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Edited with Commentaries by Tatsuo Tabata
Foreword by John H. Hubbell

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Abstracts of Selected Papers Published by Tatsuo Tabata and His Coworkers
Volume 2: 1981–1998
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To Teiko

We are nothing without the work of others our predecessors, others our teachers, others our contemporaries.

J. Robert Oppenheimer, *Uncommon Sense* (Birkhäuser, 1984)

Contents

Commentary and Erratum, when available, are placed next to the abstract page of a paper. Their availability is indicated by the symbols C (for Commentary) and E (for Erratum) in the parentheses after the titles in the following list.

Foreword

(Written for "Selected Papers of Tatsuo Tabata and His Coworkers")

IT is my pleasure and an honor to introduce this impressive second volume of useful and scholarly works by researchers at the Research Institute for Advanced Science and Technology, Osaka Prefecture University, and other institutions under the direction and collaboration of Professor Tatsuo Tabata, on the interactions of radiation with matter. This collection of papers published in the period 1981–1998 is a sequel to those published in the period 1959–1980 in Volume 1 of this series. Although some important measurements are reported in this collection, the main focus is on the development and exploitation of new theoretical methods, and on the construction of semi-empirical formulas and other means to facilitate practical applications of these useful results.

The first section of this collection focuses on the passage of fast electrons through matter, including algorithms and analytical fits to Monte Carlo results, for electron depth–dose distributions in multilayer slabs as well as in water. Besides forward penetration and energy deposition, the authors treat the backscattering, or the albedo, of both electrons and photons under electron bombardment, over the broad energy range of from 0.1 to 100 MeV. Included in this section are useful treatments of detour factors, and their use for range and depth scaling in water, plastic phantoms, and in other condensed materials.

The second section presents discussions and data on the interaction of ions with solids, with emphasis on the backscattering of light ions, generally in the keV energy range, from elemental and compound solid targets. Empirical formulas and universal relations are developed and presented, to facilitate application to practical problems.

The third section is a cluster of papers on the measurement and use of radiations, particularly on electron beam dosimetry for processing. Included in this group of papers is work on the nondestructive detection of small voids and other anomalies using transmission electron spectrometry. Dye film electron dosimetry is also included in the topics in this section, with some results on the perturbation of the dose field from insertion of the film in a solid medium.

The fourth section is comprised of three papers presenting original semiempirical information on atomic and molecular collisions. The topics of these papers include collision charge-transfer cross sections for hydrogen atoms and ions in metal vapors, a semiempirical formula for single-electron-capture cross sections of multiply-charged ions, and scaling cross sections for the ionization of H, H_2 and He by multiply-charged ions.

The fifth and sixth sections of this collection consist of one paper each, on (V) effects of radiations, in particular the effect of high gamma doses on the thermal properties of muscovite mica, with applications to dosimetry, and on (VI) nuclear physics, in particular the cross section for the reaction $^{9}Be(\gamma, n)$ near threshold.

One appendix consists of a paper in Japanese, a review paper on the stopping power of matter for electrons below 10 keV. In addition to this and all the other above papers published in refereed journals, a second appendix is included consisting of five papers appearing in internal publications of Osaka Prefecture and Nagoya Universities. The topics covered in these papers include backscatter of ions, electrons and photons, depth–dose curves of electrons in matter, linac electron-beam measurements, and theoretical evaluation of absorbed doses in materials irradiated by low-energy electron beams.

Taken together with those in Volume 1 (1959–1980), this Volume 2 (1981–1998) collection of papers by Professor Tatsuo Tabata and his colleagues is a valuable, scholarly and practical resource for both the experienced researcher and the advanced student in radiation physics, particularly in electron irradiation physics which is the main thrust of the collection.

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November 1998

I The Passage of Fast Electrons through Matter

An accurate theoretical treatment of the penetration of electrons through thick foils is made very complicated by the combination of multiple scattering and energy loss.

H. A. Bethe and J. Ashkin, "Passage of Radiations through Matter" in *Experimental Nuclear Physics*, edited by E. Segrè, Vol. 1 (Wiley & Sons, New York, 1953) p. 166

Paper 1

An algorithm for electron depth–dose distributions in multilayer slab absorbers

T. Tabata and R. Ito

Jpn. J. Appl. Phys. ***20****, 249–58 (1981)*

Abstract

An algorithm to evaluate depth–dose distributions produced by plane-parallel electron beams incident on two- or three-layer slab absorbers has been developed. It is based on a simple model of electron penetration across the interface, and makes use of empirical equations previously formulated as well as ones newly developed. Distributions obtained by the algorithm have been compared with available experimental and Monte Carlo results for electrons of incident energies from 0.1 to 10 MeV, showing good agreement in most cases. The algorithm is considered to be valid for incident energies from 0.1 to 20 MeV and for absorbers consisting of slabs of atomic numbers from about 5.6 (polystyrene) to 82.

Commentary

IN 1979 Tabata visited National Bureau of Standards in U. S. A. (presently National Institute of Standards and Technology). He talked about this work with Lewis Spencer, the author of prestigious publications[1,2] on an electron-transport theory. After listening to the basic idea of the work, Spencer said, "The matter is not so simple." Being shown the graphs of results, however, he was silent, possibly wondering about the unexpected working of the simple method proposed in this paper.

The FORTRAN code for the algorithm described in this paper is called EDMULT, which is an acronym of Energy Deposition in MULTilayer absorbers. The work related to version 5 of this code was published.[3] Version 6.3 of the code[4] is available from Radiation Safety Information Computational Center, Oak Ridge National Laboratory. Papers related to this version also appeared.[5]

In 1996 Tabata visited one of his senior friends, Takeo Ueno, at Shizuoka University. In his junior high school days, the former rented a room in the latter's house, and they studied at the same senior high school. Interestingly Ueno's doctoral thesis was related to depolymerization of cellulose by electron beam irradiation and its application to measurements of absorbed-dose distributions including cases with various metal backscatterers for effective irradiation.[6] Prediction of the results of such measurements was just one of the purposes of developing EDMULT by Tabata and Ito.

Erratum

In the last row of Table I on page 253, the second number 7 9 should read 7.9.

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[1] L. V. Spencer, Phys. Rev. **98**, 1597 (1955).

[2] L. V. Spencer, *Energy Dissipation by Fast Electrons*, NBS Monograph 1, National Bureau of Standards, U. S. A. (1959).

[3] Paper 29 in this volume. In this paper the code used is named ED510, and is equivalent to version 5.10 of EDMULT.

[4] RSICC, *EDMULT 6.3: Electron Depth–Dose Distributions in Multilayer Slab Absorbers*, Computer Code Collection CCC-430, Radiation Shielding Information Center, Oak Ridge Natl. Lab. (in preparation).

[5] Papers 26 and 27 in this volume.

[6] R. Inamura, T. Ueno and K. Murakami, Bull. Inst. Chem. Res. Kyoto Univ. **50**, 51 (1972).

Paper 2

Review of the work at the Radiation Center of Osaka Prefecture on the passage of electrons through matter
T. Tabata
Acta Radiol. Suppl. 364, 21–4 (1983)

Abstract

During the past twenty years problems concerning the passage of electrons through matter have been investigated at the Radiation Center of Osaka Prefecture (RCOP). In the beginning the work was experimental, later mostly computational. In the present review the main experimental and computational results are described.

Commentary

THE supplement issue of the *Acta Radiologica* in which this paper was published was devoted to the Proceedings of a Conference on Computed Electron Beam Dose Planning held at the Department of Radiation Physics, Karolinska Institute, Stockholm, Sweden, in September 1982. Tabata did not attend the conference, but the paper was read by Kiyomitsu Kawachi of the National Institute of Radiological Sciences, Japan.

A more detailed version of this paper was also published.[1] In one of the notes in that version the authors cited Kawachi's important paper,[2] which was one of the earliest papers that analytically treated the two dimensional depth–dose distributions of electron beams in materials.[3] Quite regrettably, however, the authors missed to include his paper in the list of references.

[1] T. Tabata and R. Ito, *The Passage of Fast Electrons through Matter: The Work at the RCOP and Related Topics*, Radiation Center of Osaka Prefecture Technical Report No. 3 (1983).

[2] K. Kawachi, Phys. Med. Biol., **20**, 571 (1975).

[3] Because of this fact, A. Brahme, the organizer of the conference, told Kawachi, "You have to come, because we are going to discuss *your problem*."

Paper 3

Analytic fits to Monte Carlo calculated depth-dose curves of 1- to 50-MeV electrons in water
T. Tabata, P. Andreo and R. Ito
*Nucl. Instrum. & Methods B **58**, 205–10 (1991)*

Abstract

An analytic expression is given for depth–dose curves of plane-parallel electron beams normally incident on semi-infinite water absorbers with initial energies from 1 to 50 MeV. The expression consists of two terms representing the main component due to collision energy-loss of primary electrons and the component via radiative process. To study the profile of the bremsstrahlung component, Monte-Carlo calculations have been made with the MCEF code. The results show that this component has a maximum around $0.9\,r_0$, where r_0 is the csda (continuous slowing-down approximation) range of electrons in water. Values of the constants in the main term have been determined so as to minimize the deviations of the expression from the depth–dose data calculated with three Monte-Carlo codes (MCEF, EGS4 and ITS). The maximum value of the deviations is from 0.7 to 3.5% of the maximum dose at each energy, and is less than or comparable to the maximum deviations among the different Monte-Carlo results.

