UDC 539.12.04; 621.039.587

RESEARCH OF HIGH-CURRENT PULSED ELECTRON BEAM ENERGY DISTRIBUTION IN DEPTH OF SHEET OF WATER

A.I. Pushkarev, R.V. Sazonov

High voltages Research Institute of Tomsk Polytechnic University
E-mail: aipush@mail.ru

Distribution of the absorbed doze and energy of the high-current pulsed electron beam formed by accelerator TEU-500 (350...500 kV, 60 ns, current density 0,3...0,4 kA/sm²) in water sheet depth has been measured. The high-resolution measurement technique of doze and energy distribution with application of dosimetric film based on lavsan with phenazine covering was used. Spatial resolution at registration of the absorbed doze in the range of 5...100 kGr amounts to 20...30 mkm. It was shown that at absorption of electron beam with high current density (in conditions of track overlapping on surface of the absorbing layer) distribution of the absorbed doze in the depth within the limits of ±10 % coincides with distribution obtained for low-current beam.

Introduction

Electron energy distribution in the depth at absorption in condensed media is well studied and approximated by various empirical relations [1, 2]. Distribution of absorbed doze typical for a substance in a condensed phase is conditioned by multiple scattering of primary electrons and formation of secondary electrons. By electron delay in the medium ionization loss increase and at the same time a number of secondary electrons as well as a number of back-scattered electrons from deeper layers grows; density of medium atom ionization increases and as a result energy absorbed in a substance grows. On the other hand, multiple scattering of primary electrons results in significant spread of their range in a substance and thereby, decreases not only a number of electrons moving in original direction but also a number of back-scattered electrons. Presence of these two processes results in formation of wide superimposed maximum in absorbed energy distribution in substance depth. Owing to scattering processes the distribution maximum (in comparison with Bragg curves for heavy particles) is not at the end of extreme range but it is considerably shifted to the surface layers of the substance [2].

This mechanism describes the absorption of electron beams with low current density (one-electron approximation). At radiation water interaction the main part of secondary electrons formed as a result of medium ionization has a low range owing to its low energy and therefore, generates ionization and excitation in immediate proximity to the place of its formation. Pulse radiolysis of liquid-phase compounds in conditions of influence of electron beam with high current density (more than 100 A/cm²) when tracks are overlapped on the surface of irradiated liquid is of great interest. In this case conditions favorable for multiple collisions of particles with excess energy storage at internal degrees of freedom are formed. In these conditions deviation of absorbed doze distribution from known dependences is possible. The given conditions of carrying out radiolysis of liquid compounds are not studied and they are of scientific and practical interest for studying mechanism of electron beam dissipation.

In work [3] electron energy absorption was estimated by filter method according to the indices of two detectors arranged behind the filters of different thickness and calculation by empirical formulas. In works [4, 5] film plastic detectors CPD-2-F2 were used for measuring absorbed doze [6]. Field of electron absorbed doze (0,5...1 MeV) was measured in water by the depth by filter method in narrow beam geometry. Measuring electron energy absorption in liquid layer by filter method it is difficult to support homogeneous thickness of absorption layer and possibility of varying thickness with a pitch less than 0,1 mm that results in low accuracy of measurements.

The aim of the work is to study distribution of electron beam with high current density in water sheet depth and development of high-resolution technique of measuring electron energy distribution at absorption in liquid.

1. Experimental device

The experiments were carried out at pulse electron accelerator TEU-500 (350...500 kV, 60 ns, current density 0,3...0,4 kA/cm²) [7]. Capacitance divider arranged in oil-filled chamber was used for measuring voltage. Total current of electron beam was measured by Faraday cup. Oscillograms of accelerating voltage at planar diode cathode at irradiation of water and total current of electron beam are given in Fig. 1.

