^+; RN [4]He [+1] Be , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Be



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Be – Energy Reflection R_E

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	2.08E−01	1.38E−01	4.63E−02	6.19E−02
2.00E−02	1.77E−01	1.09E−01	3.61E−02	4.89E−02
5.00E−02	1.39E−01	7.86E−02	2.58E−02	3.52E−02
1.00E−01	1.07E−01	6.17E−02	1.97E−02	2.73E−02
2.00E−01	7.35E−02	4.70E−02	1.42E−02	2.10E−02
5.00E−01	3.45E−02	2.77E−02	7.70E−03	1.37E−02
1.00E+00	1.56E−02	1.47E−02	4.03E−03	8.71E−03
2.00E+00	6.05E−03	6.28E−03	1.84E−03	4.73E−03
5.00E+00	1.48E−03	1.63E−03	5.63E−04	1.69E−03
1.00E+01	4.81E−04	5.37E−04	2.16E−04	6.94E−04
2.00E+01	–	–	–	2.68E−04
5.00E+01	–	–	–	7.27E−05

Accuracy: H^+ : 30 %, D^+ : 30 %, T^+ : 30 %, $^4He^+$: 30 %

Comments: (1) There are no satisfactory simulations (or experiments) for this case. More over the mass ratios do not correspond to the bands we have analyzed. To provide an estimate of behaviour we recommended data based on our six parameter formula (see text) with coefficients taken as follows. For H^+, $15 \geq \mu \geq 12$; for D^+, $\mu \approx 6$; for T^+ $\mu \approx 3$; and for $^4He^+$ $\mu \approx 3$. The accuracy limits reflect the resulting uncertainty.

(2) Calculations by Zhengming et al [ZH91] lie considerably above the recommended data and exhibit a different functional dependence on energy.

(3) There is a single simulation for H^+ + Be [BE87] based on a code that differs from TRIM and MARLOWE. The data (0.7 - 2.0 keV only) lie 2 to 20 times above the recommended data exhibit a functional dependence on energy quite different from any other case considered here. We suggest they should be disregarded.

(4) No data is provided above 10 keV for H^+, D^+ and T^+ and for $^4He^+$ above 50 keV. The formulae should not be used for extrapolation.

Analytic fitting function data

$$R_E = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.4484	1.059E+02	38.44	0.6598	95.07	1.822
D^+	0.4222	10.96	26.07	0.5393	48.05	1.877
T^+	0.2058	12.49	33.85	0.4872	1.041E+02	1.638
$^4He^+$	0.2058	5.348	22.39	0.4872	25.94	1.638

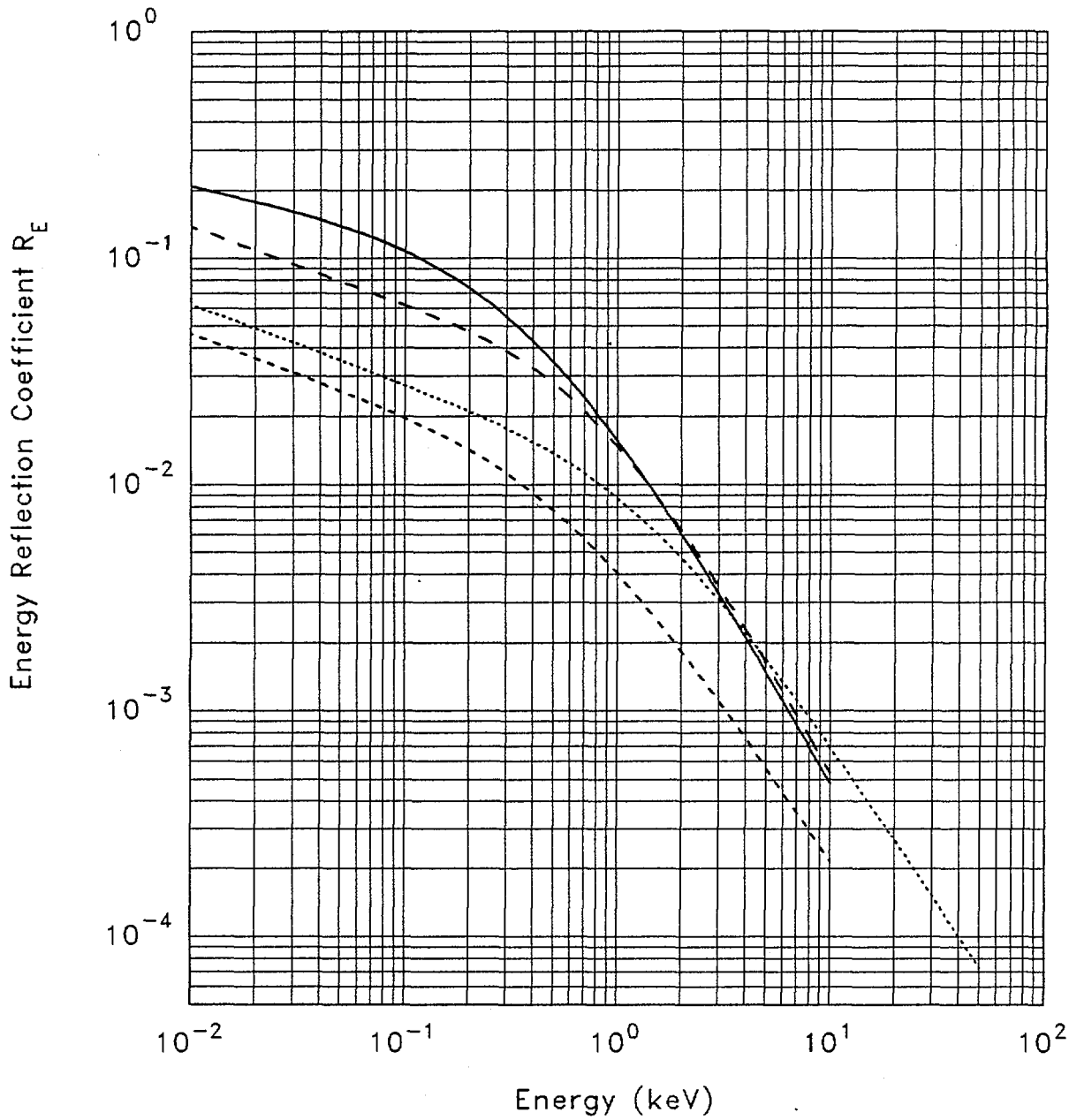
ALADDIN evaluation function for R_E: REFL1

ALADDIN hierarchical labelling:

RE H [+1] Be , for H^+; RE D [+1] Be , for D^+.

RE T [+1] Be , for T^+; RE [4]He [+1] Be , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Be



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + B – Particle Reflection R_N

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	3.99E−01	3.15E−01	2.03E−01	2.44E−01
2.00E−02	3.56E−01	2.69E−01	1.68E−01	2.10E−01
5.00E−02	3.03E−01	2.12E−01	1.25E−01	1.64E−01
1.00E−01	2.58E−01	1.75E−01	9.74E−02	1.31E−01
2.00E−01	2.07E−01	1.43E−01	7.31E−02	1.03E−01
5.00E−01	1.29E−01	1.00E−01	4.46E−02	7.03E−02
1.00E+00	7.40E−02	6.42E−02	2.67E−02	4.86E−02
2.00E+00	3.44E−02	3.24E−02	1.39E−02	2.99E−02
5.00E+00	9.44E−03	9.37E−03	4.87E−03	1.27E−02
1.00E+01	3.10E−03	3.14E−03	2.01E−03	5.76E−03
2.00E+01	9.59E−04	9.82E−04	7.92E−04	2.41E−03
5.00E+01	–	–	–	7.05E−04

Accuracy: H^+ : 30 %, D^+ : 30 %, T^+ : 30 %, $^4He^+$: 30 %

Comments: (1) There are no simulations (or experiments) on this case. The recommended data is based on the six parameter formula (see text) with the coefficients listed below. The coefficients are based on fits to composite data as follows. For H^+, $15 \geq \mu \geq 12$; for D^+, $\mu \approx 6$; for T^+ $\mu \approx 3$; and for $^4He^+$ $\mu \approx 3$.

(2) The calculations by Zhengming et al [ZH91] lie considerably above the recommended data and exhibit a different functional dependence on energy.

(3) These data should be treated with extreme caution and we ascribe broad limits of reliability.

(4) No data is provided above 20 keV for H^+, D^+ and T^+ and for $^4He^+$ above 50 keV. The formulae should not be used for extrapolation.

Analytic fitting function data

$$R_N = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.6192	60.11	18.58	0.6669	15.04	1.899
D^+	0.5173	7.061	9.536	0.5719	7.841	1.933
T^+	0.3680	7.663	12.31	0.5802	18.99	1.597
$^4He^+$	0.3680	3.337	7.598	0.5802	5.032	1.597

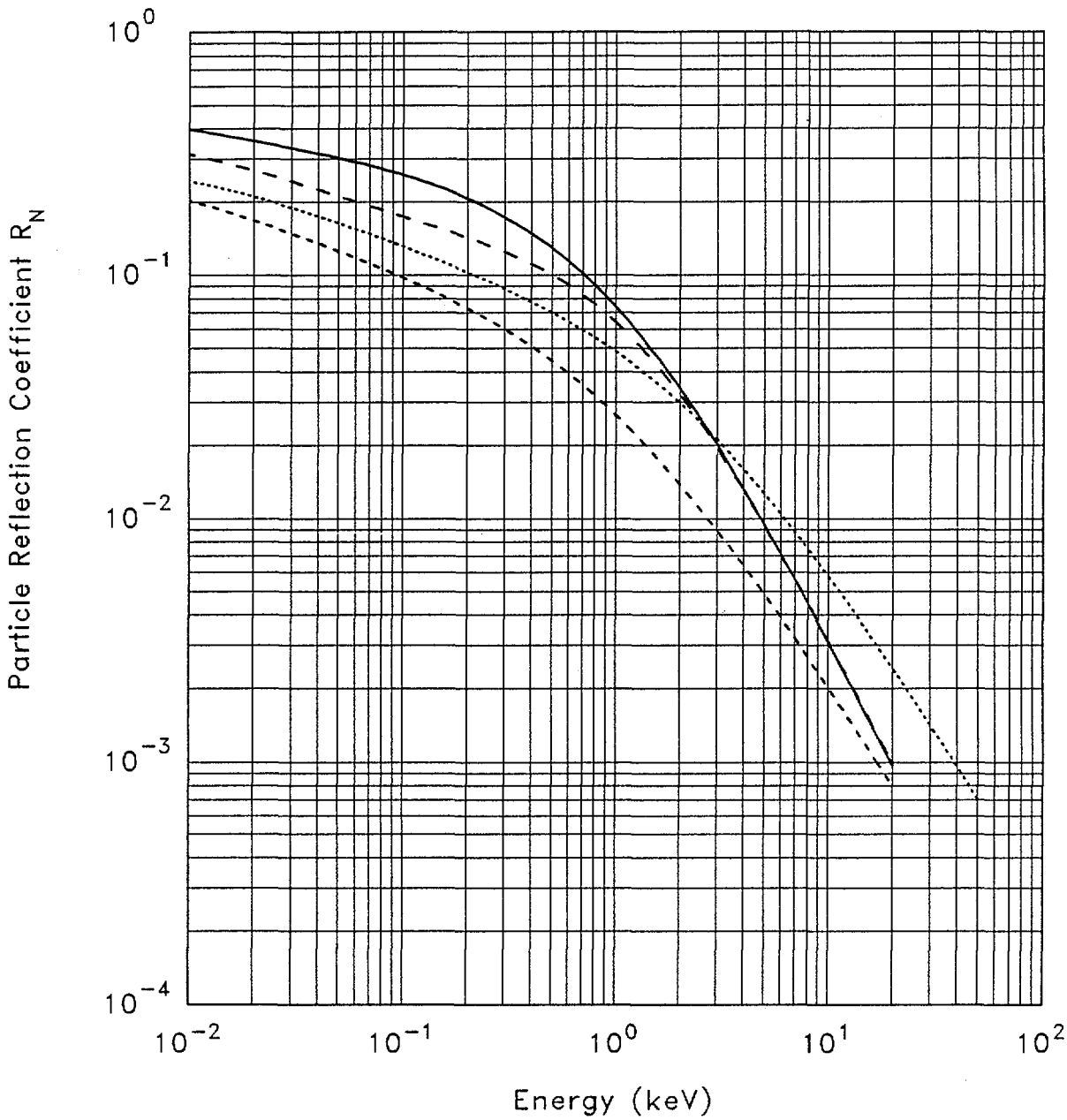
ALADDIN evaluation function for R_N: REFL1

ALADDIN hierarchical labelling:

RN H [+1] B , for H^+; RN D [+1] B , for D^+.

RN T [+1] B , for T^+; RN [4]He [+1] B , for $^4He^+$.

$H^+, D^+, T^+, {}^4He^+ + B$



Legend:

—— H^+ ----- T^+

- - - D^+ ..... ${}^4He^+$

H^+, D^+, T^+, $^4He^+$ + B – Energy Reflection R_E

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	2.21E−01	1.50E−01	5.03E−02	6.65E−02
2.00E−02	1.88E−01	1.18E−01	3.93E−02	5.27E−02
5.00E−02	1.50E−01	8.57E−02	2.81E−02	3.81E−02
1.00E−01	1.19E−01	6.73E−02	2.16E−02	2.96E−02
2.00E−01	8.61E−02	5.21E−02	1.60E−02	2.28E−02
5.00E−01	4.43E−02	3.29E−02	9.25E−03	1.54E−02
1.00E+00	2.15E−02	1.89E−02	5.11E−03	1.02E−02
2.00E+00	8.77E−03	8.69E−03	2.43E−03	5.83E−03
5.00E+00	2.24E−03	2.39E−03	7.71E−04	2.20E−03
1.00E+01	7.38E−04	8.02E−04	3.00E−04	9.24E−04
2.00E+01	2.35E−04	2.57E−04	1.12E−04	3.63E−04
5.00E+01	–	–	–	9.95E−05

Accuracy: H^+ : 30 %, D^+ : 30 %, T^+ : 30 %, $^4He^+$: 30 %

Comments: (1) There are no simulations (or experiments) on this case. The recommended data is based on the six parameter formula (see text) with the coefficients listed below. The coefficients are based on fits to composite data as follows. For H^+, $15 \geq \mu \geq 12$; for D^+, $\mu \approx 6$; for T^+ $\mu \approx 3$; and for $^4He^+$ $\mu \approx 3$.

(2) The calculations by Zhengming et al [ZH91] lie considerably above the recommended data and exhibit a different functional dependence on energy.

(3) These data should be treated with extreme caution and we ascribe broad limits of reliability.

(4) No data is provided above 20 keV for H^+, D^+ and T^+ and for $^4He^+$ above 50 keV. The formulae should not be used for extrapolation.

Analytic fitting function data

$$R_E = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.4484	81.59	32.37	0.6598	59.13	1.822
D^+	0.4222	8.565	22.82	0.5393	30.24	1.877
T^+	0.2058	9.880	30.19	0.4872	70.87	1.638
$^4He^+$	0.2058	4.302	20.13	0.4872	18.16	1.638

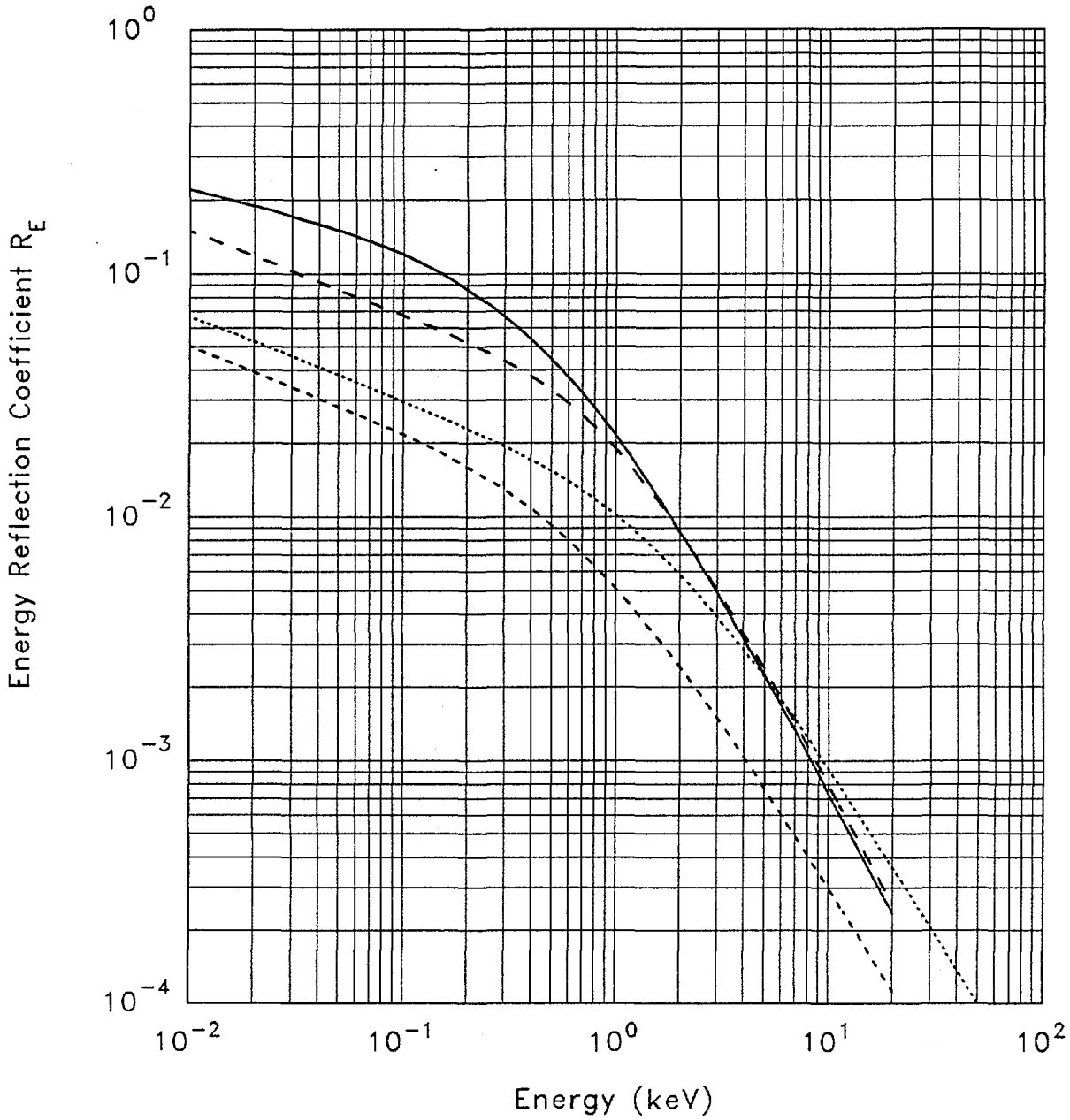
ALADDIN evaluation function for R_E: REFL1

ALADDIN hierarchical labelling:

RE H [+1] B , for H^+; RE D [+1] B , for D^+.

RE T [+1] B , for T^+; RE [4]He [+1] B , for $^4He^+$.

$H^+, D^+, T^+, {}^4He^+ + B$



Legend:

—— H^+ ----- T^+

- - - D^+ ····· ${}^4He^+$

H^+, D^+, T^+, $^4He^+$ + C – Particle Reflection R_N

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	4.13E−01	3.29E−01	2.13E−01	2.53E−01
2.00E−02	3.69E−01	2.83E−01	1.78E−01	2.20E−01
5.00E−02	3.15E−01	2.24E−01	1.34E−01	1.74E−01
1.00E−01	2.73E−01	1.85E−01	1.05E−01	1.40E−01
2.00E−01	2.24E−01	1.52E−01	8.00E−02	1.10E−01
5.00E−01	1.48E−01	1.10E−01	5.06E−02	7.67E−02
1.00E+00	9.03E−02	7.53E−02	3.15E−02	5.45E−02
2.00E+00	4.49E−02	4.10E−02	1.71E−02	3.48E−02
5.00E+00	1.32E−02	1.28E−02	6.25E−03	1.55E−02
1.00E+01	4.45E−03	4.43E−03	2.63E−03	7.26E−03
2.00E+01	1.40E−03	1.41E−03	1.05E−03	3.10E−03
5.00E+01	–	–	–	9.21E−04

Accuracy: H^+ : 10 %, D^+ : 20 %, T^+ : 30 %, $^4He^+$: 10 %

Comments: (1) Recommended data is based on the six parameter formula (see text) with the coefficients given below. The coefficients are based on fits to composite data as follows. For H^+, $15 \geq \mu \geq 12$; for D^+, $\mu \approx 6$; for T^+ $\mu \approx 3$; and for $^4He^+$ $\mu \approx 3$.

(2) These data are for a pure target. Under H^+(D^+ and T^+) bombardment the C will retain hydrogen and the reflection coefficient of the composite CH_x will be lower than for pure C; see Aratari and Eckstein [AR89i]. Also carbon has many forms with widely varying surface topography; it is not known how this effects reflection.

(3) The recommended data are in rather poor agreement with the calculations of Zhengming et al [ZH91] being 30 % lower for H^+, 50 % lower for D^+ and 75 % lower (with a different energy dependence) for $^4He^+$. The recommended data are in excellent agreement with TRIM and MARLOWE simulations [EC79], [EC90].

(4) Experimental studies [EC79], [OV80] (1.5 - 10 keV)] are generally consistent with the recommended data. Certain experiments should be disregarded due too poor reliability [BR82] or because the target was saturated with hydrogen [AR89i].

(5) There is no confirmatory data for T^+ and the proposed data is by interpolation. No data is provided above 20 keV for H^+, D^+ and T^+ and for $^4He^+$ above 50 keV. The formulae should not be used for extrapolation.

Analytic fitting function data

$$R_N = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.6192	48.25	16.05	0.6669	9.912	1.899
D^+	0.5173	5.710	8.445	0.5719	5.199	1.933
T^+	0.3680	6.235	10.92	0.5802	13.66	1.597
$^4He^+$	0.3680	2.745	6.784	0.5802	3.684	1.597

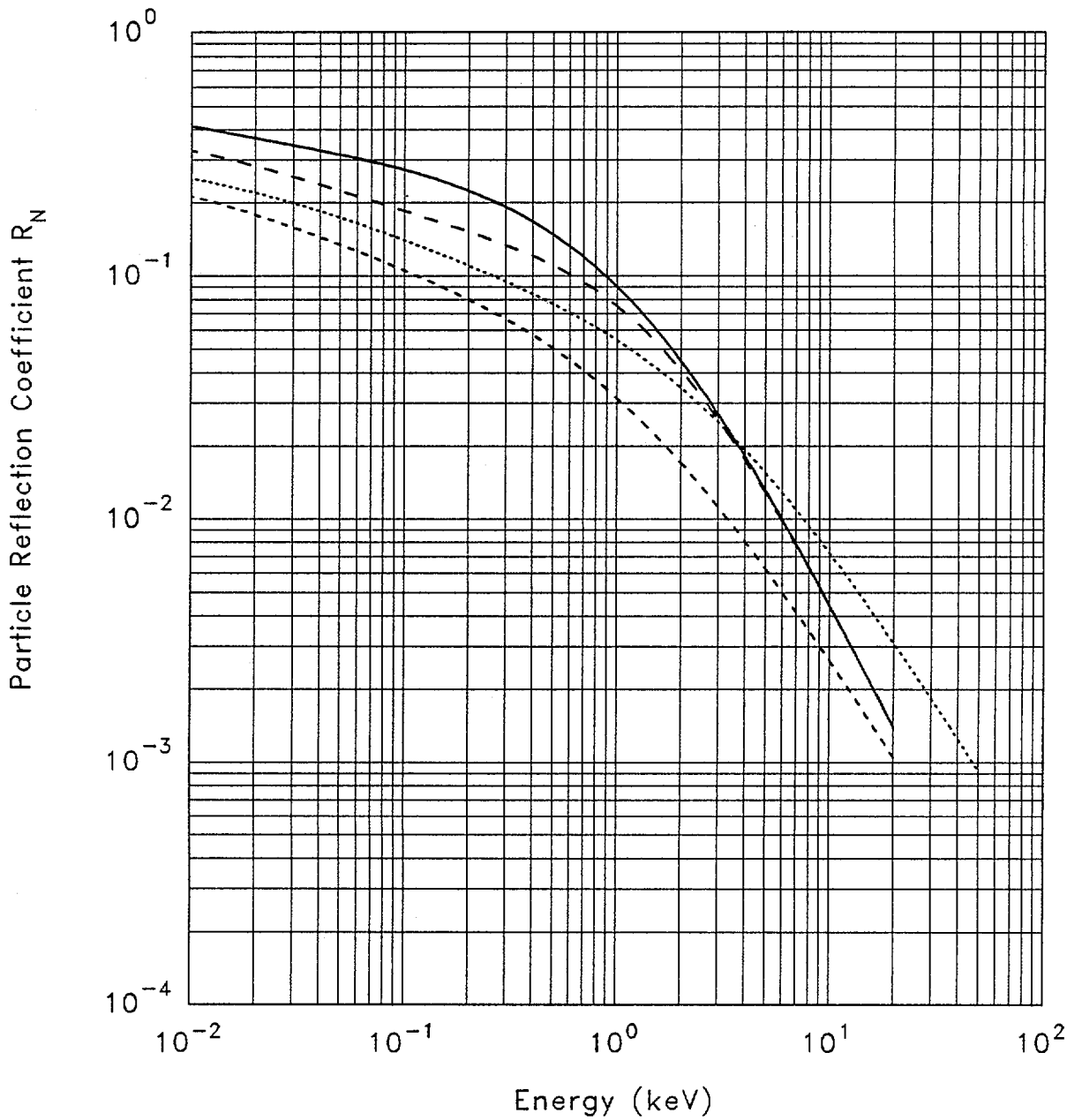
ALADDIN evaluation function for R_N: REFL1

ALADDIN hierarchical labelling:

RN H [+1] C , for H^+; RN D [+1] C , for D^+.

