# EFFECTIVE ATOMIC NUMBERS OF TISSUE EQUIVALENT COMPOUNDS IN THE ENERGY REGION OF 1 TO 100 MeV FOR ELECTRONS AND IONS .

S. GURU PRASAD AND K. PARTHASARADHI*
Division of Medical Physics, Evanston Hospital, Northwestern University Medical School,
2560 Ridge Avenue, Evanston, Il 60201, U.S.A.

*Present Address:
Department of Nuclear Physics, Andhra University, Visakhapatman-530003
INDIA

**ABSTRACT**-A study of effective atomic numbers of tissue equivalent compounds has been carried out in the energy region 1 to 100 MeV for electrons and ions. It is noticed that in general the effective atomic number for electrons increases slightly with energy, for Helium ions remains more or less the same and for heavy ions it increases initially and then decreases.

## 1. INTRODUCTION

A systematic study of the interaction of photons, electrons and ions with biological materials and tissue equivalent compounds is important in the field of Radiation Physics. Accurate data about effective atomic numbers is required to evaluate the absorbed dose for the high energy beams produced by accelerators used in medicine. Reports on the attenuation coefficients and stopping powers of individual elements and a few compounds, mixtures and biological materials have appeared[1],[2]. White[4] performed a detailed study on the effective atomic numbers for photons and electrons for partial processes in biological materials. However, these studies are restricted to the Z exponents and their variation with energy. Investigations on effective atomic numbers and its variation with energy for partial as well as total interactions for photons are reported [4] in the energy region 10 to 200 KeV. On the basis of cross-section per electron, Yang et al[5] have derived effective atomic numbers which are less energy dependent in the low energy region. It appears that, in the high energy region, no study has been previously published on the total effective atomic numbers particularly for charged particles and ions. The present study is a comparison of the effective atomic numbers of tissue equivalent materials such as polyethylene, polystyrene, Nylon, Lexon, Plexiglass and Bakelite in the energy region 1 to 100 MeV for electrons and ions.

## 2. EVALUATIONS

The effective atomic numbers for photons of composite materials can be computed from the cross-section data of the con-

stituent elements according to the previous suggested procedures [5]. The mass attenuation coefficient of the composite material is the arithmetic sum of the mass attenuation coefficients of the constituent elements in the proportions they exist in the composite material (additivity law). The effective atomic number of the composite material can be directly extracted from a plot of the attenuation coefficient (expressed per atom) as a function of atomic number. Similarly, the effective numbers for the tissue equivalent materials are obtained by using the same procedures by substituting the stopping powers of electrons and ions in the place of attenuation coefficients. The proportions of the constituent elements of the materials are obtained from their chemical formulae. Mass stopping powers of the composite materials are tabulated in Table 1 and the derived effective atomic numbers are listed in Table 2. The error in the derived effective atomic numbers from the plots is of the order of 0.2.

## 3. DISCUSSION

It can be seen from Table 2 that, in general, the effective atomic numbers for the electrons increases slightly with the energy, for Helium ions it remains more or less the same and for Carbon and Neon ions it increases initially and then decreases. The effective atomic number at a particular energy depends on the relative dominations of the individual partial processes and their dependence on Z. The collisional and radiative processes are predominant for electrons. The relative contribution of the radiative process increases with the energy and has a higher Z dependence than the collisional process. Hence the effective atomic number for electrons increases with energy. Collisional loss is the dominant interaction for ions in the present energy region. Consequently, the effective atomic number for He ions remains more or less the same. However, in the case of C and Ne ions, the observed trends may be due to charge exchange effects.

In the present study the chemical effects due to elemental bonding are neglected by the application of additivity law. This effect is not well understood for ions and is not expected to be higher at higher energies [2]. The usual way for accounting for chemical effect for electrons is to use the mean excitation energy of the compound computed theoretically. The effective atomic numbers are evaluated for four materials from the available data [1],[2] and are listed in Table 3. It is seen that the chemical bonding on the effective atomic number is not very significant in those materials within the range of errors.

## REFERENCES

[1] ICRU Reports 35, and 37, Stopping Powers for Electrons and Positrons, 1984.

