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Preface

'Dosimetry' in its generic sense is concerned with the identification and measurement of physical field parameters for quantification of the effectiveness of ionizing radiations in biological systems. The usefulness of track structure parameters for the field quantities has been long-established(1–7) but determination of the best quantities, or combinations of quantities, to express the radiation quality has not been satisfactorily resolved and is the subject of on-going research. Important applications are: in the system of cancer risk limitation for the radiological protection of people against the deleterious effects of radiation(8); for optimization of treatment of patients in nuclear medicine in which Auger electron or beta emitters may be incorporated into cells or organs(9); in neutron, heavy particle and low LET radiotherapy(10); for interpretation of biophysical damage mechanisms and modelling of effects in radiobiology and radiobotany(11,12); in the design of appropriate response characteristics for new dosimetry instrumentation(13,14); in the description of indirect effects due to the action of free radical diffusion in radiochemistry(15); for environmental radiation protection, e.g. radon in the home; health physics—especially in the vicinity of nuclear reactor shielding and high energy accelerators; for the radioprotection of space travellers, aircraft crews and passengers at high altitude who are exposed to cosmic radiation(16). Other applications abound.

The tables of data presented here have evolved over the past decade to meet a personal need for an extensive self-consistent set of biophysical quantities, descriptive of the charged particle track structures generated by directly and indirectly ionizing radiations, for application in the interpretation of radiobiological damage mechanisms, for subsequent design of instrument response and for use in a proposed system of dosimetry which will be more meaningful for radiological protection(17). Calculations of the energy loss quantities for electrons, protons and alpha particles are based on the excellent specialist reports on stopping power by the International Committee on Radiation Quantities and Units and Ziegler's compilation for heavy charged particles(18–20). As the importance has now been established of the damaging role of the end-of-track region, which includes the stopping power maximum, methods have had to be devised to extend the data for electrons and charged particles heavier than alpha particles down to sufficiently low particle energies. This is essential also to enable computation of average values for the equilibrium charged particle spectrum which contains a preponderance of degraded energies in the critical region. Also included for the first time in a general compilation are the two new quality parameters, 'the mean free path for primary ionization' and the approximately related quantity 'dose restricted LET with 100eV cut-off'—both recently proposed as more meaningful parameters for specification of radiation quality. They have properties which are superior to the conventionally accepted quantities LET and RBE. The tables include various other relevant quantities which frequently appear in model formulations, are not normally available in a single compilation, but which are essential for fundamental dosimetry.

The results are determined for a liquid water medium as this is considered to be a good substitute for soft tissue with regard to track interaction as it corresponds well in electron density and approximately in nuclear composition[21]. One may argue that Monte Carlo techniques[22–25] may be better for calculation of distributions of data because then the stochastical fluctuations of the particle interactions can be properly described. However, such an exercise would be impracticable for the extensive range of particle types and energies listed here and in any event single-valued quantities are required for the expression of radiation quality in a practical system. Averaged values are believed to be justified on the basis of Poisson statistics and because often the calculated quantities, based on appropriately weighted averages, agree well with experiment, e.g. measured LET distributions. In this context selected examples are given of calculated microdose distributions for electron, photon and neutron radiations. The frequency-mean and dose-mean lineal energies and specific energy densities of regional microdosimetry are tabulated for indirectly ionizing radiations and for beta spectra.

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Part 1
Electrons and Photons

1.0 INTRODUCTION

Calculations have been performed, in extensions of the continuous slowing down approximation, of commonly used track structure parameters for electron and photon irradiations interacting in liquid water. Water is known to be a good dosimetry material because of the close correspondence in magnitude of the energy loss interactions of ionizing radiations in cellular material, including DNA and soft tissues[(1)]. The lower energy threshold is 50eV. Quantities calculated are: the track- and dose-average LET; restricted LET with 100eV cut-off; relative variances; the mean linear primary ionization rate; the mean free path between primary ionizations; csda ranges; the mean energy expenditure required to produce a primary ion pair and kerma factors for electron and photon radiations from external beams and for incorporated radioisotopes.

Results are presented in five sets of four tables. Tables 1 (a to d) are for monoenergetic electrons (50eV to 30MeV). Tables 2 (a to d) are for characteristic K_α X-ray line spectra from C to Am targets. Tables 3 (a to d) contain data for some commonly used X- and gamma-ray spectra (50kV to 300kV, 8MV and 26MV bremsstrahlung, ^{241}Am, ^{137}Cs and ^{60}Co gamma-rays). Tables 4 (a to d) and tables 5 (a to d) respectively are for important electron-capture nuclides which emit Auger electron cascades and for some β-emitting nuclides typically used in radiopharmaceuticals for nuclear medicine. Graphs of selected data are provided to assist interpolation.

The data in table sets 1 to 3 may be applied to irradiations performed with external beams incident on radiobiological samples, or on the patient in radiotherapy. Table sets 4 and 5 are applicable to situations where a concentration of radionuclide is distributed within the sample, or patient in nuclear medicine. An appropriate choice of the tabulated quantities can be made either for interpretation of track segment experiments or for experiments performed under conditions of transient or complete equilibrium.

Poisson statistics are assumed to apply. Consequently the mean values given are adequate if more detailed analyses involving the stochastical distributions of the radiation interactions are desired. Relative variances are calculated for the track- and dose-average LETs as these are a measure of the spread of values about the mean (ICRU Report No. 16)[(2)].

Each table set 1–5 comprises four sections (a), (b), (c) and (d). Section (a) contains information on the primary electron tracks at their instantaneous initial energies (in keV), e.g. for the initial electron energies from an accelerator beam; from β-emitting radionuclides incorporated into mammalian cells; for the photoelectrons and Compton electrons generated in the sample by internally or externally emitted X-rays or gamma-rays. In section (b), the parameters are averaged over the whole primary electron tracks stopping in water and frequency (i.e. track or fluence)-weighted for their initial distribution wherever applicable, e.g. for β and photon spectra. This is the situation pertaining for the electron spectrum at charged particle equilibrium. In section (c), the results are calculated for the electron tracks emitted from a source having a spectrum approximately equivalent to the slowing down equilibrium spectrum. Thus data in tables (c) are of rather specialized application and would be used in those cases where the irradiation is carried out with an ‘applicator’ or ‘radiator’ containing a homogeneous distribution of the radiation, e.g. a plastic disc with incorporated tritium. Finally in section (d) of the tables values are expressed per unit source concentration of the emitted radiation, assumed to be distributed uniformly throughout the sample, of: the space density of primary electrons generated along the initial electron tracks; the space density of all (primary plus secondary) electrons; the equilibrium electron fluence (primary fluence per unit source concentration is equivalent to the csda range); build-up factor for the space density of electrons and for the fluence; and the mean energy expended in production of a primary ion pair (i.e. excludes delta-rays).

2.0 CALCULATION OF THE PHYSICAL QUANTITIES

2.1 Electrons

Values of collisional stopping power and ranges for electron energies above 10keV are based on ICRU Report No. 37[(3)]. In the biologically important energy region below 10keV, the stopping powers were deduced down to a threshold energy of 50eV from the theoretical results of Ashley, 1982[(4)] and the experimental results of Iskef, Cunningham and Watt, 1983[(5)] and Al-Ahmad and Watt, 1984[(6)]. For computation, analytical expressions were fitted and reproduced the original data to better than 2% over the whole energy range.

Linear primary ionization, at energies above 10keV, was calculated from an adjusted Mott and Massey formula (Watt, Al-Affan, Chen and Thomas, 1985)[(7)]. At energies below 10keV, Tung and Chen’s 1982[(8)] results were used. Conservation of energy was used as the criterion to check the internal self-consistency of the results.

Equilibrium slowing down spectra, generated by the primary electron source, were calculated using the McGinnies, 1959 method[(9)], which is based on Spencer-Fano theory (see also ICRU Report No. 16[(2)]), The lower threshold energy of 400eV in that work was extended down to 30eV in the present calculations by applying a version of Sugiyama’s theory of stopping power as described in Watt et al. 1985[(7)].

Details of the Auger-electron and internal conversion-electron yields and energies were obtained from the decay schemes for the electron capture nuclides (tables 4 a–d) given in the MIRD compilation of radionuclide data, 1989[(10)]. The yields and shapes of β-spectra from radionuclides were taken from Cross’s recent calculations, 1994[(11)] and from Mantel[(12)].

2.2 Indirectly ionizing radiations: X-rays and gamma-rays

Cross-sections for photoelectric absorption, coherent and incoherent scatter, and pair-production were obtained from standard tables (Hubbell 1977, 1982)[(13,14)], over the photon energy range 10eV to 30 MeV and used to calculate the primary distributions of photoelectrons and Compton electrons for both incident complex bremsstrahlung spectra from X-ray machines (Birch, Marshall and Ardran, 1979[(15)]; Seelentag and Panzer, 1979[(16)] and Seelentag et al., 1979[(17)]) and for monoenergetic photon sources from radionuclides. The source strength (concentration) of primary electrons is calculated per unit volume of water. From the differential primary electron spectra, calculation of the desired data for the slowing down spectra then proceeds by separating the differential spectrum into monoenergetic bands and using the McGinnies procedure for each band of electrons as indicated above. The mean energies of successive bands were selected to be in the ratio $2^{1/8}$ as this type of scaling improves the precision of the numerical integration over the wide energy ranges involved. Frequency-weighting was used to recombine the results to yield the net slowing down equilibrium spectrum and the single average values obtained for the various physical parameters tabulated.

