Pramāṇa, Vol. 18, No. 2, February 1982, pp. 121-126. © Printed in India.

Mass absorption coefficients and range of beta particles in Be, Al, Cu, Ag and Pb

NATHU RAM, I S SUNDARA RAO and M K MEHTA*
Radiological Standards Laboratory, Division of Radiological Protection,
*Nuclear Physics Division, Bhabha Atomic Research Centre,
Trombay, Bombay 400 085, India

MS received 19 September 1981; revised 28 December 1981

Abstract. It is demonstrated that the practical range of a beta spectrum ($E_{max} = E$) in any material can be obtained from mass absorption coefficient (μ/ρ) values. It is further shown that a semiempirical relation like $\mu/\rho = AE^{-B}$ in which A and B are related to the atomic number Z, of the absorber can be used for determining μ/ρ of any material of known atomic number Z. The β particle ranges are compared with theoretical CSDA and practical ranges from literature.

Keywords. Attenuation of beta particles; passage of beta particles through matter; range of beta particles.

1. Introduction

Several measurements on transmission of electrons and positrons in various elements, liquids and compounds have been reported in literature (Katz and Penfold 1952; Gosslett and Thomas 1964; Takhar 1967). These measurements were made to study the range-energy relationships. Other workers (Seliger 1955; Takhar 1968; Patrik and Rupaal 1971; Thontandarya and Umakantha 1971; and Nathuram *et al* 1981) have also reported transmission studies but these were intended to compare the ranges of electrons and positrons. Using the published results of several workers, Tabata *et al* (1972) proposed a semiempirical relation applicable to monoenergetic electrons from which the extrapolated range of electrons of energy between 0·3 keV to 30 MeV can be determined for any desired material of $Z = 1$ to $Z = 92$. There is also a theoretical compilation of electron and positron ranges by Berger and Seltzer (1964) based on continuous slowing down approximation model (R_{CSDA}). Recently Batra and Sehgal (1981) have reported a theoretical method for determining the practical range of monoenergetic electrons and positrons. The literature referred to above is for monoenergetic particles. However, radiation physicists often need information on transmission of continuous beta spectra for which no simple relation is yet available. The present work, therefore, is an attempt to establish a semiempirical relation based on particle transmission experiments. It is demonstrated that the mass attenuation coefficients value (μ/ρ) for any beta spectrum in a chosen absorber material can be determined from the semiempirical relation and the range of beta particles* corresponding to 5% transmission can be readily

*Beta particles refer to continuous emission of electrons from radioactive sources whereas monoenergetic electrons refer to emission of electrons produced by other means.

determined applying the Katz and Penfold (1952) relationship between the range and μ/ρ value.

2. Details of experimental work

The procedure for determining the mass absorption coefficient and beta particle range consisted of the following—(a) experimental determination of mass absorption coefficients of beta particles chosen to cover the energy† range of 0·167 MeV to 3·6 MeV and in elemental solids whose atomic number ranged from 4 to 82, (b) relating E_{max}, Z and (μ/ρ) empirically so that (μ/ρ) value for any other elemental or composite material of known effective Z can be found and (c) determining the range of beta particles corresponding to 5% transmission applying the Katz and Penfold formula.

The experimental arrangement is schematically shown in figure 1. A narrow beam of beta particles of about 2 mm diameter was allowed to incident on the window of a gas flow proportional counter placed at about 10 cm from the source. The radionuclides selected for this study were ^{35}S(0·167), ^{147}Pm(0·225), ^{204}Tl(0·760), ^{32}P(1·71), ^{90}Y(2·27) and ^{42}K(3·60) where the number in bracket indicates the beta energy in MeV. Each source consisted of about 5 microcuries of chosen beta radionuclide placed in a shielded container provided with 5 cm long collimator. The proportional counter had a 4 cm diameter window of aluminised mylar having 1 mg/cm^2 surface density. Commercial fuel gas Burshane was flown through the counter at a steady rate of about 10 ml/min. The principal constituents of the flow gas are butane and propane but its exact composition is not readily available. Burshane as a flow gas gave excellent reproducibility of plateau length, starting potential, etc. The absorbers were placed close to the window of the counter so that almost all the transmitted particles could be detected. The absorbers were of 99·9% purity available as thin foils of uniform thickness. The proportional counter was operated in plateau region and was used with standard counting system. The absorber thickness was increased in