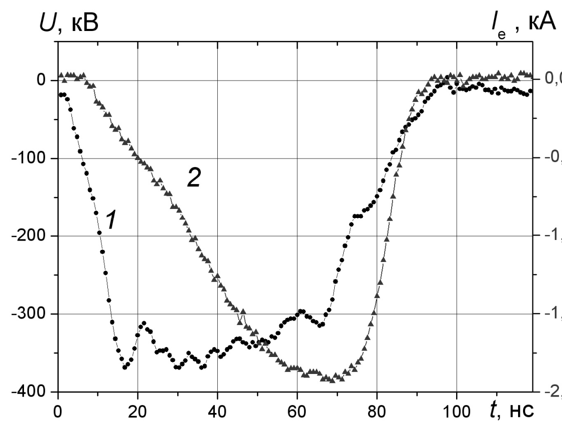

Fig. 1. *Oscillograms of: 1) voltage applied to planar diode, 2) electron beam current*

To measure absorbed doze at irradiation by continuous and pulse electron beams the dosimetric radiation-sensitive film (copolymer with phenazine dye) of the type POR are widely used [6]. Film thickness is 0,1 mm (sensitive layer thickness is 15 mkm) that allows recording the value of absorbed doze with high spatial resolution. At electron energy more than 200 keV losses in dosimetric film are insignificant. To measure distribution of absorbed doze of pulsed electron beam in liquid sheet depth (water) a special reactor was made, Fig. 2. There is a dimple on the merit of 9° in reactor metal case – 1. Disk of dosimetric film – 2 is placed on a surface. Lower part of reactor case is closed with thin aluminum foil. There is a device for pulling aluminum foil in reactor construction.

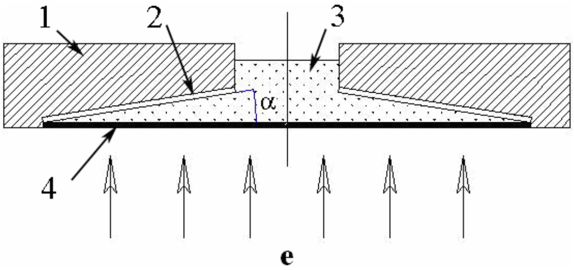

Fig. 2. *Diagram of measuring the absorbed doze of pulsed electron beam in liquid: 1) chamber case, 2) dosimetric film, 3) liquid, 4) 10 mkm aluminum foil*

The volume between the foil and dosimetric film is filled up with the examined liquid – 3. Narrow strip of dosimetric film is arranged below the aluminum foil. Distribution of density of electron beam energy at reactor input was determined by optical density of this strip.

2. Calculation of the absorbed doze of electron beam in water

Measurement of distribution of the absorbed doze of electrons having energy less than 500 keV in liquid depth is technically complicated as the depth of their total absorption does not exceed 1,5 mm. Measuring by filter method it is necessary to support uniform thickness of liquid layer and change it with a pitch less than 0,1 mm. Therefore, experimental data of distribution of the absorbed doze of electrons with energy less than 1 MeV in water existing in literature differ significantly, Fig. 3.

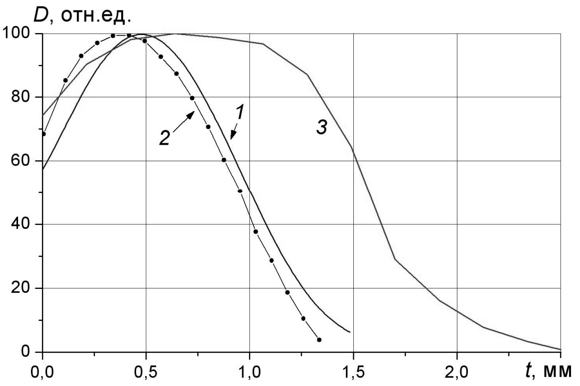

Fig. 3. *Distribution of the absorbed doze of electrons with energy 0,5 MeV in water. Data: 1) calculation, 2) works [2], 3) works [8]*

Distribution of the absorbed doze of electrons in aluminum is measured with high accuracy. To determine the depth of electron absorption in a substance their distribution in aluminum is recalculated by known values of extrapolated range for the examined substance [1, 2]. The experimental data of distribution of the absorbed doze of monoenergetic electron beam (with different energy) in aluminum coincide well at normalization of proper values of depth *t* per extrapolated range of electrons *R* with this energy.