[2] Northcliffe, L.C. and Schlling, R.F., Range and Stopping Power Tables for Heavy Ions, Nuclear Data Tables **A7**, 233-292, 1970.

[3] Thirumala Rao, B.V., Raju, M. L. N., Narasimham, K.L., Parthasaradhi, K. and Mallikarjuna Rao, B., Interaction of low energy photons with biological materials and the Effec-

tive Atomic Numbers, Medical Physics **12**, 745-748, 1985.

[4] White, D.R., Analysis of the Z-dependence of the Photon and Electron Interactions, Physics in Medicine and Biology, **22**, 219-228, 1971.

[5] Yang, N.C., Leichner, P.K. and Hawkins, W.G., Effective Atomic Numbers for the low Energy Photon interactions in human tissues, Medical Physics, **14**, 759-766, 1987.

## TABLE 1

MASS STOPPING POWERS

ELECTRONS (MeV $cm^2/gm$)

| | Energy in MeV | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 5 | 10 | 20 | 50 | 100 |
| Polyethylene | 1.936 | 2.071 | 2.255 | 2.536 | 3.245 | 4.345 |
| Polystyrene | 1.790 | 1.911 | 2.082 | 2.353 | 3.056 | 4.174 |
| Nylon | 1.849 | 2.010 | 2.210 | 2.517 | 3.285 | 4.465 |
| Lexan | 1.749 | 1.892 | 2.078 | 2.371 | 3.124 | 4.308 |
| Plexiglass | 1.810 | 1.967 | 2.180 | 2.495 | 3.286 | 4.505 |
| Bakelite | 1.753 | 1.893 | 2.077 | 2.368 | 3.115 | 4.292 |

C IONS (MeV $cm^2/gm$)

| | Energy in MeV | | | | | |
|---|---|---|---|---|---|---|
| | 0.96 | 4.80 | 9.60 | 19.20 | 48.00 | 96.00 |
| Polyethylene | 6.415 | 11.166 | 9.671 | 6.833 | 3.649 | 2.128 |
| Polystyrene | 5.897 | 9.671 | 8.413 | 6.023 | 3.327 | 1.954 |
| Nylon | 5.602 | 10.097 | 8.729 | 6.195 | 3.394 | 1.990 |
| Lexan | 5.393 | 5.393 | 7.916 | 5.679 | 3.186 | 1.879 |
| Plexiglass | 5.358 | 9.637 | 8.336 | 5.934 | 3.285 | 1.932 |
| Bakelite | 5.444 | 9.165 | 7.961 | 5.711 | 3.119 | 1.886 |

He IONS (MeV $cm^2/gm$)

| | Energy in MeV | | | | |
|---|---|---|---|---|---|
| | 1.007 | 5.008 | 10.007 | 20.013 | 48.031 |
| Polyethylene | 2.684 | 1.138 | 0.618 | 0.347 | 0.173 |
| Polystyrene | 2.368 | 0.555 | 0.317 | 0.159 | 0.996 |
| Nylon: | 2.408 | 1.025 | 0.568 | 0.324 | 0.162 |
| Lexan: | 2.216 | 0.935 | 0.527 | 0.305 | 0.153 |
| Plexiglass: | 2.303 | 0.979 | 0.547 | 0.313 | 0.158 |
| Bakelite: | 2.230 | 0.941 | 0.530 | 0.306 | 0.154 |

Ne IONS (MeV $cm^2/gm$)

| | Energy in MeV | | | | | |
|---|---|---|---|---|---|---|
| | 0.996 | 4.998 | 9.996 | 19.992 | 49.980 | 99.960 |
| Polyethylene: | 7.101 | 18.280 | 22.012 | 18.673 | 11.708 | 7.733 |
| Polystyrene: | 6.549 | 16.129 | 18.974 | 16.259 | 10.515 | 7.076 |
| Nylon: | 6.187 | 16.401 | 19.911 | 16.764 | 10.767 | 7.210 |
| Lexan: | 5.977 | 15.096 | 17.898 | 15.229 | 9.998 | 6.789 |
| Plexiglass: | 5.917 | 15.687 | 18.998 | 15.982 | 10.336 | 6.989 |
| Bakelite: | 6.036 | 15.193 | 17.993 | 15.324 | 10.046 | 6.815 |