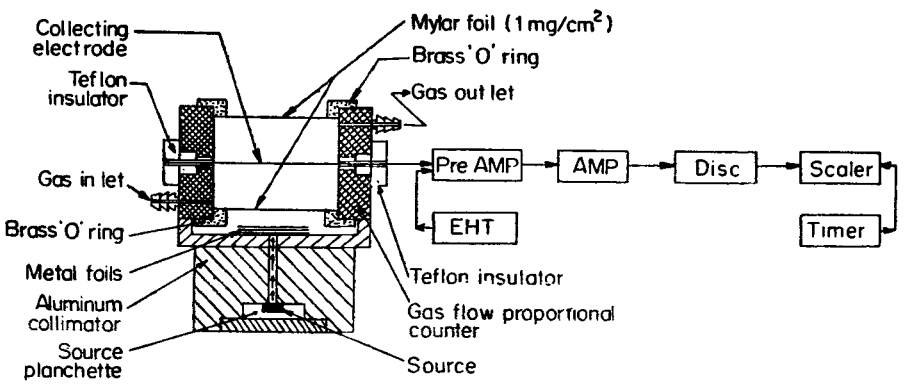

Figure 1. Schematic diagram of electron counting system.

†Energy refers to maximum energy of the beta spectrum.

steps and the corresponding transmitted particles were counted in preset count mode in which the time for 10,000 counts was noted. The counting rates corrected for background and resolving time were determined for each absorber thickness. The shape of the absorption curve on semilog graph was initially convex towards the origin (as expected because of the low energy component of β spectrum) and became a straight line representing the exponential nature of beta absorption. The mass absorption coefficients were determined from least square fit of experimental data on the linear part of the curve. The values of mass absorption coefficients thus obtained when plotted against beta energy (E) on a log-log graph for each element, represents a set of nearly parallel lines which could be fitted to an empirical relation of the form $\mu/\rho = AE^{-B}$, where A and B are empirical constants. A and B were found to vary with atomic number Z of the absorbers as shown in figure 2. The overall uncertainty in the experimentally determined values of (μ/ρ) is believed to be less than $\pm 3\%$. This uncertainty had the following components: counting statistics, thickness and uniformity of absorber foils and the least square fitting error of the experimental data, all added in quadrature. The magnitude of total error against each value is shown in table 1.

Table 1. Mass absorption coefficients (μ/ρ) in $cm^2 \cdot g^{-1}$ of beta particles in Be, Al, Cu, Ag and Pb.

Radio-nuclide	Energy (MeV)	Beryllium	Aluminium	Copper	Silver	Lead
^{35}S	0·167	245·0 ± 7·2	271·9 ± 8·1	317·7 ± 9·3	349·3 ± 10·1	376·6 ± 11·2
^{147}Pm	0·225	131·6 ± 4·0	177·3 ± 4·7	205·0 ± 5·6	235·8 ± 6·4	244·0 ± 6·7
^{204}Tl	0·760	18·7 ± 0·37	24·2 ± 0·48	26·2 ± 0·5	32·8 ± 0·6	35·4 ± 0·7
^{32}P	1·710	6·6 ± 0·13	8·4 ± 0·16	11·6 ± 0·22	12·3 ± 0·24	14·8 ± 0·3
^{90}Y	2·270	3·1 ± 0·06	5·0 ± 0·1	5·9 ± 0·1	7·3 ± 0·15	8·3 ± 0·16
^{42}K	3·600	1·7 ± 0·03	3·2 ± 0·06	3·6 ± 0·065	4·3 ± 0·077	4·8 ± 0·086