Commentary

THE algorithm given in this paper was superseded by a more general one published recently.[1]

Being motivated by the paper of Meigooni and Das,[2] Tabata and Ito started a preliminary study[3] of this work. However, the ETRAN Monte Carlo results[4] used by them to determine the values of adjustable coefficients were known to have errors due to inappropriate treatment of the cutoff parameter for the Landau energy-loss straggling distribution.[5] In 1989 Tabata called on H. Svensson at IAEA and talked with him about this. Then the latter recommended the former to collaborate with Pedro Andreo, who had developed a good Monte Carlo program, MCEF, for solving the problem of electron transport in water.[6] Thus the joint work of Andreo and Tabata began, and continued for many years.

Before starting the preliminary work, Tabata requested Meigooni and Das a reprint of their paper. This led to the friendship between Indra Das and Tabata and to their cooperative work.[7]

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[1] Paper 14 in this volume.

[2] Reference 23 of this paper.

[3] Reference 24 of this paper.

[4] Reference 26 of this paper.

[5] Reference 2 of this paper.

[6] References 4, 6–8 of this paper.

[7] Paper 28 in this volume.

Paper 4

Simple calculation of the electron-backscatter factor
T. Tabata and R. Ito
Med. Phys. ***19****, 1423–6 (1992)*

Abstract

The authors have studied the dependence of the electron backscatter factor (EBF) on mean electron energy and on backscatterer atomic number by using the semiempirical depth–dose code EDMULT. A plane-parallel electron beam is assumed to be normally incident on a polystyrene slab, which is backed with a layer (backscatterer) of different materials of effectively semi-infinite thickness. A small air cavity to measure ionization is embedded in the polystyrene slab at the boundary facing the backscatterer. The EBF is defined as the ratio of the ionization with the backscatterer to the ionization with a full polystyrene medium, and is approximated by the ratio of the doses computed at the depth of the cavity. Values of EBF obtained show trends similar to the experimental data of Klevenhagen et al. [Phys. Med. Biol. **27**, 263-373 (1982)], although the former are generally lower than the latter. When the typical energy spread of clinical electron beams is taken into account, the difference between the experimental and the calculated values is reduced. The present results also show the same trend of increase of the backscatter factor with increasing energy as observed by Klevenhagen et al. in some series of measurements for the lead backscatterer at the lowest energies. This is explained by the rapid buildup of the dose with depth for electrons of low initial energies incident on the full polystyrene medium.

Commentary

IN this paper the authors explained the reason for the strange trend of increase of the backscatter factor with increasing energy as observed by Stanley Klevenhagen et al.[1] The trend happened in some series of measurements for the lead backscatterer at the lowest energies.

Browsing Klevenhagen's book[2] in 1986, Tabata wrote the author as follows:

> At one point I feel pity for your book and for its readers. You have made no mention of our important contributions to the interactions of electrons with matter.

Klevenhagen wrote back:

> Thank you very much for your letter of 28th June and for copies of your publications. I only had a very short look at your publications and I find them of great interest to me. I am currently working on a review of my book and I will encorporated [sic] your work in a new edition of the book.

When Tabata visited London in 1989, Klevenhagen was very kind to him.

Hearing the death of Klevenhagen, Tabata et al. wrote at the end of one of their papers[3]:

> The authors dedicate this paper to the late Dr. Stanley C. Klevenhagen, former Director of the Department of Medical Physics, The Royal London Hospital, and Professor at the University of London. After many years of research in physics against cancer he died of a brain tumor on October 29, 1996. He made substantial contributions to electron-beam physics and its medical applications, and is known as the author of the books, "Physics of Electron Beam Therapy" and "Physics and Dosimetry of Therapy Electron Beams."

The latter book[4] is the one Klevenhagen called "the new edition" in his first letter to Tabata, and it surely cited some of publications by Tabata and his coworkers.

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[1] Reference 2 of this paper.

[2] S. C. Klevenhagen, *Physics of electron beam therapy*, Medical Physics Handbooks, Vol. 13 (Adam Hilger, Bristol, 1985).

[3] T. Tabata, P. Andreo and K. Shinoda, Bull. Osaka Pref. Univ. A, **45**, 99 (1996).

[4] S. C. Klevenhagen, "Physics and Dosimetry of Therapy Electron Beams" (Medical Physics Publishing, Madison, Wisconsin, 1993).

In January 1997 a remembrance service for Klevenhagen was held at the Royal London Hospital Chapel. The program included the song of Beatles, “Yesterday,” which he had possibly liked very much.

Paper 5

Reflection of electrons and photons from solids bombarded by 0.1- to 100-MeV electrons

R. Ito, P. Andreo and T. Tabata

Radiat. Phys. Chem. ***42****, 761–4 (1993)*

Abstract

Electron and photon reflection ratios (in number and energy) for absorbers bombarded by electrons have been computed with the ITS Monte Carlo system version 3. Electrons of energies from 0.1 to 100 MeV have been assumed normally incident on an effectively semi-infinite absorber. The absorbers considered are elemental solids of atomic numbers from 4 to 92. The data on the electron reflection ratios agree rather well with the experimental data collected from literature except some discrepancies when the number-reflection ratio is small. For photons, the number-reflection ratio increases with increasing energy, but the energy-reflection ratio shows a maximum around 10 MeV. Empirical equations for the electron reflection ratios and the photon energy-reflection ratio are given (for electrons, graphs only).

Commentary

THIS paper was presented at the 8th International Meeting on Radiation Processing held in Beijing in 1992. Because of the limitation to the number of pages available, an empirical equation for the electron number-reflection ratio (number-backscattering coefficient) was given only graphically. The equation was published elsewhere[1] and was cited in Appendix of a later paper.[2] It supersedes the one published earlier.[3]

[1] Paper 37 in this volume.
[2] Paper 16 in this volume.
[3] Reference of this paper: T. Tabata et al. (1972) [paper 7 in Vol. 1 of this series].

Paper 6

Energy-deposition distributions in materials irradiated by plane-parallel electron beams with energies between 0.1 and 100 MeV
T. Tabata, P. Andreo and R. Ito
At. Data & Nucl. Data Tables ***56****, 105–31 (1994)*

Abstract

Tables of energy-deposition distributions in absorbers irradiated by plane-parallel electron beams with incident energies between 0.1 and 100 MeV are presented. The absorbers considered are elemental materials with atomic numbers between 4 and 92 (Be, C, Al, Cu, Ag, Au and U) and compound and mixture materials of interest in health physics (tissue-equivalent plastic A150, air, air-equivalent plastic C552, polymethylmethacrylate, water, and “solid water” WT1). The distributions have been computed by using the ITS Monte Carlo system version 3 to simulate 10^5 primary-electron histories and subsequent electron and photon generations. The transport of all generations of electrons has been followed down to a cut-off energy, which is the smaller of 0.5 MeV and 5% of the incident-electron energy; photon transport has been simulated down to 10 keV. Tabulated values have been obtained by applying numerical smoothing to the direct Monte Carlo results, and are given in scaled quantities to facilitate interpolation as a function of incident energy and absorber atomic-number. Comparisons with other Monte Carlo calculations and experiments are included.

Commentary

On page 120, two numbers at the top of the ninth column are illegible. They are 20 (for T_0) and 10.59 (for r_0).

An algorithm has been published precisely to interpolate the energy-deposition distributions given in this paper as a function of incident energy (up to 20 MeV) and absorber atomic number.[1]

[1] Paper 14 in this volume.

Paper 7

Energy deposition through radiative processes in absorbers irradiated by electron beams

T. Tabata, P. Andreo, K. Shinoda and R. Ito

Nucl. Instrum. Methods B ***93****, 447–56 (1994)*

Abstract

The component of energy deposition due to radiative processes (bremsstrahlung component) in absorbers irradiated by electron beams has been computed together with the total energy deposition by using the ITS Monte Carlo system version 3.0. Plane-parallel electron beams with energies from 0.1 to 100 MeV have been assumed to be incident normally on the slab absorber, whose thickness is 2.5 times the continuous slowing-down approximation (csda) range of the incident electrons. Absorber materials considered are elemental solids with atomic numbers between 4 and 92 (Be, C, Al, Cu, Ag, Au and U). An analytic formula is given to express the depth profile of the bremsstrahlung component as a function of scaled depth (depth in units of the csda range), incident-electron energy and absorber atomic number. It is also applicable to compounds.

Commentary

IN Equation (6) on page 449, a multiplication factor, $\sqrt{p}/2$, was missing before the second term. This happened because the authors wrongly used a less common definition of the complementary error function without the multiplication factor of $2/\sqrt{p}$ in deriving the form of the normalization factor f. While using Equation (6) as written in this paper, the authors employed the complementary error function given by the common definition in determining the values of adjustable coefficients and in constructing a FORTRAN code EDBREM. This inconsistency, however, scarcely affects the precision of the formula obtained, so far as the bremsstrahlung component $D_b(z; Z, T_0)$ of energy deposition down to the depth $z = 2.4r_0$ is concerned. This is due to the compensation effect of curve fitting. Therefore, it is recommended to use Equation (6) without inserting the missing multiplication factor.

Sorcini et al.[1] also proposed an analytic expression for the bremsstrahlung component of energy deposition. The accuracy of their expression is much worse than the present formula for higher atomic number absorbers.

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[1] B. B. Sorcini, S. Hyödynmaa and A. Brahme, Phys. Med. Biol. **41**, 2657 (1996).