Distribution of the absorbed doze of monoenergetic electron beam with different energy in the normalized depth of aluminum $d=t/R$ is given in Fig. 4. Magnitude *R* was calculated by the formula of Flammersfield [1].

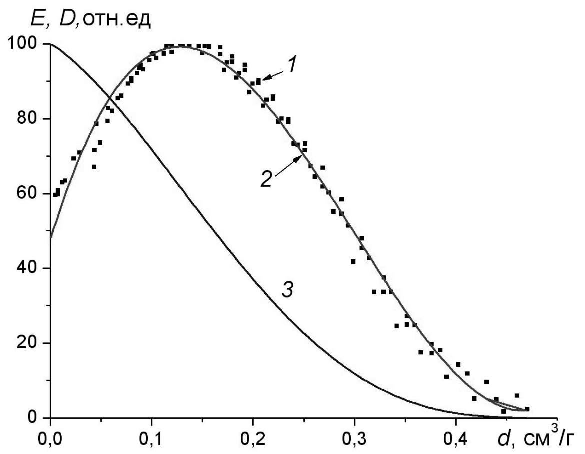

Fig. 4. *Distribution of monoenergetic electron beam in aluminum: 1) experimental data, 2) approximating dependence of the absorbed doze, 3) density of electron beam energy*

Experimental values of the absorbed doze given in Fig. 4 were approximated by polynomial of the third degree (curve 2, Fig. 4) which was further used for calculating distribution of the absorbed doze of pulsed electron beam at different accelerating voltage. Electron range in the examined liquid was calculated by the ratio [1]:

$$t = d\,R\frac{(Z/A)_{\mathrm{Al}}}{(Z/A)_x}\frac{\rho_{\mathrm{Al}}}{\rho_x}, \qquad (1)$$

where *Z* is the charge in positron unit charge, *A* is the atomic mass (in aem) of target (of aluminum or the studied substance), ρ_{Al} is the aluminum density, ρ_x is the density of the studied substance.

Distribution of density of electron beam energy in the depth of absorbing layer equals to:

$$E(t) = E_0 - \rho\int_0^t D\,dt, \qquad (2)$$

where E_0 is the density of energy on a surface (J/cm^2), ρ is the substance density.

The obtained normalized dependence of energy density distribution in aluminum depth is shown in Fig. 4 (Curve 3).

Distributions of absorbed doze in water for monoenergetic electron beam with energy 0,5 MeV given in works [2, 8] and dependence calculated by the above given technique are shown in Fig. 3 for comparison. It is seen that distribution of the absorbed doze in water obtained on the basis of the range in aluminum coincides well with the experimental data given in paper [2]. Our experimental data were further compared with dependence 1 Fig. 3.

3. Measurement of distribution of density of electron beam energy in water

Dosimetric film POR represents a thin layer of radiation-sensitive cover coated on lavsan substrate. Measuring electron beam absorption in water two variants of dosimetric film arrangement are possible – by phenazine cover to water or to reactor vessel.

In the first series of experiments dosimetric film was arranged by phenazine cover to reactor vessel. Beam electrons passed water sheet, lavsan film and then occurred in phenazine cover of dosimetric film causing the change of its color. According to the technique [9] change of energy density in cross section of pulsed electron beam at reactor input and at passage of water sheet was determined by the change of optical density of dosimetric film. Experimental data, Fig. 5, correspond to three different sectors of disc of dosimetric film irradiated by one pulse. Value r=0 corresponds to outer edge of the disc of dosimetric film.