For X- and gamma-ray emission from the incorporated radionuclides (tables 4 a–d), details of the decay schemes were obtained from the MIRD compilation, Weber et al., 1989[(10)]; ICRP Publ. No. 38, 1983[(18)] and the Table of Isotopes, Browne et al., 1978[(19)].

2.3 W values for primary ionization

Approximate values of the mean energy expended to produce a primary ion pair along the initial electron tracks were calculated from the relation:

$$W\ (eV) = \frac{\overline{L_{100,T}}\ (keV.\mu m^{-1})}{\bar{I}\ (\mu m^{-1})} \times 10^{3} \qquad (1.1)$$

Use of the restricted LET, in effect, excludes the contribution from the delta-rays and the W value applies to the track core.

2.4 Calculation of kerma fluence and kerma activity factors

If the irradiation conditions ensure that complete charged particle equilibrium exists then kerma can be expressed in several different ways compatible with energy conservation. In addition to their practical value for interpretive purposes, comparison of the results can be used as a self-consistency test of the reliability of the calculated parameters.

The kerma fluence factor (kerma per unit incident fluence), $K_{f,\,v}$, for irradiation with an external beam of photons of total fluence Φ_v, is given by:

$$K_{f,\,v} = \frac{K_v}{\Phi_v} = 1.6\times10^{-13} \, . \sum_i f_i(E_{v,\,i}).E_{v,\,i}\, .\, N\sigma_{tr}(E_{v,\,i}).\Delta(E_{v,\,i}) \quad Gy.cm^2 \qquad (1.2)$$

where K_v(Gy) is the kerma for the incident photon field, f_i is the fractional photon fluence per keV energy interval, $N\sigma_{tr}$ ($cm^2.g^{-1}$) is the mass energy transfer coefficient and $E_{v,\,i}$ is the incident photon energy in keV in energy band i of width $\Delta E_{v,\,i}$.

Alternatively, the kerma fluence factor is given by the product of the primary electron source density and the mean electron energy, i.e.

$$K_{f,\,v} = \frac{K_v}{\Phi_v} = 1.6\times10^{-13} \, . \sum_i f_i(E_{v,\,i}).N\sigma_a(E_{v,\,i}).\sum_j f_j.(E_{el,\,j}).E_{el,\,j}.\Delta E_j \quad Gy.cm^2 \qquad (1.3)$$

Here the subscript ‘i’ denotes the incident photon and ‘j’ the primary electrons released. As before, energies are in keV. $N\sigma_a$ is the mass incoherent scattering coefficient for electron production in cm^2/g. f_i is the fractional number of photons of energy $E_{v,\,i}$ in the incident spectrum and f_j, the fractional fluence of primary electrons generated per keV energy interval.

Values of the mass scattering coefficients (i.e. for number of electrons produced, in equation 1.3) and the mass energy transfer coefficients (i.e. for kinetic energy transfer to electrons, in equation 1.2) are listed in columns 2 and 3 of tables 2a and 3a respectively. The frequency and kerma-weighted mean photon energies, $E_{f,\ v}$ and $E_{k,\ v}$, are listed in column 1 of table 3a. The kerma-weighted energy is:

$$\overline{E_{k.\ v}} = \frac{\sum f(E_v).E_v.N\sigma_{tr}(E_v).\Delta E_v}{\sum f(E_v).N\sigma_{tr}(E_v).\Delta E_v} \qquad (1.4)$$

For internally incorporated radionuclides with a homogeneously distributed concentration of activity, A ($Bq.kg^{-1}$), a partial kerma factor rate, $K_{A,\ v}$, can be expressed as a function of the source concentration of emitted photons as:

$$K_{A.\ v} = \frac{K_v}{A} = 1.6\times10^{-16}.\ n_d.\sum_j f_{el.\ j}.E_{el.\ j}.\Delta E_{el.\ j} = 1.6\times10^{-16}.n_d.\overline{E_{i.\ el}} \quad Gy.kg.Bq^{-1} \qquad (1.5)$$

where the quantities under the summation for numerical integration refer to the composite primary photoelectron plus Compton electron spectrum generated by the photon component emitted at a rate n_d per decay of the radionuclide (n_d is listed in col. 3; $E_{i,\ el}$ in col. 6 and $K_{A,\ el}$ in col. 12 of table 4a and in cols. 3 and 9 of table 5a (n_β=1).

Similarly, the partial kerma factor rate per source concentration of radionuclide that decays by emission of monoenergetic electron lines (e.g. Auger electron emission or internal conversion electrons) is:

$$K_{A.\ el} = \frac{K_{el}}{A} = 1.6\times10^{-16}\ .\ \sum_j [\ n_{d.\ j}.E_j\ ] \quad Gy.kg.Bq^{-1} \qquad (1.6)$$

In the case of beta-emitters, if the activity concentration of beta rays is $A.n_\beta$, with n_β as the number of beta events per transformation, the kerma rate per unit source concentration of beta, $K_{A,\ \beta}$, is:

$$K_{A.\ \beta} = \frac{K_\beta}{A} = 1.6\times10^{-16}.n_\beta.\sum_i f_{\beta.\ i}.E_{\beta.\ i}.\Delta E_{\beta.\ i} \quad Gy.kg.Bq^{-1} \qquad (1.7)$$

where $E_{\beta,\ i}$ (keV) is the mean electron energy at the i^{th} channel of width $\Delta E_{\beta,\ i}$ for the beta-ray spectrum and $f_{\beta,\ i}$, the fractional β-emission per keV energy interval.

In general, the kerma fluence factor and the kerma activity factor are related by:

$$K_{f.v}\ (Gy.cm^2)=N.\sigma_a(cm^2/g).\ 10^3.K_{A,\ v}\ Gy.kg.Bq^{-1} \qquad (1.8)$$

pand can be expressed in terms of the fluence and LET of the equilibrium spectrum as:

$$K_{f.\ v} = \frac{K_v}{\phi_v} = \frac{A_v.K_{A,\ v}}{\phi_v} \qquad (1.9)$$

$$= 1.6.10^{-9}.\sum_i f_{i.\ v}(E_v).N\sigma_{a.\ i}(E_v).\sum_j f_{j.\ v}.F_{p.\ j}(E_{el}).\overline{L_{T.\ j}}(E_{el}).\Delta E_{el.\ j}.\Delta E_{v,\ i}\ \ Gy.cm^2$$

The term under the i^{th} summation is equivalent to the initial concentration of primary electrons generated by unit fluence of the photon field and the term under the j^{th}

summation is the energy deposited by electrons in the equilibrium spectrum per unit source concentration of primary electrons. Values of F_p (cm), the electron fluence per unit source concentration of events, is equivalent to the csda range given in tables 1 and 2 (a) col. 6; tables 3 and 4 (a), col. 7 and table 5 (a) col. 4. LETs averaged over the whole electron track, ${}^{W}L_T$, are listed in tables 1–5 (b). This LET, for electrons of energy E, is equivalent to the average LET for the equilibrium spectrum generated by an electron of energy E.

2.5 Precision of data

Values of stopping powers, linear primary ionization and particle ranges are accurate to better than 5% at instantaneous electron energies above 10keV (ICRU Report No. 37[3]). At lower electron energies the accuracy deteriorates towards 10% at 1keV and may be as much as 25% in error at 100eV. When these quantities are compounded into the spectra of recoils generated by photons, and into the equilibrium spectra, some further loss of accuracy must result but the self-consistency tests suggest that this adds only 1 or 2 % and that the overall accuracy of the data above 1keV electron energy is unlikely to be worse than 10%. Results have been calculated down to a lower threshold energy of 30eV. As the equilibrium electron fluence changes rapidly in that energy region, the magnitudes of the quantities given in tables (c) and (d) will be influenced by changes in the threshold energy.

3.0 SOME GENERAL PRACTICAL RELATIONSHIPS FOR CONVERSION OF QUANTITIES

The irradiations are assumed to be carried out under conditions of complete charged particle equilibrium in which case the dose can be taken to be equal to kerma to a good approximation. [In the case of transient equilibrium, Rossi and Kellerer[20,21] suggest that a new quantity, called 'cema', be introduced to take account of the energy per unit mass transported downstream in kerma. In that situation equation 1.2 would give the kerma factor and equation 1.3 would give cema. Cema would be more generally equivalent to absorbed dose.][17,18]

3.1 Dose, fluence, kerma fluence factor and kerma activity factor

For indirectly ionizing radiations,

$$D(\text{Gy}) = K_{f,\nu} . \Phi_{\nu} \tag{1.10}$$

where Φ_ν is the fluence of the incident photon field and $K_{f,\nu}$ is the kerma fluence factor (from equation 1.2 or 1.3).