Paper 8

Depth profile of charge deposition by 0.1- to 100-MeV electrons in elemental absorbers

T. Tabata, P. Andreo and R. Ito

Nucl. Instrum. Methods B ***94****, 103–6 (1994)*

Abstract

Charge-deposition distributions in absorbers irradiated by electrons have been computed by using the ITS Monte Carlo system version 3.0. Plane-parallel electron beams with energies from 0.1 to 100 MeV have been assumed to impinge normally on absorbers of effectively semi-infinite thickness. Absorber materials considered are elemental solids with atomic numbers between 4 and 92. Trends displayed by the results are discussed. The results at 10 MeV are compared with experimental data at 11.5 MeV published earlier, showing good agreement. The comparison also reveals that an appreciable discrepancy reported for Be between the experimental data and the result computed with an old version of the ETRAN Monte Carlo code has been resolved by the recent improvement of the energy-loss straggling algorithm used both in ETRAN and ITS.

Commentary

THIS paper pointed out that the discrepancy found between the earlier experimental result of Tabata et al.[1] for the charge-deposition distribution by electrons in Be and the result of an old version of the ETRAN Monte Carlo code was resolved by the improvement of the energy-loss straggling algorithm in the Monte Carlo method.

The authors intended their manuscript to be a contribution to the Letters section of the journal. However, it was somehow treated as a regular paper.

Erratum

In the eighth line of the left column of page 105, "meV" should read "MeV."

[1] Reference 3 of this paper (paper 4 in Vol. 1 of this series).

Paper 9

Depth profiles of charge deposition by electrons in elemental absorbers: Monte Carlo results, experimental benchmarks and derived parameters
T. Tabata, P. Andreo, K. Shinoda and R. Ito
*Nucl. Instrum. Methods B **95**, 289–99 (1995)*

Abstract

Depth profiles of charge deposition in absorbers irradiated by electrons have been computed by using the ITS Monte Carlo system version 3.0. Plane-parallel electron beams with energies from 0.1 to 100 MeV have been assumed to impinge normally on slab absorbers of effectively semi-infinite thickness. Absorber materials considered are elemental solids of atomic numbers between 4 and 92 (Be, C, Al, Cu, Ag, Au and U). To study the accuracy of the Monte Carlo results, benchmarks at the energies of 5, 10 and 20 MeV have been generated by interpolating published experimental results. Extrapolated ranges r_{ex}, most probable depths z_{m} of charge deposition and average depths z_{av} of charge deposition have been determined from both the ITS and interpolated experimental charge-deposition distributions. The depth profiles and derived parameters show good agreement between calculation and experiment, except for small discrepancies for Au absorbers, where the ITS results show a slightly lower penetrability of electrons. The Monte Carlo results of r_{ex} have been compared with the semiempirical formula of Tabata et al. [Nucl. Instr. and Meth. 103 (1972) 85], and some deficiencies of the latter, due to the lack of data used in determining adjustable coefficients of the formula, have been found. The use of the ratio of the continuous slowing-down approximation range r_0 to z_{av} as an estimate of multiple scattering detours is discussed.

Commentary

IN this work not only the Monte Carlo results for the charge-deposition distribution by electrons were analyzed in detail, but also earlier experimental data[1] were interpolated and analyzed to give good benchmarks. The results of analysis indicated possible small discrepancies between the Monte Carlo and experimental results for Au absorbers.

The reviewer of this paper commented:

> This is a good report on the reliability of charge deposition, results of interest to the readership of this journal. The text is well written, clear and concise. The only quibble I would have is that I would prefer consideration of the quantity z_{av}/r_0, rather than of its reciprocal, in Fig. 8 and the corresponding discussion in the text. This, however, is a very minor point, and one that I will leave to the discretion of the authors.

With respect to the reviewer's preference of z_{av}/r_0, the authors replied to the editor as follows:

> We well understand the reviewer's preference of defining the detour factor as z_{av}/r_0 rather than as its reciprocal. However, we consider that the detour factor defined as r_0/z_{av} is better, because it takes on larger values when the extent of detour is larger. Further, definitions consistent with ours have been used by many authors.

However, Tabata and his coworkers began to use the definition of the detour factor with r_0 as the denominator in later papers except the next one. See also the commentary on the next paper.

[1] Reference 7 of this paper (paper 4 in Vol. 1 of this series).

Paper 10

Range distributions and projected ranges of 0.1- to 100-MeV electrons in elemental absorbers

T. Tabata, P. Andreo, K. Shinoda and R. Ito

Nucl. Instrum. Methods B ***108****, 11–7 (1996)*

Abstract

Range distributions of electrons in elemental solids of atomic numbers between 4 and 92 (Be, C, Al, Cu, Ag, Au and U) have been computed with the ITS Monte Carlo system version 3.0. Incident energies of electrons considered are from 0.1 to 100 MeV. Values of the projected range $r_{\rm pr}$, the relative deviation of $r_{\rm pr}$ from the average depth of charge deposition and the detour factor have been obtained; the last parameter is defined as the ratio of the continuous slowing-down approximation range to $r_{\rm pr}$. Present values of the detour factor are compared with other authors' results as well as the semiempirical equation proposed by Tabata et al. [J. Appl. Phys. 42 (1971) 3361]. Prospective use of the equation in the field of therapeutic electron beams is suggested.

Commentary

THIS paper treats detour factors in addition to range distributions and projected ranges of electrons in elemental absorbers. The definition of the detour factor adopted in this paper is the ratio of the continuous slowing-down approximation range to the projected range. This definition dates back to the 1938 paper of Hans Bethe et al.[1] However, the reciprocal of the above definition is adopted these days.[2] We follow the newer definition in our later papers.[3]

The reviewer of this paper recommended to the authors that they should combine Figures 1–3 and the rest of the data into a three-dimensional plot and that then they should show two-dimensional cross sections to describe the physics. The authors replied that a "four-dimensional plot" was necessary to draw the dependence of range distribution as a function of depth, energy and atomic number in a single figure.

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[1] Reference 2 of this paper.

[2] Reference 1 of this paper.

[3] Papers 12, 13 and 15 in this volume.

Paper 11

An analytic formula for the extrapolated range of electrons in condensed materials

T. Tabata, P. Andreo and K. Shinoda

Nucl. Instrum. Methods B ***119****, 463–70 (1996)*

Abstract

A single analytic formula for the extrapolated range r_{ex} of electrons in condensed materials of atomic numbers from 4 to 92 is given. It has the form of the product of the continuous-slowing-down approximation (CSDA) range r_0 and a factor f_d related to multiple scattering detours. The factor f_d is expressed as a function of incident electron energy T_0 and atomic number Z of medium. Values of adjustable parameters in f_d have been optimized for data on the ratio r_{ex}/r_0, in which the Monte-Carlo evaluated values of Tabata et al. [Nucl. Instr. Meth. B 95 (1995) 289] (from 0.1 to 100 MeV) and experimental data collected from literature (from 1 keV to 0.1 MeV) for r_{ex} have been used together with NIST-database values of r_0. For r_0 in the extrapolated-range formula, accurate database values or an approximate analytic expression developed as a function of T_0, Z, atomic weight A and mean excitation energy I of medium can be used. The maximum deviation of the resultant formula from the Monte Carlo data is about 2% for either option of r_0. The determination of the expression for f_d at energies below 0.1 MeV is tentative. By using an effective atomic number and atomic weight, the formula can also be applied to light compounds and mixtures.

Commentary

THE formula for the extrapolated range of electrons given in this paper supersedes the previous formula by Tabata et al.[1] at least in the energy region above 0.1 MeV.

[1] Reference 5 of this paper (paper 9 in Vol. 1 of this series).

Paper 12

Detour factors in water and plastic phantoms and their use for range and depth scaling in electron-beam dosimetry
J. M. Fernández-Varea, P. Andreo and T. Tabata
Phys. Med. Biol. ***41****, 1119–39 (1996)*

Abstract

Average penetration depths and detour factors of 1–50 MeV electrons in water and plastic materials have been computed by means of analytical calculation, within the continuous-slowing-down approximation and including multiple scattering, and using the Monte Carlo codes ITS and PENELOPE. Results are compared to detour factors from alternative definitions previously proposed in the literature. Different procedures used in low-energy electron-beam dosimetry to convert ranges and depths measured in plastic phantoms into water-equivalent ranges and depths are analyzed. A new simple and accurate scaling method, based on Monte Carlo-derived ratios of average electron penetration depths and thus incorporating the effect of multiple scattering, is presented. A study of scaled depth–dose curves and mean energies as a function of depth for some plastics of common usage shows that the method improves the consistency and results of other scaling procedures in dosimetry with electron beams at therapeutic energies.

Commentary

THIS work was motivated by the earlier work by Tabata, Andreo et al.[1] The first author, Jose Maria Fernández-Varea, is a brilliant youth who came from Barcelona to Stockholm to work under Andreo and was one of the authors of the Monte Carlo code, PENELOPE,[2] for the penetration of electrons and positrons through matter. Tabata thought PENELOPE to be the name of the author of a code when he found it for the first time in the figure attached to Pedro Andreo's letter.

In 1995 Tabata attended an international workshop held in Seattle. On this occasion he was invited to Philadelphia by Indra Das, and gave a talk on part of this work at a meeting of the Delaware Valley Chapter of the American Association of Physicists in Medicine. The organizer of the meeting by the name of Saiful Huq asked some keen questions about the talk. On returning Osaka, Tabata found that Huq was one of the authors of the just-published article[3], which treated the problem closely related to this work, i.e., an evaluation of the recommendations of the TG-25 protocol[4] for determination of depth–dose curves for electron beams by ionization chambers.

The two reviewers of this paper reported:

> This paper reports on a new method of determining detour factors and compares the use of these factors in the scaling of electron ranges with other scaling methods. The paper is extremely well written, well organized and has the right level of detail. There are no significant changes that I would recommend, . . .