RN T [+1] C , for T^+; RN [4]He [+1] C , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + C



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + C – Energy Reflection R_E

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	2.32E−01	1.60E−01	5.40E−02	7.07E−02
2.00E−02	1.98E−01	1.27E−01	4.23E−02	5.64E−02
5.00E−02	1.59E−01	9.24E−02	3.03E−02	4.09E−02
1.00E−01	1.29E−01	7.25E−02	2.34E−02	3.18E−02
2.00E−01	9.68E−02	5.66E−02	1.76E−02	2.46E−02
5.00E−01	5.35E−02	3.75E−02	1.07E−02	1.69E−02
1.00E+00	2.76E−02	2.30E−02	6.20E−03	1.16E−02
2.00E+00	1.18E−02	1.13E−02	3.07E−03	6.94E−03
5.00E+00	3.15E−03	3.28E−03	1.01E−03	2.76E−03
1.00E+01	1.05E−03	1.13E−03	3.99E−04	1.19E−03
2.00E+01	3.38E−04	3.65E−04	1.51E−04	4.75E−04
5.00E+01	–	–	–	1.32E−04

Accuracy: H^+ : 10 %, D^+ : 40 %, T^+ : 30 %, $^4He^+$: 10 %

Comments: (1) Recommended data is based on the six parameter formula (see text) with the coefficients given below. The coefficients are based on fits to composite data as follows. For H^+, $15 \geq \mu \geq 12$; for D^+, $\mu \approx 6$; for T^+ $\mu \approx 3$; and for $^4He^+$ $\mu \approx 3$.

(2) These data are for a pure target. Under H^+(D^+ and T^+) bombardment the C will retain hydrogen and the reflection coefficient of the composite CH_x will be lower than for pure C; see Aratari and Eckstein [AR89i]. Also carbon has many forms with widely varying surface topography; it is not known how this effects reflection.

(3) The recommended data are in rather poor agreement with the calculations of Zhengming et al [ZH91] being 30 % lower for H^+, 50 % lower for D^+ and 75 % lower (with a different energy dependence) for $^4He^+$. The recommended data are in excellent agreement with TRIM and MARLOWE simulations [EC79].

(4) Experimental studies [EC79] (1.5 - 10 keV)] for H^+ and D^+ are 100 % or more higher than the recommended data.

(5) There is no confirmatory data for T^+ and the proposed data is by interpolation. No data is provided above 20 keV for H^+, D^+ and T^+ and for $^4He^+$ above 50 keV. The formulae should not be used for extrapolation.

Analytic fitting function data

$$R_E = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.4483	65.49	28.00	0.6598	39.62	1.822
D^+	0.4222	6.925	20.35	0.5393	20.30	1.877
T^+	0.2058	8.039	27.30	0.4872	50.56	1.638
$^4He^+$	0.2058	3.539	18.31	0.4872	13.20	1.638

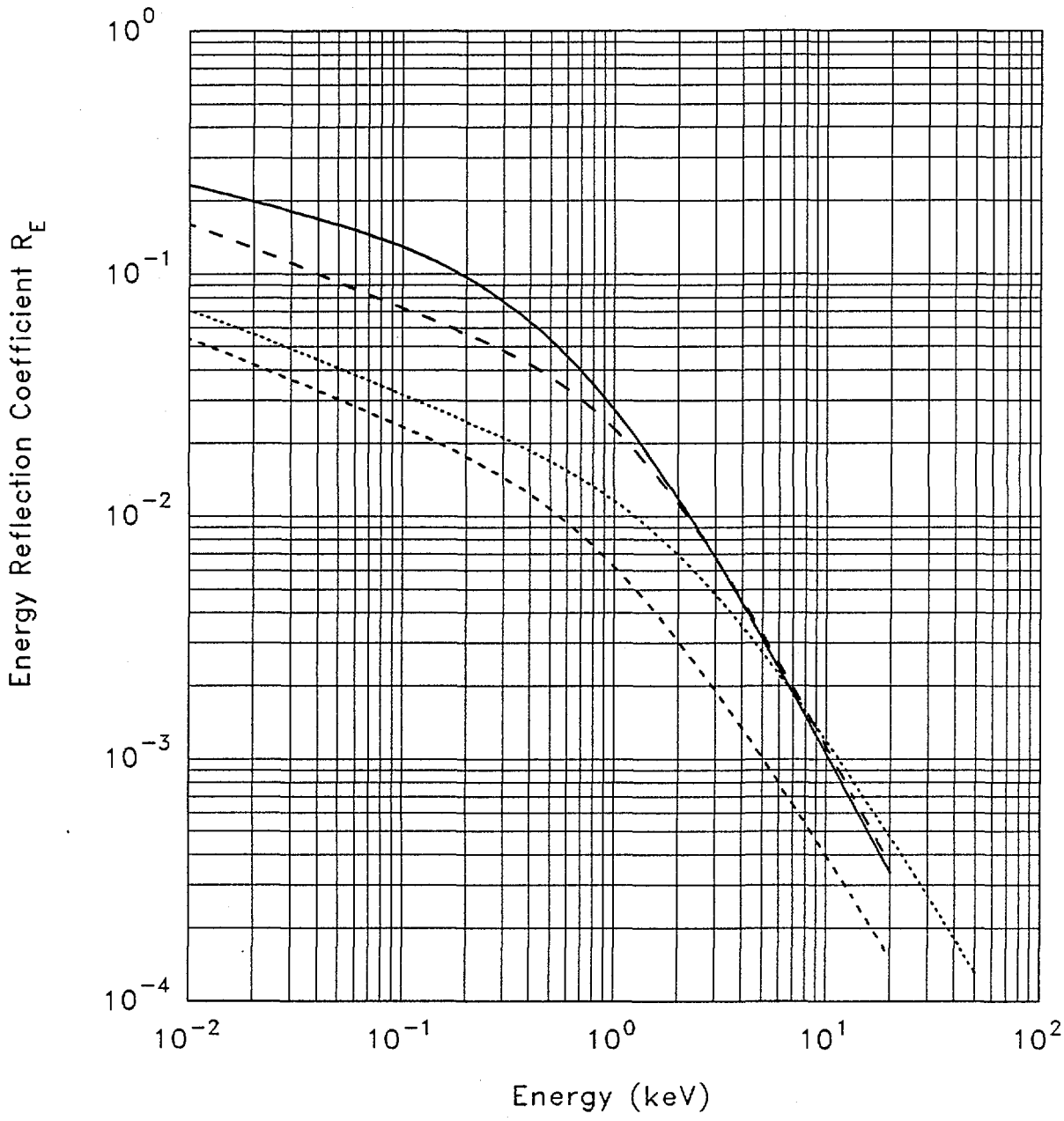
ALADDIN evaluation function for R_E: REFL1

ALADDIN hierarchical labelling:

RE H [+1] C , for H^+; RE D [+1] C , for D^+.

RE T [+1] C , for T^+; RE [4]He [+1] C , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + C



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Al – Particle Reflection R_N

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	6.18E−01	4.75E−01	4.77E−01	4.22E−01
2.00E−02	5.62E−01	4.31E−01	4.33E−01	3.89E−01
5.00E−02	4.90E−01	3.73E−01	3.75E−01	3.34E−01
1.00E−01	4.41E−01	3.32E−01	3.34E−01	2.89E−01
2.00E−01	3.92E−01	2.91E−01	2.93E−01	2.44E−01
5.00E−01	3.11E−01	2.28E−01	2.31E−01	1.90E−01
1.00E+00	2.35E−01	1.72E−01	1.75E−01	1.56E−01
2.00E+00	1.52E−01	1.13E−01	1.16E−01	1.25E−01
5.00E+00	6.15E−02	4.79E−02	4.98E−02	8.01E−02
1.00E+01	2.42E−02	1.97E−02	2.07E−02	4.51E−02
2.00E+01	8.18E−03	6.98E−03	7.36E−03	1.99E−02
5.00E+01	1.73E−03	1.54E−03	1.63E−03	5.13E−03
1.00E+02	–	–	–	1.64E−03

Accuracy: H^+ : 10 %, D^+ : 10 %, T^+ : 30 %, $^4He^+$: 50 %

Comments: (1) Recommended data is based on a six parameter formula (see text) with the coefficients given below. The coefficients are based on fits to composite data in certain mass ratio ranges as follows. For H^+, $\mu \geq 20$; for D^+, $15 \geq \mu \geq 12$; for $^4He^+$ $\mu \approx 6$. T^+ on Al ($\mu = 9.3$) does not fall in the mass ratio bands we have analyzed and there is no independent data to provide guidance. We have chosen to use parameters from $15 \geq \mu \geq 12$ and believe the resulting uncertainty should be no more than 30 %.

(2) The recommended data for H^+ agree well with a MARLOWE simulation [OE84]; for $^4He^+$ a MARLOWE simulation is 50 % lower and has a different functional dependance on energy.

(3) The recommended data lie 20 - 25 % below the calculations of Zhengming et al [ZH91] but have the same functional dependance on energy.

(4) Experimental data for H^+ [SI76] (10 - 30 keV) is consistent with the recommended data.

(5) No data is provided for H^+, D^+ and T^+ beyond 50 keV. The formulae should not be used for extrapolation.

Analytic fitting function data

$$R_N = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.8250	20.21	8.294	0.6425	1.707	1.927
D^+	0.6192	18.240	8.388	0.6669	1.563	1.899
T^+	0.6192	17.63	8.199	0.6669	1.465	1.899
$^4He^+$	0.5173	1.042	3.192	0.5719	0.1940	1.933

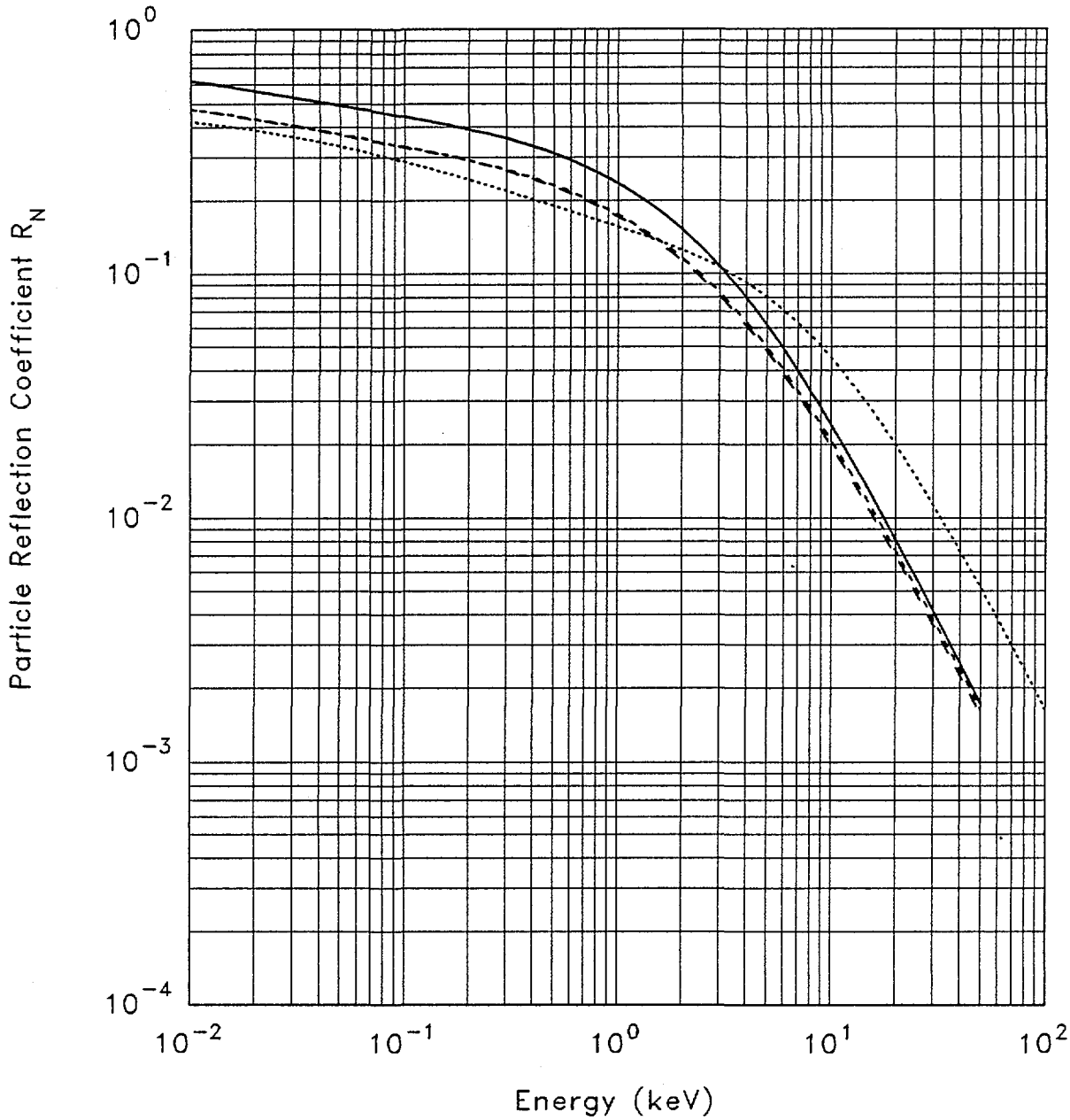
ALADDIN evaluation function for R_N: REFL1

ALADDIN hierarchical labelling:

RN H [+1] Al , for H^+; RN D [+1] Al , for D^+.

RN T [+1] Al , for T^+; RN [4]He [+1] Al , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Al



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Al – Energy Reflection R_E

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	4.32E−01	2.85E−01	2.87E−01	2.53E−01
2.00E−02	3.73E−01	2.47E−01	2.49E−01	2.15E−01
5.00E−02	3.04E−01	2.01E−01	2.02E−01	1.65E−01
1.00E−01	2.58E−01	1.71E−01	1.72E−01	1.31E−01
2.00E−01	2.13E−01	1.42E−01	1.43E−01	1.03E−01
5.00E−01	1.49E−01	9.95E−02	1.01E−01	7.48E−02
1.00E+00	9.83E−02	6.61E−02	6.77E−02	5.86E−02
2.00E+00	5.43E−02	3.69E−02	3.81E−02	4.41E−02
5.00E+00	1.86E−02	1.28E−02	1.34E−02	2.48E−02
1.00E+01	6.95E−03	4.80E−03	5.06E−03	1.26E−02
2.00E+01	2.38E−03	1.65E−03	1.74E−03	5.17E−03
5.00E+01	5.34E−04	3.72E−04	3.93E−04	1.31E−03
1.00E+02	–	–	–	4.25E−04

Accuracy: H^+ : 10 %, D^+ : 10 %, T^+ : 30 %, $^4He^+$: 20 %

Comments: Recommended data is based on a six parameter formula (see text) with the coefficients given below. The coefficients are based on fits to composite data in certain mass ratio ranges as follows. For H^+, $\mu \geq 20$; for D^+, $15 \geq \mu \geq 12$; for $^4He^+$ $\mu \approx 6$. T^+ on Al ($\mu = 9.3$) does not fall in the mass ratio bands we have analyzed and there is no independent data to provide guidance. We have chosen to use parameters from $15 \geq \mu \geq 12$ and believe the resulting uncertainty should be no more than 30 %.

(2) The recommended data agree with a MARLOWE simulation [OE76] for $^4He^+$.

(3) The recommended data lie significantly below the calculations of Zhengming et al [ZH91] (20% for D^+ and 50 % for $^4He^+$).

(4) Experimental data for H^+ [SI76] (10 - 30 keV) and for $^4He^+$ [HI76] (1.2 - 1.4 keV) are consistent with the recommended data.

(5) No data is provided for H^+, D^+ and T^+ beyond 50 keV. The formulae should not be used for extrapolation.

Analytic fitting function data

$$R_E = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.6831	25.64	15.08	0.6598	7.174	1.822
D^+	0.4483	24.76	14.74	0.6598	6.730	1.822
T^+	0.4483	23.92	14.41	0.6598	6.323	1.822
$^4He^+$	0.4222	1.263	8.129	0.5393	0.8327	1.877

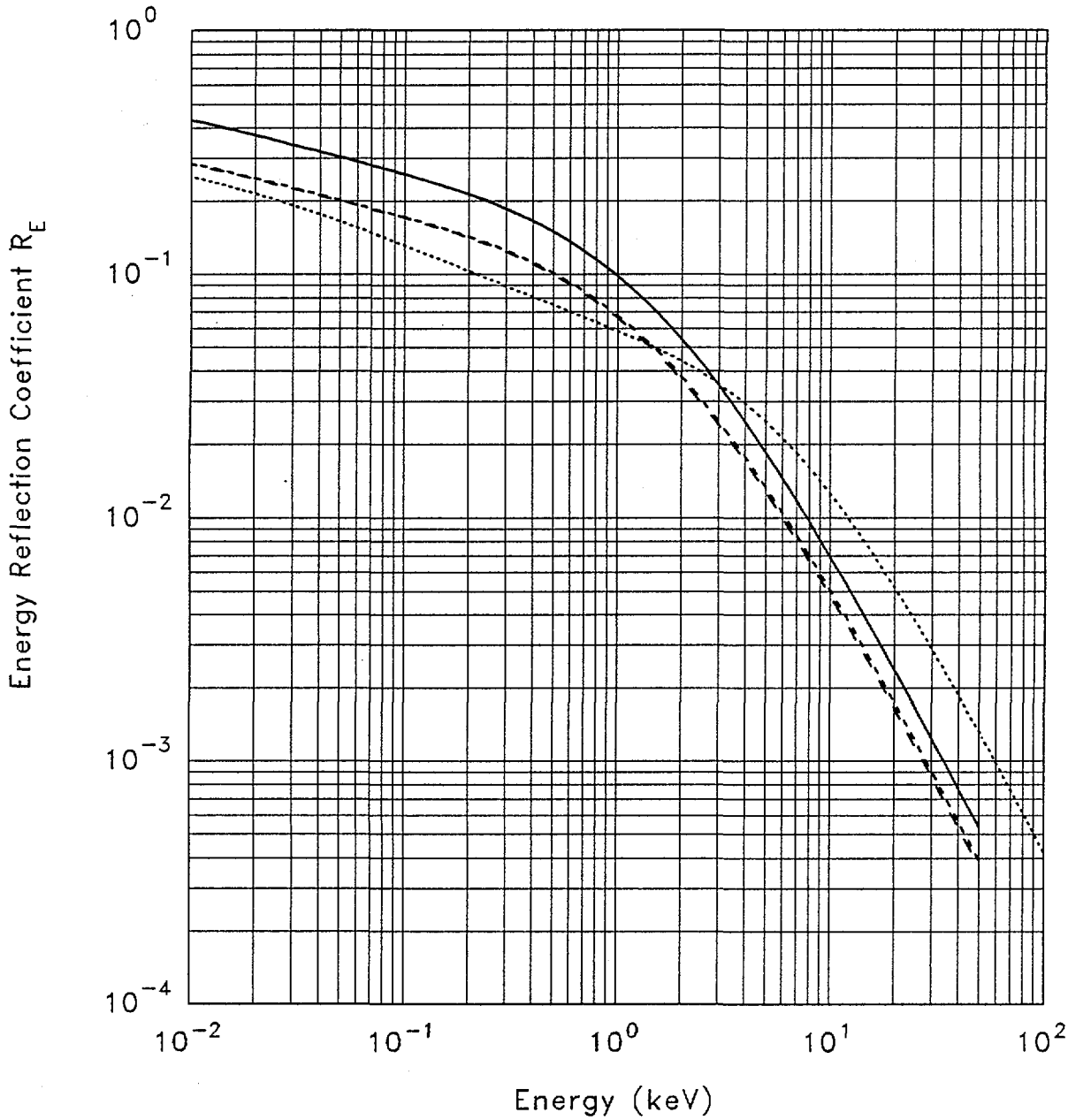
ALADDIN evaluation function for R_E: REFL1

ALADDIN hierarchical labelling:

RE H [+1] Al , for H^+; RE D [+1] Al , for D^+.

RE T [+1] Al , for T^+; RE [4]He [+1] Al , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Al



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Si – Particle Reflection R_N

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	6.26E−01	4.80E−01	4.82E−01	4.26E−01
2.00E−02	5.69E−01	4.37E−01	4.39E−01	3.93E−01
5.00E−02	4.97E−01	3.78E−01	3.80E−01	3.40E−01
1.00E−01	4.48E−01	3.37E−01	3.39E−01	2.95E−01
2.00E−01	3.99E−01	2.96E−01	2.98E−01	2.49E−01
5.00E−01	3.21E−01	2.35E−01	2.38E−01	1.95E−01
1.00E+00	2.46E−01	1.80E−01	1.83E−01	1.60E−01
2.00E+00	1.63E−01	1.20E−01	1.23E−01	1.29E−01
5.00E+00	6.87E−02	5.31E−02	5.50E−02	8.48E−02
1.00E+01	2.77E−02	2.25E−02	2.35E−02	4.92E−02
2.00E+01	9.52E−03	8.07E−03	8.49E−03	2.23E−02
5.00E+01	2.03E−03	1.80E−03	1.90E−03	5.90E−03
1.00E+02	–	–	–	1.91E−03

Accuracy: H^+ : 10 %, D^+ : 10 %, T^+ : 30 %, $^4He^+$: 10 %

Comments: (1) There are no detailed simulations (or experiments) covering a sufficient range of energy to establish a reliable data base. Our recommended data is based on a six parameter formula (see text) with the coefficients listed below. The coefficients are based on fits to composite data in certain mass ratio ranges as follows. For H^+, $\mu \geq 20$; for D^+, $15 \geq \mu \geq 12$; for $^4He^+$ $\mu \approx 6$. T^+ on Si ($\mu = 9.6$) does not fall in the mass ratio bands we have analyzed and there is no independent data to provide guidance. We have chosen to use parameters from $15 \geq \mu \geq 12$ and believe the results uncertainty should be no more than 30 %.