Alternatively,

$$D\ (\text{Gy}) = A.t.K_{A,\,el} \tag{1.11}$$

where A is the concentration of source activity of the photon-emitting radionuclide, t is the irradiation time and $K_{A,\,el}$ is the kerma concentration factor for the primary electrons generated (equation 1.6). In the case of incorporated radionuclides with complex decay schemes, the above equation should be summed over the fractional components (see table 4).

3.2 Track cross-sections for induction of biological effects

In radiobiology, the effectiveness of indirectly ionizing radiations for induction of a specified effect in mammalian cells is conventionally expressed as the logarithm of the surviving fraction, F, as a function of absorbed dose, D. Results are usually compatible with either the pure exponential or the sigmoid formulae for survival, i.e.

$$F=\exp[-\alpha.D] \text{ or } \exp[-(\alpha.D+\beta.D^2)] \qquad (1.12)$$

The exponent represents the yield of lesions caused by the radiation. For analysis of damage mechanisms, it is convenient to use effect cross-sections for the associated charged particles as these represent the probability of the specified damage per unit fluence of charged particle tracks and permit absolute quantification of biological effectiveness. Comparison can then be made more readily with results for directly ionizing radiations which are often obtained in the form of cross-sections. At low doses, the biological effect cross-section,

$$\sigma_B\ (\text{cm}^2) = 1.6\times10^{-9}\times\frac{\alpha(\text{Gy}^{-1}).\overline{L_T}\ (\text{keV}/\mu\text{m})}{\rho\ (\text{g/cm}^3)} \qquad (1.13)$$

or, for incorporated radionuclides,

$$\sigma_B\ (\text{cm}^2) = \frac{k_r}{A(\text{Bq.kg}^{-1}).t(\text{s}).n_d.F_p\ (\text{cm})} \qquad (1.14)$$

where kr is a dimensionless repair factor determined by the duration of the irradiation. A is the concentration of activity; n_d is the number of events (e.g. Auger electrons) per decay of the nuclide (table 4a, col. 3) and F_p (cm) is the fluence per unit source concentration of events. The track LET, $^{W}L_T$, in equations 1.9 and 1.13, is averaged over the whole tracks weighted for the equilibrium spectrum of electrons [tables 1–5 (b)].

3.3 Equilibrium fluence spectra and space concentration of electrons

Equilibrium fluence spectra as a function of energy (figures 1.6(a) and (b), 2.3, 3.1, and 5.1(a) to 5.4(a) inclusive) and the space concentration of equilibrium electrons produced (figures 1.5 and 3.5) are conveniently expressed dimensionlessly as ratios to the initial source concentration of electrons. To get the fluence (in $\text{cm}^{-2}.\text{keV}^{-1}$) or the space concentration (in cm^{-3}) multiply by the initial source concentration of electrons released in the material. If the fluence spectra are expressed also per unit logarithmic interval of energy, then the ordinate should be multiplied by the energy, E (keV).

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The Tables

TABLE 1a

MONOENERGETIC ELECTRONS: DATA AT INSTANTANEOUS ELECTRON ENERGY

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
E_P keV	β^2_{el}	L_∞ keV/µm	L_{100} keV/µm	I μm^{-1}	λ nm	R_{csda} g/cm^2	$K_{A, el}$ Gy.cm^3
5.000E−02	1.957E−04	2.249E+01	2.249E+01	3.730E+02	2.681E+00	2.530E−07	8.000E−15
6.000E−02	2.348E−04	2.454E+01	2.454E+01	5.322E+02	1.879E+00	3.038E−07	9.600E−15
7.000E−02	2.739E−04	2.608E+01	2.608E+01	6.440E+02	1.553E+00	3.517E−07	1.120E−14
8.000E−02	3.130E−04	2.714E+01	2.714E+01	7.033E+02	1.422E+00	3.976E−07	1.280E−14
9.000E−02	3.522E−04	2.776E+01	2.776E+01	7.201E+02	1.389E+00	4.419E−07	1.440E−14
1.000E−01	3.913E−04	2.778E+01	2.778E+01	7.080E+02	1.412E+00	4.851E−07	1.600E−14
1.500E−01	5.868E−04	2.414E+01	2.414E+01	6.300E+02	1.587E+00	6.928E−07	2.400E−14
2.000E−01	7.823E−04	2.215E+01	2.215E+01	5.630E+02	1.776E+00	8.992E−07	3.200E−14
3.000E−01	1.173E−03	1.962E+01	1.933E+01	4.627E+02	2.161E+00	1.333E−06	4.800E−14
4.000E−01	1.564E−03	1.786E+01	1.694E+01	3.931E+02	2.544E+00	1.810E−06	6.400E−14
5.000E−01	1.954E−03	1.646E+01	1.476E+01	3.422E+02	2.922E+00	2.336E−06	8.000E−14
6.000E−01	2.344E−03	1.529E+01	1.320E+01	3.035E+02	3.295E+00	2.914E−06	9.600E−14
7.000E−01	2.734E−03	1.428E+01	1.183E+01	2.729E+02	3.665E+00	3.544E−06	1.120E−13
8.000E−01	3.124E−03	1.341E+01	1.097E+01	2.481E+02	4.031E+00	4.228E−06	1.280E−13
9.000E−01	3.513E−03	1.264E+01	9.897E+00	2.276E+02	4.394E+00	4.965E−06	1.440E−13
1.000E+00	3.902E−03	1.195E+01	9.234E+00	2.104E+02	4.754E+00	5.756E−06	1.600E−13
1.500E+00	5.845E−03	9.399E+00	6.750E+00	1.533E+02	6.523E+00	1.052E−05	2.400E−13
2.000E+00	7.782E−03	7.747E+00	5.463E+00	1.212E+02	8.251E+00	1.661E−05	3.200E−13
3.000E+00	1.164E−02	5.739E+00	3.923E+00	8.608E+01	1.162E+01	3.260E−05	4.800E−13
4.000E+00	1.547E−02	4.574E+00	3.149E+00	6.717E+01	1.489E+01	5.330E−05	6.400E−13
5.000E+00	1.929E−02	3.820E+00	2.589E+00	5.531E+01	1.808E+01	7.815E−05	8.000E−13
6.000E+00	2.308E−02	3.296E+00	2.240E+00	4.716E+01	2.121E+01	1.066E−04	9.600E−13
7.000E+00	2.684E−02	2.913E+00	2.030E+00	4.121E+01	2.427E+01	1.380E−04	1.120E−12
8.000E+00	3.059E−02	2.622E+00	1.790E+00	3.667E+01	2.727E+01	1.718E−04	1.280E−12
9.000E+00	3.432E−02	2.396E+00	1.646E+00	3.309E+01	3.022E+01	2.076E−04	1.440E−12
1.000E+01	3.802E−02	2.321E+00	1.468E+00	3.020E+01	3.312E+01	2.463E−04	1.600E−12
1.500E+01	5.622E−02	1.643E+00	1.079E+00	2.131E+01	4.693E+01	5.155E−04	2.400E−12
2.000E+01	7.391E−02	1.300E+00	8.330E−01	1.672E+01	5.979E+01	8.650E−04	3.200E−12
3.000E+01	1.078E−01	9.503E−01	6.156E−01	1.201E+01	8.323E+01	1.777E−03	4.800E−12
4.000E+01	1.399E−01	7.694E−01	4.796E−01	9.590E+00	1.043E+02	2.943E−03	6.400E−12
5.000E+01	1.703E−01	6.574E−01	4.119E−01	8.102E+00	1.234E+02	4.335E−03	8.000E−12