> This is an excellent paper and should be accepted for publication in its present form. Many recommendations for the conversion of ranges of low energy electrons in plastic material to equivalent values in water given in dosimetry protocols have been evaluated by using two Monte Carlo codes. The strengths and weaknesses of these recommendations have been demonstrated and a new simple method based on Monte Carlo results is suggested. A careful study of this paper should improve the readers' understanding of the topic of detour factors in electron dosimetry.

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[1] References of this paper: Tabata et al. (1995, 1996) (papers 9 and 10 in this volume).

[2] Reference of this paper: Baró et al (1995).

[3] M. S. Huq, A. G. Agostinelli and R. Nath, Med. Phys. **22**, 1333 (1995).

[4] AAPM, American Association of Physicists in Medicine, Task Group No. 25, Radiation Therapy Committee, Med. Phys. **18**, 73 (1991).

This paper was selected as one of two featured articles to be displayed on the Internet home page of *Physics in Medicine and Biology* from October 1996 to June 1997.

Paper 13

A method to convert absolute depth–dose curves of electrons between different phantom materials

T. Tabata and P. Andreo

Jpn. J. Med. Phys. ***17****, 151–60 (1997)*

Abstract

A method to convert absolute depth–dose curves of electron beams obtained in plastic phantoms to distributions in another phantom material is proposed. The procedure has been verified by using depth–dose distributions for plane-parallel beams calculated by the Monte Carlo method. Results better than other scaling methods have been obtained along the complete depth–dose curve for incident energies between 5 and 20 MeV.

Commentary

PEDRO Andreo asked Tabata some questions by e-mail when the latter sent the first draft of this paper to the former. To most of Tabata's reply, Andreo wrote, "I don't understand this." Being quite perplexed, Tabata revised the manuscript in a style understandable even to undergraduate students. Then Andreo wrote, "It looks clear now, almost too clear for a scientific paper," and made a further revision to make it a paper with moderate clarity.

Erratum

The following errors have been found:

(i) In Figure 5 (a) on page 158, the legend, "20 MeV" should read "25 MeV."

(ii) In the last line of page 159, "Fernándes-Varea" should read "Fernández-Varea."

Paper 14

An algorithm for depth–dose curves of electrons fitted to Monte Carlo data

T. Tabata, P. Andreo and K. Shinoda

Radiat. Phys. Chem. ***53****, 205–15 (1998)*

Abstract

An accurate algorithm has been developed for the depth profiles of energy deposition by plane-parallel electron beams normally incident on semi-infinite absorbers. The energies of electrons considered are from 0.1 to 20 MeV, and the absorbers considered are elemental materials of atomic numbers between 4 and 92. Adjustable coefficients in the algorithm have been determined so as to minimize its deviations from the Monte Carlo data published by Tabata et al. (1994). The algorithm is also applicable to light compounds and mixtures.

Commentary

THE issue of *Radiation Physics and Chemistry* in which this paper appeared is a special issue for radiation transport theory and contains papers based on the presentations on the "2nd International Workshop on Electron and Photon Transport Theory Applied to Dose Calculation (IWEPT), " held in Seattle, June 1997 and the "$E=mc^2$ Meeting: Monte Carlo in Monte Carlo," held in Monaco, September 1997.

Tabata gave a talk on the preliminary result of this work together with its historical background at the 1st IWEPT held in Seattle, September 1995. He cited a joke on a physicist: A physicist, among the specialists called in as a consultant to a dairy farm to increase its production, began, "Assume the cow is a sphere . . ." Then he likened the principle underlying the semiempirical method of evaluating the energy-deposition distribution of electrons to this physicist's simple assumption.

The above joke became popular among the participants of the 1st IWEPT, and joking became one of the features of this series of workshop. In one of e-mail messages to the participants of the 2nd IWEPT, Edward Larsen, one of the organizers, appended the following joke, which was a twice-modified version of a joke intermediated by another organizer, Alex Bielajew:

> Two women are walking down a street and they meet this frog. The frog says, "Hey, stop." They stop. The frog says, "An evil fairy put a spell on me and turned me into a frog. If you kiss me, I shall turn back into a transport theorist." One of the women picks up the frog, puts it in her purse, and starts to walk off. The other woman asks, "Hey, aren't you going to kiss it and turn it back into a transport theorist?" The first woman replies, "Are you kidding? A talking frog is worth much more than a transport theorist!"

Following this story, Tabata gave an appendix to his talk at the 2nd IWEPT:

> (Pointing a caricature of Tabata on the viewgraph) This is I in the present state and says, "I'm a young transport experimentalist turned into a semi-old transport semi-empiricist. If a young lady kiss me, I shall . . ." Then this frog asks, "Which was the evil fairy for you, this Workshop, the EDMULT code or Time?" The answer should be a weighted average of the three.

Erratum

In line 6 in the left column of page 212, Z should read $\overline{Z}$.

Paper 15

Semiempirical formulas for the detour factors of 1- to 50-MeV electrons in condensed materials

T. Tabata and P. Andreo

Radiat. Phys. Chem. ***53****, 353–60 (1998)*

Abstract

Two semiempirical formulas for the detour factor, defined as the ratio of the average penetration depth to the continuous slowing-down approximation range, have been developed for electrons of energies from 1 to 50 MeV. One of them is of simpler form and is applicable to absorbers consisting of light compounds or mixtures (phantom materials) with mean atomic numbers between 4.75 (polyethylene) and 6.61 ("plastic water"), thus being useful for obtaining scaling factors in medical electron-beam dosimetry. Though being less precise, the other is applicable to condensed materials of atomic numbers between 4 and 92.

Commentary

THE formulas for the detour factors of electrons given in this paper supersede those given in earlier papers.[1]

The dates of receiving and accepting of this paper is missing due to the error in publication processes. This is quite an unacceptable error for the journal to be prestigious. In his e-mail message to John Hubbell, one of Editors-in-Chief of the journal, Tabata likened this paper to a gentleman who had come to an official place without a necktie.

[1] The following references in this paper: Tabata, 1968; Tabata et al. 1971b; Tabata et al. 1996a; Fernández-Varea et al. 1996 (papers 2 and 5 in Vol. 1 of this series; papers 10 and 12 in this volume).

Paper 16

Average depths of electron penetration: Use as characteristic depths of exposure

V. Lazurik, V. Moskvin and T. Tabata

IEEE Transactions on Nuclear Science ***45***, *626–631 (1998)*

Abstract

The average depth of electron penetration is introduced as the physical quantity useful in electron beam irradiation. It is defined as the average of the maximum depth on the trajectories of electrons passing through finite, semi-infinite or infinite medium. The relation between the transmission coefficient as a function of slab thickness and the distribution of the maximum depths is analyzed, and a semiempirical equation to calculate the average depth of electron penetration is given for 0.1- to 50-MeV electrons incident on materials of atomic numbers from 4 to 92. It is shown that the quantity introduced is usable as the characteristic depths of the energy and charge depositions in a target and can be generalized to the case of heterogeneous targets.

Commentary

IN April 1994 Tabata received a letter from Vadim Moskvin, then a graduate student under Valentin Lazurik at the Physical Technical Department, Kharkov State University, in Ukraine. The letter began with flattering words, “Your name and works are well known in our country,” and Moskvin asked Tabata an advice for making a universal phenomenological expression for the charge-deposition distribution produced by electrons in matter. Thus the cooperative work between Lazurik’s group and Tabata started.

The average depth of electron penetration is defined in this paper as the average of the maximum depths on the trajectories of electrons passing through finite, semi-infinite or infinite medium. Note that this is different from the “average penetration depth of electrons” (also called projected range) used commonly. The latter is defined as the average depth of the endpoints of electron trajectories.

Paper 17

Fractional energies of backscattered electrons and photon yields by electrons

T. Tabata, P. Andreo and K. Shinoda

Radiat. Phys. Chem. ***54*** *, 11 (1999)*

Abstract

Fractional energies f_{BE} of backscattered electrons and the photon yields Y from semi-infinite absorbers bombarded by electrons have been calculated with the ITS Monte Carlo system, and analytic expressions have been formulated for these parameters. Besides the Monte Carlo results, experimental data collected from the literature have been used to determine the expression for f_{BE}. The two expressions are applicable to absorbers of atomic numbers from 4 to 92. The region of incident-electron energy considered is from 5 keV to 100 MeV for f_{BE}, and from 0.1 to 100 MeV for Y.

Commentary

THIS paper was accepted for publication in *Radiation Physics and Chemistry* (RPC) on September 6, 1997, which was earlier than the dates of acceptance of other two papers published in the same journal. However, the former was strangely published much later than the latter two, after 16 months from its acceptance (volume 54, No. 1; January issue of 1999). John Hubbell, one of the editor-in-chief of the journal, says that such a delay is not unusual in RPC.

II Interaction of Ions with Solids

Furthermore [Grand Unified Theory] emphasizes that the asymmetry of today is a result of the breaking of symmetry, and this reminds us of a truth in aesthetics,

symmetry + defect = beauty.

Fang Li Zhi and Li Shu Xian, *Creation of the Universe* (World Scientific, Singapore, 1989)

Paper 18

Empirical formulas for the backscattering of light ions from solids
T. Tabata, R. Ito, K. Morita and Y. Itikawa
Jpn. J. Appl. Phys. ***20****, 1929–37 (1981)*

Abstract

Empirical formulas have been developed for the backscattering of H, D and He ions normally incident on solid targets. The parameters considered are the number-backscattering coefficient R_N, the energy-backscattering coefficient R_E and the mean fractional energy r_E of backscattered particles (ions and neutrals). The formulation utilizes the fact that the scaling law predicted earlier for R_N and R_E as a function of the Thomas-Fermi reduced energy ε is improved when these parameters are multiplied by S_t/S_e^{LSS}. Here S_t is the total stopping power, and S_e^{LSS} is the electronic stopping power given by the LSS theory when the projectiles are much lighter than the target atoms. The formulas obtained are valid for ε between 10^{-3} and 10^2.