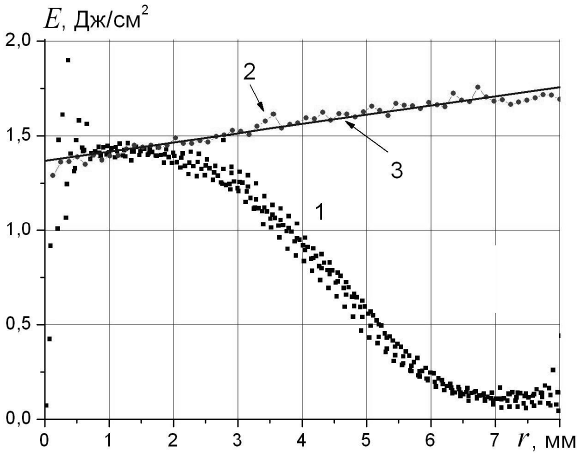

Fig. 5. *Change of energy density by section of pulsed electron beam: 1) after passing water sheet, 2) at reactor input*

Measuring absorption in water sheet the change of density of electron beam energy in cross section at the reactor input should be taken into account (Curve 2 Fig. 5). It is well described by linear dependence 3 (Fig. 5) $E(d)=E_0\cdot(1+0{,}04\cdot d)$. Adjusted dependence of density of electron beam energy subject to its inhomogeneity by the section is given in Fig. 6 (Curve 1). Transition from distribution of beam energy density in cross section $E(r)$ to distribution of energy density $E(t)$ after passing water sheet with the thickness t is fulfilled by the formula $t=d\cdot\text{tg}(9°)$.

Distribution $E(t)$ of monoenergetic beam in water sheet depth was calculated by the ratio (2) in this case electron range in water was determined by the (1). The obtained dependences are shown in Fig. 6 (Curves 2–4). The calculated dependence of distribution of the absorbed doze of electrons with energy 350 keV is shown as well in Fig. 6. Dependences (3) and (5) are interconnected. Integral of distribution of the absorbed doze of monoenergetic electron beam in the depth (dimension J·cm/kg) multiplied by water density equals energy density on water sheet surface (1,4 J/cm²).

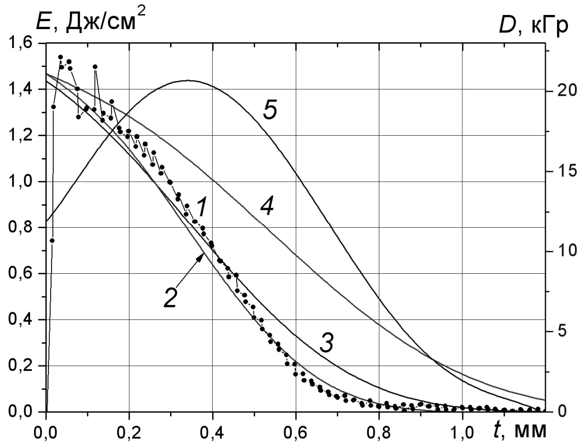

Fig. 6. *Distribution of density of pulsed electron beam energy in water depth: 1) experimental data, 2–4) calculation for electrons with energy 300, 350, 400 keV, 5) calculation for the absorbed doze of electron beam*

It is seen that experimental points correspond to distribution of electrons with energy from 300 to 500 keV in water depth that coincides with average accelerating voltage on diode (Fig. 1).

4. Measurement of distribution of the absorbed doze of electron beam in water

In the next series of experiments the disk of dosimetric film was arranged by phenazine cover to water. Calculated dependences of distribution of energy and absorbed doze of electrons with energy 350 keV as well as the experimental data are shown in Fig. 7. Integral of distribution of the absorbed doze in the depth multiplied by water density equals to density of electron beam energy on water sheet surface. It is seen that experimental points corresponds to a large extent to distribution of electron absorbed doze in water sheet depth but not to energy distribution.