6.000E+01	1.991E−01	5.805E−01	3.605E−01	7.092E+00	1.410E+02	5.935E−03	9.600E−12
7.000E+01	2.264E−01	5.242E−01	3.198E−01	6.358E+00	1.573E+02	7.727E−03	1.120E−11
8.000E+01	2.524E−01	4.808E−01	2.868E−01	5.800E+00	1.724E+02	9.699E−03	1.280E−11
9.000E+01	2.771E−01	4.463E−01	2.672E−01	5.359E+00	1.866E+02	1.184E−02	1.440E−11
1.000E+02	3.005E−01	4.181E−01	2.505E−01	5.003E+00	1.999E+02	1.414E−02	1.600E−11
1.500E+02	4.024E−01	3.291E−01	1.926E−01	3.904E+00	2.561E+02	2.783E−02	2.400E−11
2.000E+02	4.835E−01	2.808E−01	1.657E−01	3.332E+00	3.002E+02	4.469E−02	3.200E−11
3.000E+02	6.030E−01	2.282E−01	1.369E−01	2.736E+00	3.654E+02	8.631E−02	4.800E−11
4.000E+02	6.854E−01	2.153E−01	1.243E−01	2.428E+00	4.118E+02	1.287E−01	6.400E−11
5.000E+02	7.445E−01	2.040E−01	1.164E−01	2.241E+00	4.462E+02	1.763E−01	8.000E−11
6.000E+02	7.884E−01	1.968E−01	1.122E−01	2.116E+00	4.726E+02	2.262E−01	9.600E−11
7.000E+02	8.219E−01	1.919E−01	1.093E−01	2.028E+00	4.931E+02	2.777E−01	1.120E−10
8.000E+02	8.481E−01	1.884E−01	1.078E−01	1.963E+00	5.093E+02	3.302E−01	1.280E−10
9.000E+02	8.688E−01	1.860E−01	1.068E−01	1.915E+00	5.222E+02	3.835E−01	1.440E−10
1.000E+03	8.856E−01	1.843E−01	1.058E−01	1.878E+00	5.324E+02	4.373E−01	1.600E−10
1.500E+03	9.354E−01	1.816E−01	1.053E−01	1.808E+00	5.531E+02	7.085E−01	2.400E−10
2.000E+03	9.586E−01	1.834E−01	1.067E−01	1.769E+00	5.654E+02	9.761E−01	3.200E−10
3.000E+03	9.788E−01	1.846E−01	1.100E−01	1.736E+00	5.761E+02	1.517E+00	4.800E−10
4.000E+03	9.872E−01	1.869E−01	1.137E−01	1.723E+00	5.805E+02	2.039E+00	6.400E−10
5.000E+03	9.914E−01	1.891E−01	1.163E−01	1.716E+00	5.828E+02	2.550E+00	8.000E−10
6.000E+03	9.938E−01	1.911E−01	1.188E−01	1.712E+00	5.841E+02	3.051E+00	9.600E−10
8.000E+03	9.964E−01	1.943E−01	1.235E−01	1.708E+00	5.854E+02	4.025E+00	1.280E−09
9.000E+03	9.971E−01	1.957E−01	1.251E−01	1.707E+00	5.858E+02	4.501E+00	1.440E−09
1.000E+04	9.976E−01	1.969E−01	1.266E−01	1.706E+00	5.861E+02	4.969E+00	1.600E−09
1.500E+04	9.989E−01	2.015E−01	1.333E−01	1.704E+00	5.867E+02	7.212E+00	2.400E−09
2.000E+04	9.994E−01	2.047E−01	1.378E−01	1.704E+00	5.870E+02	9.317E+00	3.200E−09
3.000E+04	9.997E−01	2.088E−01	1.447E−01	1.703E+00	5.872E+02	1.318E+01	4.800E−09

TABLE 1b

MONOENERGETIC ELECTRONS: DATA AVERAGED OVER WHOLE TRACK (EQUILIBRIUM SPECTRUM)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
E_P	**$^{W}L_T$**	**$^{W}L_D$**	**V**	**$^{W}L_{100,T}$**	**$^{W}L_{100,D}$**	**V_{100}**	**$^{W}I_T$**	**$^{W}\lambda_T$**
keV	**keV/µm**	**keV/µm**		**keV/µm**	**keV/µm**		**μm^{-1}**	**nm**
5.000E−02	1.521E+01	1.636E+01	7.565E−02	1.521E+01	1.636E+01	7.565E−02	9.175E+01	1.090E+01
6.000E−02	1.661E+01	1.807E+01	8.807E−02	1.661E+01	1.807E+01	8.807E−02	1.524E+02	6.562E+00
7.000E−02	1.780E+01	1.948E+01	9.465E−02	1.780E+01	1.948E+01	9.465E−02	2.124E+02	4.709E+00
8.000E−02	1.882E+01	2.065E+01	9.746E−02	1.882E+01	2.065E+01	9.746E−02	2.661E+02	3.758E+00
9.000E−02	1.969E+01	2.161E+01	9.761E−02	1.969E+01	2.161E+01	9.761E−02	3.111E+02	3.214E+00
1.000E−01	2.042E+01	2.237E+01	9.580E−02	2.042E+01	2.237E+01	9.580E−02	3.472E+02	2.880E+00
1.500E−01	2.202E+01	2.357E+01	7.063E−02	2.202E+01	2.357E+01	7.063E−02	4.437E+02	2.254E+00
2.000E−01	2.226E+01	2.346E+01	5.378E−02	2.226E+01	2.346E+01	5.378E−02	4.785E+02	2.090E+00
3.000E−01	2.177E+01	2.263E+01	3.926E−02	2.171E+01	2.258E+01	3.995E−02	4.885E+02	2.047E+00

4.000E−01	2.096E+01	2.171E+01	3.554E−02	2.068E+01	2.150E+01	3.966E−02	4.719E+02	2.119E+00
5.000E−01	2.010E+01	2.083E+01	3.638E−02	1.952E+01	2.043E+01	4.679E−02	4.481E+02	2.232E+00
6.000E−01	1.926E+01	2.002E+01	3.955E−02	1.838E+01	1.944E+01	5.815E−02	4.231E+02	2.364E+00
7.000E−01	1.846E+01	1.927E+01	4.405E−02	1.730E+01	1.854E+01	7.190E−02	3.990E+02	2.506E+00
8.000E−01	1.771E+01	1.859E+01	4.937E−02	1.631E+01	1.773E+01	8.694E−02	3.765E+02	2.656E+00
9.000E−01	1.701E+01	1.795E+01	5.520E−02	1.541E+01	1.699E+01	1.026E−01	3.559E+02	2.810E+00
1.000E+00	1.637E+01	1.737E+01	6.137E−02	1.459E+01	1.632E+01	1.185E−01	3.370E+02	2.967E+00
1.500E+00	1.372E+01	1.501E+01	9.401E−02	1.148E+01	1.372E+01	1.947E−01	2.648E+02	3.776E+00
2.000E+00	1.180E+01	1.330E+01	1.264E−01	9.461E+00	1.193E+01	2.609E−01	2.174E+02	4.600E+00
3.000E+00	9.248E+00	1.097E+01	1.860E−01	7.037E+00	9.606E+00	3.652E−01	1.602E+02	6.244E+00
4.000E+00	7.635E+00	9.451E+00	2.380E−01	5.645E+00	8.148E+00	4.433E−01	1.273E+02	7.856E+00
5.000E+00	6.532E+00	8.381E+00	2.832E−01	4.747E+00	7.143E+00	5.048E−01	1.061E+02	9.423E+00
6.000E+00	5.734E+00	7.585E+00	3.228E−01	4.119E+00	6.407E+00	5.554E−01	9.141E+01	1.094E+01
7.000E+00	5.133E+00	6.969E+00	3.577E−01	3.657E+00	5.846E+00	5.985E−01	8.062E+01	1.240E+01
8.000E+00	4.665E+00	6.478E+00	3.886E−01	3.303E+00	5.404E+00	6.363E−01	7.239E+01	1.381E+01
9.000E+00	4.293E+00	6.079E+00	4.160E−01	3.022E+00	5.048E+00	6.701E−01	6.591E+01	1.517E+01
1.000E+01	3.980E+00	5.736E+00	4.412E−01	2.788E+00	4.745E+00	7.020E−01	6.052E+01	1.652E+01
1.500E+01	2.905E+00	4.425E+00	5.233E−01	1.971E+00	3.607E+00	8.303E−01	4.195E+01	2.384E+01
2.000E+01	2.317E+00	3.674E+00	5.856E−01	1.550E+00	2.959E+00	9.098E−01	3.257E+01	3.070E+01
3.000E+01	1.690E+00	2.819E+00	6.684E−01	1.112E+00	2.234E+00	1.009E+00	2.302E+01	4.344E+01
4.000E+01	1.357E+00	2.332E+00	7.184E−01	8.822E−01	1.827E+00	1.071E+00	1.812E+01	5.518E+01
5.000E+01	1.149E+00	2.010E+00	7.502E−01	7.395E−01	1.563E+00	1.114E+00	1.512E+01	6.613E+01
6.000E+01	1.005E+00	1.780E+00	7.709E−01	6.416E−01	1.376E+00	1.144E+00	1.308E+01	7.643E+01