Commentary

THIS work was done as part of the joint program of data compilation at the Research Information Center, Institute of Plasma Physics, Nagoya University, to aid thermonuclear fusion research. Tabata got a motivation for this work by attending the VIII International Conference on Atomic Collisions in Solids held in Hamilton, Canada, in 1979. Soon after they started the formulation of empirical equations for the backscattering coefficients of hydrogen ions, Tabata and Ito were invited to join the above program.

Other four papers in this section are also the products of the joint program. The experimental and computer simulation data compiled of the backscattering coefficients of H, D and He ions for solids were published in a separate paper.[1] The latest stage of the continued work for the joint program was reviewed by Tabata and Ito.[2]

Mamoru Mohri, who was then at Hokkaido University, requested Tabata a reprint of this paper. It was just after the former was accepted for the position of the first Japanese astronaut in NASA space projects. Tabata sent a short message of congratulations together with a reprint.

Erratum

The following typographical errors have been found.

(i) In the eighth line from bottom of the text in the right column of page 1929, “elemtnts” should read “elements.”

(ii) In Equation (8) on page 1931, $\left(Z_1^{2/3} + Z_2^{2/3}\right)$ should read $\left(Z_1^{2/3} + Z_2^{2/3}\right)^{1/2}$. This error is only typographical, and the formulation and the evaluation of the empirical formulas were made with the correct relation.[3]

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[1] T. Tabata, R. Ito, Y. Itikawa, N. Itoh and K. Morita, At. Data & Nucl. Data Tables **28**, 493 (1983).

[2] Paper 36 in this volume.

[3] The same typographical error was inherited by the next publication of Tabata et al.: Equation (A2) on page 496 of the reference given as footnote 1 above.

Paper 19

Reflection of keV light ions from compound targets
K. Morita and T. Tabata
J. Appl. Phys. ***55****, 776–80 (1984)*

Abstract

The particle and energy reflection coefficients and the energy distribution of reflected particles for compound targets have been calculated using the single collision approximation. It is shown that for any compound target the reflection coefficients are expressed in terms of a universal function such as was empirically determined for elemental targets, when the Bragg rule is assumed for the stopping cross section. The results calculated numerically for WO_3 TiC, and TiB_2 are compared with the experimental ones to show reasonable agreement.

Paper 20

Universal relations for reflection of keV light ions from solid targets
K. Morita, T. Tabata and R. Ito
J. Nucl. Mater. ***128 & 129****, 681–6 (1984)*

Abstract

By using the single collision approximation (SCA), universal relations including the dependence on the projectile have been derived for the particle- and energy-reflection coefficients of light ions normally incident on elemental targets with energies in the keV region. Expressions for the reflection coefficients for compound or alloy targets have also been obtained in terms of the universal functions in these relations. To confirm the universal relations to a higher approximation, a numerical calculation has been made on the basis of the modified version of SCA, in which multiple collisions of incident and scattered ions have been taken into account. The calculated values of the particle-reflection coefficient of H, D, T and He ions impinging on C, Ti, W and Au targets, when scaled by the universal relations, lie well on a single curve as a function of the Thomas-Fermi reduced energy of the incident ions. Universal semi-empirical formulas for the reflection coefficients have been obtained by applying the new scaling law to the experimental data compiled.

Paper 21

Empirical formulas for the backscattering coefficients of light ions obliquely incident on solids

T. Tabata, R. Ito, K. Morita and H. Tawara

Radiat. Eff. ***84****, 45–56 (1985)*

Abstract

The dependence on the angle of incidence θ pf the number-backscattering coefficient R_{N} and the energy-backscattering coefficient R_{E} of H, D and He ions has been found to be fitted by the expression $R(\theta) = R(0) + [1 - R(0)]/(1 + A_1 \cot^{2A_2} \theta)$, where R represents R_{N} or R_{E} and the parameters A_i $(i = 1, 2)$ are functions only of the Thomas-Fermi reduced energy ε. By using the semiempirical formulas of Tabata *et al*. for $R(0)$, universal formulas for $R(\theta)$ have been obtained. These formulas are valid for all the mass regions of the target atom and for ε between 2×10^{-2} and 10.

Commentary

THE referee's report cited below would be a good introduction to this paper.

> This paper presents analytical formulas for the fitting of experimental results, both laboratory and computational (i.e., simulation, typically Monte Carlo). The object is to provide estimates of number and energy reflection coefficients for the case of light ions from solid targets. As stated in the introduction by the authors, such formulas are of direct application in the modeling of plasma-wall interactions in thermonuclear fusion devices. Furthermore this area of research is of fundamental interest, because the nature of the collision processes means that normal cascade processes are no longer dominant. The paper represents in a sense a generalization of the author's previous work on light ions for the case of normal particle incidence. The paper appears on the whole well written, and in my opinion should be published in *Radiation Effects* subject to a few corrections.

Paper 22

Unified empirical formulas for the back-scattering coefficient of light ions

T. Tabata, R. Ito, K. Morita and H. Tawara

Nucl. Instrum. Methods ***B9****, 113-22 (1985)*

Abstract

Empirical formulas for the number- and energy-backscattering coefficients of light ions normally incident on elemental solid targets are given. The formulas are valid for all the light ions of atomic numbers up to two with incident energies from about 10 eV to 100 MeV. Constants in the formulas have been determined by the least-squares fit to available experimental and selected computer-simulation data. The rms deviation of the data from the formulas is 31%.

Commentary

PREVIOUSLY the authors published the papers entitled "*Empirical formulas* for the backscattering of light ions from solids" and "*Universal relations* for reflection of keV light ions from solid targets"; and the title of this paper is "*Unified empirical formulas* for the backscattering coefficient of light ions." Tabata often said to his colleagues, "The title of our next paper should be *Grand unified empirical formulas* . . ."

At the International Conference on Atomic Collision in Solids held in 1987 in Okayama, Tabata saw Jens Lindhard of the Lindhard-Scharff-Schiøtt (LSS) theory. The former told the latter how the LSS theory was useful for empirical formulas for the backscattering of light ions. Tabata also asked Lindhard to tell him one of anecdotes of Niels Bohr. Lindhard told a short story: Bohr used to say, "Philosophers did nothing, but I did a great thing." On hearing this story from Tabata, one of his colleagues responded, "Bohr was not a great man after all!" Bohr's saying was so compact that he was unable to understand that Bohr had not boasted about his own work but had meant the big unexpected effect of quantum mechanics on philosophy. —Lindhard died on 15 October 1997 after a normal day at the Institute of Physics, Aarhus University, in Denmark, where he had worked for the last 40 years.[1]

[1] J. U. Andersen and P. Sigmund, Phys. Today **51**, No. 9, 89 (1998).

III The Measurement and Use of Radiation

If the lives of scientists are on the whole joyful, it is because our friendships are deep and lasting. Our friendships are lasting because we are engaged in a collective enterprise. Our enterprise, the exploration of nature's secrets, had no beginning and will have no end.

Freeman Dyson, *From Eros to Gaia* (Pantheon Books, New York, 1992)

Paper 23

Influence of a dye film dosimeter inserted in a solid on electron behaviors and dosimetry

S. Okuda, K. Fukuda, T. Tabata and S. Okabe

Nucl. Instrum. Methods ***200****, 443–7 (1982)*

Abstract

The depth–dose distribution in aluminum irradiated with a 15 MeV electron beam has been measured by inserting a dye film dosimeter in parallel with the beam. The distribution near the irradiated surface has shown a profile theoretically unexpected. The cause of this erroneous profile has been studied and attributed to the streaming of the incident electrons through air gaps formed between the film and the medium. The effect has been found to be suppressed by the increase of the angle between the film and the electron beam.

Commentary

THIS work clarified the effect of electron-beam streaming on the measurement of depth–dose curves with film dosimeters inserted in material in parallel to the electron beam. Klevenhagen cited this paper in his book in detail.[1]

[1] S. C. Klevenhagen, "Physics and Dosimetry of Therapy Electron Beams" (Medical Physics Publishing, Madison, Wisconsin, 1993).

Paper 24

Dosimetry and processing anomalies due to heterogeneties of materials irradiated with high-energy electrons

S. Okuda, S. Nakamura, T. Tabata, K. Fukuda, T. Seiyama and S. Okabe

Radiat. Phys. Chem. ***26****, 679–83 (1985)*

Abstract

Nonuniform dose distributions in heterogeneous materials irradiated by high-energy electron beams were mapped by using blue cellophane thin dosimeter strip (20 μm thickness). The absorbed doses and dose distributions in solid state dosimeters and in products irradiated for practical use have been estimated from the measurement. Deviations from uniformity of absorbed doses as large as several tens of percent have been found near material interfaces.

Erratum

The running title was mistakenly printed also after the title of the paper, which should therefore read as given in the previous page.

Paper 25

Nondestructive detection of small voids in solids by transmission electron spectrometry
S. Okuda, T. Tabata and T. Seiyama
Jpn. J. Appl. Phys. ***25****, L848–L9 (1986)*

Abstract

A nondestructive method for detecting small voids in solids by means of transmission electron spectrometry has been investigated. With collimated probe-beams of 10 MeV electrons, transmission momentum-spectra have been measured for model samples of silicon carbide 5-mm thick in which a slit type 200 or 600 μm cavity simulated a void. Between the spectra measured for regions with and without the cavity, small difference has been observable. The results have shown that, according to the change in the spectra, voids 200 μm or smaller can be detected by the present method.