(2) The recommended data are in agreement with MARLOWE simulations by Eckstein and Verbeek [EC79].

(3) The recommended data lie 30 % (for D^+) to 50 % (for $^4He^+$) below the calculations of Zhengming et al [ZH91].

(4) The sole experimental data is a single point at 5 keV for H^+ [EC79] which lies 50 % below the recommended data.

(5) No data is provided for H^+, D^+ and T^+ beyond 50 keV. The formulae should not be used for extrapolation.

Analytic fitting function data

$$R_N = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.8250	18.40	7.810	0.6425	1.425	1.927
D^+	0.6192	16.63	7.887	0.6669	1.312	1.899
T^+	0.6192	16.09	7.715	0.6669	1.232	1.899
$^4He^+$	0.5173	0.9535	3.034	0.5719	0.1635	1.933

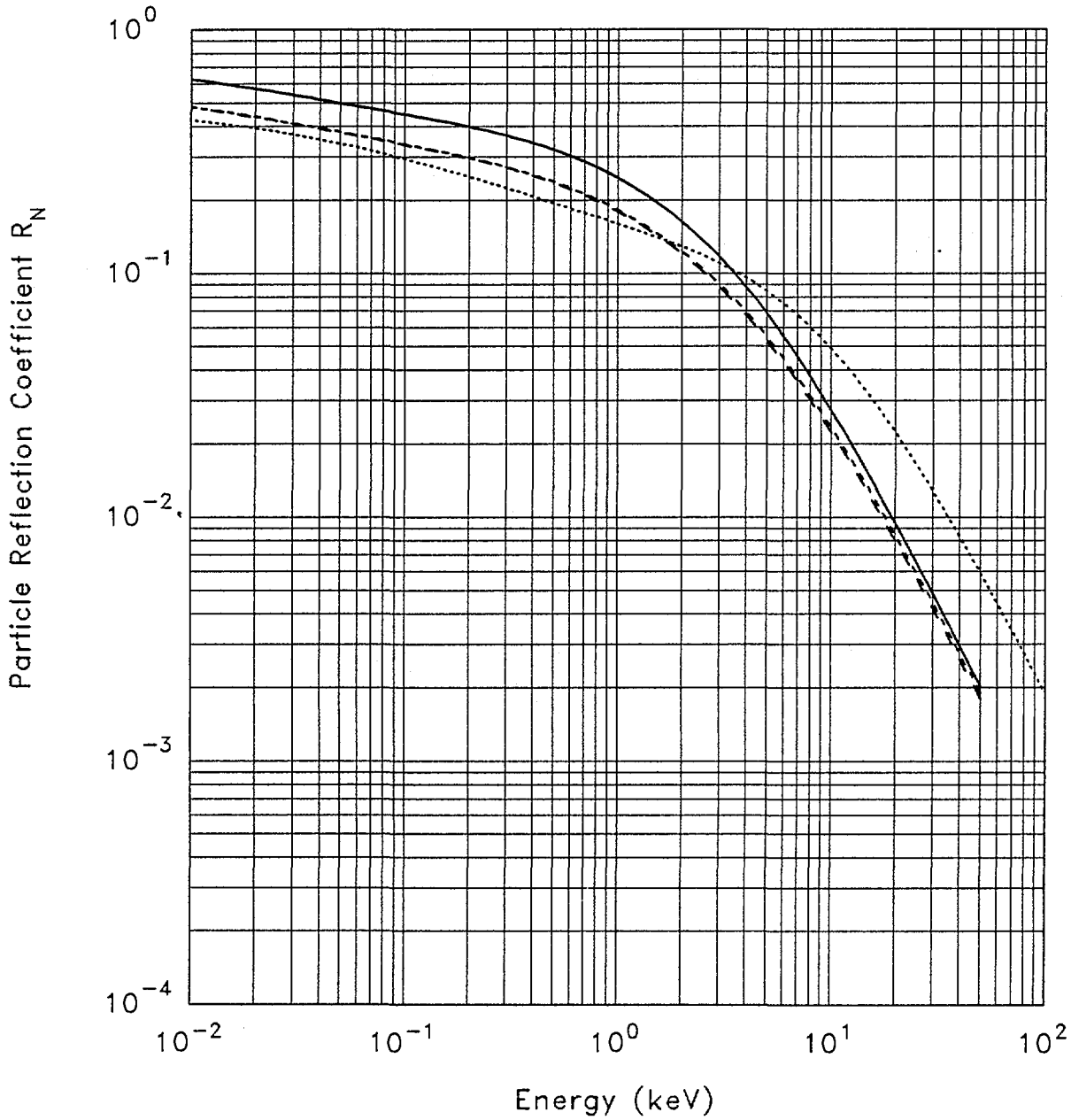
ALADDIN evaluation function for R_N: REFL1

ALADDIN hierarchical labelling:

RN H [+1] Si , for H^+; RN D [+1] Si , for D^+.

RN T [+1] Si , for T^+; RN [4]He [+1] Si , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Si



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Si – Energy Reflection R_E

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	4.40E−01	2.91E−01	2.93E−01	2.57E−01
2.00E−02	3.81E−01	2.52E−01	2.54E−01	2.19E−01
5.00E−02	3.10E−01	2.05E−01	2.07E−01	1.70E−01
1.00E−01	2.64E−01	1.75E−01	1.76E−01	1.35E−01
2.00E−01	2.19E−01	1.45E−01	1.47E−01	1.06E−01
5.00E−01	1.56E−01	1.04E−01	1.06E−01	7.72E−02
1.00E+00	1.05E−01	7.05E−02	7.20E−02	6.05E−02
2.00E+00	5.95E−02	4.03E−02	4.16E−02	4.59E−02
5.00E+00	2.10E−02	1.44E−02	1.50E−02	2.66E−02
1.00E+01	7.98E−03	5.51E−03	5.78E−03	1.39E−02
2.00E+01	2.76E−03	1.91E−03	2.01E−03	5.84E−03
5.00E+01	6.24E−04	4.33E−04	4.57E−04	1.50E−03
1.00E+02	–	–	–	4.92E−04

Accuracy: H^+ : 10 %, D^+ : 10 %, T^+ : 30 %, $^4He^+$: 10 %

Comments: (1) There are no detailed simulations (or experiments) covering a sufficient range of energy to establish a reliable data base. Our recommended data is based on a six parameter formula (see text) with the coefficients listed below. The coefficients are based on fits to composite data in certain mass ratio ranges as follows. For H^+, $\mu \geq 20$; for D^+, $15 \geq \mu \geq 12$; for $^4He^+$ $\mu \approx 6$. T^+ on Si ($\mu = 9.6$) does not fall in the mass ratio bands we have analyzed and there is no independent data to provide guidance. We have chosen to use parameters from $15 \geq \mu \geq 12$ and believe the results uncertainty should be no more than 30 %.

(2) The recommended data are in agreement with MARLOWE simulations by Eckstein and Verbeek [EC79].

(3) The recommended data lie 30 % (for D^+) to 50 % (for $^4He^+$) below the calculations of Zhengming et al [ZH91].

(4) A single experimental data point for H^+ at 5 keV [EC79] lies 50 % below the recommended data. Experimental data for for $^4He^+$ (12 - 70 keV) [AN76], [HI76] have considerable scatter but are consistent with the recommended data.

(5) No data is provided for H^+, D^+ and T^+ beyond 50 keV. The formulae should not be used for extrapolation.

Analytic fitting function data

$$R_E = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.6831	23.35	14.18	0.6598	6.048	1.822
D^+	0.4483	22.57	13.86	0.6598	5.687	1.822
T^+	0.4483	21.84	13.57	0.6598	5.355	1.822
$^4He^+$	0.4222	1.156	7.751	0.5393	0.7054	1.877

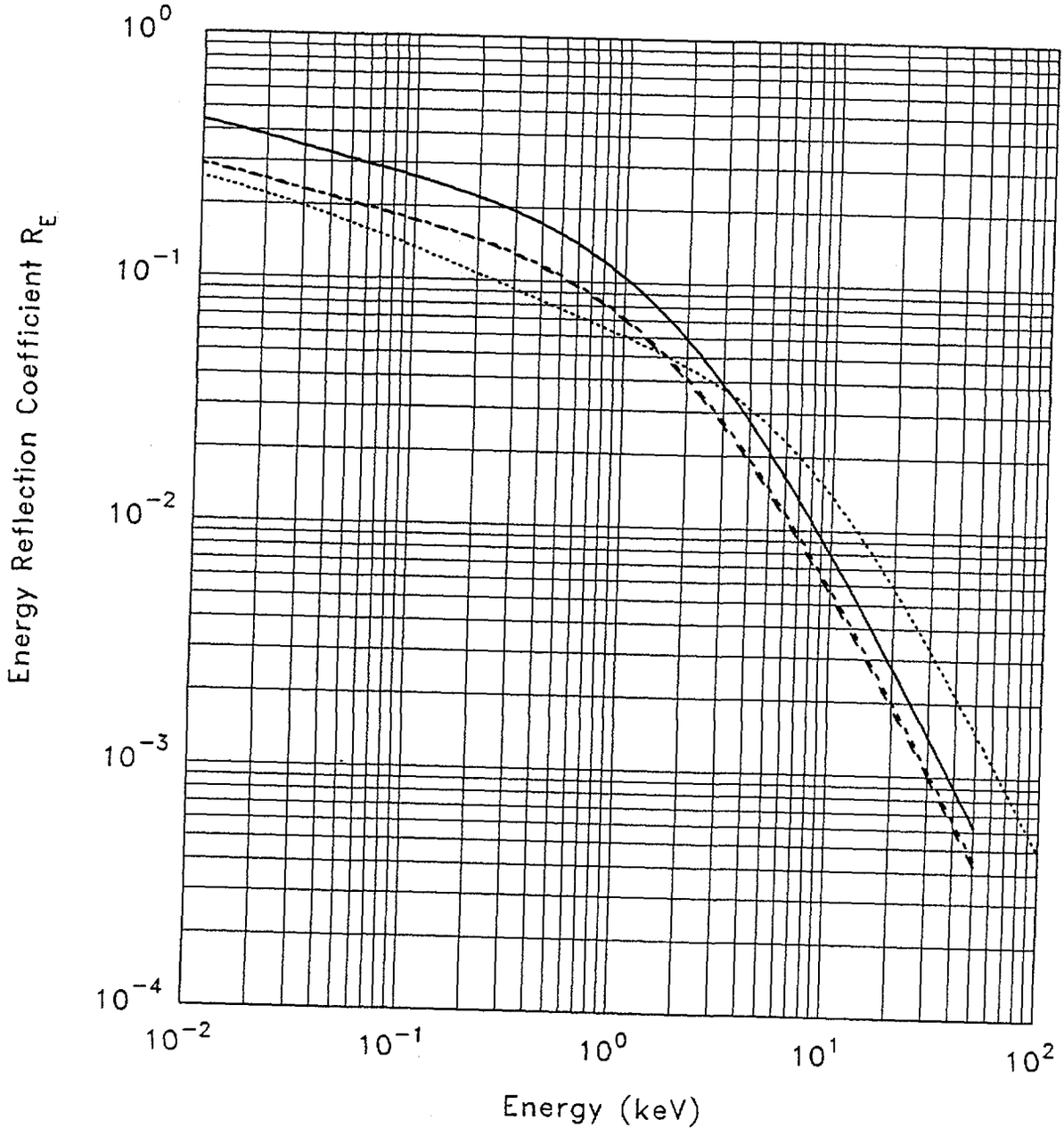
ALADDIN evaluation function for R_E: REFL1

ALADDIN hierarchical labelling:

RE H [+1] Si , for H^+; RE D [+1] Si , for D^+.

RE T [+1] Si , for T^+; RE [4]He [+1] Si , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Si



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Ti – Particle Reflection R_N

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	6.68E−01	6.70E−01	5.12E−01	5.46E−01
2.00E−02	6.16E−01	6.17E−01	4.73E−01	5.15E−01
5.00E−02	5.41E−01	5.43E−01	4.15E−01	4.63E−01
1.00E−01	4.88E−01	4.89E−01	3.71E−01	4.18E−01
2.00E−01	4.39E−01	4.40E−01	3.30E−01	3.74E−01
5.00E−01	3.72E−01	3.73E−01	2.75E−01	3.20E−01
1.00E+00	3.08E−01	3.10E−01	2.26E−01	2.78E−01
2.00E+00	2.31E−01	2.34E−01	1.70E−01	2.30E−01
5.00E+00	1.23E−01	1.25E−01	9.27E−02	1.55E−01
1.00E+01	5.93E−02	6.07E−02	4.65E−02	9.67E−02
2.00E+01	2.31E−02	2.38E−02	1.90E−02	4.93E−02
5.00E+01	5.37E−03	5.55E−03	4.68E−03	1.49E−02
1.00E+02	1.64E−03	1.69E−03	1.47E−03	5.09E−03

Accuracy: H^+ : 10 %, D^+ : 10 %, T^+ : 30 %, $^4He^+$: 20 %

Comments: (1) There are no detailed simulations (or experiments) covering a sufficient range of energy to establish a reliable data base. Our recommended data is based on a six parameter formula (see text) with the coefficients listed below. The coefficients for H^+ and D^+ are based on a fit to composite data for $\mu \geq 20$. The coefficients for T^+ and $^4He^+$ are based on a fit to composite data for $15 \geq \mu \geq 12$.

(2) The data are for a pure Ti target only. Under H^+($D^+$and T^+) bombardment the Ti will retain hydrogen and the reflection coefficient of the composite TiH_x will be lower than for pure Ti.

(3) The recommended data for D^+ are in good agreement with calculations by Zhengming et al [ZH91] above 100 eV; and fair agreement for $^4He^+$.

(4) Experimental studies (1 - 10 keV) for H^+ and D^+ lie below the recommended data by up to 30 % [EC79], [BO76]; perhaps due to hydrogen retention in the target. Experimental data for $^4He^+$ [EC79] (5 - 15 keV) are in adequate agreement.

(5) There is no supporting data for T^+.

Analytic fitting function data

$$R_N = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.8250	10.42	5.419	0.6425	0.4762	1.927
D^+	0.8250	10.21	5.349	0.6425	0. 4580	1.927
T^+	0.6192	9.356	5.374	0.6669	0.4401	1.899
$^4He^+$	0.6192	4.444	3.271	0.6669	0.1071	1.899

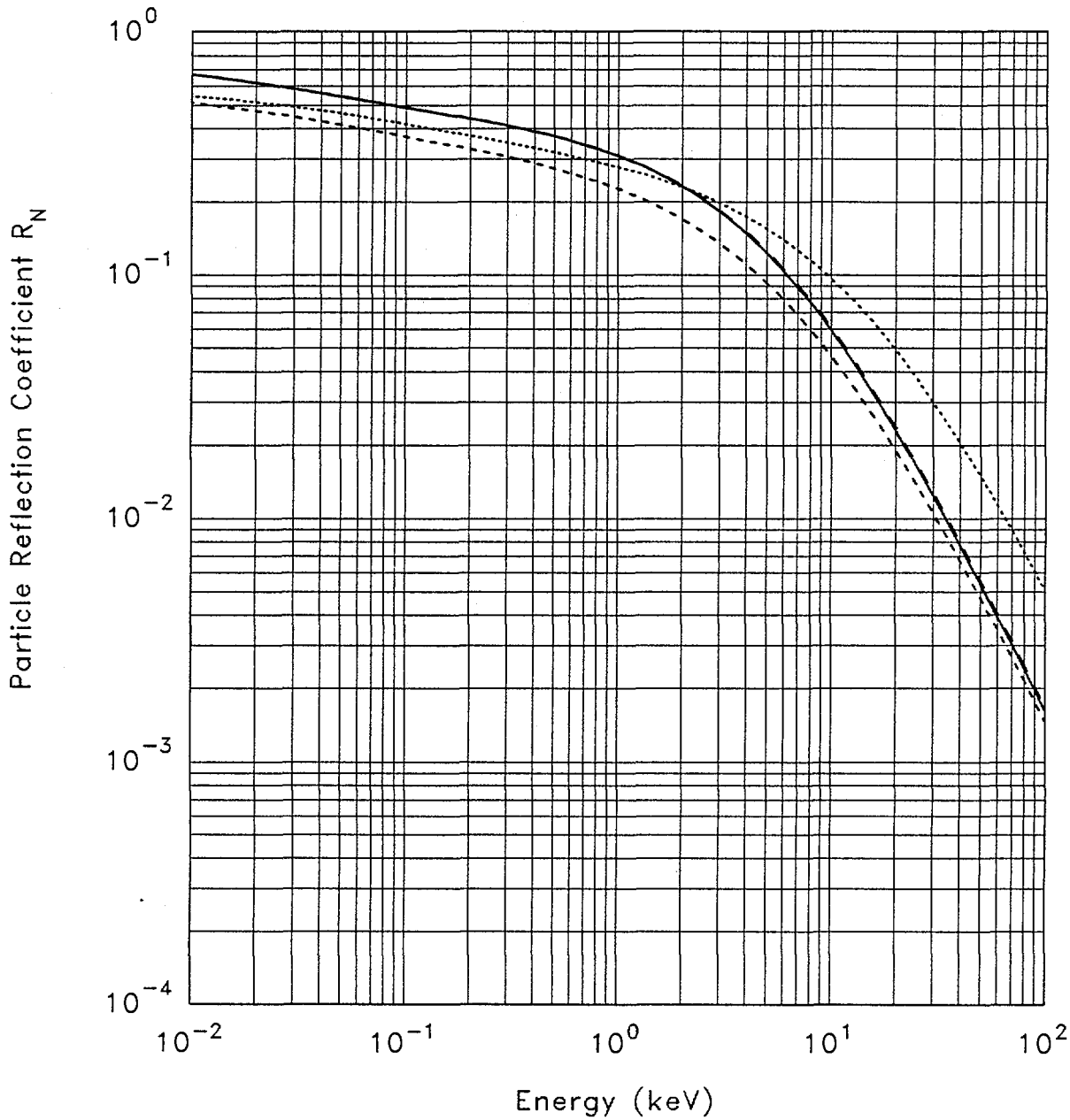
ALADDIN evaluation function for R_N: REFL1

ALADDIN hierarchical labelling:

RN H [+1] Ti , for H^+; RN D [+1] Ti , for D^+.

RN T [+1] Ti , for T^+; RN [4]He [+1] Ti , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Ti



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Ti – Energy Reflection R_E

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	4.88E−01	4.89E−01	3.22E−01	3.58E−01
2.00E−02	4.29E−01	4.31E−01	2.84E−01	3.25E−01
5.00E−02	3.53E−01	3.54E−01	2.34E−01	2.74E−01
1.00E−01	3.01E−01	3.03E−01	2.00E−01	2.36E−01
2.00E−01	2.56E−01	2.57E−01	1.70E−01	2.02E−01
5.00E−01	1.96E−01	1.98E−01	1.31E−01	1.62E−01
1.00E+00	1.47E−01	1.48E−01	9.83E−02	1.33E−01
2.00E+00	9.61E−02	9.75E−02	6.49E−02	1.01E−01
5.00E+00	4.16E−02	4.25E−02	2.85E−02	5.71E−02
1.00E+01	1.78E−02	1.83E−02	1.23E−02	3.01E−02
2.00E+01	6.63E−03	6.84E−03	4.63E−03	1.32E−02
5.00E+01	1.58E−03	1.63E−03	1.11E−03	3.57E−03
1.00E+02	5.08E−04	5.25E−04	3.56E−04	1.20E−03

Accuracy: H^+ : 10 %, D^+ : 10 %, T^+ : 30 %, $^4He^+$: 20 %

Comments: (1) There are no detailed simulations (or experiments) covering a sufficient range of energy to establish a reliable data base. Our recommended data is based on a six parameter formula (see text) with the coefficients listed below. The coefficients for H^+ and D^+ are based on a fit to composite data for $\mu \geq 20$. The coefficients for T^+ and $^4He^+$ are based on a fit to composite data for $15 \geq \mu \geq 12$.

(2) The data are for a pure Ti target only. Under H^+(D^+andT^+) bombardment the Ti will retain hydrogen and the reflection coefficient of the composite TiH_x will be lower than for pure Ti.

(3) The recommended data are in good (D^+) to adequate ($^4He^+$) agreement with calculations by Zhengming et al [ZH91] above 4 keV.

(4) Experimental studies (1 - 10 keV) [EC79], [HI76] and [KO83] are in adequate agreement with the recommended data for $^4He^+$ but lie below the recommended data for H^+ and D^+ by up to 50 %. This may be caused by retained hydrogen.

(5) There is no supporting data for T^+.

Analytic fitting function data

$$R_E = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.6831	13.22	9.741	0.6598	2.146	1.822
D^+	0.6831	12.96	9.612	0.6598	2.068	1.822
T^+	0.4483	12.70	9.486	0.6600	1.994	1.822
$^4He^+$	0.4483	6.032	5.805	0.6598	0.5135	1.822

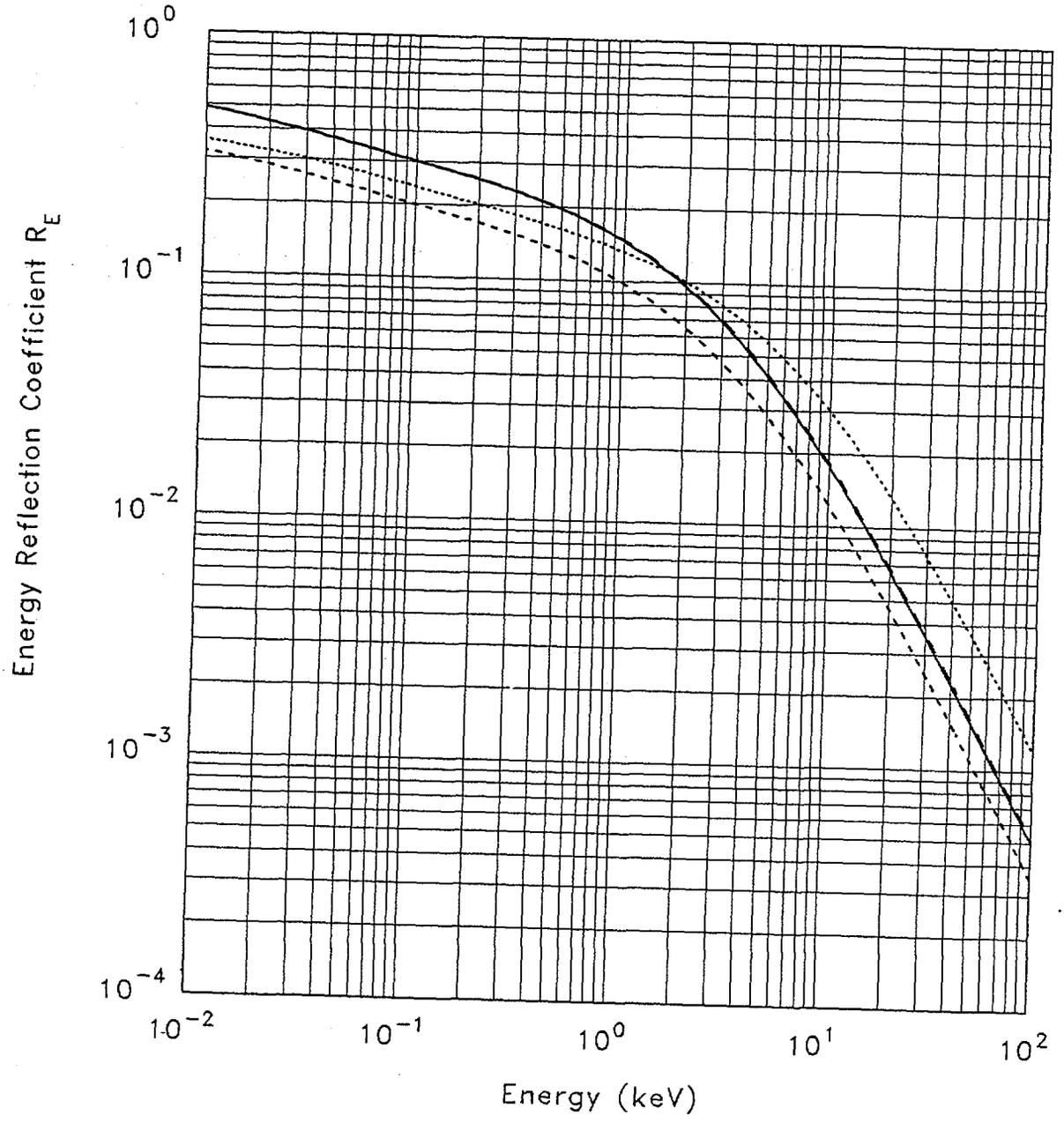
ALADDIN evaluation function for R_E: REFL1

ALADDIN hierarchical labelling:

RE H [+1] Ti , for H^+; RE D [+1] Ti , for D^+.