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
E_P	**$^{W}L_T$**	**$^{W}L_D$**	**V**	**$^{W}L_{100,T}$**	**$^{W}L_{100,D}$**	**V_{100}**	**$^{W}I_T$**	**$^{W}\lambda_T$**
keV	**keV/µm**	**keV/µm**		**keV/µm**	**keV/µm**		**μm^{-1}**	**nm**
6.000E+01	1.005E+00	1.780E+00	7.709E−01	6.416E−01	1.376E+00	1.144E+00	1.308E+01	7.643E+01
7.000E+01	8.998E−01	1.606E+00	7.844E−01	5.699E−01	1.235E+00	1.167E+00	1.160E+01	8.618E+01
8.000E+01	8.188E−01	1.468E+00	7.929E−01	5.150E−01	1.124E+00	1.183E+00	1.048E+01	9.544E+01
9.000E+01	7.545E−01	1.357E+00	7.981E−01	4.716E−01	1.035E+00	1.194E+00	9.591E+00	1.043E+02
1.000E+02	7.019E−01	1.264E+00	8.007E−01	4.363E−01	9.604E−01	1.201E+00	8.872E+00	1.127E+02
1.500E+02	5.370E−01	9.633E−01	7.938E−01	3.269E−01	7.205E−01	1.204E+00	6.655E+00	1.503E+02
2.000E+02	4.485E−01	7.953E−01	7.734E−01	2.698E−01	5.868E−01	1.175E+00	5.497E+00	1.819E+02
3.000E+02	3.530E−01	6.092E−01	7.256E−01	2.108E−01	4.388E−01	1.081E+00	4.286E+00	2.333E+02
4.000E+02	3.104E−01	5.177E−01	6.678E−01	1.838E−01	3.673E−01	9.984E−01	3.717E+00	2.690E+02
5.000E+02	2.831E−01	4.561E−01	6.113E−01	1.664E−01	3.192E−01	9.185E−01	3.342E+00	2.992E+02
6.000E+02	2.648E−01	4.135E−01	5.614E−01	1.548E−01	2.859E−01	8.469E−01	3.084E+00	3.242E+02
7.000E+02	2.517E−01	3.821E−01	5.181E−01	1.466E−01	2.614E−01	7.834E−01	2.896E+00	3.453E+02
8.000E+02	2.419E−01	3.581E−01	4.804E−01	1.405E−01	2.426E−01	7.270E−01	2.753E+00	3.633E+02
9.000E+02	2.343E−01	3.391E−01	4.475E−01	1.358E−01	2.278E−01	6.771E−01	2.640E+00	3.789E+02
1.000E+03	2.282E−01	3.237E−01	4.186E−01	1.322E−01	2.158E−01	6.327E−01	2.548E+00	3.925E+02
1.500E+03	2.107E−01	2.769E−01	3.144E−01	1.219E−01	1.792E−01	4.708E−01	2.280E+00	4.386E+02
2.000E+03	2.029E−01	2.536E−01	2.500E−01	1.175E−01	1.611E−01	3.711E−01	2.144E+00	4.663E+02
3.000E+03	1.959E−01	2.302E−01	1.747E−01	1.143E−01	1.433E−01	2.537E−01	2.004E+00	4.991E+02
4.000E+03	1.933E−01	2.192E−01	1.340E−01	1.138E−01	1.355E−01	1.907E−01	1.933E+00	5.173E+02

5.000E+03	1.923E−01	2.131E−01	1.085E−01	1.141E−01	1.314E−01	1.517E−01	1.890E+00	5.290E+02
6.000E+03	1.919E−01	2.094E−01	9.104E−02	1.147E−01	1.291E−01	1.255E−01	1.861E+00	5.372E+02
7.000E+03	1.919E−01	2.070E−01	7.841E−02	1.155E−01	1.279E−01	1.069E−01	1.840E+00	5.433E+02
8.000E+03	1.921E−01	2.053E−01	6.886E−02	1.164E−01	1.272E−01	9.310E−02	1.825E+00	5.480E+02
9.000E+03	1.924E−01	2.042E−01	6.142E−02	1.173E−01	1.269E−01	8.251E−02	1.812E+00	5.518E+02
1.000E+04	1.928E−01	2.035E−01	5.546E−02	1.181E−01	1.269E−01	7.416E−02	1.802E+00	5.548E+02
1.500E+04	1.948E−01	2.022E−01	3.766E−02	1.220E−01	1.281E−01	5.020E−02	1.772E+00	5.643E+02
2.000E+04	1.967E−01	2.024E−01	2.892E−02	1.251E−01	1.300E−01	3.914E−02	1.757E+00	5.692E+02
3.000E+04	1.997E−01	2.038E−01	2.038E−02	1.300E−01	1.338E−01	2.910E−02	1.741E+00	5.744E+02

TABLE 1c

MONOENERGETIC ELECTRONS: DATA AVERAGED OVER SPECTRUM EMITTED FROM A HOMOGENEOUS RADIATOR SOURCE

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
E_P keV	E_S keV	R_S µm	L_T keV/µm	L_D keV/µm	V	$L_{100,T}$ keV/µm	$L_{100,D}$ keV/µm	V_{100}	l µm^{-1}	λ nm
5.000E−02	2.409E−02	1.004E−03	1.282E+01	1.622E+01	2.652E−01	1.282E+01	1.622E+01	2.652E−01	7.527E+01	1.329E+01
6.000E−02	2.816E−02	1.239E−03	1.384E+01	1.801E+01	3.017E−01	1.384E+01	1.801E+01	3.017E−01	1.257E+02	7.959E+00
7.000E−02	3.213E−02	1.459E−03	1.482E+01	1.948E+01	3.143E−01	1.482E+01	1.948E+01	3.143E−01	1.760E+02	5.682E+00
8.000E−02	3.598E−02	1.664E−03	1.567E+01	2.067E+01	3.195E−01	1.567E+01	2.067E+01	3.195E−01	2.210E+02	4.525E+00
9.000E−02	3.992E−02	1.867E−03	1.646E+01	2.167E+01	3.168E−01	1.646E+01	2.167E+01	3.168E−01	2.607E+02	3.836E+00
1.000E−01	4.382E−02	2.062E−03	1.711E+01	2.247E+01	3.131E−01	1.711E+01	2.247E+01	3.131E−01	2.924E+02	3.420E+00
1.500E−01	6.428E−02	3.018E−03	1.859E+01	2.371E+01	2.754E−01	1.859E+01	2.371E+01	2.754E−01	3.791E+02	2.638E+00
2.000E−01	8.482E−02	3.919E−03	1.867E+01	2.352E+01	2.599E−01	1.867E+01	2.352E+01	2.599E−01	4.047E+02	2.471E+00
3.000E−01	1.250E−01	5.649E−03	1.807E+01	2.263E+01	2.521E−01	1.801E+01	2.257E+01	2.529E−01	4.043E+02	2.473E+00
4.000E−01	1.654E−01	7.443E−03	1.746E+01	2.177E+01	2.469E−01	1.723E+01	2.157E+01	2.518E−01	3.892E+02	2.569E+00
5.000E−01	2.069E−01	9.387E−03	1.693E+01	2.102E+01	2.418E−01	1.648E+01	2.066E+01	2.538E−01	3.727E+02	2.683E+00
6.000E−01	2.497E−01	1.151E−02	1.646E+01	2.037E+01	2.376E−01	1.578E+01	1.987E+01	2.588E−01	3.569E+02	2.802E+00
7.000E−01	2.937E−01	1.383E−02	1.602E+01	1.979E+01	2.348E−01	1.514E+01	1.918E+01	2.663E−01	3.423E+02	2.922E+00
8.000E	3.387E	1.635E	1.562E+01	1.926E+01	2.335E	1.456E	1.857E+01	2.759E	3.289E	3.041E

−01	−01	−02			−01	+01		−01	+02	+00
9.000E−01	3.948E−01	1.968E−02	1.515E+01	1.868E+01	2.326E−01	1.391E+01	1.792E+01	2.884E−01	3.138E+02	3.187E+00
1.000E+00	4.341E−01	2.218E−02	1.485E+01	1.833E+01	2.344E−01	1.350E+01	1.755E+01	2.996E−01	3.046E+02	3.284E+00
1.500E+00	7.021E−01	4.197E−02	1.313E+01	1.649E+01	2.553E−01	1.138E+01	1.569E+01	3.785E−01	2.557E+02	3.911E+00
2.000E+00	9.727E−01	6.699E−02	1.183E+01	1.525E+01	2.898E−01	9.947E+00	1.455E+01	4.628E−01	2.227E+02	4.490E+00
3.000E+00	1.544E+00	1.356E−01	9.855E+00	1.357E+01	3.772E−01	8.006E+00	1.310E+01	6.366E−01	1.780E+02	5.620E+00
4.000E+00	2.127E+00	2.261E−01	8.488E+00	1.250E+01	4.722E−01	6.769E+00	1.222E+01	8.048E−01	1.495E+02	6.689E+00
5.000E+00	2.722E+00	3.381E−01	7.476E+00	1.173E+01	5.693E−01	5.896E+00	1.160E+01	9.680E−01	1.295E+02	7.721E+00
6.000E+00	3.330E+00	4.709E−01	6.691E+00	1.115E+01	6.664E−01	5.237E+00	1.114E+01	1.127E+00	1.145E+02	8.736E+00
7.000E+00	3.906E+00	6.123E−01	6.106E+00	1.072E+01	7.556E−01	4.754E+00	1.080E+01	1.272E+00	1.035E+02	9.662E+00
8.000E+00	4.541E+00	7.833E−01	5.581E+00	1.033E+01	8.510E−01	4.325E+00	1.050E+01	1.428E+00	9.379E+01	1.066E+01
9.000E+00	5.126E+00	9.533E−01	5.187E+00	1.004E+01	9.351E−01	4.004E+00	1.027E+01	1.566E+00	8.656E+01	1.155E+01
1.000E+01	5.768E+00	1.151E+00	4.822E+00	9.760E+00	1.024E+00	3.708E+00	1.006E+01	1.714E+00	7.992E+01	1.251E+01
1.500E+01	8.843E+00	2.371E+00	3.695E+00	8.818E+00	1.386E+00	2.780E+00	9.381E+00	2.374E+00	5.928E+01	1.687E+01
2.000E+01	1.196E+01	4.028E+00	3.022E+00	8.273E+00	1.737E+00	2.252E+00	8.975E+00	2.985E+00	4.768E+01	2.097E+01
3.000E+01	1.816E+01	8.396E+00	2.268E+00	7.632E+00	2.365E+00	1.670E+00	8.496E+00	4.087E+00	3.508E+01	2.851E+01
4.000E+01	2.441E+01	1.409E+01	1.846E+00	7.242E+00	2.922E+00	1.348E+00	8.208E+00	5.090E+00	2.820E+01	3.547E+01
5.000E+01	3.059E+01	2.087E+01	1.578E+00	6.972E+00	3.418E+00	1.144E+00	8.012E+00	6.005E+00	2.387E+01	4.189E+01
6.000E+01	3.676E+01	2.867E+01	1.391E+00	6.768E+00	3.867E+00	1.001E+00	7.866E+00	6.856E+00	2.087E+01	4.791E+01