Commentary

WHEN the authors of this paper were planning to prepare a full paper of this work, the main author, Shuichi Okuda, moved to Osaka University, and the full paper never appeared. Tabata included some results, which would have been written in the full paper, in a review paper of the work done in their laboratory.[1]

[1] Paper 39 in this volume.

Paper 26

Simple method of evaluating absorbed dose in electron-beam processing

T. Tabata, R. Ito, I. Kuriyama and Y. Moriuchi

Radiat. Phys. Chem. ***33****, 411–6 (1989)*

Abstract

The use of semiempirical multilayer depth–dose code EDMULT for evaluating the absorbed-dose coefficient *K* was studied with a personal computer. When multiplied by the charge per unit area, the coefficient gives the absorbed dose in the sample irradiated by electrons. This relation presupposes the model configuration of the plane-parallel beam normally incident on the four-layer slab absorber. The absorber consists of the accelerator window, the air layer, the sample and the substratum. The initial energies of electrons above 100 keV were considered. The value of *K* obtained agreed reasonably well with the values in the literature. The absorbed doses estimated from K were compared with the values measured by the radiochromic dosimeter for various sets of irradiation conditions. The r.s.m. deviation of the former from the latter was 6.7%. A calculated example of the effects of different substratum materials is given.

Erratum

In Equation (7) on page 414, the right hand side should read $10^2\, S(E_0)$.

Paper 27

Semiempirical algorithms for dose evaluation in electron-beam processing
T. Tabata, R. Ito and S. Tsukui
Radiat. Phys. Chem. ***35****, 821–5 (1990)*

Abstract

The code EDEPOS to compute the depth–dose curve of electrons normally incident on the semi-infinite absorber has been revised to improve its own output and the output of the multilayer depth–dose code EDMULT, in which EDEPOS serves as a subprogram. The values of adjustable parameters in the algorithm of EDEPOS have been determined by the least-squares fit to the depth–dose data collected from the literature. The data used cover the energies from 0.1 to 20 MeV, and the atomic numbers from 5.28 (an effective atomic number for polyethylene) to 82. The revision has removed the spurious cusp in the depth–dose curve generated by the old code, and has resulted in better agreement with a majority of the data. Illustrative results of computation by the revised version of EDMULT are given.

Commentary

THIS paper was presented at the 7th International Meeting on Radiation Processing held in the Netherlands in 1990. In the bag given at the registration desk of the meeting, Tabata found an invitation card for the dinner party of the organizing committee. In the evening of the party, he went to the party room. A person near the entrance of the room asked him, “Are you a member of the organizing committee?” Tabata answered, “No, I’m not, but I have this card.” The person inspected the invitation card and the nametag on Tabata’s jacket and said, “Oh, this should have been in Epsilon Tabata’s bag!” Yoneho Tabata, a famous radiation chemist and Professor Emeritus of the University of Tokyo, was one of the two Honorary Chairmen of the meeting. T. Tabata was unable to think of the error in distributing the card but thought, “*The dinner party of the organizing committee* might be the party sponsored by the committee to entertain all the participants. The members of the committee are very generous.”

In the above meeting, Stephen Seltzer of the National Institute of Standards and Technology, U. S. A., was present. He was one of the developer of the famous Monte Carlo code, ETRAN, for coupled electron–photon transport, and said to Tabata jokingly, “These days they don’t use ETRAN, but use EDMULT.” Surely, the latter code, a revised algorithm of which had been described in this paper, was used extensively, for example, in a document of ASTM Standards.[1]

Erratum

In the 12th line from the bottom of page 821, “the the depth–dose curve” should read “the depth–dose curve.”

[1] American Society for Testing and Materials, *Standard Practice for Dosimetry in an Electron Beam Facility for Radiation Processing at Energies Between 300 keV and 25 MeV*, ASTM Standard E 1649-94 (1995).

Paper 28

Harvesting backscatter electrons for radiation therapy

I. J. Das, L. R. Coia and T. Tabata

Int. J. Radiat. Oncol. Biol. Phys. ***33***, *695–703 (1995)*

Abstract

An innovative technique is used to harvest backscatter electrons for the treatment of superficial small lesions of skin, oral cavity, and rectum where a significant dose gradient and maximum surface dose is desired. Backscatter electrons are harvested out of the primary electron beams from the linear accelerators. The design consists of a short cylindrical cone that fits snugly over a long cylindrical electron cone. The short cylindrical cone has a thick circular plate of high atomic number medium (Pb) attached to the distal end, and a lateral slit of variable length and width. The width of the slit could be closed as desired by rotating the two cones and the length can be increased by lowering the short cylindrical cone. Primary electrons strike the Pb plate perpendicularly and produce backscatter electrons that pass through the lateral slit for treatment. Using film and a parallel plate ion chamber, backscattered electron dose characteristics are studied. The depth dose characteristic of the backscatter electron is very similar to that of the 0.2 mm Al half-value layer x-ray beam that is commonly used for the intracavitary and superficial lesions. The backscatter electron energy is nearly constant and effectively less than 1 MeV from the clinical megavoltage beams. The backscatter electron dose rate of 0.32–0.8 Gy/min could be achieved from modern accelerators without any modification. The beam flatness is dependent on the slit size and the depth of treatment, but is satisfactory to treat small lesions. The measured data for backscatter electron energy, fluence, depth dose, flatness, dose rate, and absolute dose indicate that the harvested backscattered electrons are suitable for clinical use.

Commentary

THE report of one of the reviewer of this paper is cited below.

> The authors have produced an interesting paper which describes how low energy electrons can be generated using a conventional megavoltage electron beam incident on a lead foil resulting in low energy backscattered electrons. They present the concept as well as some experimental results that show the feasibility of the method.

Paper 29

A comparison of calculated and measured absorbed doses of electron beams

Wang Chuanshan, Luo Wenyun, Zhang Limin, Gu Jiqing, T. Tabata and R. Ito

Radiat. Phys. Chem. ***47****, 167–70 (1996)*

Abstract

A semiempirical code to compute the absorbed dose in single- to five-layer slab absorbers irradiated by electron beams has been developed. The doses estimated by the code have been compared with the experimental results obtained with a pyrolitic-graphite calorimeter for the electron beams of 1.5- and 1.75-MeV energy, and these have shown agreement within about 3%.

Commentary

THE semiempirical depth–dose code ED510 described in this paper is equivalent to EDMULT Version 5.10.

In 1986 Wang Chuanshan sent to Tabata a letter written in Japanese and requested a copy of the EDMULT program to calculate the depth–dose curves of electrons in multilayer absorbers. In the next autumn Tabata had a chance of meeting her boss, Feng Yong Xiang, in Tokyo. These occurrences became the motive for cooperation between Wang's group and Tabata's.

Feng spent nine years in U. S. A. in his student days, and worked under Raymond Herb at the University of Wisconsin–Madison for the development of "Pelletron accelerators." At the 1963 dinner for Nobel prizewinners, Eugene Wigner praised his teachers and said, "We also learn from contemporaries and younger colleagues . . . . In leadership, a young man at the time, Ray Herb was my tutor."[1] Having been a student of such a teacher, Feng also became a good teacher at Shanghai University to make Shanghai Applied Radiation Institute an active center for radiation sciences there.

Erratum

In Abstract, "a single- to five-layer slab absorbers" should read "single- to five-layer slab absorbers."

[1] H. T. Richards, Phys. Today **50**, No. 2, 87 (1988).

IV Atomic and Molecular Collisions

We might define science to be the search for compressions [of information].

John D. Barrow, "Theories of Everything" in *Nature's Imagination* edited by John Cornwell (Oxford University Press, Oxford, 1995) p. 45

Paper 30

Analytic cross sections for charge transfer of hydrogen atoms and ions colliding with metal vapors

T. Tabata, R. Ito, Y. Nakai, T. Shirai, M. Sataka and T. Sugiura

Nucl. Instrum. Methods B ***31****, 375–81 (1988)*

Abstract

Analytic formulas are given for the total cross sections, s, for the charge transfer in collisions of H^+, H^- and H with metal vapors. The cross sections considered are s_{10}, s_{0-1}, s_{1-1}, s_{01}, s_{-10} and s_{-11}, where the subscripts represent the initial and the final charge state of the projectile. The functional form of the formulas is a modification of the semiempirical formulas proposed by Green and McNeal for s_{10} of H^+ in gaseous atoms and molecules. Values of adjustable parameters in the formulas have been determined by least-squares fits to a compiled set of experimental data. The root-mean-square deviation of the data from the formula is from 7 to 34% for each type of cross section. The main cause of larger deviations is the discrepancy among the data.

Commentary

BY courtesy of Yohta Nakai, whose doctoral thesis[1] was the measurement of energy dissipation of electron beams with energies from 1 to 2 MeV in matter, the contract work of Tabata and Rinsuke Ito with Japan Atomic Energy Research Institute began in 1982. This and the following two papers are the products of the contract work. The work has been continuing for 17 years. Meanwhile Toshizo Shirai succeeded Nakai to organize the contract jobs. Publications related to the contract work and not included in this volume are listed in Commentary on Paper 32.