RE T [+1] Ti , for T^+; RE [4]He [+1] Ti , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Ti



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Fe – Particle Reflection R_N

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	6.83E−01	6.84E−01	6.85E−01	5.54E−01
2.00E−02	6.33E−01	6.34E−01	6.35E−01	5.25E−01
5.00E−02	5.58E−01	5.60E−01	5.61E−01	4.75E−01
1.00E−01	5.04E−01	5.05E−01	5.06E−01	4.31E−01
2.00E−01	4.54E−01	4.55E−01	4.56E−01	3.87E−01
5.00E−01	3.89E−01	3.90E−01	3.91E−01	3.32E−01
1.00E+00	3.29E−01	3.31E−01	3.33E−01	2.91E−01
2.00E+00	2.56E−01	2.58E−01	2.60E−01	2.45E−01
5.00E+00	1.47E−01	1.49E−01	1.51E−01	1.72E−01
1.00E+01	7.61E−02	7.76E−02	7.91E−02	1.13E−01
2.00E+01	3.15E−02	3.23E−02	3.31E−02	6.14E−02
5.00E+01	7.65E−03	7.88E−03	8.10E−03	1.99E−02
1.00E+02	2.37E−03	2.44E−03	2.52E−03	7.03E−03

Accuracy: H^+ : 10 %, D^+ : 10 %, T^+ : 10 %, $^4He^+$: 10 %

Comments: (1) The recommended data are based on the six parameter fit to high mass ratio data (see text) for H^+, D^+ and T^+. For $^4He^+$ + Fe we use a fit to the data covering the mass ratios 12 to 15.

(2) The recommended data are in good agreement with the MARLOWE simulation of Eckstein and Verbeek [EC79].

(3) Calculations by Zhengming et al [ZH91] are in adequate to poor agreement with the recommended data.

(4) The recommended data agree well with experimental measurements of Eckstein and Verbeek [EC79], Sidenius and Lenskjaer [SI76] and Thomas [TH80].

Analytic fitting function data

$$R_N = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.8250	8.415	4.724	0.6425	0.3154	1.927
D^+	0.8250	8.269	4.671	0.6425	0.3050	1.927
T^+	0.8250	8.128	4.619	0.6425	0.2950	1.927
$^4He^+$	0.6192	3.629	7.289E−02	1.899	2.857	0.6669

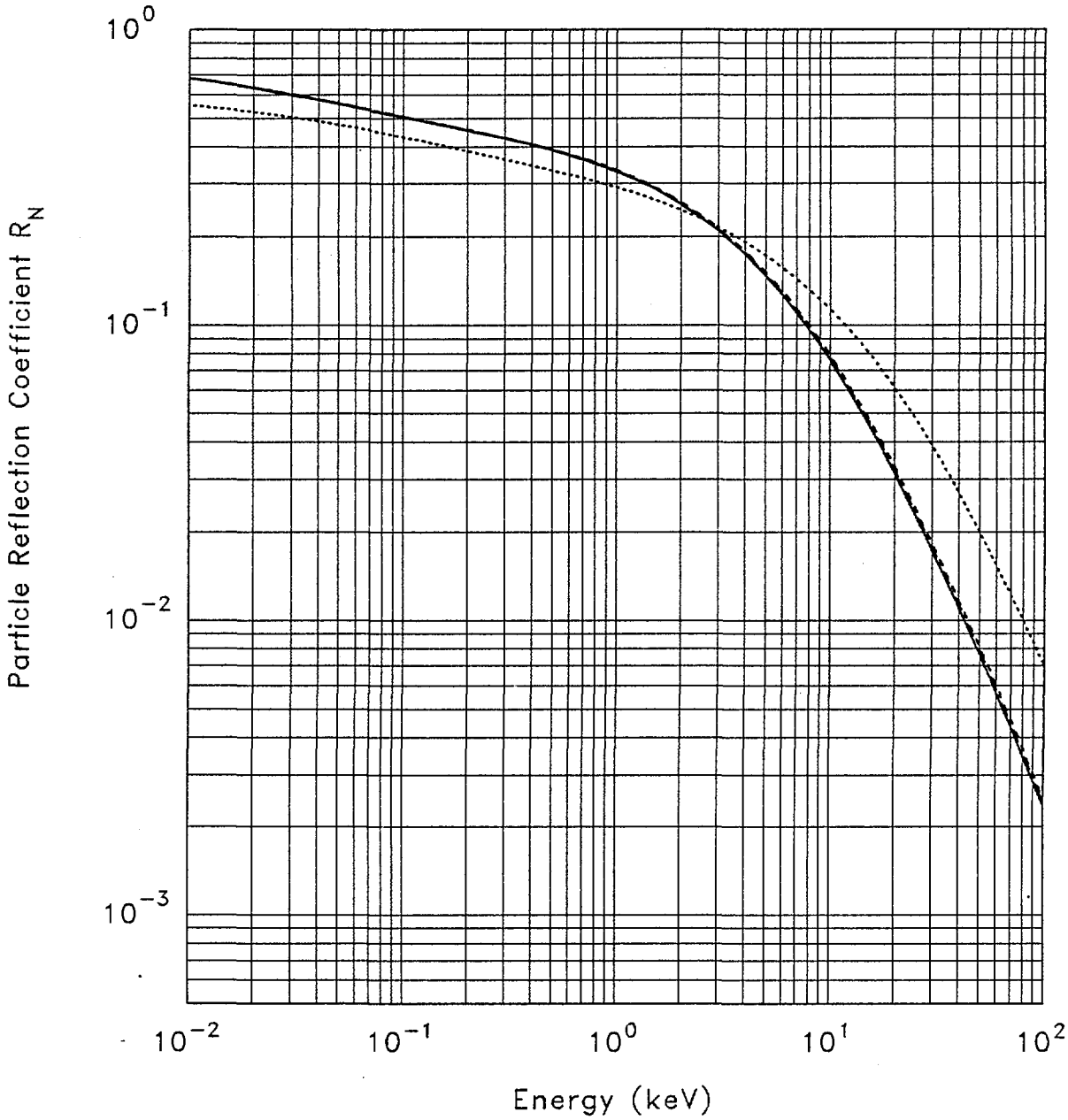
ALADDIN evaluation function for R_N: REFL1

ALADDIN hierarchical labelling:

RN H [+1] Fe , for H^+; RN D [+1] Fe , for D^+.

RN T [+1] Fe , for T^+; RN [4]He [+1] Fe , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Fe



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Fe – Energy Reflection R_E

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	5.05E−01	5.06E−01	5.07E−01	3.67E−01
2.00E−02	4.48E−01	4.49E−01	4.51E−01	3.35E−01
5.00E−02	3.70E−01	3.71E−01	3.73E−01	2.86E−01
1.00E−01	3.16E−01	3.18E−01	3.19E−01	2.47E−01
2.00E−01	2.70E−01	2.71E−01	2.72E−01	2.12E−01
5.00E−01	2.11E−01	2.12E−01	2.13E−01	1.71E−01
1.00E+00	1.62E−01	1.64E−01	1.65E−01	1.42E−01
2.00E+00	1.11E−01	1.13E−01	1.14E−01	1.10E−01
5.00E+00	5.21E−02	5.31E−02	5.40E−02	6.64E−02
1.00E+01	2.36E−02	2.41E−02	2.46E−02	3.71E−02
2.00E+01	9.10E−03	9.34E−03	9.58E−03	1.71E−02
5.00E+01	2.23E−03	2.29E−03	2.36E−03	4.84E−03
1.00E+02	7.23E−04	7.44E−04	7.66E−04	1.66E−03

Accuracy: H^+ : 10 %, D^+ : 10 %, T^+ : 10 %, $^4He^+$: 10 %

Comments: (1) The recommended data are based on the six parameter fit to high mass ratio data (see text) for H^+, D^+ and T^+. For $^4He^+$ + Fe we use a fit to the data covering the mass ratios 12 to 15.

(2) The recommended data are in good agreement with the MARLOWE simulation of Eckstein and Verbeek [EC79].

(3) Calculations by Zhengming et al [ZH91] agree adequately with the recommended data for H^+ and $^4He^+$ except below 200 eV; they differ significantly for D^+.

(4) The recommended data agree well with experimental measurements of Eckstein and Verbeek [EC79], Sidenius and Lenskjaer [SI76] and Tanaka et al [TA78].

Analytic fitting function data

$$R_E = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.6831	10.68	8.460	0.6598	1.453	1.822
D^+	0.6831	10.49	8.363	0.6598	1.408	1.822
T^+	0.6831	10.31	8.268	0.6598	1.364	1.822
$^4He^+$	0.4483	4.925	5.078	0.6598	0.3549	1.822

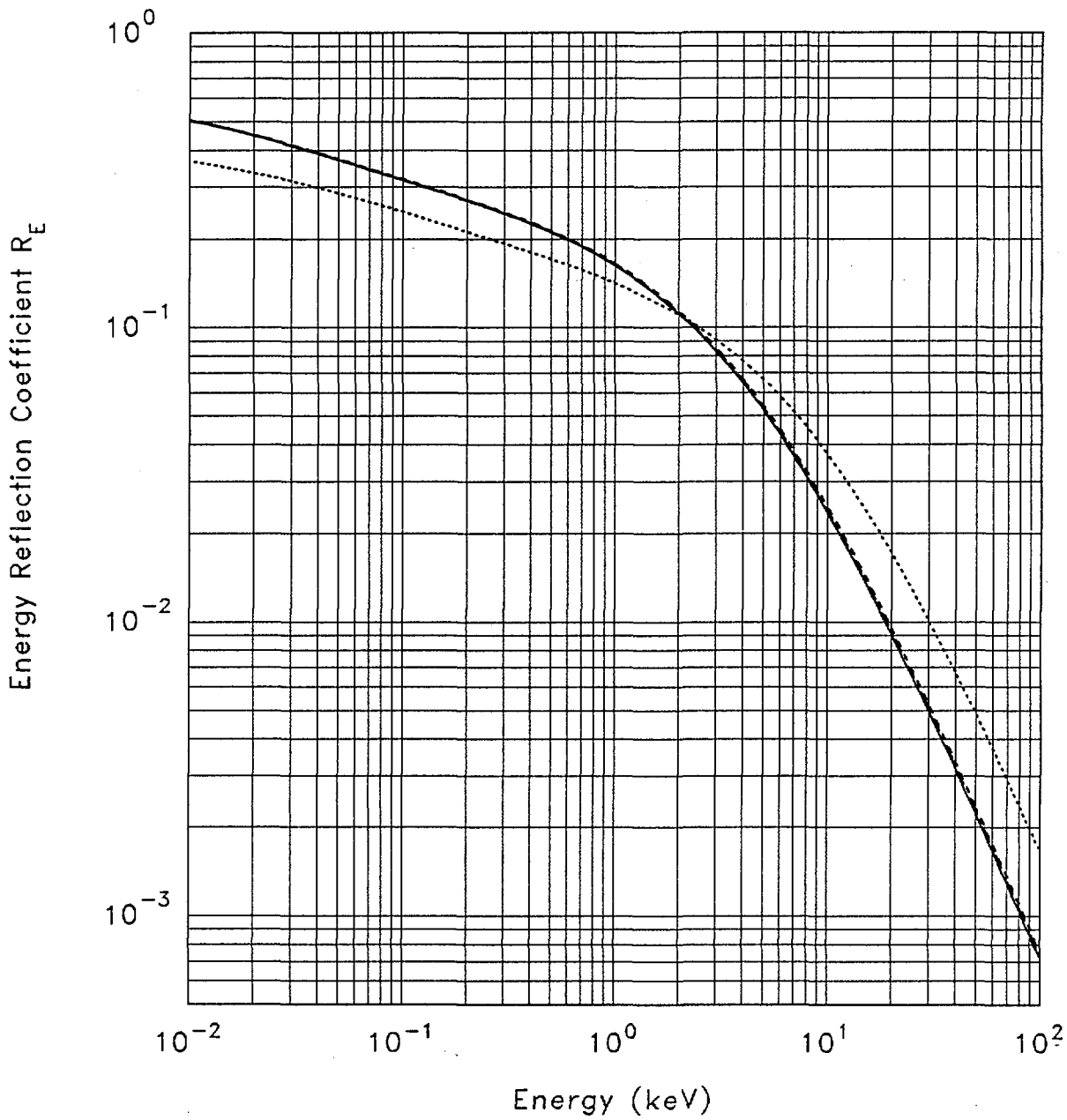
ALADDIN evaluation function for R_E: REFL1

ALADDIN hierarchical labelling:

RE H [+1] Fe , for H^+; RE D [+1] Fe , for D^+.

RE T [+1] Fe , for T^+; RE [4]He [+1] Fe , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Fe



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Ni – Particle Reflection R_N

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	6.89E−01	6.90E−01	6.91E−01	5.57E−01
2.00E−02	6.40E−01	6.41E−01	6.42E−01	5.29E−01
5.00E−02	5.66E−01	5.68E−01	5.69E−01	4.81E−01
1.00E−01	5.11E−01	5.12E−01	5.14E−01	4.37E−01
2.00E−01	4.61E−01	4.62E−01	4.63E−01	3.92E−01
5.00E−01	3.96E−01	3.97E−01	3.98E−01	3.37E−01
1.00E+00	3.38E−01	3.40E−01	3.41E−01	2.97E−01
2.00E+00	2.67E−01	2.69E−01	2.71E−01	2.52E−01
5.00E+00	1.58E−01	1.60E−01	1.62E−01	1.80E−01
1.00E+01	8.45E−02	8.60E−02	8.75E−02	1.21E−01
2.00E+01	3.60E−02	3.68E−02	3.76E−02	6.74E−02
5.00E+01	8.95E−03	9.19E−03	9.44E−03	2.26E−02
1.00E+02	2.79E−03	2.88E−03	2.96E−03	8.13E−03

Accuracy: H^+ : 10 %, D^+ : 10 %, T^+ : 10 %, $^4He^+$: 10 %

Comments: (1) The recommended data are based on the six parameter fit to high mass ratio data (see text) for H^+, D^+ and T^+. For $^4He^+$ we use a fit to the data in the range $15 \geq \mu \geq 12$.

(2) The recommended data are in good agreement with the TRIM simulation of Eckstein [EC84] and Aratari and Eckstein [AR89i].

(3) The recommended data agree well with experimental data of Eckstein [EC79]. Data by Aratari and Eckstein [AR89i] are inaccurate due to the presence of a contaminant hydrogen layer.

(4) Theoretical calculations by Zhengming et al [ZH91] for this case are widely variant from the simulations and from experiment and they should be disregarded.

(5) There is no supporting data for T^+.

Analytic fitting function data

$$R_N = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.8250	7.649	4.443	0.6425	0.2624	1.927
D^+	0.8250	7.523	4.396	0.6425	0.2541	1.927
T^+	0.8250	7.400	4.349	0.6425	0.2462	1.927
$^4He^+$	0.6192	3.310	2.688	0.6669	0.6122	1.899

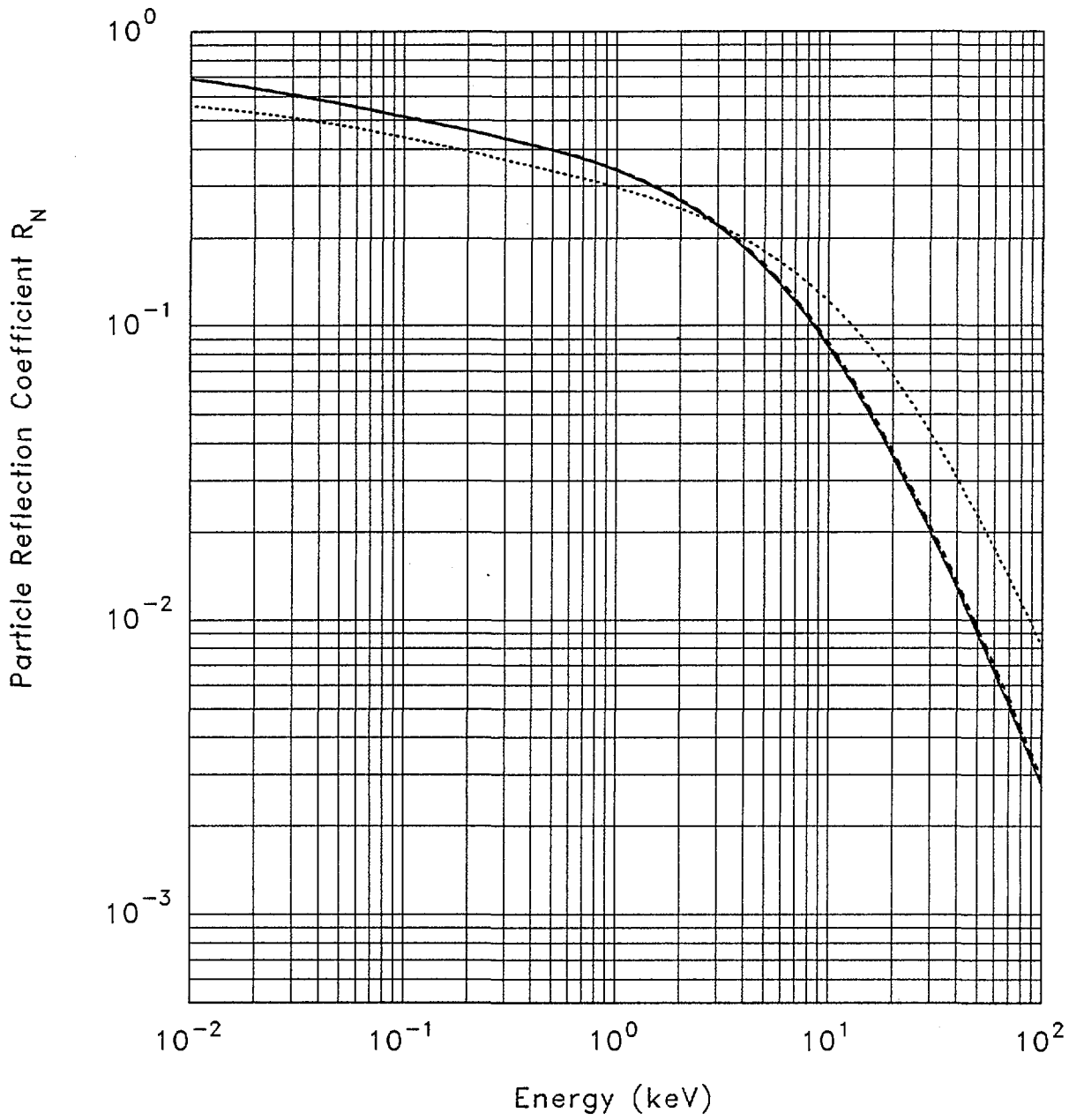
ALADDIN evaluation function for R_N: REFL1

ALADDIN hierarchical labelling:

RN H [+1] Ni , for H^+; RN D [+1] Ni , for D^+.

RN T [+1] Ni , for T^+; RN [4]He [+1] Ni , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Ni



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Ni – Energy Reflection R_E

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	5.12E−01	5.13E−01	5.15E−01	3.71E−01
2.00E−02	4.56E−01	4.57E−01	4.59E−01	3.40E−01
5.00E−02	3.78E−01	3.79E−01	3.80E−01	2.91E−01
1.00E−01	3.23E−01	3.25E−01	3.26E−01	2.52E−01
2.00E−01	2.76E−01	2.77E−01	2.78E−01	2.16E−01
5.00E−01	2.17E−01	2.18E−01	2.19E−01	1.75E−01
1.00E+00	1.69E−01	1.71E−01	1.72E−01	1.46E−01
2.00E+00	1.18E−01	1.20E−01	1.21E−01	1.15E−01
5.00E+00	5.73E−02	5.83E−02	5.92E−02	7.07E−02
1.00E+01	2.66E−02	2.71E−02	2.77E−02	4.05E−02
2.00E+01	1.05E−02	1.07E−02	1.10E−02	1.91E−02
5.00E+01	2.60E−03	2.66E−03	2.73E−03	5.55E−03
1.00E+02	8.46E−04	8.70E−04	8.93E−04	1.92E−03

Accuracy: H^+ : 10 %, D^+ : 10 %, T^+ : 10 %, $^4He^+$: 10 %

Comments: (1) The recommended data are based on the six parameter fit to high mass ratio data (see text) for H^+, D^+ and T^+. For $^4He^+$ we use a fit to the data in the range $15 \geq \mu \geq 12$.

(2) The recommended data are in good agreement with the TRIM simulation of Eckstein [EC84].

(3) Theoretical calculations by Zhengming et al [ZH91] for this case are widely variant from the simulations and from experiment and they should be disregarded.

(4) Experimental studies [EC79] anfd [HI76] are in general agreement with the recommended data.

(5) There is no supporting data for T^+.

Analytic fitting function data

$$R_E = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.6831	9.704	7.943	0.6598	1.221	1.822
D^+	0.6831	9.544	7.857	0.6598	1.185	1.822
T^+	0.6831	9.388	7.772	0.6598	1.150	1.822
$^4He^+$	0.4484	4.493	4.779	0.6598	0.3002	1.822

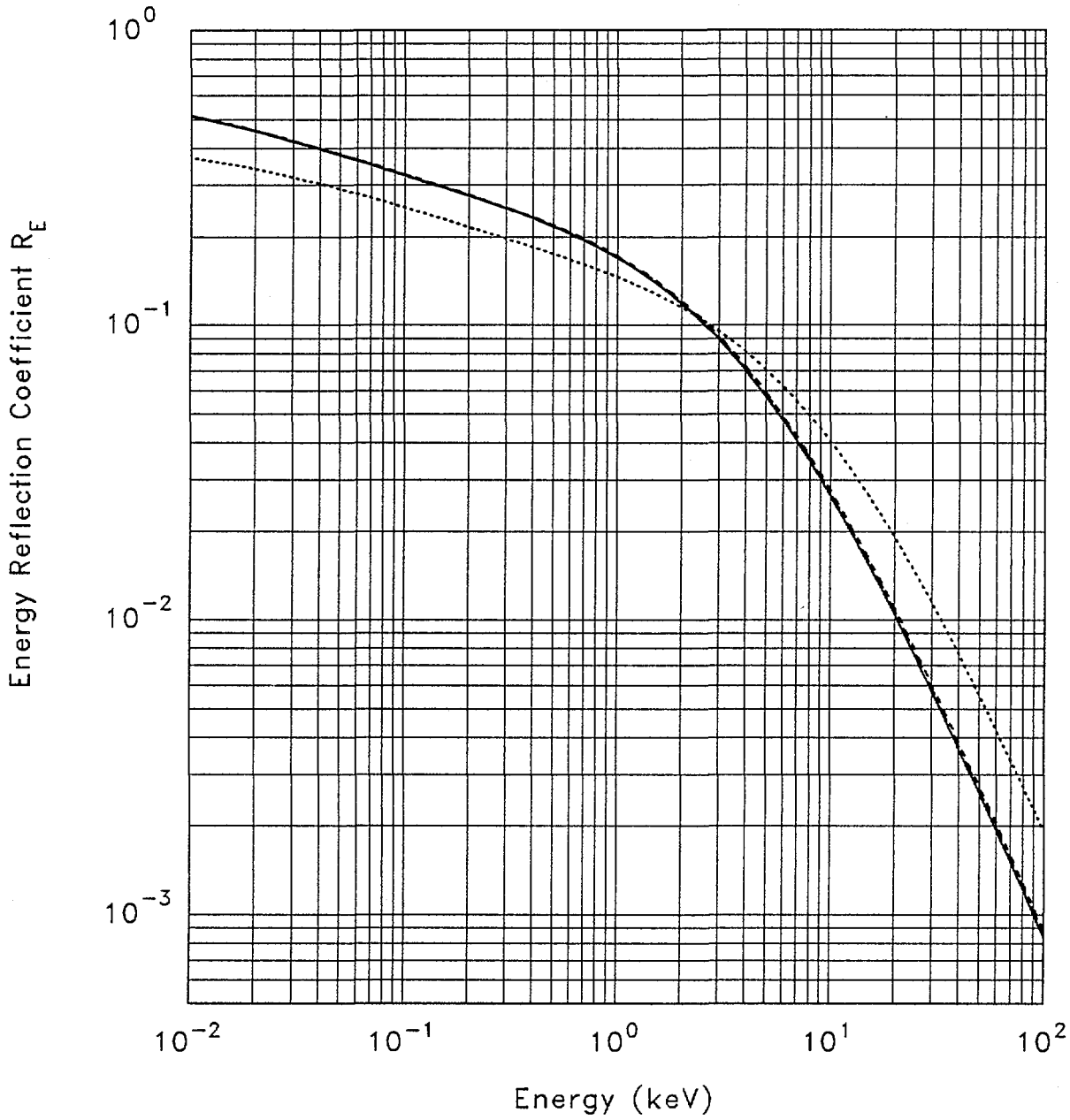
ALADDIN evaluation function for R_E: REFL1

ALADDIN hierarchical labelling:

RE H [+1] Ni , for H^+; RE D [+1] Ni , for D^+.