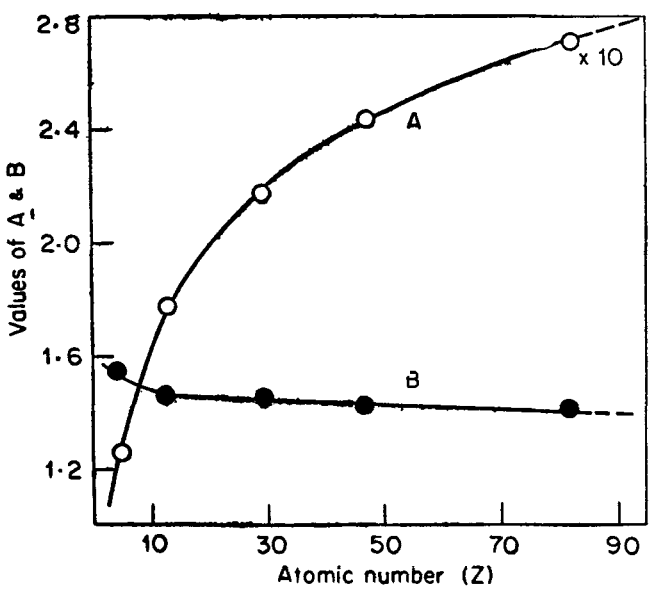

Figure 2. Variation of constants A and B with atomic number of the absorber.

3. Determination of beta particle range

The values of mass absorption coefficients of six radionuclides emitting beta particles of maximum energy 0·167 MeV to 3·6 MeV in Be, Al, Cu, Ag and Pb are shown in table 1. The ranges $R_{0.05}$ corresponding to 5% transmission of beta particles in each element obtained by combining the corresponding values of μ/ρ from table 1 and I/I_0 in $R_{0.05} = \log (I/I_0)/(\mu/\rho)$ are tabulated in table 2. The values of $R_{0.05}$ are less when compared with extrapolated range (Tabata *et al* 1972) or practical (Batra and Sehgal 1981) range for monoenergetic electrons in corresponding elements. This difference can be attributed to the fact that the published results are applicable to monoenergetic electrons, whereas our results are for continuous beta spectrum. Since $R_{0.05}$ decreases and R_{CSDA} (Berger and Seltzer 1964) increases with Z, the ratio $R_{0.05}/T_{CSDA}$ (table 3) also decreases with Z implying larger values of $R_{0.05}$ in low Z and smaller values in high Z materials. The interpolated values of μ/ρ for some rare earth elements (Y, Nd, Ho, Nb) for a chosen beta energy of 1·77 MeV (^{86}Rb) obtained by combining the values of A and B from figure 2 when compared with published values (Takhar 1967) show good agreement in case of Y and Nb (table 4). However, our values for these elements are lower and consistently increasing with Z. The values determined from interpolation may not be justified because experimentally measured values represent the true picture and may reflect difference due to crystal structure or electronic configuration of rare earth elements. The μ/ρ values

Table 2. Range $R_{0.05}$ of beta particle of various energies in Be, Al, Cu, Ag and Pb.

Energy	Range $R_{0.05}$ (g.cm^2)				
	Be	Al	Cu	Ag	Pb
0·167	0·012	0·011	0·0095	0·0086	0·0082
0·225	0·022	0·017	0·015	0·013	0·012
0·760	0·157	0·124	0·114	0·091	0·083
1·710	0·452	0·352	0·260	0·238	0·204
2·27	0·965	0·595	0·500	0·408	0·360
3·60	1·750	0·940	0·835	0·700	0·615

Table 3. Ratio of ranges $R_{0.05}/R_{CSDA}$ for beta particles of various energies in Be, Al, Cu, Ag and Pb.

Energy	Ratio $R_{0.05}/R_{CSDA}$				
	Be	Al	Cu	Ag	Pb
0·167	0·30	0·24	0·19	0·14	0·11
0·225	0·31	0·24	0·19	0·14	0·11
0·760	0·42	0·33	0·26	0·19	0·15
1·710	0·45	0·34	0·26	0·20	0·15
2·270	0·69	0·40	0·32	0·25	0·17
3·600	0·74	0·41	0·36	0·28	0·23

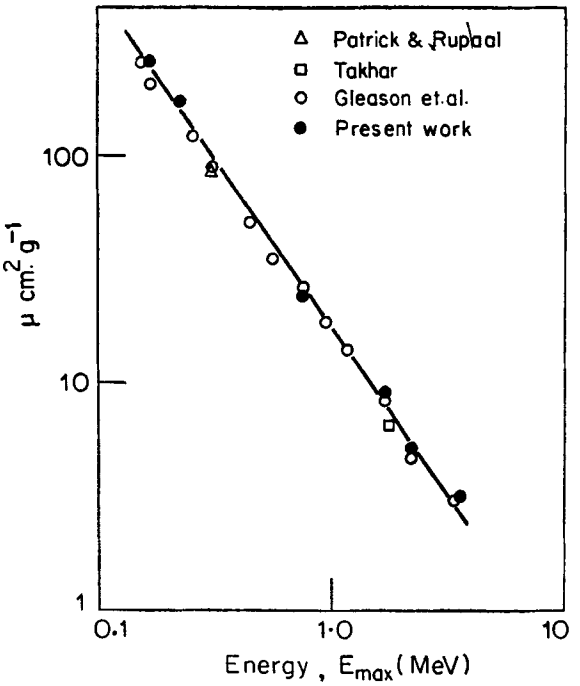

Figure 3. Mass absorption coefficient of beta particles in aluminium.