For this continued contract work, a report, entitled "Analytic cross sections for inelastic collisions of protons and hydrogen atoms with atomic and molecular gases" and prepared by A. E. S. Green and R. J. McNeal[2] in 1970, was extremely useful. Tabata got its copy from the Japan Information Center for Science and Technology for his part-time work of translating abstracts of scientific and technological papers and reports into Japanese. Being interested in the method of formulating semiempirical equations, he made a copy of the copy and kept it, without anticipating that it would become such an important reference of their own work in the near future.

[1] Y. Nakai, Jpn. J. Appl. Phys. **2**, 743 (1963).

[2] Later published in: A. E. S. Green and R. J. McNeal, J. Geophys. Res. **76**, 133 (1971).

Paper 31

A semiempirical formula for single-electron-capture cross sections of multiply charged ions

Y. Nakai, T. Shirai, T. Tabata and R. Ito

Phys. Scr. ***T28****, 77–80 (1989)*

Abstract

A universal analytic formula is given for the total cross sections of single-electron capture by multiply-charged ions colliding with H, H_2 or He. Values of constants in the formula have been determined by the least-squares fit to experimental data collected from the literature. The formula is applicable to ions of almost all atomic species with charge q greater than 4 (for the H and H_2 targets) or 5 (for the He target) in the energy region from about 1 to 10^7 eV amu^{-1}. The root-mean-square deviation of the data from the formula is 29%. The formula shows that the cross sections are proportional to $q^{1.07}$ at low energies and to $q^{2.86}$ at high energies. Other trends of the cross sections that can be derived from the formula are also discussed.

Paper 32

Extended scaling of cross-sections for the ionization of H, H_2 and He by multiply charged ions

T. Tabata, R. Ito, T. Shirai, Y. Nakai, H. T. Hunter and R. A. Phaneuf

*At. Plasma–Mater. Interaction Data for Fusion **2**, 91–4 (1992)*

Abstract

An analytic cross-section formula is given for the impact ionization of H, H_2 and He by multiply-charged ions. The formula is expressed as a modified Bethe cross-section for ionization by protons, multiplied by the square of the ionic-charge and an analytic scaling factor. This scaling factor behaves as E^n at low energies, where E represents the projectile energy and n is approximately equal to 0.9. The values of adjustable parameters in the formula was determined by least-squares fits to the experimental data collected from the literature. The lowest projectile energy of the available data was 6 keV/amu and the root-mean-square deviation of all data from the analytic formula is 21%.

Commentary

REFEREE'S comments on this paper was as follows:

> This paper presents a new analytic semi-empirical formula for the ionization of H_1, H_2 and He by multiply charged ions. The description and signification of the parameters entering the formula are well established. The formula provides physicists with a useful tool for data handling in an energy range that has been extended towards the lowest available experimental data. This paper is worth to be published without change.

Publications related to the contract work with Japan Atomic Energy Research Institute and not included in this volume are listed below.

T. Tabata, R. Ito, Y. Nakai and T. Shirai, "Cross sections for charge transfer of helium atoms and ions colliding with gaseous atoms and molecules," Radiation Center of Osaka Prefecture Technical Report No. 7 (1987).

T. Tabata, R. Ito, Y. Nakai and T. Shirai, "Single-electron-capture cross sections of multiply-charged ions colliding with H, H_2 and He," Radiation Center of Osaka Prefecture Technical Report No. 9 (1987).

Y. Nakai, T. Shirai, T. Tabata and R. Ito, "Cross sections for charge transfer of hydrogen atoms and ions colliding with gaseous atoms and molecules," Atomic Data and Nuclear Data Tables **37**, 69 (1987).

T. Tabata, R. Ito, Y. Nakai, T. Shirai and Y. Funatake, "Partial cross-sections for single-electron capture of hydrogen ions," Osaka Prefectural Radiation Research Institute Technical Report No. 11 (1990).

R. Ito, T. Tabata, T. Shirai and R. A. Phaneuf, "Analytic cross sections for collisions of H, H_2, He and Li atoms and ions with atoms and molecules. I," Japan Atomic Energy Research Institute Report JAERI-M 93-117 (1993).

R. Ito, T. Tabata, T. Shirai and R. A. Phaneuf, "Analytic cross sections for collisions of H, H_2, He and Li atoms and ions with atoms and molecules. II," Japan Atomic Energy Research Institute Report JAERI-Data/Code 94-005, (1994).

R. Ito, T. Tabata, T. Shirai and R. A. Phaneuf, "Analytic cross sections for collisions of H, H_2, He and Li atoms and ions with atoms and molecules. III," Japan Atomic Energy Research Institute Report JAERI-Data/Code 95-008 (1995).

R. Ito, T. Tabata, T. Shirai and R. A. Phaneuf, “Analytic cross sections for collisions of H, H_2, He and Li atoms and ions with atoms and molecules. IV,” Japan Atomic Energy Research Institute Report JAERI-Data/Code 96-024, (1996).

V Effects of Radiations

Scientific papers must be regarded in the same way as we look at a new word in a crossword puzzle. When it fits in well with the words already present, it is likely to be correct. In a case where it contradicts earlier entries, we simply cannot write over the earlier ones.

Robert Shapiro, *Origins* (Penguin, Harmondsworth, 1988)

Paper 33

The effect of high gamma-ray doses on the thermal properties of muscovite mica: Application to dosimetry

K. Fukuda, H. Fujimoto, Y. Sato, T. Tabata, T. Oka, S. Okuda and R. Taniguchi

Nucl. Instrum. Methods A ***251****, 374–9 (1986)*

Abstract

Differential thermal analysis has been made for muscovite mica exposed to ^{60}Co gamma rays of doses up to 1.2¥10^{10} R. The thermal curves show an endothermic peak below 950 deg C. The starting temperature of the endothermic reaction increases from 770 to 855 deg C with increasing dose. The resistance to the thermal decomposition of muscovite mica is increased by gamma-ray irradiation. The change in thermal properties has been utilized for measuring and recording high gamma-ray and electron doses. A simple mechanism is suggested to understand the radiation-induced effect on the thermal properties of muscovite mica.

VI Nuclear Physics

Thus began a period in which pions and nucleons were regarded as the ultimate building blocks of matter. The meson theory of nuclear forces was analogous to quantum electrodynamics, with electrons replaced by nucleons and photons by pions. It was a useful but wrong model.

Sheldon L. Glashow with Ben Bova, *Interactions* (Warner Books, New York, 1978)

Paper 34

Cross section of the reaction ^{9}Be(g, n) near threshold

M. Fujishiro, T. Tabata, K. Okamoto and T. Tsujimoto

Can. J. Phys. ***60****, 1672–7 (1982)*

Abstract

Six kinds of radioisotopes were used to measure cross sections of the ^{9}Be(g, n) reaction near its threshold. The results obtained were 0.88 ± 0.16, 1.33 ± 0.24, 1.10 ± 0.20, 0.73 ± 0.13, 0.47 ± 0.09, and 0.18 ± 0.04 mb at 1674.7, 1705.2, 1724.9, 1778.9, 1836.0, and 2167.6 keV, respectively. The cross sections measured show a sharp peak near the threshold, and its width is narrower than that observed by Jakobson with Bremsstrahlung X-rays. Comparison of the present results with theories based on the valence neutron model indicates that the agreement is only qualitative.

Commentary

BARKER[1] showed that R-matrix fit to the experimental results of this paper gave parameters that were in reasonable agreement with those obtained from fits to data from other reactions. Fujishiro and Tabata also tried the same fitting, but it was too late to publish. Fujishiro wrote later[2], "Barker also referred to the applicability of the complex eigenvalue theory to our data. We did not notice it. So we have to admit that he was much keener than us."

[1] F. C. Barker, Can. J. Phys. **61**, 1372 (1983).

[2] M. Fujishiro, *25 Years with Beryllium: At a Nook of Radiation Paradigm* (private printing, 1995) in Japanese. The passage cited has been translated into English by T. Tabata.

Appendix I A Paper in Japanese

A clash of doctrines is not a disaster—it is an opportunity.

Alfred North Whitehead, “Religion and Science” in *Great Essays in Science*, ed. Martin Gardner (Prometheus, Buffalo, NY, 1994) p. 215

Paper 35

Stopping power of matter for electrons below 10 keV (A review)
Y. Nakai, T. Tabata and S. Okabe
Oyo Buturi ***51****, 279–85 (1982)*

Abstract

Knowledge on the passage of electrons with energies below 10 keV has important applications in radiation biology, solid-state physics and thermo-nuclear fusion research. Recent theoretical and experimental results on the stopping power, the mean free path and the range of these electrons are reviewed. From comparison with some experimental results and the data on these parameters previously obtained at energies above 10 keV, it is found that a series of computational results based on the free electron gas model and the electron gas statistical model are appropriate to be used in place of scarce experimental data. (Translated from Japanese by T. Tabata.)

Appendix II Papers in Internal Publications

"The rule of thumb is that you don't do much first-class work past forty. That's mostly wrong, of course. There are lots of great discoveries made late in life. But on the average, yes, you feel the ability slipping away from you. It's like composers, I guess. Flashes out of nowhere when you're young, and . . . and more a sense of consolidation, layering things on, when you're older."

Gregory Benford, *Timescape* (Simon & Shuster, New York, 1992)

Paper 36

Present status of data compilation on ion backscattering
T. Tabata and R. Ito
Report IPPJ-AM-64, Inst. Plasma Phys., Nagoya Univ. pp. 84–89 (1989)

Abstract

Recent results are briefly described of the joint work made at the Institute of Plasma Physics, Nagoya University, to compile the data on the backscattering coefficients of ions and to develop empirical formulas for these coefficients. Computer-simulation data on light-ion backscattering at low energies and both experimental and computer-simulation data on heavy-ion backscattering have been added to the compilation. The computer-simulation data for heavy ions have been found to show deviations from a universal curve onto which experimental data are well scaled.