RE T [+1] Ni , for T^+; RE [4]He [+1] Ni , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Ni



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Cu – Particle Reflection R_N

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	6.92E−01	6.93E−01	6.94E−01	6.24E−01
2.00E−02	6.43E−01	6.44E−01	6.46E−01	5.92E−01
5.00E−02	5.70E−01	5.71E−01	5.72E−01	5.37E−01
1.00E−01	5.14E−01	5.16E−01	5.17E−01	4.89E−01
2.00E−01	4.64E−01	4.65E−01	4.66E−01	4.42E−01
5.00E−01	3.99E−01	4.00E−01	4.01E−01	3.85E−01
1.00E+00	3.42E−01	3.44E−01	3.45E−01	3.44E−01
2.00E+00	2.72E−01	2.74E−01	2.75E−01	2.96E−01
5.00E+00	1.64E−01	1.66E−01	1.67E−01	2.17E−01
1.00E+01	8.86E−02	9.00E−02	9.15E−02	1.47E−01
2.00E+01	3.82E−02	3.90E−02	3.98E−02	8.12E−02
5.00E+01	9.62E−03	9.86E−03	1.01E−02	2.64E−02
1.00E+02	3.02E−03	3.10E−03	3.18E−03	9.19E−03

Accuracy: H^+ : 10 %, D^+ : 20 %, T^+ : 20 %, $^4He^+$: 20 %

Comments: (1) The recommended data are based on the six parameter fit to high mass ratio data (see text) for H^+, D^+ and T^+. In the case of $^4He^+$ the fit line lies above a recent TRIM simulation [EC90] systematically by 15 %. While this is within the accuracy range of the simulation, we have chosen to reduce A_1 by 15 % in this case so that the recommended data better represent the simulation. As a consequence we ascribe broad accuracy limits to this case. A similar adjustment is needed for R_E.

(2) The recommended data are in good agreement with MARLOWE simulations for H^+ [OE76] and $^4He^+$ [ÖE76] and are in excellent agreement (with the adjusted A_1) with TRIM simulations for $^4He^+$ [EC90]. They are also in good agreement with calculations by Zhengming et al [ZH91] except at energies below 100 eV.

(3) Experimental data [SI76] (5 - 30 keV) for H^+ are in good agreement with the recommended data.

(4) There are no simulations or experiments for D^+.

Analytic fitting function data

$$R_N = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

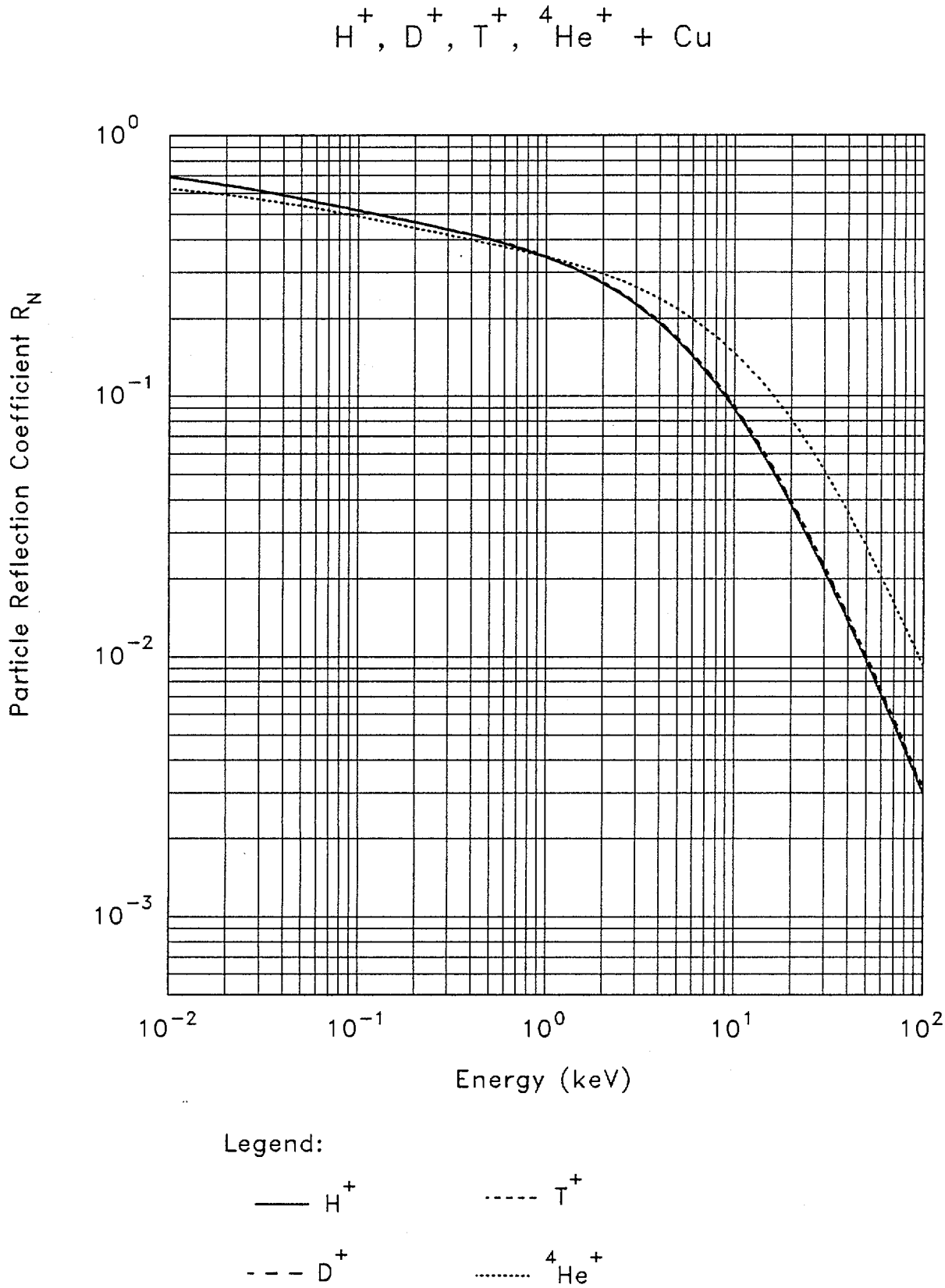
	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.8250	7.317	4.318	0.6425	0.2409	1.927
D^+	0.8250	7.205	4.275	0.6425	0.2339	1.927
T^+	0.8250	7.096	4.234	0.6425	0.2271	1.927
$^4He^+$	0.7013	3.402	2.640	0.6425	5.507E−02	1.927

ALADDIN evaluation function for R_N: REFL1

ALADDIN hierarchical labelling:

RN H [+1] Cu , for H^+; RN D [+1] Cu , for D^+.

RN T [+1] Cu , for T^+; RN [4]He [+1] Cu , for $^4He^+$.


H^+, D^+, T^+, $^4He^+$ + Cu
Particle Reflection Coefficient R_N
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
Energy (keV)
Legend:
H^+
T^+
D^+
$^4He^+$

H^+, D^+, T^+, $^4He^+$ + Cu – Energy Reflection R_E

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	5.15E−01	5.17E−01	5.18E−01	3.97E−01
2.00E−02	4.60E−01	4.61E−01	4.62E−01	3.65E−01
5.00E−02	3.81E−01	3.83E−01	3.84E−01	3.13E−01
1.00E−01	3.27E−01	3.28E−01	3.29E−01	2.71E−01
2.00E−01	2.79E−01	2.80E−01	2.81E−01	2.32E−01
5.00E−01	2.20E−01	2.21E−01	2.22E−01	1.88E−01
1.00E+00	1.73E−01	1.74E−01	1.75E−01	1.57E−01
2.00E+00	1.22E−01	1.23E−01	1.24E−01	1.24E−01
5.00E+00	5.99E−02	6.07E−02	6.16E−02	7.75E−02
1.00E+01	2.81E−02	2.86E−02	2.91E−02	4.49E−02
2.00E+01	1.11E−02	1.14E−02	1.16E−02	2.15E−02
5.00E+01	2.79E−03	2.86E−03	2.93E−03	6.28E−03
1.00E+02	9.12E−04	9.35E−04	9.58E−04	2.19E−03

Accuracy: H^+ : 10 %, D^+ : 20 %, T^+ : 20 %, $^4He^+$: 30 %

Comments: (1) The recommended data are based on the six parameter fit to high mass ratio data (see text) for H^+, D^+ and T^+. In the case of $^4He^+$ the fit line lies above a recent TRIM simulation [EC90] systematically by 30 %. While this is within the accuracy range of the simulation, we have chosen to reduce A_1 by 30 % in this case so that the recommended data better represent the simulation. As a consequence we ascribe broad accuracy limits to this case. A similar adjustment is needed for R_N.

(2) The recommended data are in good agreement with MARLOWE simulations for H^+ [OE76] and $^4He^+$ [OE76] and are in excellent agreement (with the adjusted A_1) with TRIM simulations for $^4He^+$ [EC90]. They are also in good agreement with calculations by Zhengming et al [ZH91] except at energies below 100 eV.

(3) Various experimental data [SI76], [TA78], [HI76], [KO83] and [SC78] are in adequate to excellent agreement with the recommended data for H^+ and $^4He^+$.

(4) There are no simulations or experiments for D^+.

Analytic fitting function data

$$R_E = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.6831	9.282	7.714	0.6598	1.126	1.822
D^+	0.6831	9.141	7.636	0.6598	1.095	1.822
T^+	0.6831	9.002	7.560	0.6598	1.065	1.822
$^4He^+$	0.4782	4.316	4.654	0.6598	0.2790	1.822

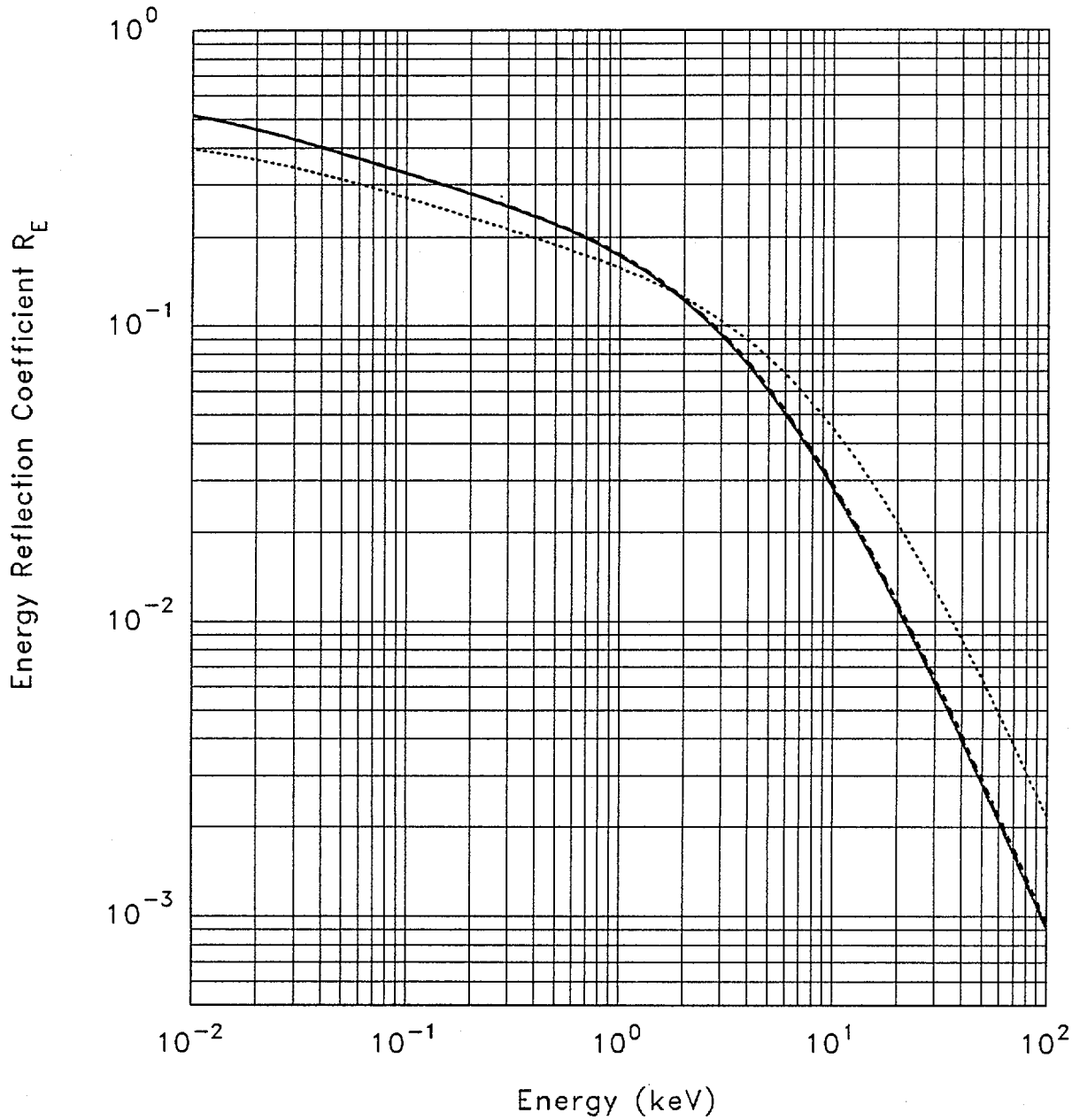
ALADDIN evaluation function for R_E: REFL1

ALADDIN hierarchical labelling:

RE H [+1] Cu , for H^+; RE D [+1] Cu , for D^+.

RE T [+1] Cu , for T^+; RE [4]He [+1] Cu , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Cu



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Mo – Particle Reflection R_N

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	7.20E−01	7.21E−01	7.21E−01	7.55E−01
2.00E−02	6.78E−01	6.78E−01	6.79E−01	7.23E−01
5.00E−02	6.09E−01	6.10E−01	6.10E−01	6.66E−01
1.00E−01	5.52E−01	5.53E−01	5.54E−01	6.13E−01
2.00E−01	4.98E−01	4.99E−01	5.00E−01	5.56E−01
5.00E−01	4.33E−01	4.34E−01	4.35E−01	4.85E−01
1.00E+00	3.83E−01	3.84E−01	3.84E−01	4.37E−01
2.00E+00	3.22E−01	3.23E−01	3.24E−01	3.87E−01
5.00E+00	2.21E−01	2.22E−01	2.24E−01	3.05E−01
1.00E+01	1.39E−01	1.40E−01	1.41E−01	2.27E−01
2.00E+01	6.99E−02	7.07E−02	7.15E−02	1.45E−01
5.00E+01	2.03E−02	2.07E−02	2.10E−02	5.70E−02
1.00E+02	6.76E−03	6.88E−03	6.99E−03	2.20E−02

Accuracy: H^+ : 30 %, D^+ : 30 %, T^+ : 30 %, $^4He^+$: 30 %

Comments: (1) The recommended data are based on the six parameter fit to high mass ratio data (see text).

(2) The recommended data is in excellent agreement with the calculations of Zhengming et al [ZH91].

(3) Experimental data by Eckstein and Verbeek [EC79] and Sidenius and Lenskjaer [SI76] lie 50 % below the recommended data for all cases. This may be due to a surface oxide contaminant.

(4) Since there are no detailed simulations and reliable experiments to validate these data, the recommended data should be treated with caution and we ascribe broad limits to the reliability.

Analytic fitting function data

$$R_N = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.8250	4.537	3.176	0.6425	9.591E−02	1.927
D^+	0.8250	4.490	3.155	0.6425	9.403E−02	1.927
T^+	0.8250	4.445	3.135	0.6425	9.219E−02	1.927
$^4He^+$	0.8250	2.153	1.967	0.6425	2.280E−02	1.927

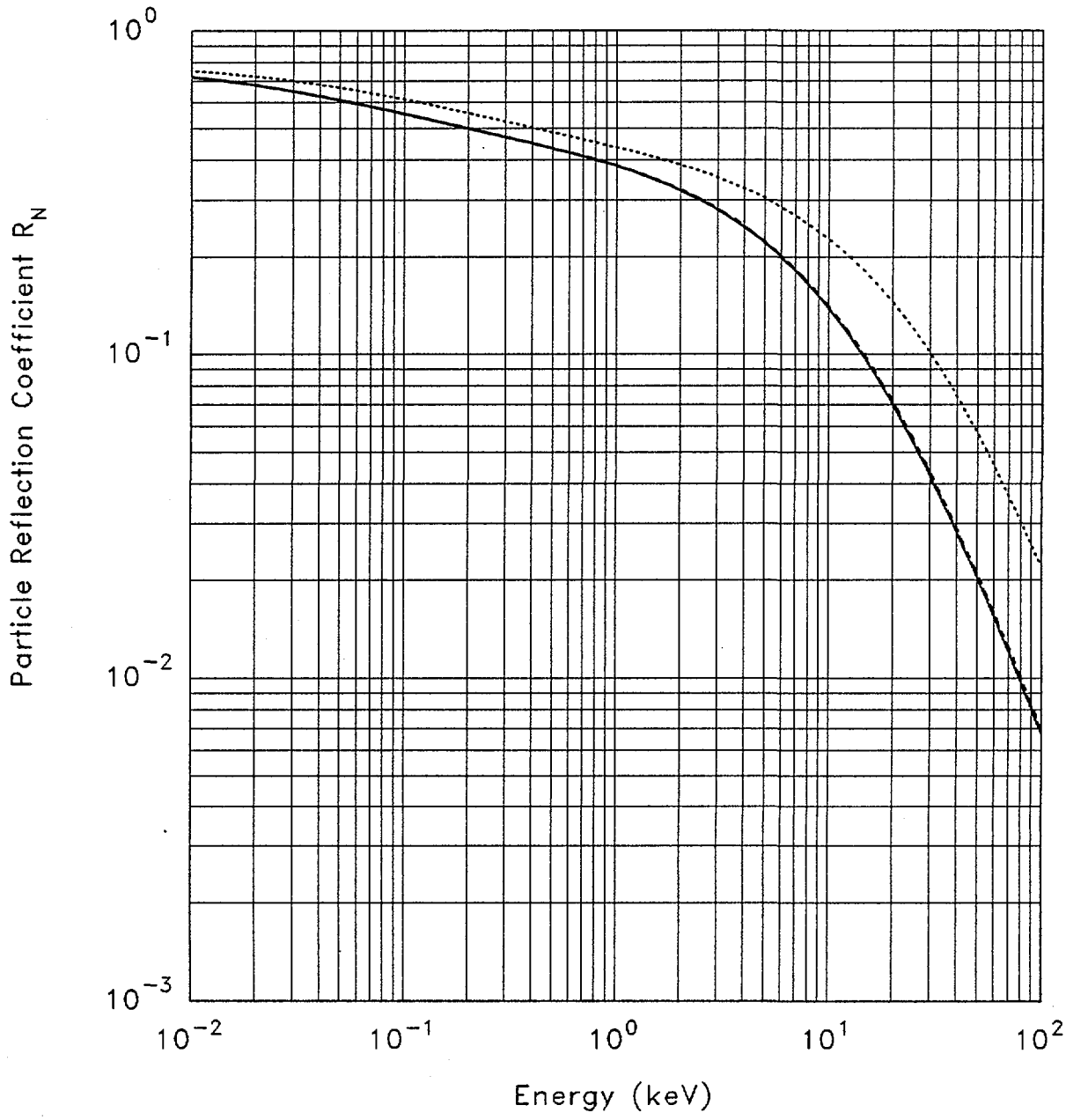
ALADDIN evaluation function for R_N: REFL1

ALADDIN hierarchical labelling:

RN H [+1] Mo , for H^+; RN D [+1] Mo , for D^+.

RN T [+1] Mo , for T^+; RN [4]He [+1] Mo , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Mo



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Mo – Energy Reflection R_E

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	5.49E−01	5.50E−01	5.51E−01	5.92E−01
2.00E−02	4.99E−01	5.00E−01	5.00E−01	5.53E−01
5.00E−02	4.22E−01	4.23E−01	4.24E−01	4.85E−01
1.00E−01	3.64E−01	3.65E−01	3.65E−01	4.26E−01
2.00E−01	3.11E−01	3.12E−01	3.13E−01	3.68E−01
5.00E−01	2.51E−01	2.51E−01	2.52E−01	2.99E−01
1.00E+00	2.06E−01	2.06E−01	2.07E−01	2.54E−01
2.00E+00	1.57E−01	1.58E−01	1.58E−01	2.09E−01
5.00E+00	9.02E−02	9.09E−02	9.16E−02	1.44E−01
1.00E+01	4.83E−02	4.88E−02	4.93E−02	9.38E−02
2.00E+01	2.14E−02	2.17E−02	2.20E−02	5.09E−02
5.00E+01	5.84E−03	5.93E−03	6.02E−03	1.71E−02
1.00E+02	1.98E−03	2.01E−03	2.04E−03	6.32E−03

Accuracy: H^+ : 30 %, D^+ : 30 %, T^+ : 30 %, $^4He^+$: 30 %

Comments: (1) The recommended data are based on the six parameter fit to high mass ratio data (see text).

(2) The recommended data is in poor agreement with the calculations of Zhengming et al [ZH91].

(3) Experimental data by Eckstein and Verbeek [EC79], Sidenius and Lenskjaer [SI76] and Hilderbrandt and Manns [HI76] (2.5 - 25 keV) lie 50 % below the recommended data for all cases. This may be due to a surface oxide contaminant.

(4) Since there are no detailed simulations and reliable experiments to validate these data, the recommended data should be treated with caution and we ascribe broad limits to the reliability.