When radiation-sensitive phenazine cover is arranged in water where electron beam is absorbed change of coating optical transparency are caused not only by beam electrons but also by secondary electrons. Section of interaction of electrons with low energy with the material of phenazine cover is higher than for electrons with high energy. Therefore, we record mainly concentration of secondary electrons which is proportional to the density of energy release in water (absorbed doze). If dosimetric film is arranged by lavsan film to water then only primary electrons of beam get into radiation-sensitive coating and we record decrease of beam energy by increase of thickness of water absorption layer.

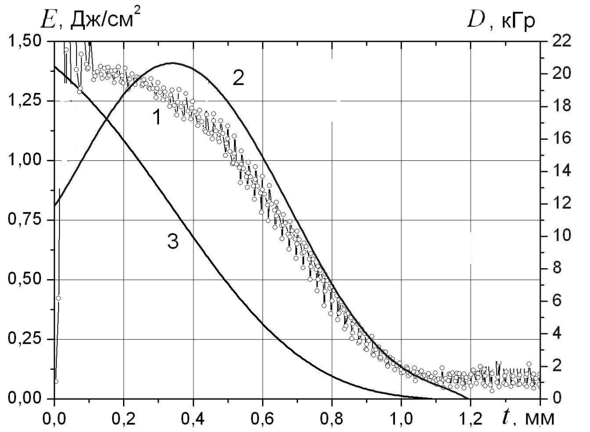

Fig. 7. *Distribution of pulsed electron beam with energy 350 keV at absorption in water: 1) experimental data (for spectrum), 2) for the absorbed doze D, 3) for energy density E*

Conclusion

At absorption of electron beam with high current density (in conditions of track overlapping on absorbing layer surface) distribution of the absorbed doze in the depth coincides satisfactorily with distribution obtained for low-current beam. The advanced technique recording distribution by one pulse was used for measuring. The developed technique allows measuring independently distribution of energy and absorbed doze of electron beam in absorptive liquid layer. Spatial resolution is not lower than 30 mkm that supports high accuracy of recording distribution in water sheet of the absorbed doze of electrons with energy less than 500 keV. Error of measuring average energy of beam electrons does not exceed 20 % therefore, the developed technique may be used as express method of calibration of accelerating voltage sensors on electron diode cathode.

The work was fulfilled with support of RFBR, grant 06-08-00147.

REFERENCES

1. Tables of physical magnitudes. Reference book. / Ed. by I.K. Kikoin. – Moscow: Atomizdat, 1976. – 1006 p.
2. Chepel L.V. Application of electron accelerators in radiation chemistry. – Moscow: Atomizdat, 1975. – 152 p.
3. Fedorov V.M. Measuring electron energy of high-current megavolt beams by hardness of X-ray radiation from thick target. – Novosibirsk: Nauka, 1986. – 128 p.
4. Kotov Yu.A., Sokovnin S.Yu. X-ray diagnostics of high-current E-beam // Proc. of 8th IEEE Pulsed Power Conf. – San Diego, California, 1991. – P. 629–632.
5. Sokovnin S.Yu. X-ray diagnostics of parameters of high-current electron beam // Pribory i Tehnika Eksperimenta. – 1992. – № 4. – P. 125–130.
6. Generalova V.V., Gurskii M.N. Dosimetry in radiotechnology. – Moscow: Izdatelstvo Standartov, 1981. – 184 p.
7. Remnev G.E., Furman E.G., Pushkarev A.I., Karpuzov S.B., Kondratiev N.A., Goncharov D.V. A high-current pulsed accelerator with a matching transformer // Instruments and experemental techniques. – 2004. – V. 4. – № 3. – P. 394–398.
8. Pikaev A.K. Modern radiation chemistry. Main points. Experimental technology and methods. – Moscow: Nauka, 1985. – 375 p.
9. Goncharov D.V., Ezhov V.V., Pushkarev A.I., Remnev G.E. Studying distribution of energy density of high-current pulsed electron beam // Bulletin of the Tomsk Polytechnic University. – 2005. – V. 308. – № 6. – P. 76–80.

Received on 28.11.2006