Commentary

BY modifying those published by Tabata et al.,[1] Ito et al. gave empirical formulas for the number and energy backscattering (reflection) coefficients of light ions at normal incidence in an earlier report.[2] Wolfgang Eckstein[3] commented on the report as "the most complete data compilation for values of the reflection coefficients," and also cited the empirical formulas, which Ito et al. had never published in an external journal. Unfortunately, Eckstein's citation had a misprint. In the seventh line in the left column on page 28 of his article, the expression for f should be multiplied by r_a/r_t.

In this paper Tabata and Ito describes about a trial for the extension of their formulas to include heavy ions as well as the joint work on data compilation at the Institute of Plasma Physics, Nagoya University (presently National Institute for Fusion Science). The latest review on the backscattering of ions was given by Eckstein.[4]

Eckstein visited Osaka during his stay at Nagoya University in 1987 to meet one of his old friends, Kenji Murata, at Osaka Prefecture University (OPU). This was Tabata's first occasion to see both of them in spite of the following facts: He received from Eckstein many numerical data on the backscattering coefficient of ions in the early 1980s, and knew Murata's good work[5] on Monte Carlo calculations of the passage through matter of electrons with energies around 10 keV. Thereafter Eckstein visited OPU almost every time when he came to Japan.

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[1] Paper 22 in this volume.

[2] Ref. 1 of this paper.

[3] W. Eckstein, Atomic and Plasma-Mater. Interaction Data for Fusion, **1**, 17 (1991).

[4] W. Eckstein, J. Nucl. Materials **248**, 1 (1997).

[5] For example: K. Murata, T. Matsukawa and R. Shimizu, Jpn. J. Appl. Phys. **10**, 678 (1971); D. F. Kyser and K. Murata, IBM J. Res. Dev. **18**, 352 (1974): M. Kotera, K. Murata and K. Nagami, J. Appl. Phys. **52**, 997 (1981); K. Murata, D. F. Kyser and C. H. ting, J. Appl. Phys. **52**, 4396 (1981). See also a review article on Monte Carlo methods and microlithography simulation: K. Murata and D. F. Kyser, in Advances in Electronics and Electron Physics Vol. 69 (Academic, New York, 1987) p. 175.

Paper 37

Reflection ratios of electrons and photons from solids
R. Ito, P. Andreo and T. Tabata
Bull. Univ. Osaka Pref. A ***41****, 69–76 (1992)*

Abstract

Electron and photon reflection ratios (in number and energy) for absorbers bombarded by electrons have been computed with the ITS Monte Carlo system version 3, and results are given in the form of tables. Electrons of energies from 0.1 to 100 MeV have been assumed normally incident on an effectively semi-infinite absorber. The absorbers considered are elemental solids of atomic numbers from 4 to 92 (Be, C, Al, Cu, Ag, Au and U). An empirical equation for the electron number-reflection ratio has been formulated, by least-squares fit to experimental data collected from the literature. Values of parameters derived from the Monte Carlo data on photon number- and energy-reflection ratios are graphically presented.

Commentary

THE empirical formula for the number backscattering coefficient of electrons given in this paper supersedes the previous formula[1] published in 1971. Tabata wished to publish a modified version of this paper in an external journal, but was unable to find time for preparing the manuscript.

Erratum

The last two column titles of Table 1 on page 71 should read h_{pN} and h_{pE} instead of h_{eN} and h_{eE}.

[1] T. Tabata, R. Ito and S. Okabe, Nucl. Instrum. Methods 94, 509 (1971) (Paper 7 in Vol. 1 of this series).

Paper 38

Semiempirical models for depth–dose curves of electrons in matter: An introductory review

T. Tabata

Bull. Univ. Osaka Pref. A ***41****, 103–18 (1992)*

Abstract

The basic principle of a semiempirical model, proposed by Kobetich and Katz, for depth–dose curves of electrons in homogeneous semi-infinite absorbers is described. The development, by the present author and his coworker, of an algorithm based on this model is reviewed. A possible method of further improvement of the algorithm is briefly described, and examples of new Monte Carlo data to aid the improvement are shown. An outline and some examples of application are also described of a semiempirical model for multilayer absorbers.

Commentary

IN this and many other papers published by Tabata et al. from 1992 to 1998, Tabata acknowledges Nissin–High Voltage Co. Ltd., a manufacturer of accelerators, for financial support. It happened that the Japanese version of this paper, published in *Hoshasen Kagaku* (*Radiation Chemistry*) was printed next to the opening essay of the issue written by the then President of the above company, Isamu Sakamoto. He was also a scientist and engineer, and his essay was entitled “Radiation chemistry and makers of electron-beam machines.” The policy of making reprints of *Hoshasen Kagaku* was not to make the irrelevant pages blank. Thus the reprints of the Japanese version of this paper included Sakamoto’s essay on its first page together with his photograph. This was good for Tabata to remember his kindness for a long time.

Paper 39

Experiments on electron-beam measurement: A review of a series of studies made with the UOP Electron Linac and related studies

T. Tabata, K. Fukuda, K. Kawabata, R. Ito, S. Nakamura, R. Taniguchi, T. Seiyama, K. Tsumori and S. Okuda

Bull. Univ. Osaka Pref. A ***42****, 193–207 (1993)*

Abstract

Important experiments on electron-beam measurement, carried out with the linear electron accelerator of University of Osaka Prefecture, are reviewed together with related studies by other authors. Topics treated are measurement of electron-beam characteristics, anomalies in dosimetry and absorbed dose due to heterogeneities, and an application of electron-beam measurement to nondestructive inspection.

Commentary

AS described in the first footnote to it, this paper was adapted from part of lectures delivered by Tabata at the Shanghai University of Science and Technology (presently Shanghai University) and Beijing Normal University in 1988. Tabata was invited to the latter university by Chen Wenxiu, whom he had seen for the first time at the Conference on Radiation Curing Asia held in Tokyo in 1986. At the Conference Chen asked Tabata a question about his presentation (later published as a paper[1]), and he talked to her during the lunchtime on a corridor of the conference building. Thus they became good friends. Chen visited Sakai three times on the occasion of coming to Japan, and stayed in Tabata's house twice among the three visits. Chen again invited Tabata to Beijing Normal University in 1998.

[1] Paper 26 in this volume.

Paper 40

Theoretical evaluation of absorbed doses in materials irradiated by low-energy electron beams: A short review

T. Tabata

Bull. Univ. Osaka Pref. A ***44****, 41–6 (1995)*

Abstract

Recent work by the author's group to improve semiempirical algorithms for depth–dose curves of electrons in single- and multilayer absorbers are reviewed. Different methods studied by other authors to calculate absorbed doses under low-energy electron beam irradiation are also briefly described.

Commentary

UNIVERSITY of Osaka Prefecture changed its English name to Osaka Prefecture University in 1996. Therefore, its journal, *Bulletin of University of Osaka Prefecture* also changed its name to *Bulletin of Osaka Prefecture University*. However, the needs for its publication became low, and the journal was discontinued in 1998. In its last issue, Vol. 46, No. 2, Tabata contributed a paper[1] entitled "Smoothing and interpolation by moving-window least squares polynomial fits: Application to energy- and charge-deposition distributions by electrons."

[1] T. Tabata, Bull. Osaka Pref. Univ. A, **46**, 71 (1997).

Afterword

(Written for "Selected Papers of Tatsuo Tabata and His Coworkers")

In the two volumes of "Selected Papers of Tatsuo Tabata and His Coworkers" a total of 90 papers has been included from more than 170 academic publications of me, mostly co-authored with my colleagues. Some of the earliest papers were published when I was a graduate student at Kyoto University. From 1960 I worked at the Radiation Center of Osaka Prefecture. In 1990 the Center was united with the university located next door, and was renamed Research Institute for Advanced Science and Technology, Osaka Prefecture University. Since then, I have been working there. Thus my career had least detours, but I liked mental detours, as can be seen from some of commentaries in the two volumes.

It was initially planned to include in Vol. 2 the list of all the publications and the data on the number of citation times of these. However, the number of the pages of Vol. 2 has become too large to include such things. Also I have been unable to find enough time to analyze recent citation data. I am considering therefore to make a small book that includes these as well as an adapted collection of commentaries from the two volumes and to distribute its copies to my colleagues in the near future.

I received warm messages for the receipt of Vol. 1 from many of my friends, and these have worked as a spur for me in preparing Vol. 2. Thanking for all those messages, I cite some of them here.

> Your Vol. 1 has arrived, and it looks great! It is such a good idea to have all the publications compiled!
>
> — Pedro Andreo

> I especially liked reading the commentaries. It will make a nice addition to my library on electron transport and measurement.

— Alex Bielajew

I have copies of your old papers, which I cannot even read due to poor Xerox. I am pleased to acknowledge the copy of your volume 1 and feel privileged.

— Indra Das

This is extensive, excellent work, and you can be really proud of it!

— David Jette

It is no doubt that your papers are a huge contribution to all mankind.

— Zhang Limin

Your measurements, empirical equations and theories presented in these papers made outstanding contributions to the field.

— Ruqing Wang

The commentaries are fun to read. It is truly an amazing body of work you have collected there, and it is only part I!

— Eugene Wong

I wish to be able to continue to publish academic papers for many coming years after my leaving from Osaka Prefecture University at the end of March 1999, on the model of Hans Bethe, who edited his own "Selected Papers" from the work of seventy years.

Tatsuo Tabata
December 1998