Analytic fitting function data

$$R_E = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

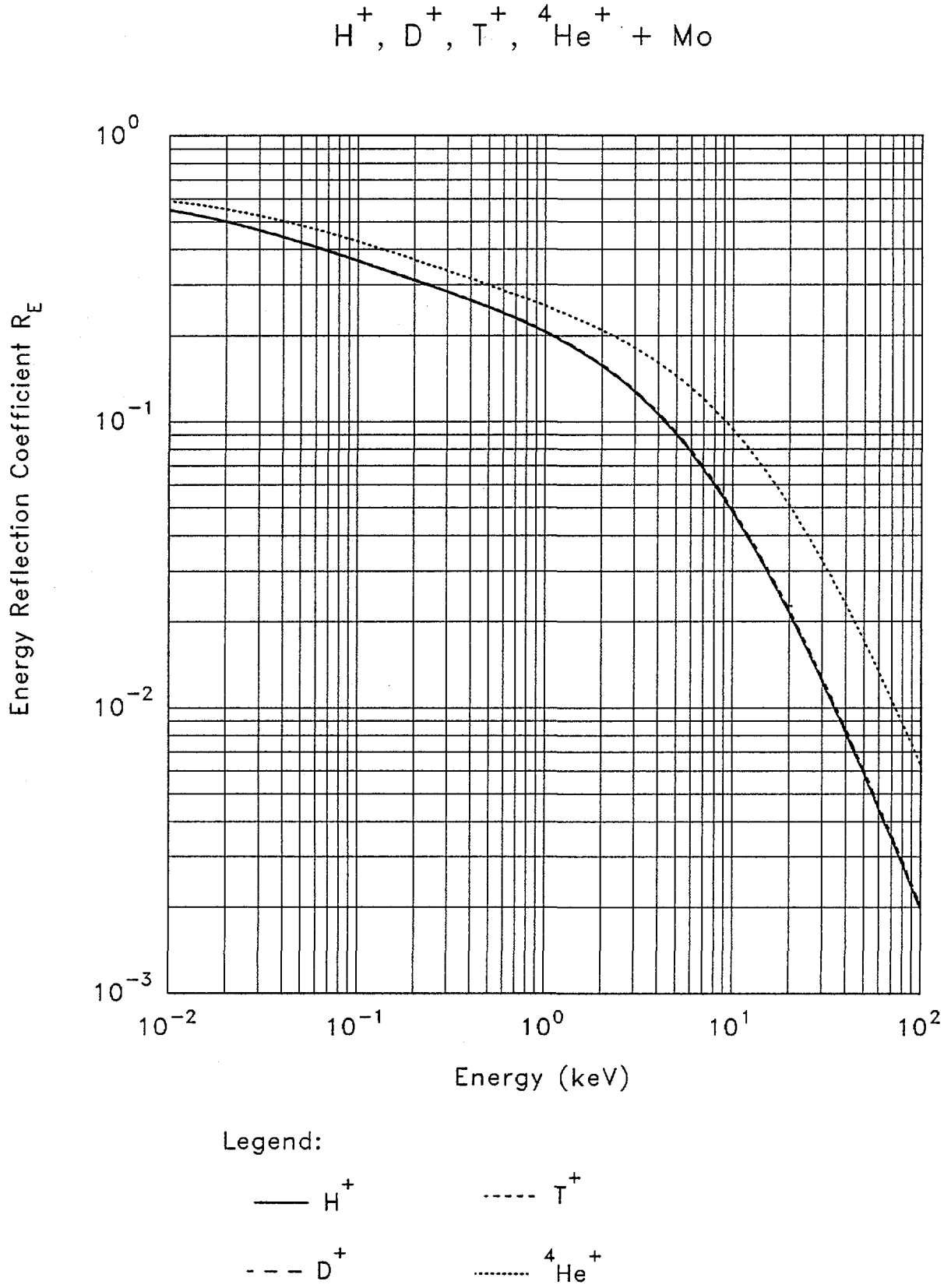
	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.6831	5.756	5.628	0.6598	0.4714	1.822
D^+	0.6831	5.697	5.590	0.6598	0.4627	1.822
T^+	0.6831	5.639	5.552	0.6598	0.4541	1.822
$^4He^+$	0.6831	2.731	3.441	0.6598	0.1212	1.822

ALADDIN evaluation function for R_E: REFL1

ALADDIN hierarchical labelling:

RE H [+1] Mo , for H^+; RE D [+1] Mo , for D^+.

RE T [+1] Mo , for T^+; RE [4]He [+1] Mo , for $^4He^+$.


H^+, D^+, T^+, $^4He^+$ + Mo
Energy Reflection Coefficient R_E
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
Energy (keV)
Legend:
H^+
T^+
D^+
$^4He^+$

H^+, D^+, T^+, $^4He^+$ + W – Particle Reflection R_N

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	7.54E−01	7.54E−01	7.55E−01	7.78E−01
2.00E−02	7.22E−01	7.23E−01	7.23E−01	7.55E−01
5.00E−02	6.65E−01	6.66E−01	6.66E−01	7.12E−01
1.00E−01	6.12E−01	6.13E−01	6.13E−01	6.68E−01
2.00E−01	5.56E−01	5.56E−01	5.57E−01	6.15E−01
5.00E−01	4.85E−01	4.85E−01	4.86E−01	5.40E−01
1.00E+00	4.36E−01	4.37E−01	4.37E−01	4.87E−01
2.00E+00	3.86E−01	3.87E−01	3.87E−01	4.39E−01
5.00E+00	3.04E−01	3.05E−01	3.05E−01	3.71E−01
1.00E+01	2.27E−01	2.27E−01	2.28E−01	3.07E−01
2.00E+01	1.44E−01	1.44E−01	1.45E−01	2.30E−01
5.00E+01	5.64E−02	5.68E−02	5.72E−02	1.22E−01
1.00E+02	2.18E−02	2.19E−02	2.21E−02	5.87E−02

Accuracy: H^+ : 10 %, D^+ : 10 %, T^+ : 10 %, $^4He^+$: 10 %

Comments: (1) The recommended data are based on the six parameter fit to high mass ratio data (see text).

(2) The recommended data are in good to excellent agreement with the MARLOWE simulation of Eckstein and Verbeek [EC79] and are in good (H^+ and $^4He^+$) to adequate (D^+) agreement with the calculations of Zhengming et al [ZH91] except at energies below 100 eV.

(3) Experimental data by Amano and Seidman [AM81] for $^4He^+$ (0.1 - 1.0 keV) on a clean W target is within 10 % of the the recommended data. Experimental data for H^+, D^+ and $^4He^+$ (5 - 20 keV) by Eckstein and Verbeek [EC79] lie below the recommended data by a factor of approximately two. This may be due to surface oxide contaminant.

Analytic fitting function data

$$R_N = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.8250	2.169	1.977	0.6425	2.313E−02	1.927
D^+	0.8250	2.157	1.970	0.6425	2.289E−02	1.927
T^+	0.8250	2.145	1.963	0.6425	2.265E−02	1.927
$^4He^+$	0.8250	1.051	1.241	0.6425	5.724E−03	1.927

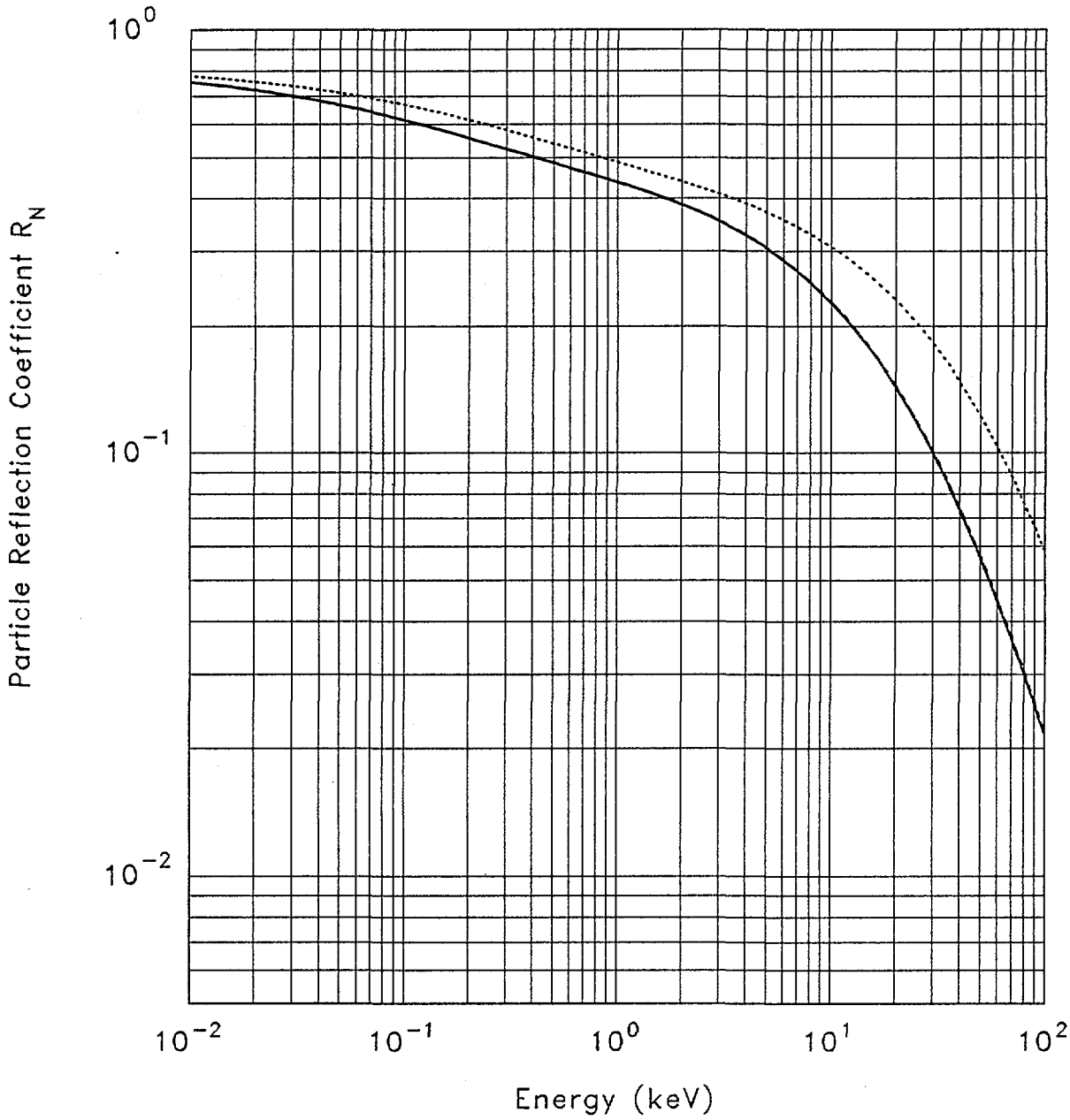
ALADDIN evaluation function for R_N: REFL1

ALADDIN hierarchical labelling:

RN H [+1] W , for H^+; RN D [+1] W , for D^+.

RN T [+1] W , for T^+; RN [4]He [+1] W , for $^4He^+$.

$H^+, D^+, T^+, {}^4He^+ + W$



Legend:

—— H^+ ----- T^+

- - - D^+ ..... ${}^4He^+$

H^+, D^+, T^+, $^4He^+$ + W – Energy Reflection R_E

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	5.92E−01	7.11E−01	5.92E−01	6.23E−01
2.00E−02	5.52E−01	6.63E−01	5.53E−01	5.93E−01
5.00E−02	4.84E−01	5.82E−01	4.85E−01	5.39E−01
1.00E−01	4.26E−01	5.12E−01	4.27E−01	4.87E−01
2.00E−01	3.67E−01	4.41E−01	3.68E−01	4.29E−01
5.00E−01	2.99E−01	3.59E−01	2.99E−01	3.52E−01
1.00E+00	2.53E−01	3.04E−01	2.54E−01	3.01E−01
2.00E+00	2.09E−01	2.51E−01	2.09E−01	2.55E−01
5.00E+00	1.44E−01	1.73E−01	1.45E−01	1.96E−01
1.00E+01	9.33E−02	1.12E−01	9.41E−02	1.46E−01
2.00E+01	5.05E−02	6.10E−02	5.11E−02	9.55E−02
5.00E+01	1.69E−02	2.04E−02	1.71E−02	4.12E−02
1.00E+02	6.25E−03	7.56E−03	6.35E−03	1.76E−02

Accuracy: H^+ : 20 %, D^+ : 20 %, T^+ : 20 %, $^4He^+$: 10 %

Comments: (1) The recommended data are based on the six parameter fit to high mass ratio data (see text) for H^+, T^+ and $^4He^+$. In the case of D^+ the fit line lies below a MARLOWE simulation by about 20 %. While this is within the accuracy range of the simulation, we have chosen to increase the coefficient A_1 by 20 % in this case so that the recommended data better represent the simulation. As a consequence we ascribe broad accuracy limits in this case.

(2) The recommended data are in excellent agreement with the MARLOWE simulation of Eckstein [EC79] and are in good agreement with the calculations of Zhengming et al [ZH91] except for energies below 1 keV.

(3) Experimental measurements by Eckstein [EC79] (1.5 - 15 keV) and Hilderbrandt [HI76] (1.2 keV), lie consistently below the recommended data by a factor of about two. This may be due to a surface oxide contaminant.

Analytic fitting function data

$$R_E = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.6831	2.751	3.458	0.6598	0.1228	1.822
D^+	0.8197	2.737	3.446	0.6598	0.1216	1.822
T^+	0.6831	2.722	3.434	0.6598	0.1204	1.822
$^4He^+$	0.6831	1.333	2.144	0.6598	3.279E−02	1.822

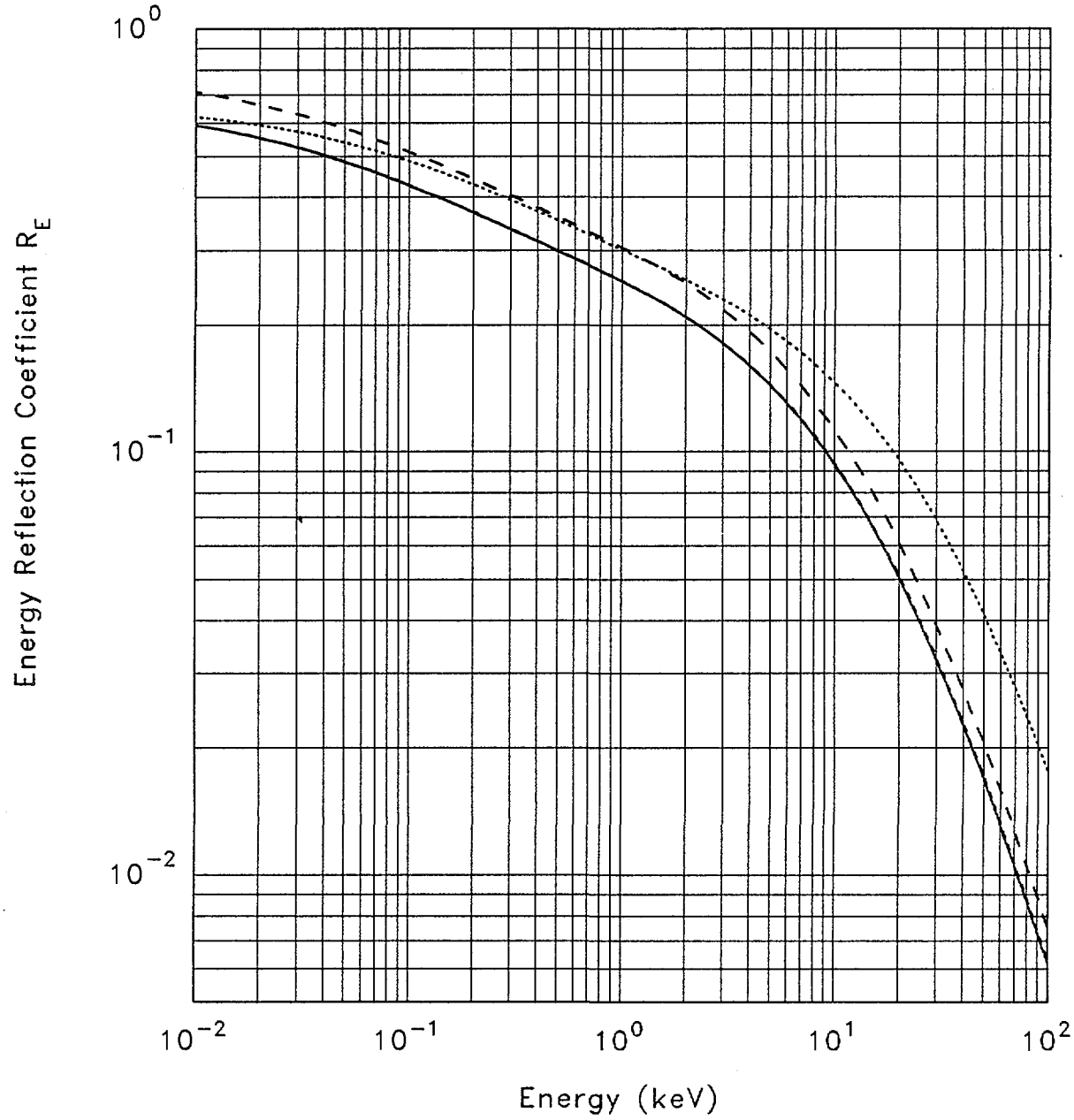
ALADDIN evaluation function for R_E: REFL1

ALADDIN hierarchical labelling:

RE H [+1] W , for H^+; RE D [+1] W , for D^+.

RE T [+1] W , for T^+; RE [4]He [+1] W , for $^4He^+$.

$H^+, D^+, T^+, {}^4He^+ + W$



Legend:

—— H^+ ----- T^+

- - - D^+ ..... ${}^4He^+$

H^+, D^+, T^+, $^4He^+$ + Au – Particle Reflection R_N

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	5.68E−01	7.58E−01	7.58E−01	7.80E−01
2.00E−02	5.45E−01	7.27E−01	7.27E−01	7.59E−01
5.00E−02	5.04E−01	6.72E−01	6.72E−01	7.17E−01
1.00E−01	4.64E−01	6.20E−01	6.20E−01	6.73E−01
2.00E−01	4.22E−01	5.63E−01	5.64E−01	6.22E−01
5.00E−01	3.68E−01	4.92E−01	4.92E−01	5.47E−01
1.00E+00	3.32E−01	4.43E−01	4.43E−01	4.93E−01
2.00E+00	2.95E−01	3.93E−01	3.94E−01	4.44E−01
5.00E+00	2.35E−01	3.13E−01	3.14E−01	3.78E−01
1.00E+01	1.78E−01	2.37E−01	2.38E−01	3.16E−01
2.00E+01	1.15E−01	1.54E−01	1.55E−01	2.40E−01
5.00E+01	4.70E−02	6.30E−02	6.34E−02	1.32E−01
1.00E+02	1.85E−02	2.49E−02	2.51E−02	6.49E−02

Accuracy: H^+ : 25 %, D^+ : 25 %, T^+ : 25 %, $^4He^+$: 10 %

Comments: (1) The recommended data are based on the six parameter fit to high mass ratio data (see text) for D^+, T^+ and $^4He^+$. In the case of H^+ the fit lines for both R_N and R_E lie above detailed simulations [EC83] systematically by about 25 %; it lies also above experiment. While the discrepancy is within the accuracy range of simulations [EC80], we have chosen to reduce A_1 by 25 % in this case so that the recommended data better represent the simulation. The same adjustment is used for R_E. As a consequence we ascribe broad accuracy limits to this case.

(2) The recommended data are in excellent agreement with TRIM and MARLOWE simulations [EC83], [EC79], [OE84]; calculations of Zhengming et al [ZH91] lie 20 % higher and disagree in energy dependence below 1 keV.

(3) Experimental data by Verbeek et al [VE80] for H^+ (2.5 - 16 keV) agree with the recommended data but for $^4He^+$ lie 50 % below; data by Sidenius and Lenskjaer [SI76] (5 - 50 keV) for H^+ lie 50 to 100 % above the recommended data.

Analytic fitting function data

$$R_N = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.6188	1.991	1.871	0.6425	1.961E−02	1.927
D^+	0.8250	1.981	1.865	0.6425	1.942E−02	1.927
T^+	0.8250	1.971	1.859	0.6425	1.923E−02	1.927
$^4He^+$	0.8250	0.9661	1.176	0.6425	4.869E−03	1.927

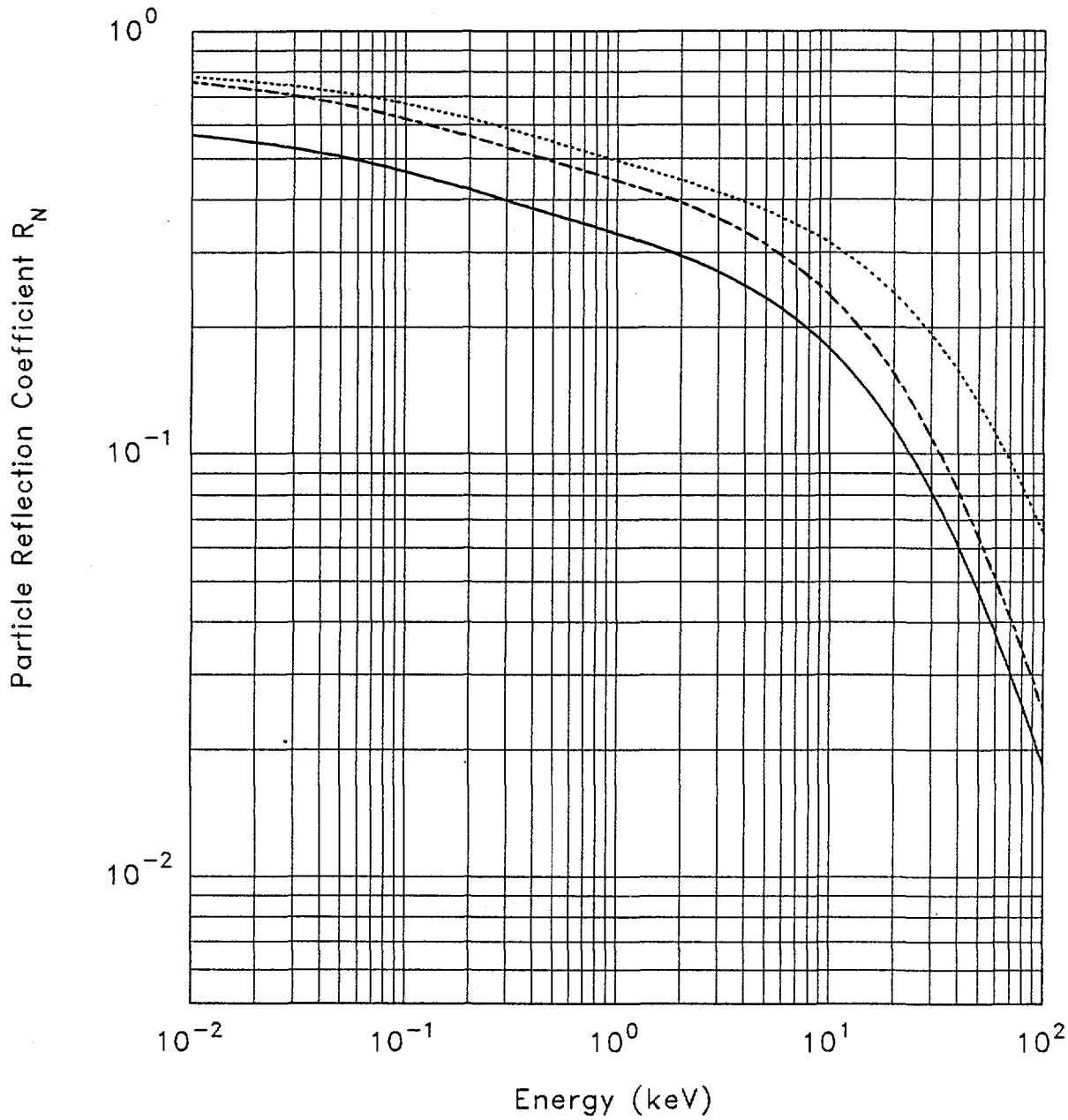
ALADDIN evaluation function for R_N: REFL1

ALADDIN hierarchical labelling:

RN H [+1] Au , for H^+; RN D [+1] Au , for D^+.

