ENERGY DEPOSITION BY LOW ENERGY IONS*

Liu Xiaowei (刘小伟), Zhang Chunxiang (张纯祥), Li Mianfeng (李冕丰)
and Luo Daling (罗达玲)

(Zhongshan University, Guangzhou 510275, China)

(Received July 1992)

ABSTRACT

Considering the ionizing energy of bound electrons, the energy depositions around the path of an ion whose energy is below 1 MeV/u are calculated by using track structure model. The results are in good agreement with experiments.

Keywords: Energy deposition Track structure model Numerical solution Ionizing radiation

1 INTRODUCTION

The energy deposition of ionizing radiation is the result of the interaction of an ion with atoms in matter through which it passes. A full physical description of all interaction which occur in an irradiated medium is extremely complex, and at present time virtually unmanageable for purpose of interpreting radiation effects. For explaining ion radiation effects, the track structure mode[1,2] was introduced which is based on the joint application of the radial distribution of energy deposition and the dose-response function after irradiation with gamma rays. Since this model was introduced, a number of measurements and theoretical calculations have been made, and the theoretical results are in good agreement with the experimental for ions of above 1 MeV/u.

According to the classical collision theory, the maximum energy of secondary electron is equal to 4 mE_i/M, where E_i is the ion incident energy, M and m are the masses of the ion and electron respectively. When the ion energy is as low as that the maximum energy of secondary electron ejected through the interaction of the ion with atoms of absorbed medium is comparable with the binding energy of inner-shell electrons, the ionizing energy of electrons must be considered in more details than that of just considering it as a average energy.

2 RADIAL ENERGY DEPOSITION

From classical collision dynamics, the number of secondary electrons per unit ion

* The Project Supported by National Natural Science Foundation of China

path having energies between w and $w+dw$ liberated from matter having N free electrons per cm^3 by a passing ion of effective charge number Z_{eff} is

$$dn/dw = [2\pi N Z^2_{eff} e^4/mv^2] \cdot (1/w^2) \qquad (1)$$

where v is the incident velocity of ion. The effective charge number Z_{eff} of an atomic number Z is given by Bradt and Peters[3] as

$$Z_{eff} = Z[1 - \exp(-125\beta Z^{-2/3})] \qquad (2)$$

where $\beta = v/c$, c is the speed of light.

Assuming the secondary electrons are produced through two steps, firstly the incident ion encounters a bound electron and transmits energy $w+I_i$ to it; secondly the electron is ejected from atom and losses a binding energy I_i to overcome the interaction with atoms, the equation (1) is extended to the case of bounded electrons just by replacing w by $w+I_i$ and summing for all electrons.

According to the track structure model, the energy deposition of an ion with energy E_i is equal to

$$D(t) = -(2\pi t)^{-1}(d\varepsilon/dt) \qquad (3)$$

The ε is the energy flux carried by secondary electrons through a cylindrical surface of radial distance t whose axis is the ion path.

$$\varepsilon = \Sigma_i \int_{w_t}^{w_{im}} W(t,w)(dn_i/dw)dw \qquad (4)$$

where $w_{im} = (4mE_i/M) - I_i$, $W(t,w)$ is residual energy of electron which penetrates radial distance t from ion path. It may be written as

$$W(t,w) = w_r[w^{-1}_r(w) - t] \qquad (5)$$

$w_r(r)$ is the energy- range relation of electron. w_t is equal to $w_r(t)$.

In our present calculation, we use a new empirical energy- range relation $w_r(r)$ which is fitted to the experiment data of range r in aluminum in the range of electron energy w from 20 eV to 20 MeV by using logarithmic polynomial[4].

$$w_r(r) = \exp[\Sigma^3_{i=0} A_i(\ln r)^i] \qquad (6)$$

The constants have the values $A_0 = 3.062$, $A_1 = 0.6018$, $A_2 = -0.0011$, $A_3 = 0.0015$. The units of r and energy are mg/cm^2 and keV, respectively.

For water, the molecular H_2O has eight electrons in outer- shell and two electrons in inner- shell. Assuming all outer- shell electrons have same binding energy of 15 eV, and inner- shell electrons have same binding energy of 500 eV, the calculation of energy depositions is carried out by numerical method.

3 RESULTS

Using the new empirical energy- range relation of Eq.(6), the numerical computations of energy deposition of 33.25 MeV and 61.9 MeV I^{+53}, 42.0 MeV Br^{+35} ions have been done for liquid water. For illustrating the effects of binding energy, the energy depositions are also calculated by having binding energy $I=10$ eV as an average value. The results comparing with the experiments of Varma *et al*[5,6] are displayed in Figs.1—3.