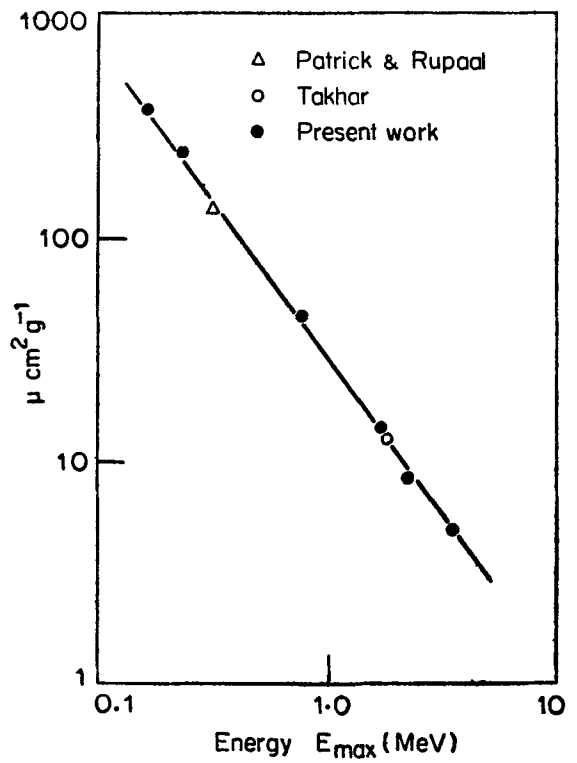

Figure 4. Mass absorption coefficient of beta particles in lead.

Table 4. Comparison of mass absorption coefficient of some rare earth elements for beta particles of 1·77 MeV.

Element	Mass absorption coefficient μ/ρ (cm^2 g^{-1}) (Present work)	(Takhar)
Y	10·22	10·9 ± 0·23
Nd	11·38	13·6 ± 0·23
Ho	11·65	13·4 ± 0·38
Nb	11·91	11·97 ± 0·24

of Patrick and Rupaal at 0·312 MeV, of Takhar at 1·77 MeV in Al and Pb and of Gleason *et al* (1951) for 0·154-3·55 MeV in Al fit the curve (figures 3, 4) obtained in this work.

4. Conclusion

In the present work, the transmission of beta particles for a range of absorbers and energy has been measured down to a value of about 5% transmission. The extended range of transmission measurement has enabled high accuracy in the value of μ/ρ and extrapolated range determined in this work. An empirical relation has been established between μ/ρ and E_{max} (E) as $\mu/\rho = AE^{-B}$ where A and B are function of Z. Thus it will be possible to determine (μ/ρ) for any absorber for a specified beta spectrum. The agreement between the interpolated and measured value established the confidence based on interpolation.

References

Batra R K and Sehgal M L 1981 *Phys. Rev.* **B23** 4448
Berger M J and Seltzer S M 1964 National Aeronautic Space Agency Report No. 1133, 205
Gosslett V E and Thomas R N 1964 *Br. J. Appl. Phys.* **15** 883
Gleason G I, Taylor J D and Taberen D L 1951 *Nucleonics* **8** 12
Katz L and Penfold A S 1952 *Rev. Mod. Phys.* **24** 28
Nathu Ram, Sundara Rao I S and Mehta M K 1981 *Phys. Rev.* **A23** 1202
Patrick J R and Rupaal A S 1971 *Phys. Lett.* **A35** 235
Seliger H H 1955 *Phys. Rev.* **100** 1029
Tabata T, Ito R and Okabe S 1972 *Nucl. Instrum. Methods* **103** 85
Takhar P S 1967 *Phys. Rev.* **157** 257
Takhar P S 1968 *Phys. Lett.* **284** 425
Thontandarya S R and Umakantha N 1971 *Phys. Rev.* **134** 1632