RN T [+1] Au , for T^+; RN [4]He [+1] Au , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Au



Legend:

—— H^+ ----- T^+

- - - D^+ ····· $^4He^+$

H^+, D^+, T^+, $^4He^+$ + Au – Energy Reflection R_E

Energy (keV)	H^+	D^+	T^+	$^4He^+$
1.00E−02	4.47E−01	5.96E−01	5.97E−01	6.25E−01
2.00E−02	4.18E−01	5.58E−01	5.58E−01	5.97E−01
5.00E−02	3.69E−01	4.92E−01	4.92E−01	5.45E−01
1.00E−01	3.25E−01	4.34E−01	4.34E−01	4.94E−01
2.00E−01	2.81E−01	3.75E−01	3.75E−01	4.36E−01
5.00E−01	2.28E−01	3.05E−01	3.05E−01	3.59E−01
1.00E+00	1.94E−01	2.59E−01	2.59E−01	3.07E−01
2.00E+00	1.61E−01	2.15E−01	2.15E−01	2.61E−01
5.00E+00	1.13E−01	1.51E−01	1.51E−01	2.01E−01
1.00E+01	7.45E−02	9.97E−02	1.00E−01	1.52E−01
2.00E+01	4.13E−02	5.54E−02	5.57E−02	1.01E−01
5.00E+01	1.42E−02	1.91E−02	1.92E−02	4.52E−02
1.00E+02	5.33E−03	7.16E−03	7.21E−03	1.97E−02

Accuracy: H^+ : 25 %, D^+ : 25 %, T^+ : 25 %, $^4He^+$: 10 %

Comments: (1) The recommended data are based on the six parameter fit to high mass ratio data (see text) for D^+, T^+ and $^4He^+$. In the case of H^+ the fit lines for both R_N and R_E lie above detailed simulations [EC83] systematically by about 25 %; it lies also above experiment. While the discrepancy is within the accuracy range of simulations [EC80], we have chosen to reduce A_1 by 25 % in this case so that the recommended data better represent the simulation. The same adjustment is used for R_E. As a consequence we ascribe broad accuracy limits to this case.

(2) The recommended data are in excellent agreement with TRIM and MARLOWE simulations [EC83], [EC79], [OE84]; calculations of Zhengming et al [ZH91] lie 20 % higher and disagree in energy dependence below 1 keV.

(3) Experimental data for H^+ [EC79], [SI76], [SO76], [VE80] (1 - 50 keV) agree well with the recommended data; for $^4He^+$ [EC79], [HI76], [KO83], [SC78], [VE80] (1 - 10 keV) they lie lower by 30 to 50 %.

Analytic fitting function data

$$R_E = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}}, \quad \text{where E is expressed in keV.}$$

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6
H^+	0.5123	2.526	3.268	0.6598	0.1051	1.822
D^+	0.6831	2.513	3.257	0.6598	0.1041	1.822
T^+	0.6831	2.500	3.246	0.6598	0.1032	1.822
$^4He^+$	0.6831	1.226	2.028	0.6598	2.814E−02	1.822

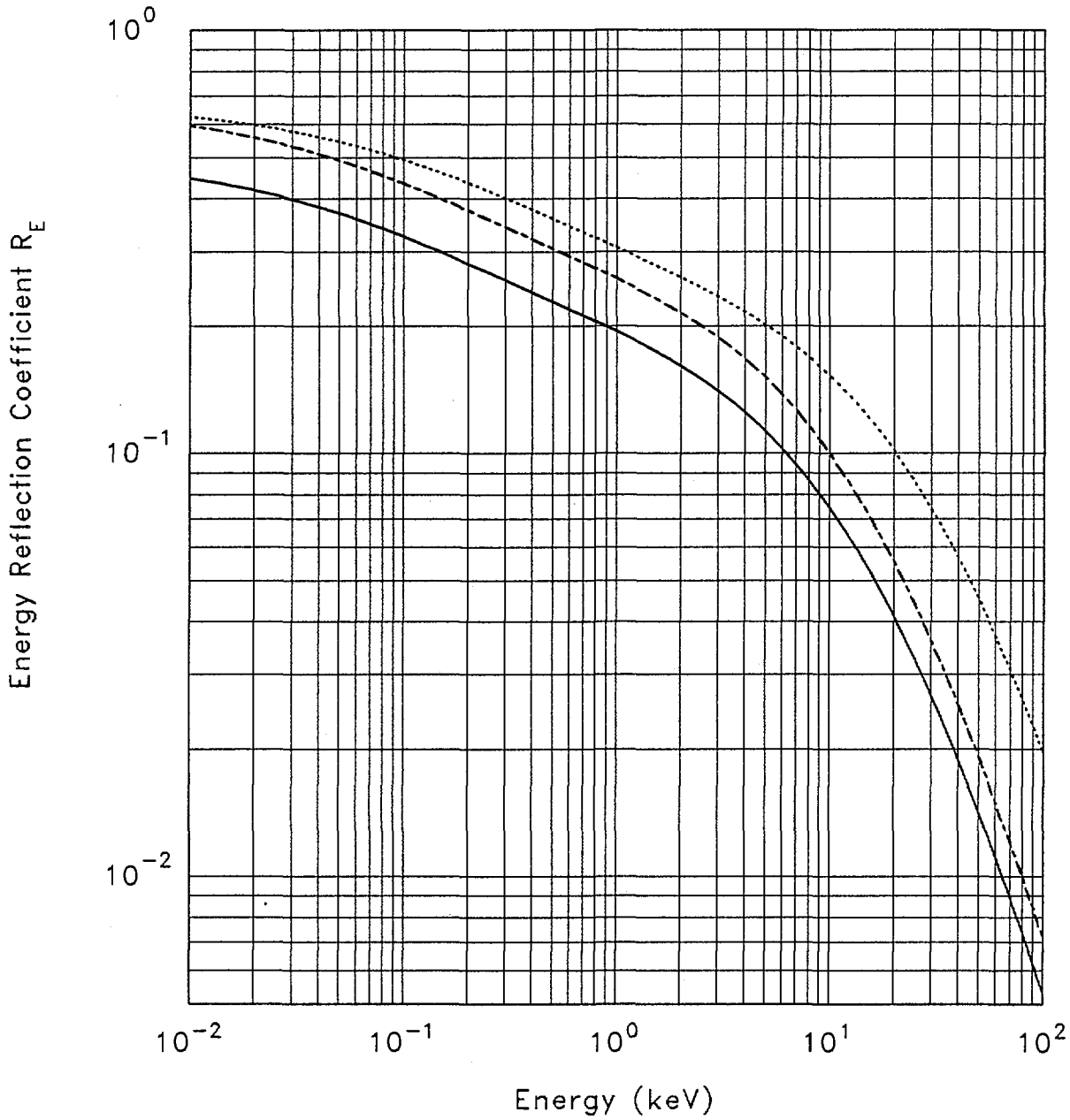
ALADDIN evaluation function for R_E: REFL1

ALADDIN hierarchical labelling:

RE H [+1] Au , for H^+; RE D [+1] Au , for D^+.

RE T [+1] Au , for T^+; RE [4]He [+1] Au , for $^4He^+$.

H^+, D^+, T^+, $^4He^+$ + Au



Legend:

—— H^+ ----- T^+

- - - D^+ ..... $^4He^+$

H^+, $^4He^+$ + Au – Particle Reflection R_N

Energy (keV)	H^+	$^4He^+$
2.00E+02	6.85E−03	2.62E−02
4.00E+02	2.48E−03	9.10E−03
6.00E+02	1.46E−03	4.76E−03
8.00E+02	1.06E−03	3.01E−03
1.00E+03	8.58E−04	2.12E−03
2.00E+03	5.36E−04	7.66E−04
4.00E+03	4.12E−04	3.40E−04
6.00E+03	3.70E−04	2.38E−04
8.00E+03	3.46E−04	1.94E−04
1.00E+04	3.29E−04	1.69E−04
2.00E+04	2.82E−04	1.20E−04
4.00E+04	2.39E−04	9.26E−05
6.00E+04	2.15E−04	8.16E−05
8.00E+04	1.99E−04	7.55E−05
1.00E+05	1.87E−04	7.16E−05

Accuracy: H^+ : 30 %, $^4He^+$: 30 %

Comments: For energies up to 100 keV recommended data, with an analysis of the comparison with experiment and simulation, have been previously defined for R_N. From 100 keV to 100 MeV there are data for H^+ and $^4He^+$ impact only by a TRIM simulation [EC83]. To accomodate these we have added a further term to the fitting equation (see below), evaluated two additional coefficients A_7 and A_8 and provided an extended range to our recommended data set. This extended description should not be used for interpolation or extrapolation.

Analytic fitting function data

$$R_N = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}} + A_7 \ln(A_8/E + e)$$

where E is expressed in keV.

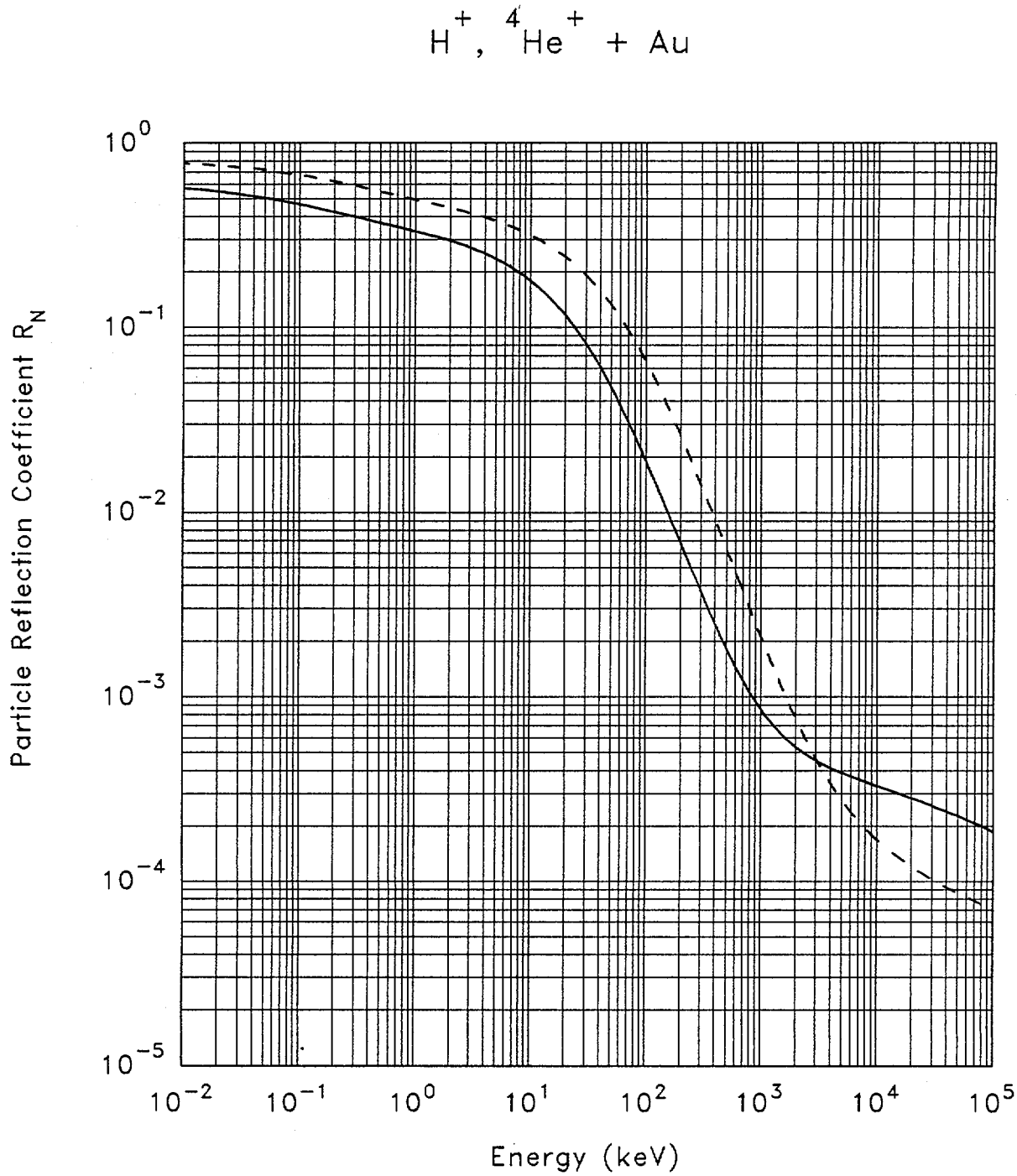
Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
H^+	0.6188	1.991	1.871	0.6425	1.961E−02	1.927	6.286E−05	1.675E+06
$^4He^+$	0.8250	0.9661	1.176	0.6425	4.869E−03	1.927	5.309E−05	1.098E+05

ALADDIN evaluation function for R_N: REFL2

ALADDIN hierarchical labelling:

RN H [+1] Au , for H^+; RN [4]He [+1] Au , for $^4He^+$.


H+, 4He+ + Au
Particle Reflection Coefficient R_N
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-2
10^-1
10^0
10^1
10^2
10^3
10^4
10^5
Energy (keV)

Legend:

—— H^+ - - - $^4He^+$

H^+, $^4He^+$ + Au – Energy Reflection R_E

Energy (keV)	H^+	$^4He^+$
2.00E+02	2.27E−03	7.56E−03
4.00E+02	1.01E−03	2.67E−03
6.00E+02	6.97E−04	1.44E−03
8.00E+02	5.67E−04	9.39E−04
1.00E+03	4.98E−04	6.80E−04
2.00E+03	3.76E−04	2.74E−04
4.00E+03	3.15E−04	1.38E−04
6.00E+03	2.90E−04	1.04E−04
8.00E+03	2.74E−04	8.83E−05
1.00E+04	2.62E−04	7.94E−05
2.00E+04	2.28E−04	6.08E−05
4.00E+04	1.95E−04	4.84E−05
6.00E+04	1.77E−04	4.24E−05
8.00E+04	1.64E−04	3.86E−05
1.00E+05	1.55E−04	3.59E−05

Accuracy: H^+ : 30 %, $^4He^+$: 30 %

Comments: For energies up to 100 keV recommended data, with an analysis of the comparison with experiment and simulation, have been previously defined for R_E. From 100 keV to 100 MeV there are data for H^+ and $^4He^+$ impact only by a TRIM simulation [EC83]. To accomodate these we have added a further term to the fitting equation (see below), evaluated two additional coefficients A_7 and A_8 and provided an extended range to our recommended data set. This extended description should not be used for interpolation or extrapolation.

Analytic fitting function data

$$R_E = \frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}} + A_7 \ln(A_8/E + e)$$

where E is expressed in keV.

Fitting coefficients

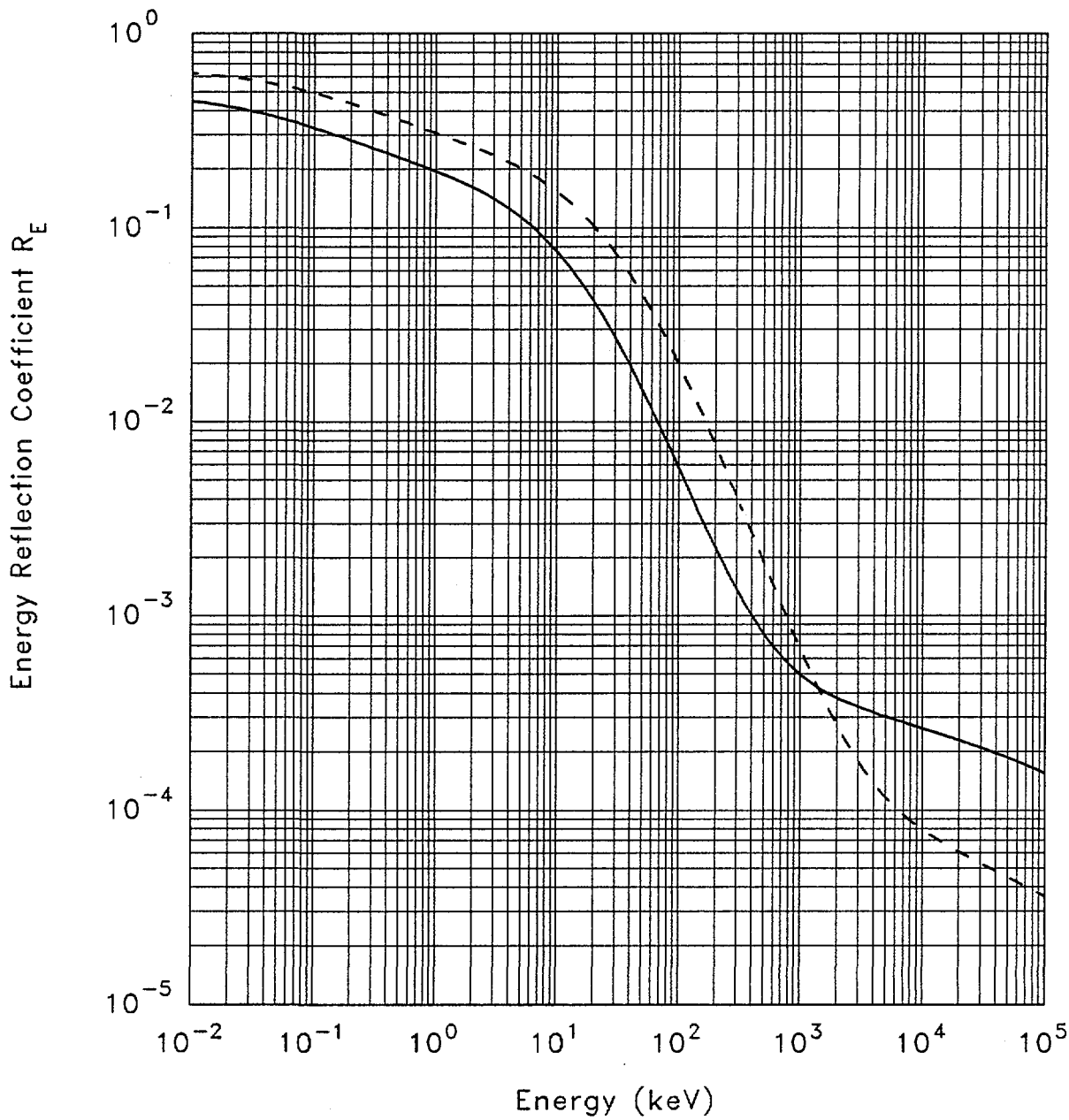
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
H^+	0.5123	2.526	0.1051	1.822	3.268	0.6598	4.766E−05	2.292E+06
$^4He^+$	0.6831	1.226	2.814E−02	1.822	2.028	0.6598	1.602E−05	6.568E+05

ALADDIN evaluation function for R_E: REFL2

ALADDIN hierarchical labelling:

RE H [+1] Au , for H^+; RE [4]He [+1] Au , for $^4He^+$.

H^+, $^4He^+$ + Au



Legend:

—— H^+ - - - $^4He^+$

$Li^+ + Li$, $Be^+ + Be$, $B^+ + B$, $C^+ + C$ – Particle Reflection R_N

Energy (keV)	$Li^+ + Li$	$Be^+ + Be$	$B^+ + B$	$C^+ + C$
2.00E−02	2.43E−04	1.48E−05	–	–
5.00E−02	3.59E−03	1.70E−03	7.52E−04	7.52E−04
1.00E−01	5.15E−03	3.45E−03	2.77E−03	2.77E−03
2.00E−01	4.79E−03	4.13E−03	4.05E−03	4.05E−03
5.00E−01	3.25E−03	3.66E−03	4.11E−03	4.11E−03
1.00E+00	2.03E−03	2.80E−03	3.43E−03	3.43E−03
2.00E+00	1.01E−03	1.82E−03	2.52E−03	2.52E−03
5.00E+00	2.40E−04	6.93E−04	1.26E−03	1.26E−03
1.00E+01	5.83E−05	2.23E−04	5.32E−04	9.58E−04
2.00E+01	1.22E−05	5.44E−05	1.59E−04	3.50E−04
5.00E+01	1.41E−06	6.82E−06	2.24E−05	5.79E−05
1.00E+02	2.67E−07	1.33E−06	4.53E−06	1.22E−05

Accuracy: Unknown

Comments: (1) The recommended data are based on a fit to TRIM simulations by Eckstein and Biersack [EC86]. The fitting equation (reproduced below) consists of the six parameter representation proposed to cover reflection when the mass ratio $\mu = 1$, multiplied by a power law expression to accomodate the near threshold behaviour. Coefficients A_1 through A_6 represent the $\mu = 1$ behaviour and A_7, A_8 and A_9 the theshold behaviour.

(2) There have been no experimental tests of this behaviour or independent calculations. Consequently the data should be treated with caution and the reliability is quite unknown.

(3) We should note that the original TRIM data exhibits some erratic behaviour that cannot be represented by the proposed formula. The data are provided only as a convenient representation for the reflection coefficient.

(4) The data for self reflection for boron have been generated by using a plausible mass interpolation between the data for beryllium and carbon.

Analytic fitting function data

$$R_N = \left[\frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}} \right] \left[1 - \left(\frac{A_7}{E}\right)^{A_8} \right]^{A_9}$$

where E is expressed in keV.

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
Li	2.129E−02	14.52	23.63	0.9131	4.592	2.550	8.400E−03	1.314	10.54
Be	2.129E−02	7.423	12.803	0.9131	0.8290	2.550	1.660E−02	0.7136	3.367
B	2.129E−02	4.410	7.959	0.9131	0.2198	2.550	2.885E−02	0.6210	2.421
C	2.129E−02	2.882	5.397	0.9131	7.427E−02	2.550	3.685E−02	0.6467	2.578

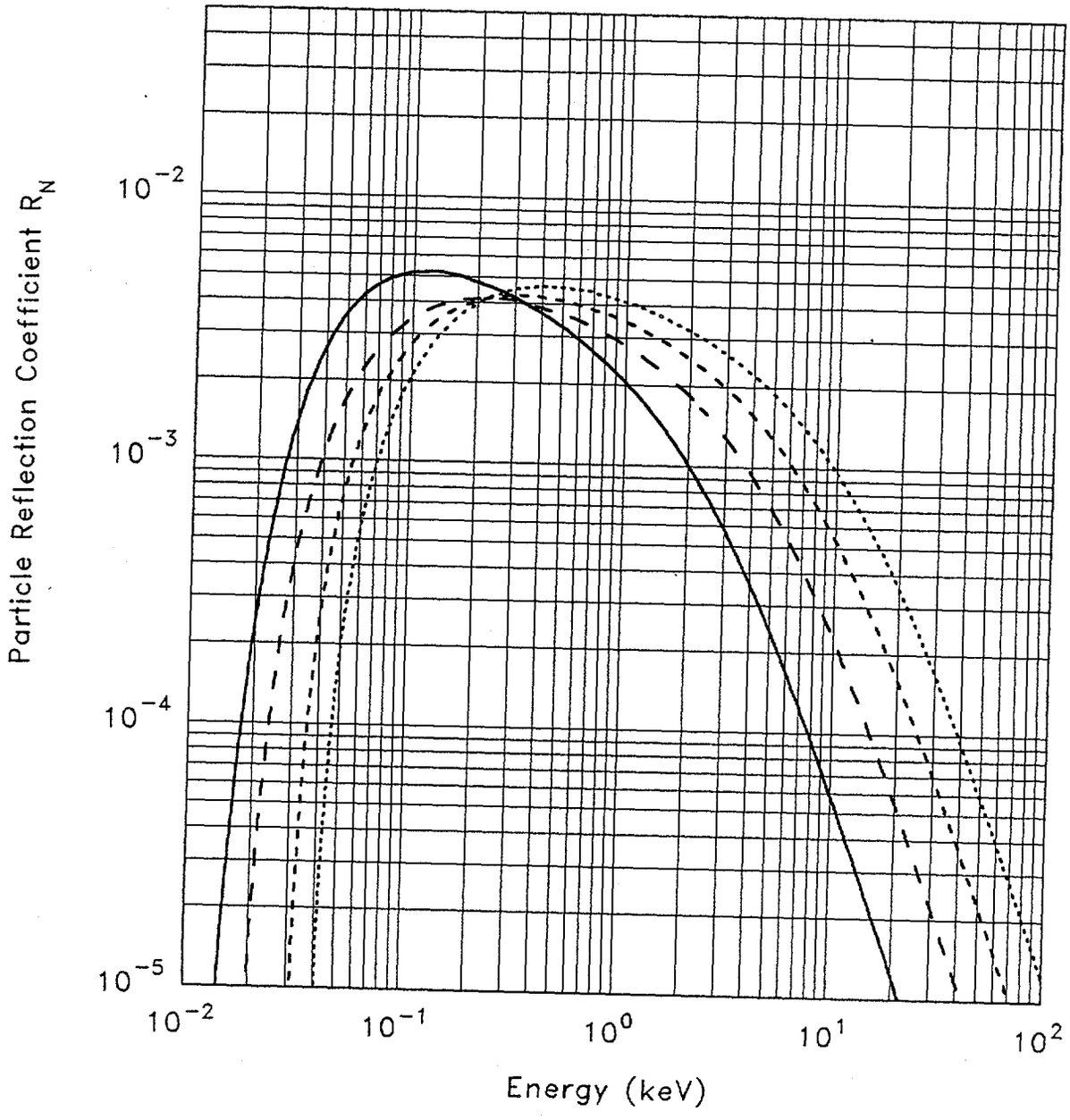
ALADDIN evaluation function for R_N: REFL3

ALADDIN hierarchical labelling:

RN Li [+1] Li , for $Li^+ + Li$; RN Be [+1] Be , for $Be^+ + Be$.