(1) E_P keV	(2) E_S keV	(3) R_S µm	(4) L_T keV/µm	(5) L_D keV/µm	(6) V	(7) $L_{100, T}$ keV/µm	(8) $L_{100, D}$ keV/µm	(9) V_{100}	(10) I μm^{-1}	(11) λ nm
6.000E+01	3.676E+01	2.867E+01	1.391E+00	6.768E+00	3.867E+00	1.001E+00	7.866E+00	6.856E+00	2.087E+01	4.791E+01
7.000E+01	4.296E+01	3.750E+01	1.250E+00	6.605E+00	4.282E+00	8.951E−01	7.751E+00	7.660E+00	1.865E+01	5.363E+01
8.000E+01	4.912E+01	4.718E+01	1.143E+00	6.473E+00	4.665E+00	8.137E−01	7.659E+00	8.412E+00	1.695E+01	5.901E+01
9.000E+01	5.518E+01	5.754E+01	1.057E+00	6.363E+00	5.017E+00	7.496E−01	7.582E+00	9.114E+00	1.561E+01	6.406E+01

1.000E+02	6.122E+01	6.869E+01	9.875E−01	6.269E+00	5.349E+00	6.972E−01	7.517E+00	9.782E+00	1.452E+01	6.888E+01
1.500E+02	9.155E+01	1.355E+02	7.642E−01	5.942E+00	6.776E+00	5.314E−01	7.287E+00	1.271E+01	1.108E+01	9.029E+01
2.000E+02	1.211E+02	2.163E+02	6.457E−01	5.753E+00	7.910E+00	4.452E−01	7.146E+00	1.505E+01	9.282E+00	1.077E+02
3.000E+02	1.791E+02	4.126E+02	5.187E−01	5.546E+00	9.692E+00	3.555E−01	6.968E+00	1.860E+01	7.404E+00	1.351E+02
4.000E+02	2.353E+02	6.281E+02	4.549E−01	5.401E+00	1.087E+01	3.095E−01	6.854E+00	2.115E+01	6.426E+00	1.556E+02
5.000E+02	2.902E+02	8.596E+02	4.162E−01	5.296E+00	1.172E+01	2.816E−01	6.770E+00	2.304E+01	5.823E+00	1.717E+02
6.000E+02	3.440E+02	1.101E+03	3.903E−01	5.215E+00	1.236E+01	2.629E−01	6.702E+00	2.449E+01	5.413E+00	1.848E+02
7.000E+02	3.966E+02	1.347E+03	3.719E−01	5.151E+00	1.285E+01	2.497E−01	6.647E+00	2.562E+01	5.117E+00	1.954E+02
8.000E+02	4.484E+02	1.598E+03	3.580E−01	5.099E+00	1.324E+01	2.398E−01	6.599E+00	2.652E+01	4.891E+00	2.044E+02
9.000E+02	4.996E+02	1.851E+03	3.472E−01	5.055E+00	1.356E+01	2.322E−01	6.557E+00	2.724E+01	4.715E+00	2.121E+02
1.000E+03	5.507E+02	2.110E+03	3.386E−01	5.017E+00	1.382E+01	2.261E−01	6.518E+00	2.783E+01	4.571E+00	2.188E+02
1.500E+03	7.972E+02	3.395E+03	3.133E−01	4.884E+00	1.459E+01	2.086E−01	6.372E+00	2.955E+01	4.150E+00	2.410E+02
2.000E+03	1.035E+03	4.659E+03	3.017E−01	4.796E+00	1.489E+01	2.006E−01	6.267E+00	3.024E+01	3.939E+00	2.539E+02
3.000E+03	1.496E+03	7.142E+03	2.910E−01	4.686E+00	1.510E+01	1.938E−01	6.117E+00	3.056E+01	3.727E+00	2.683E+02
4.000E+03	1.947E+03	9.546E+03	2.865E−01	4.616E+00	1.511E+01	1.913E−01	6.008E+00	3.040E+01	3.620E+00	2.762E+02
5.000E+03	2.388E+03	1.186E+04	2.842E−01	4.567E+00	1.507E+01	1.905E−01	5.925E+00	3.011E+01	3.556E+00	2.812E+02
6.000E+03	2.825E+03	1.413E+04	2.830E−01	4.528E+00	1.500E+01	1.903E−01	5.857E+00	2.978E+01	3.514E+00	2.846E+02
7.000E+03	3.261E+03	1.636E+04	2.824E−01	4.497E+00	1.492E+01	1.904E−01	5.798E+00	2.945E+01	3.483E+00	2.871E+02
8.000E+03	3.702E+03	1.859E+04	2.821E−01	4.470E+00	1.485E+01	1.908E−01	5.747E+00	2.912E+01	3.459E+00	2.891E+02
9.000E+03	4.123E+03	2.070E+04	2.821E−01	4.449E+00	1.477E+01	1.912E−01	5.705E+00	2.883E+01	3.442E+00	2.906E+02
1.000E+04	4.546E+03	2.278E+04	2.821E−01	4.429E+00	1.470E+01	1.917E−01	5.666E+00	2.855E+01	3.427E+00	2.918E+02
1.500E+04	6.699E+03	3.310E+04	2.831E−01	4.358E+00	1.439E+01	1.944E−01	5.515E+00	2.737E+01	3.383E+00	2.956E+02
2.000E+04	8.792E+03	4.265E+04	2.843E−01	4.312E+00	1.416E+01	1.969E−01	5.413E+00	2.649E+01	3.361E+00	2.975E+02
3.000E+04	1.314E+04	6.136E+04	2.868E−01	4.249E+00	1.382E+01	2.012E−01	5.266E+00	2.517E+01	3.338E+00	2.996E+02

TABLE 1d

MONOENERGETIC ELECTRONS: EQUILIBRIUM ELECTRON CONCENTRATION AND FLUENCE RATIOS, BUILDUP FACTORS AND W VALUES

(1) E_P keV	(2) C_P	(3) C_T	(4) B_C	(5) F_S cm	(6) B_F	(7) W eV
5.000E−02	8.818E−16	1.050E−15	1.191E+00	2.807E−07	1.110E+00	6.037E+01
6.000E−02	9.785E−16	1.155E−15	1.180E+00	3.254E−07	1.071E+00	4.614E+01
7.000E−02	1.061E−15	1.240E−15	1.169E+00	3.657E−07	1.040E+00	4.060E+01
8.000E−02	1.134E−15	1.323E−15	1.167E+00	4.055E−07	1.020E+00	3.876E+01
9.000E−02	1.201E−15	1.410E−15	1.174E+00	4.476E−07	1.013E+00	3.866E+01
1.000E−01	1.263E−15	1.497E−15	1.186E+00	4.904E−07	1.011E+00	3.962E+01
1.500E−01	1.557E−15	2.008E−15	1.289E+00	7.458E−07	1.076E+00	3.819E+01
2.000E−01	1.834E−15	2.608E−15	1.422E+00	1.057E−06	1.175E+00	3.930E+01
3.000E−01	2.349E−15	3.903E−15	1.661E+00	1.773E−06	1.330E+00	4.119E+01
4.000E−01	2.832E−15	5.204E−15	1.838E+00	2.563E−06	1.416E+00	4.216E+01
5.000E−01	3.296E−15	6.478E−15	1.965E+00	3.409E−06	1.459E+00	4.228E+01
6.000E−01	3.750E−15	7.720E−15	2.058E+00	4.301E−06	1.476E+00	4.251E+01
7.000E−01	4.198E−15	8.937E−15	2.129E+00	5.239E−06	1.478E+00	4.250E+01
8.000E−01	4.644E−15	1.013E−14	2.181E+00	6.219E−06	1.471E+00	4.293E+01
9.000E−01	5.244E−15	1.164E−14	2.219E+00	7.528E−06	1.516E+00	4.263E+01
1.000E+00	5.722E−15	1.256E−14	2.196E+00	8.393E−06	1.458E+00	4.286E+01
1.500E+00	8.080E−15	1.889E−14	2.338E+00	1.509E−05	1.435E+00	4.317E+01
2.000E+00	1.050E−14	2.489E−14	2.370E+00	2.270E−05	1.367E+00	4.393E+01
3.000E+00	1.593E−14	3.732E−14	2.343E+00	4.185E−05	1.284E+00	4.465E+01
4.000E+00	2.171E−14	5.001E−14	2.303E+00	6.543E−05	1.228E+00	4.564E+01
5.000E+00	2.785E−14	6.302E−14	2.263E+00	9.334E−05	1.194E+00	4.593E+01
6.000E+00	3.432E−14	7.656E−14	2.231E+00	1.260E−04	1.182E+00	4.651E+01
7.000E+00	4.177E−14	8.944E−14	2.141E+00	1.601E−04	1.161E+00	4.751E+01
8.000E+00	4.854E−14	1.041E−13	2.144E+00	2.022E−04	1.177E+00	4.751E+01
9.000E+00	5.643E−14	1.175E−13	2.082E+00	2.439E−04	1.174E+00	4.807E+01
1.000E+01	6.312E−14	1.325E−13	2.100E+00	2.937E−04	1.192E+00	4.770E+01
1.500E+01	1.059E−13	2.073E−13	1.957E+00	5.842E−04	1.133E+00	4.903E+01
2.000E+01	1.491E−13	2.866E−13	1.922E+00	9.596E−04	1.109E+00	4.887E+01
3.000E+01	2.557E−13	4.548E−13	1.779E+00	1.933E−03	1.087E+00	4.966E+01
4.000E+01	3.609E−13	6.346E−13	1.758E+00	3.188E−03	1.083E+00	4.912E+01
5.000E+01	4.919E−13	8.228E−13	1.673E+00	4.688E−03	1.081E+00	4.944E+01
6.000E+01	6.250E−13	1.018E−12	1.629E+00	6.416E−03	1.081E+00	4.938E+01
7.000E+01	7.554E−13	1.221E−12	1.617E+00	8.373E−03	1.084E+00	4.909E+01
8.000E+01	8.794E−13	1.429E−12	1.625E+00	1.051E−02	1.084E+00	4.865E+01
9.000E+01	1.039E−12	1.639E−12	1.578E+00	1.282E−02	1.083E+00	4.879E+01