The results show that the present results are lower than those of using binding energy $I=10$ eV as an average value, and for the lower energy of ion, the present results are in better agreement with experimental results than just considering binding energy as an average energy $I=10$ eV.

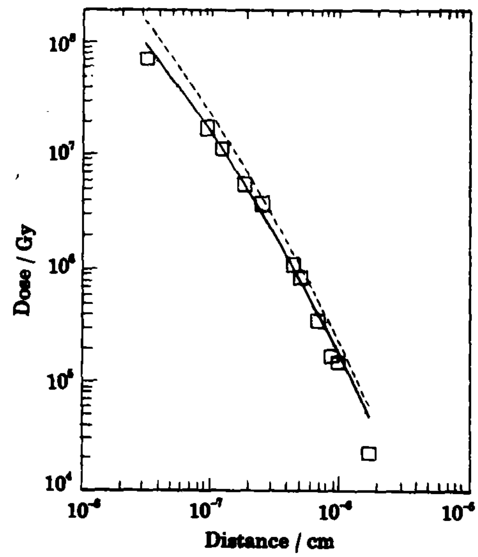
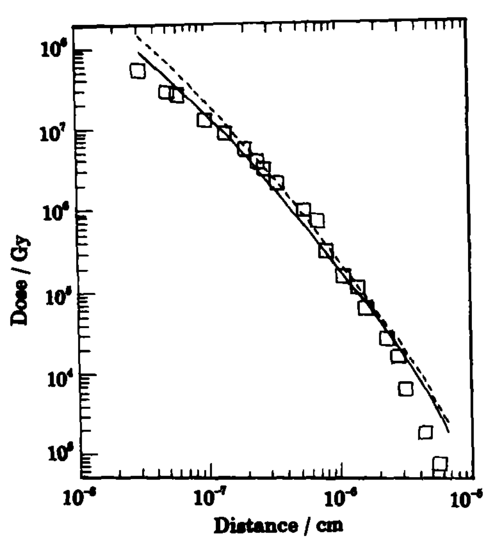


Fig.1 Energy deposition of 33.25 MeV I^{+53} ion
Solid curve: Present results; Dashed curve: The results of using binding energy $I=10$ eV as an average value; Open square: Experimental results of Varma *et al*



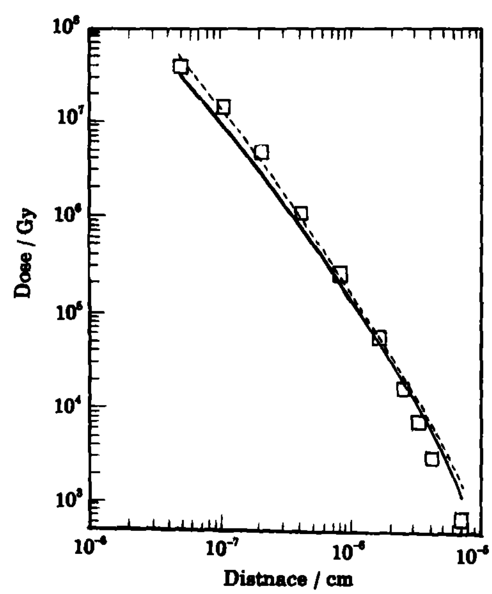


Fig.2 Energy deposition of 61.9 MeV I^{+53} ion Fig.3 Energy deposition of 42.0 MeV Br^{+35} ion
Solid curve: Present results; Dashed curve: The results of using binding energy $I=10$ eV as an average value; Open square: Experimental results of Varma *et al.*

It shows that for low energy incident ions, the binding energy of electrons must be considered in more details than as an average value.

There are some puzzling aspects of these results. If taking account of the ejecting angle of the secondary electrons as results of classical dynamics extending to bound electron

$$\cos^2 \theta_i = (w + I_i)/w_{im}$$

the results show that energy deposition approximately follows an $1/t^2$ dependence over many orders of magnitude and very close to penumbra radius there is a steeper decline. These are not in agreement with experiments well.

For interpreting this results, a theoretical treatment with more details and more accurate experimental results are required.

REFERENCES

1 Butts J J, Katz R. Radiation Res, 1967; 30:855

2 Kobetich E J, Katz R. Phys Rev, 1968; 170(2):391

3 Bradt H L, Peters B. Phys Rev, 1948; 74:1828

4 Yan Chen, Li Mianfeng, Zhang Chunxiang. Acta Scientiarum Naturalium Universitatis Sunyatsheni, 1990; 29:115

5 Varma M N, Baum J W, Kuehner A V. Phys Med Biol, 1980; 25:651

6 Varma M N, Baum J W, Kuehner A V. Radiat Res, 1975; 62:1