RN C [+1] C , for $C^+ + C$; RN Si [+1] Si , for $Si^+ + Si$.

$Li^+ + Li$, $Be^+ + Be$, $B^+ + B$, $C^+ + C$



Legend:

—— $Li^+ + Li$ ---- $B^+ + B$

- - $Be^+ + Be$ ..... $C^+ + C$

$Si^+ + Si$, $Ni^+ + Ni$, $Mo^+ + Mo$, $W^+ + W$ – Particle Reflection R_N

Energy (keV)	$Si^+ + Si$	$Ni^+ + Ni$	$Mo^+ + Mo$	$W^+ + W$
5.00E−02	1.97E−04	8.40E−04	2.48E−03	5.87E−05
1.00E−01	2.08E−03	4.24E−03	9.65E−03	2.63E−03
2.00E−01	3.96E−03	8.11E−03	1.51E−02	8.46E−03
5.00E−01	4.62E−03	1.07E−02	1.78E−02	1.47E−02
1.00E+00	4.10E−03	1.04E−02	1.75E−02	1.70E−02
2.00E+00	3.21E−03	8.89E−03	1.60E−02	1.74E−02
5.00E+00	1.87E−03	6.38E−03	1.28E−02	1.59E−02
1.00E+01	9.58E−04	4.65E−03	1.00E−02	1.37E−02
2.00E+01	3.50E−04	3.16E−03	7.50E−03	1.10E−02
5.00E+01	5.79E−05	1.53E−03	4.82E−03	7.58E−03
1.00E+02	1.22E−05	6.57E−04	3.23E−03	5.48E−03
2.00E+02	2.42E−06	2.01E−04	1.92E−03	3.78E−03
5.00E+02	2.71E−07	2.88E−05	6.68E−04	1.98E−03
1.00E+03	5.09E−08	5.81E−06	2.04E−04	9.47E−04

Accuracy: Unknown

Comments: (1) The recommended data are based on a fit to TRIM simulations by Eckstein and Biersack [EC86]. The fitting equation (reproduced below) consists of the six parameter representation proposed to cover reflection when the mass ratio $\mu = 1$, multiplied by a power law expression to accomodate the near threshold behaviour. Coefficients A_1 through A_6 represent the $\mu = 1$ behaviour and A_7, A_8 and A_9 the theshold behaviour.

(2) There have been no experimental tests of this behaviour or independent calculations. Consequently the data should be treated with caution and the reliability is quite unknown.

(3) We should note that the original TRIM data exhibits some erratic behaviour that cannot be represented by the proposed formula. The data are provided only as a convenient representation for the reflection coefficient.

Analytic fitting function data

$$R_N = \left[\frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}} \right] \left[1 - \left(\frac{A_7}{E}\right)^{A_8} \right]^{A_9}$$

where E is expressed in keV.

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
Si	2.129E−02	0.3991	0.8875	0.9131	4.801E−04	2.550	2.315E−02	0.7965	4.082
Ni	2.129E−02	7.919E−02	0.2027	0.9131	7.767E−06	2.550	2.220E−02	1.283	4.916
Mo	2.129E−02	3.075E−02	8.543E−02	0.9131	6.958E−07	2.550	3.410E−02	1.048	5.318
W	2.129E−02	8.200E−03	2.556E−02	0. 9131	2.393E−08	2.550	4.450E−02	1.003	5.258

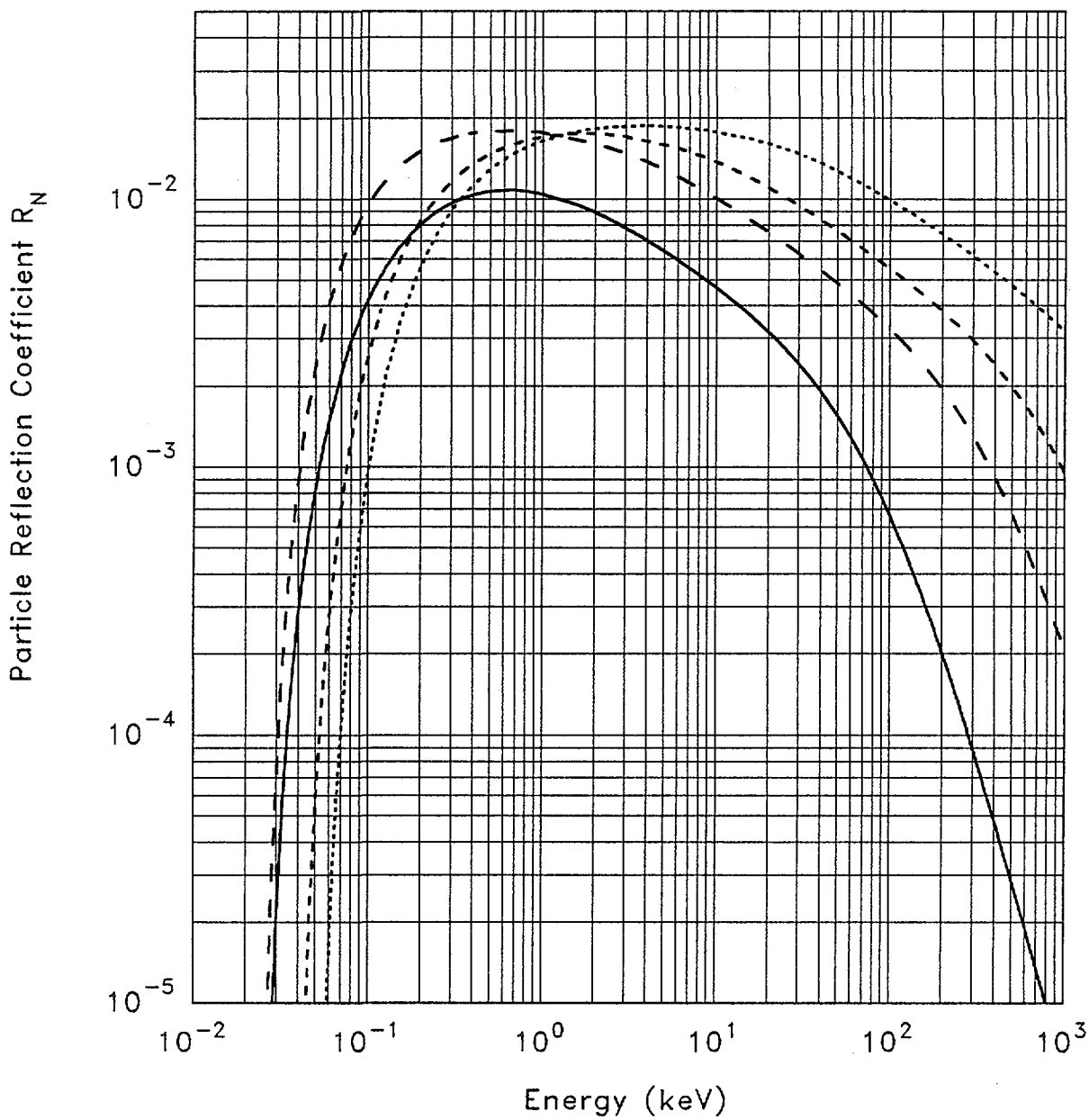
ALADDIN evaluation function for R_N: REFL3

ALADDIN hierarchical labelling:

RN Si [+1] Si , for $Si^+ + Si$; RN Ni [+1] Ni , for $Ni^+ + Ni$.

RN Mo [+1] Mo , for $Mo^+ + Mo$; RN W [+1] W , for $W^+ + W$.

$Si^+ + Si$, $Ni^+ + Ni$, $Mo^+ + Mo$, $W^+ + W$



Legend:

—— $Si^+ + Si$ ---- $Mo^+ + Mo$

- – $Ni^+ + Ni$ ····· $W^+ + W$

$Li^+ + Li$, $Be^+ + Be$, $B^+ + B$, $C^+ + C$ – Energy Reflection R_E

Energy (keV)	$Li^+ + Li$	$Be^+ + Be$	$B^+ + B$	$C^+ + C$
2.00E−02	1.94E−05	3.71E−07	–	–
5.00E−02	2.36E−04	1.05E−04	3.97E−05	7.37E−06
1.00E−01	2.76E−04	2.10E−04	1.58E−04	1.10E−04
2.00E−01	2.30E−04	2.37E−04	2.27E−04	2.15E−04
5.00E−01	1.45E−04	1.92E−04	2.19E−04	2.44E−04
1.00E+00	8.81E−05	1.38E−04	1.75E−04	2.09E−04
2.00E+00	4.42E−05	8.47E−05	1.22E−04	1.57E−04
5.00E+00	1.28E−05	3.26E−05	5.82E−05	8.63E−05
1.00E+01	4.13E−06	1.23E−05	2.59E−05	4.39E−05
2.00E+01	1.22E−06	3.97E−06	9.37E−06	1.79E−05
5.00E+01	2.29E−07	7.84E−07	1.99E−06	4.18E−06
1.00E+02	6.30E−08	2.20E−07	5.72E−07	1.24E−06

Accuracy: Unknown

Comments: (1) The recommended data are based on a fit to TRIM simulations by Eckstein and Biersack [EC86]. The fitting equation (reproduced below) consists of the six parameter representation proposed to cover reflection when the mass ratio $\mu = 1$, multiplied by a power law expression to accomodate the near threshold behaviour. Coefficients A_1 through A_6 represent the $\mu = 1$ behaviour and A_7, A_8 and A_9 the theshold behaviour.

(2) There have been no experimental tests of this behaviour or independent calculations. Consequently the data should be treated with caution and the reliability is quite unknown.

(3) We should note that the original TRIM data exhibits some erratic behaviour that cannot be represented by the proposed formula. The data are provided only as a convenient representation for the reflection coefficient.

(4) The data for self reflection for boron have been generated by using a plausible mass interpolation between the data for beryllium and carbon.

Analytic fitting function data

$$R_E = \left[\frac{A_1 \ln(A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}} \right] \left[1 - \left(\frac{A_7}{E}\right)^{A_8} \right]^{A_9}$$

where E is expressed in keV.

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
Li	1.445E−03	3.586E+02	27.31	1.971	68.14	0.6520	8.400E−03	1.859	14.82
Be	1.445E−03	1.833E+02	7.274	1.971	43.99	0.6520	1.660E−02	1.101	4.388
B	1.445E−03	1.089E+02	2.607	1.971	31.33	0.6520	2.885E−02	0.9254	2.872
C	1.445E−03	71.16	1.127	1.971	23.74	0.6520	3.685E−02	0.9572	3.213

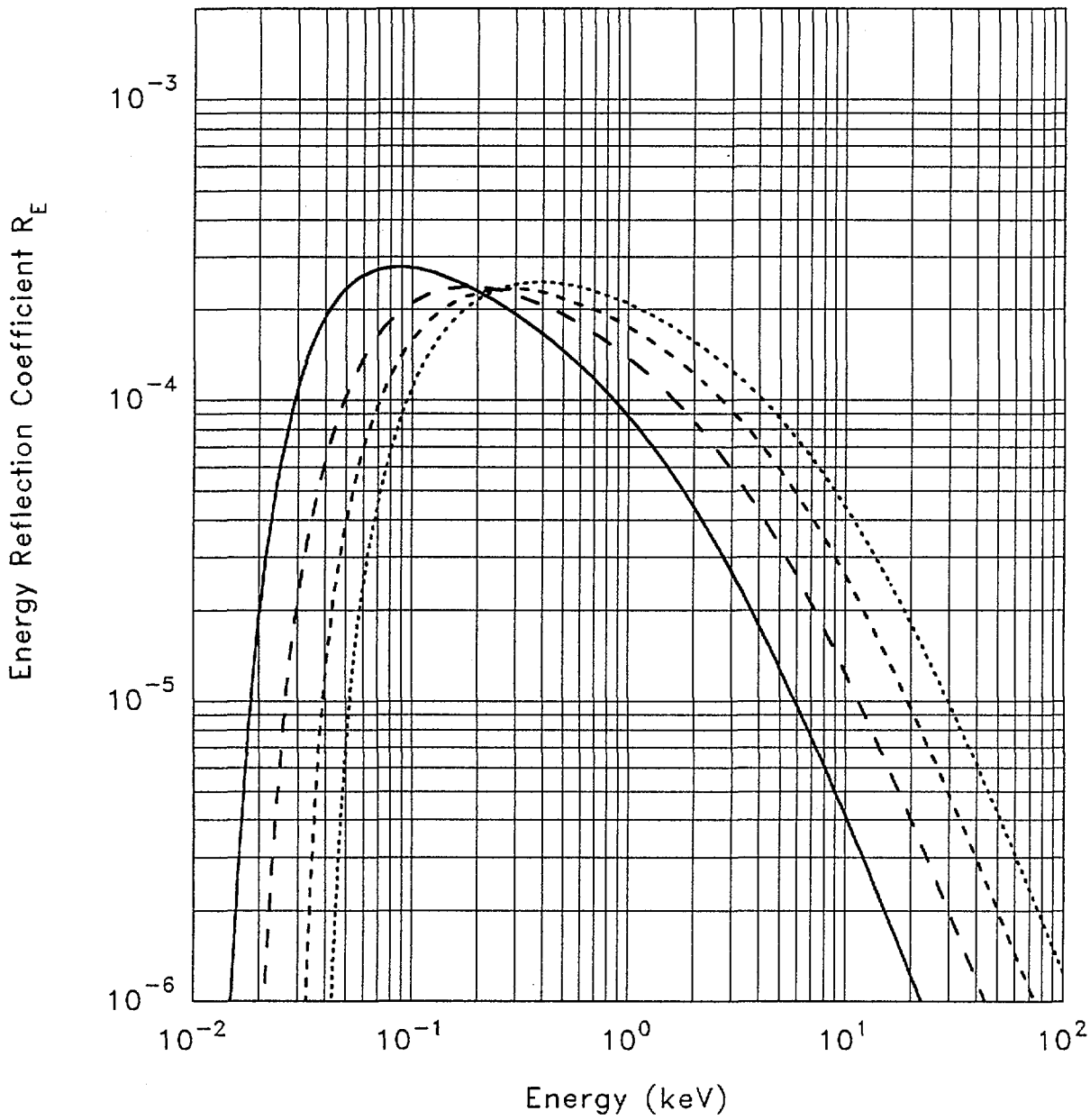
ALADDIN evaluation function for R_E: REFL3

ALADDIN hierarchical labelling:

RE Li [+1] Li , for $Li^+ + Li$; RE Be [+1] Be , for $Be^+ + Be$.

RE C [+1] C , for $C^+ + C$; RE Si [+1] Si , for $Si^+ + Si$.

$Li^+ + Li$, $Be^+ + Be$, $B^+ + B$, $C^+ + C$



Legend:

—— $Li^+ + Li$ ---- $B^+ + B$

- – $Be^+ + Be$ ····· $C^+ + C$

$Si^+ + Si$, $Ni^+ + Ni$, $Mo^+ + Mo$, $W^+ + W$ – Energy Reflection R_E

Energy (keV)	$Si^+ + Si$	$Ni^+ + Ni$	$Mo^+ + Mo$	$W^+ + W$
5.00E−02	9.55E−05	1.67E−04	2.85E−06	4.16E−08
1.00E−01	2.97E−04	5.22E−04	1.78E−04	8.49E−05
2.00E−01	4.32E−04	7.04E−04	5.22E−04	3.92E−04
5.00E−01	4.76E−04	7.14E−04	7.40E−04	7.40E−04
1.00E+00	4.42E−04	6.59E−04	7.40E−04	8.33E−04
2.00E+00	3.78E−04	5.89E−04	6.86E−04	8.21E−04
5.00E+00	2.77E−04	4.83E−04	5.93E−04	7.37E−04
1.00E+01	2.03E−04	3.96E−04	5.14E−04	6.62E−04
2.00E+01	1.37E−04	3.10E−04	4.28E−04	5.87E−04
5.00E+01	6.59E−05	2.06E−04	3.13E−04	4.78E−04
1.00E+02	2.99E−05	1.39E−04	2.33E−04	3.91E−04
2.00E+02	1.10E−05	8.18E−05	1.62E−04	3.05E−04
5.00E+02	2.38E−06	3.02E−05	8.40E−05	2.02E−04
1.00E+03	6.88E−07	1.12E−05	4.14E−05	1.35E−04

Accuracy: Unknown

Comments: (1) The recommended data are based on a fit to TRIM simulations by Eckstein and Biersack [EC86]. The fitting equation (reproduced below) consists of the six parameter representation proposed to cover reflection when the mass ratio $\mu = 1$, multiplied by a power law expression to accomodate the near threshold behaviour. Coefficients A_1 through A_6 represent the $\mu = 1$ behaviour and A_7, A_8 and A_9 the theshold behaviour.

(2) There have been no experimental tests of this behaviour or independent calculations. Consequently the data should be treated with caution and the reliability is quite unknown.

(3) We should note that the original TRIM data exhibits some erratic behaviour that cannot be represented by the proposed formula. The data are provided only as a convenient representation for the reflection coefficient.

Analytic fitting function data

$$R_E = \left[\frac{A_1 \ln (A_2 E + e)}{1 + A_3 E^{A_4} + A_5 E^{A_6}} \right] \left[1 - \left(\frac{A_7}{E}\right)^{A_8} \right]^{A_9}$$

where E is expressed in keV.

Fitting coefficients

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
Si	1.445E−03	9.854	2.289E−02	1.971	6.541	0.6520	2.315E−02	0.9764	3.473
Ni	1.445E−03	1.955	9.444E−04	1.971	2.279	0.6520	2.220E−02	1.315	4.533
Mo	1.445E−03	0.7592	1.463E−04	1.971	1.230	0.6520	3.410E−02	1.269	6.368
W	1.445E−03	0.2025	1.082E−05	1.971	0.5195	0.6520	4.450E−02	1.021	4.749

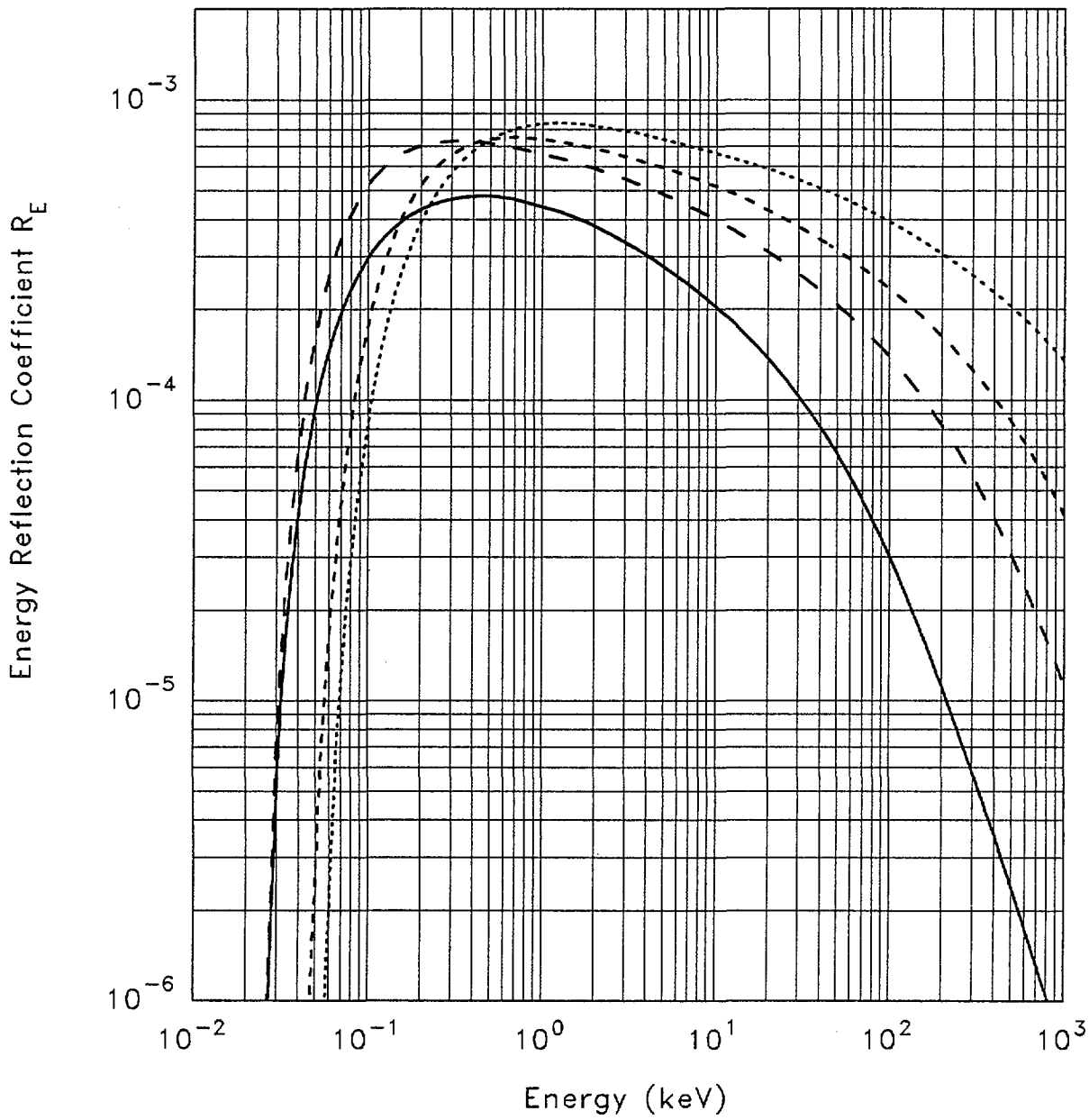
ALADDIN evaluation function for R_E: REFL3

ALADDIN hierarchical labelling:

RE Si [+1] Si , for $Si^+ + Si$; RE Ni [+1] Ni , for $Ni^+ + Ni$.

RE Mo [+1] Mo , for $Mo^+ + Mo$; RE W [+1] W , for $W^+ + W$.

$Si^+ + Si$, $Ni^+ + Ni$, $Mo^+ + Mo$, $W^+ + W$



Legend:

—— $Si^+ + Si$ ---- $Mo^+ + Mo$

- – $Ni^+ + Ni$ ····· $W^+ + W$