1.000E+02	1.200E−12	1.855E−12	1.545E+00	1.530E−02	1.082E+00	4.885E+01
1.500E+02	1.979E−12	3.001E−12	1.516E+00	3.013E−02	1.083E+00	4.850E+01
2.000E+02	2.878E−12	4.205E−12	1.461E+00	4.789E−02	1.072E+00	4.881E+01
3.000E+02	4.649E−12	6.737E−12	1.449E+00	8.990E−02	1.042E+00	4.946E+01
4.000E+02	6.643E−12	9.362E−12	1.409E+00	1.376E−01	1.069E+00	5.062E+01
5.000E+02	8.420E−12	1.203E−11	1.429E+00	1.890E−01	1.072E+00	5.162E+01
6.000E+02	1.041E−11	1.474E−11	1.416E+00	2.429E−01	1.074E+00	5.272E+01
7.000E+02	1.221E−11	1.744E−11	1.428E+00	2.982E−01	1.074E+00	5.370E+01
8.000E+02	1.452E−11	2.016E−11	1.389E+00	3.549E−01	1.075E+00	5.467E+01
9.000E+02	1.677E−11	2.289E−11	1.365E+00	4.125E−01	1.076E+00	5.552E+01
1.000E+03	1.806E−11	2.563E−11	1.419E+00	4.711E−01	1.077E+00	5.623E+01
1.500E+03	2.839E−11	3.927E−11	1.383E+00	7.679E−01	1.084E+00	5.825E+01
2.000E+03	3.664E−11	5.273E−11	1.439E+00	1.066E+00	1.092E+00	6.043E+01
3.000E+03	5.604E−11	7.949E−11	1.418E+00	1.664E+00	1.097E+00	6.362E+01
4.000E+03	7.129E−11	1.061E−10	1.488E+00	2.262E+00	1.109E+00	6.621E+01
5.000E+03	9.014E−11	1.325E−10	1.470E+00	2.855E+00	1.120E+00	6.810E+01
6.000E+03	1.072E−10	1.589E−10	1.482E+00	3.450E+00	1.131E+00	6.974E+01
7.000E+03	1.222E−10	1.856E−10	1.518E+00	4.053E+00	1.144E+00	7.120E+01
8.000E+03	1.353E−10	2.131E−10	1.575E+00	4.673E+00	1.161E+00	7.254E+01
9.000E+03	1.531E−10	2.393E−10	1.563E+00	5.265E+00	1.170E+00	7.358E+01
1.000E+04	1.701E−10	2.659E−10	1.563E+00	5.865E+00	1.180E+00	7.454E+01
1.500E+04	2.419E−10	4.074E−10	1.684E+00	9.059E+00	1.256E+00	7.850E+01
2.000E+04	3.179E−10	5.523E−10	1.737E+00	1.233E+01	1.323E+00	8.123E+01
3.000E+04	4.514E−10	8.902E−10	1.972E+00	1.996E+01	1.514E+00	8.528E+01

TABLE 2a

X-RAYS: DATA FOR THE INITIAL ELECTRON SPECTRA GENERATED BY MONOENERGETIC CHARACTERISTIC K_α X-RAYS

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Element	**E_x keV**	**$N\sigma_a$ $cm^2.g^{-1}$**	**$N\sigma_{tr}$ $cm^2.g^{-1}$**	**E_i keV**	**R_i (≡F_p) µm**	**L_∞ keV/µm**	**L_{100} keV/µm**	**I_p $µm^{-1}$**	**λ_p nm**	**K_f $Gy.cm^2$**
C	2.770E−01	9.529E+04	3.200E+04	2.633E−01	1.170E−02	2.042E+01	2.020E+01	4.950E+02	2.020E+00	1.418E−09
N	3.920E−01	4.303E+04	2.576E+04	3.783E−01	1.703E−02	1.820E+01	1.719E+01	4.063E+02	2.461E+00	1.616E−09
O	5.250E−01	2.134E+04	1.685E+04	5.113E−01	2.399E−02	1.631E+01	1.466E+01	3.373E+02	2.964E+00	1.415E−09
F	6.770E−01	1.133E+04	1.023E+04	1.340E−01	6.272E−03	2.503E+01	2.503E+01	6.541E+02	1.529E+00	1.108E−09

Ne	8.490E−01	6.335E+03	6.107E+03	3.060E−01	1.361E−02	1.950E+01	1.925E+01	4.578E+02	2.185E+00	8.296E−10
Mg	1.254E+00	2.258E+03	2.247E+03	7.106E−01	3.614E−02	1.418E+01	1.177E+01	2.700E+02	3.704E+00	4.529E−10
Al	1.486E+00	1.422E+03	1.411E+03	9.430E−01	5.299E−02	1.233E+01	9.733E+00	2.198E+02	4.549E+00	3.380E−10
Si	1.739E+00	9.165E+02	9.105E+02	1.196E+00	7.466E−02	1.080E+01	8.109E+00	1.833E+02	5.455E+00	2.551E−10
P	2.013E+00	6.055E+02	6.030E+02	1.470E+00	1.019E−01	9.521E+00	7.030E+00	1.558E+02	6.418E+00	1.950E−10
S	2.307E+00	4.092E+02	4.085E+02	1.764E+00	1.357E−01	8.448E+00	5.933E+00	1.344E+02	7.439E+00	1.510E−10
Cl	2.622E+00	2.824E+02	2.822E+02	2.079E+00	1.768E−01	7.539E+00	5.382E+00	1.174E+02	8.519E+00	1.184E−10
Ar	2.957E+00	1.990E+02	1.984E+02	2.413E+00	2.262E−01	6.769E+00	4.746E+00	1.036E+02	9.657E+00	9.384E−11
K	3.310E+00	1.428E+02	1.421E+02	2.765E+00	2.842E−01	6.113E+00	4.202E+00	9.227E+01	1.084E+01	7.528E−11
Ca	3.700E+00	1.026E+02	1.021E+02	3.154E+00	3.552E−01	5.530E+00	3.858E+00	8.255E+01	1.211E+01	6.042E−11
Ti	4.510E+00	5.674E+01	5.635E+01	3.960E+00	5.245E−01	4.639E+00	3.196E+00	6.836E+01	1.463E+01	4.066E−11
Va	4.950E+00	4.284E+01	4.252E+01	4.396E+00	6.278E−01	4.283E+00	2.979E+00	6.293E+01	1.589E+01	3.367E−11
Cr	5.410E+00	3.272E+01	3.245E+01	4.850E+00	7.436E−01	3.980E+00	2.791E+00	5.842E+01	1.712E+01	2.809E−11
Mn	5.900E+00	2.513E+01	2.489E+01	5.331E+00	8.748E−01	3.718E+00	2.628E+00	5.464E+01	1.830E+01	2.350E−11
Fe	6.399E+00	1.961E+01	1.939E+01	5.818E+00	1.016E+00	3.502E+00	2.491E+00	5.166E+01	1.936E+01	1.986E−11
Co	6.925E+00	1.540E+01	1.520E+01	6.327E+00	1.172E+00	3.322E+00	2.378E+00	4.932E+01	2.028E+01	1.685E−11
Ni	7.470E+00	1.221E+01	1.203E+01	6.849E+00	1.340E+00	3.178E+00	2.289E+00	4.762E+01	2.100E+01	1.437E−11
Cu	8.040E+00	9.742E+00	9.570E+00	7.387E+00	1.522E+00	3.066E+00	2.225E+00	4.651E+01	2.150E+01	1.231E−11
Zn	8.632E+00	7.835E+00	7.669E+00	7.938E+00	1.716E+00	2.987E+00	2.184E+00	4.598E+01	2.175E+01	1.059E−11
Ga	9.250E+00	6.341E+00	6.178E+00	8.501E+00	1.922E+00	2.939E+00	2.168E+00	4.604E+01	2.172E+01	9.144E−12
Ge	9.880E+00	5.186E+00	5.026E+00	9.061E+00	2.134E+00	2.924E+00	2.175E+00	4.666E+01	2.143E+01	7.946E−12
As	1.053E+01	4.273E+00	4.107E+00	9.622E+00	2.353E+00	2.938E+00	2.207E+00	4.781E+01	2.091E+01	6.920E−12
Se	1.121E+01	3.537E+00	3.381E+00	1.019E+01	2.645E+00	3.058E+00	2.309E+00	4.953E+01	2.019E+01	6.064E−12
Br	1.190E+01	2.958E+00	2.808E+00	1.074E+01	2.936E+00	3.107E+00	2.381E+00	5.172E+01	1.933E+01	5.346E−12