**TABLE 2**

EFFECTIVE ATOMIC NUMBERS

| | | Energy in MeV* | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 5 | 10 | 20 | 50 | 100 |
| Polyethylene | e | 2.6 | 2.5 | 2.5 | 2.6 | 2.8 | 3.1 |
| | He | 3.0 | 2.7 | 2.5 | 2.6 | 2.7 | - |
| | C | 2.8 | 3.0 | 2.8 | 2.6 | 2.5 | 2.5 |
| | Ne | 2.8 | 3.1 | 3.0 | 2.7 | 2.5 | 2.6 |
| Polystyrene | e | 3.5 | 3.5 | 3.6 | 3.6 | 3.8 | 4.0 |
| | He | 3.7 | 3.6 | 3.3 | 3.4 | 3.5 | - |
| | C | 3.2 | 3.8 | 3.8 | 3.5 | 3.4 | 3.4 |
| | Ne | 3.1 | 3.7 | 4.0 | 3.7 | 3.3 | 3.4 |
| Nylon | e | 3.3 | 3.3 | 3.3 | 3.5 | 3.6 | 4.0 |
| | He | 3.4 | 3.2 | 3.1 | 3.1 | 3.2 | - |
| | C | 3.0 | 3.7 | 4.1 | 3.2 | 3.1 | 3.2 |
| | Ne | 2.9 | 3.5 | 3.8 | 3.3 | 3.2 | 3.1 |
| Lexan | e | 4.2 | 4.2 | 4.3 | 4.4 | 4.5 | 4.6 |
| | He | 4.0 | 4.1 | 3.9 | 3.9 | 4.0 | - |
| | C | 3.4 | 4.3 | 5.0 | 4.0 | 3.9 | 4.0 |
| | Ne | 3.2 | 4.0 | 4.6 | 4.2 | 3.9 | 3.9 |
| Plexiglass | e | 3.6 | 3.7 | 3.8 | 4.0 | 4.2 | 4.3 |
| | He | 3.7 | 3.6 | 3.4 | 3.4 | 3.5 | - |
| | C | 3.1 | 3.8 | 4.0 | 3.6 | 3.4 | 3.5 |
| | Ne | 3.0 | 3.7 | 4.2 | 3.2 | 3.4 | 3.5 |
| Bakelite: | e | 4.0 | 4.1 | 4.2 | 4.4 | 4.5 | 4.6 |
| | He | 4.0 | 4.1 | 3.8 | 3.9 | 4.0 | - |
| | C | 3.4 | 4.3 | 4.9 | 3.9 | 3.9 | 3.9 |
| | Ne | 3.2 | 3.9 | 4.8 | 4.2 | 3.9 | 3.9 |

*The ion energies are very close to the energies mentioned.

**TABLE 3**

EFFECTIVE ATOMIC NUMBERS FOR ELECTRONS

| | | Energy in MeV | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 5 | 10 | 20 | 50 | 100 |
| Nylon | w/o | 3.3 | 3.3 | 3.3 | 3.5 | 3.6 | 4.0 |
| | wc | 3.2 | 3.2 | 3.1 | 3.3 | 3.4 | 4.7 |
| Lexan | w/o | 4.2 | 4.2 | 4.3 | 4.4 | 4.5 | 4.6 |
| | wc | 4.1 | 4.1 | 4.1 | 4.2 | 4.4 | 4.5 |
| Polyethylene | w/o | 2.6 | 2.5 | 2.6 | 2.6 | 2.8 | 3.1 |
| | wc | 2.6 | 2.5 | 2.5 | 2.5 | 2.7 | 2.9 |
| Polystyrene | w/o | 3.5 | 3.5 | 3.6 | 3.6 | 3.8 | 4.0 |
| | wc | 3.5 | 3.5 | 3.5 | 3.6 | 3.7 | 3.9 |

w/o - without chemical effect
wc - with chemical effect