Kr	1.260E+01	2.496E+00	2.349E+00	1.127E+01	3.236E+00	3.183E+00	2.470E+00	5.434E+01	1.840E+01	4.735E−12
Sr	1.414E+01	1.783E+00	1.634E+00	1.233E+01	3.902E+00	3.431E+00	2.766E+00	6.128E+01	1.632E+01	3.697E−12

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Element	**E_X keV**	**$N\sigma_a$ $cm^2.g^{-1}$**	**$N\sigma_{tr}$ $cm^2.g^{-1}$**	**E_i keV**	**Ri (≡F_p) µm**	**L_∞ keV/µm**	**L_{100} keV/µm**	**I_p $µm^{-1}$**	**λ_p nm**	**K_f $Gy.cm^2$**
Y	1.490E+01	1.536E+00	1.384E+00	1.279E+01	4.228E+00	3.586E+00	2.912E+00	6.513E+01	1.535E+01	3.299E−32
Zr	1.575E+01	1.316E+00	1.159E+00	1.325E+01	4.586E+00	3.779E+00	3.122E+00	6.970E+01	1.435E+01	2.920E−12
Mo	1.744E+01	9.990E−01	8.344E−01	1.401E+01	5.265E+00	4.207E+00	3.496E+00	7.925E+01	1.262E+01	2.328E−12
Tc	1.830E+01	8.818E−01	7.139E−01	1.430E+01	5.586E+00	4.442E+00	3.724E+00	8.428E+01	1.187E+01	2.090E−12
Rh	2.020E+01	6.910E−01	5.180E−01	1.475E+01	6.221E+00	4.953E+00	4.165E+00	9.472E+01	1.056E+01	1.674E−12
Pd	2.112E+01	6.227E−01	4.480E−01	1.487E+01	6.488E+00	5.191E+00	4.355E+00	9.941E+01	1.006E+01	1.514E−12
Ag	2.210E+01	5.628E−01	3.870E−01	1.494E+01	6.739E+00	5.440E+00	4.572E+00	1.042E+02	9.594E+00	1.369E−12
Cd	2.311E+01	5.116E−01	3.351E−01	1.494E+01	6.962E+00	5.692E+00	4.767E+00	1.090E+02	9.171E+00	1.239E−12
In	2.414E+01	4.683E−01	2.915E−01	1.488E+01	7.153E+00	5.904E+00	4.942E+00	1.129E+02	8.859E+00	1.126E−12
Sn	2.519E+01	4.312E−01	2.545E−01	1.477E+01	7.312E+00	6.108E+00	5.089E+00	1.165E+02	8.582E+00	1.026E−12
Sb	2.627E+01	3.995E−01	2.230E−01	1.460E+01	7.436E+00	6.308E+00	5.246E+00	1.201E+02	8.329E+00	9.375E−13
Te	2.738E+01	3.721E−01	1.961E−01	1.440E+01	7.527E+00	6.471E+00	5.358E+00	1.228E+02	8.145E+00	8.593E−13
I	2.851E+01	3.487E−01	1.733E−01	1.415E+01	7.586E+00	6.603E+00	5.458E+00	1.248E+02	8.010E+00	7.905E−13
Xe	2.967E+01	3.283E−01	1.537E−01	1.387E+01	7.612E+00	6.734E+00	5.546E+00	1.269E+02	7.881E+00	7.295E−13
Cs	3.085E+01	3.107E−01	1.369E−01	1.357E+01	7.609E+00	6.819E+00	5.607E+00	1.280E+02	7.813E+00	6.755E−13
Ba	3.206E+01	2.953E−01	1.224E−01	1.326E+01	7.580E+00	6.877E+00	5.632E+00	1.286E+02	7.778E+00	6.278E−13
Nd	3.718E+01	2.509E−01	8.158E−02	1.194E+01	7.250E+00	6.914E+00	5.586E+00	1.272E+02	7.863E+00	4.853E−13
Sm	3.991E+01	2.359E−01	6.832E−02	1.132E+01	7.000E+00	6.827E+00	5.489E+00	1.246E+02	8.027E+00	4.362E−13
Dy	4.572E+01	2.146E−01	5.037E−02	1.036E+01	6.459E+00	6.456E+00	5.129E+00	1.159E+02	8.630E+00	3.684E−13
Tm	5.039E+01	2.038E−01	4.179E−02	9.928E+00	6.080E+00	6.090E+00	4.801E+00	1.080E+02	9.262E+00	3.369E−13

W	5.883E+01	1.914E−01	3.295E−02	9.733E+00	5.600E+00	5.463E+00	4.241E+00	9.467E+01	1.056E+01	3.101E−13
Pt	6.620E+01	1.844E−01	2.889E−02	1.006E+01	5.451E+00	4.957E+00	3.807E+00	8.447E+01	1.184E+01	3.060E−13
Au	6.813E+01	1.830E−01	2.816E−02	1.029E+01	5.491E+00	4.810E+00	3.684E+00	8.164E+01	1.225E+01	3.070E−13
Hg	7.011E+01	1.816E−01	2.752E−02	1.043E+01	5.494E+00	4.698E+00	3.589E+00	7.945E+01	1.259E+01	3.087E−13
Pb	7.416E+01	1.790E−01	2.648E−02	1.090E+01	5.618E+00	4.449E+00	3.383E+00	7.470E+01	1.339E+01	3.142E−13
Bi	7.625E+01	1.779E−01	2.607E−02	1.114E+01	5.695E+00	4.336E+00	3.291E+00	7.255E+01	1.378E+01	3.180E−13
Po	7.838E+01	1.767E−01	2.572E−02	1.147E+01	5.825E+00	4.212E+00	3.190E+00	7.023E+01	1.424E+01	3.225E−13
Ra	8.765E+01	1.723E−01	2.484E−02	1.291E+01	6.521E+00	3.767E+00	2.829E+00	6.198E+01	1.613E+01	3.484E−13
U	9.700E+01	1.685E−01	2.469E−02	1.463E+01	7.562E+00	3.397E+00	2.533E+00	5.521E+01	1.811E+01	3.832E−13
Am	1.042E+02	1.658E−01	2.489E−02	1.611E+01	8.606E+00	3.152E+00	2.338E+00	5.081E+01	1.968E+01	4.150E−13

TABLE 2b

X-RAYS: TRACK-AVERAGES OVER THE PATH OF THE PRIMARY ELECTRONS GENERATED PER UNIT SOURCE STRENGTH OF CHARACTERISTIC X-RAYS. THE RESULTS ARE FREQUENCY-WEIGHTED FOR THE ELECTRON SPECTRA

(1) Element	(2) E_X keV	(3) E_p keV	(4) $^{W}L_T$ keV/µm	(5) $^{W}L_D$ keV/µm	(6) $^{W}V_{\infty}$	(7) $^{W}L_{100,T}$ keV/µm	(8) $^{W}L_{100,D}$ keV/µm	(9) $^{W}V_{100}$	(10) $^{W}I_T$ µm	(11) $^{W}\lambda_T$ nm
C	2.770E−01	1.292E−01	2.208E+01	2.296E+01	4.001E−02	2.206E+01	2.294E+01	4.021E−02	4.898E+02	2.041E+00
N	3.920E−01	1.940E−01	2.119E+01	2.191E+01	3.400E−02	2.096E+01	2.174E+01	3.710E−02	4.764E+02	2.099E+00
O	5.250E−01	2.702E−01	2.003E+01	2.074E+01	3.535E−02	1.942E+01	2.032E+01	4.659E−02	4.453E+02	2.246E+00
F	6.770E−01	6.018E−02	2.186E+01	2.345E+01	7.292E−02	2.186E+01	2.345E+01	7.292E−02	4.229E+02	2.365E+00
Ne	8.490E−01	1.531E−01	2.178E+01	2.258E+01	3.651E−02	2.171E+01	2.252E+01	3.731E−02	4.879E+02	2.050E+00