Ancient TL

www.ancienttl.org · ISSN: 2693-0935

Bowman, S. and Huntley, D., 1984. *A new proposal for the experssion of alpha efficiency in TL dating.* Ancient TL 2(1): 6-8. https://doi.org/10.26034/la.atl.1984.068

A NEW PROPOSAL FOR THE EXPRESSION OF ALPHA EFFICIENCY IN TL DATING

S. G. E. Bowman
Research Laboratory
British Museum
London, WC1B 3DG
England

D. J. Huntley
Physics Department
Simon Fraser University
Burnaby, B.C.
Canada V5A 1S6

In dating, the first description of the thermoluminescence (TL) efficiency of alpha relative to beta radiation was in terms of the k-value (Zimmerman, 1971) defined as the ratio of TL per unit of absorbed alpha dose to the TL per unit of absorbed beta dose (by beta we mean beta or gamma throughout). For alpha particles the TL per unit dose, and therefore the k-value, varies with the alpha energy. The TL per unit of alpha particle track length, however, is nearly independent of energy. This fact led to the introduction of the presently used a-value system (Aitken and Bowman, 1975). In this note we continue in a similar vein, but rewrite the alpha particle contribution to the dose-rate in a form which we believe to be more easily understood.

For beta radiation we assume that the TL per unit of absorbed energy is a constant independent of the energy of the particle. To begin with we also assume that the TL per unit track length is the same for alpha particles of all energies. With this in mind, the natural parameter to introduce is the beta energy that yields the same amount of TL as one unit length of alpha track. That is the ratio

$$\frac{TL \;\; per \;\; unit \;\; alpha \; track \;\; length}{TL \;\; per \;\; unit \;\; absorbed \;\; beta \; energy} \qquad (1)$$

which has units of J m^{-1} in the SI system.

This is closely, and very simply, related to what is actually measured in a standard laboratory determination of the relative alpha efficiency. In this, an alpha source, which delivers a known track length per unit volume per unit time, is used to irradiate a sample thinner than the individual alpha track lengths, and the resulting TL is compared to that induced by a known beta dose. This experimental ratio we define now as a new parameter

$$b = \frac{TL \;\; per \;\; unit \;\; alpha-track-length-per-unit-volume}{TL \;\; per \;\; unit \;\; of \;\; absorbed \;\; beta \; dose} \qquad (2)$$

and find it is related to (1) by the sample density,

$$b = \frac{TL \;\; per \;\; unit \;\; track \;\; length}{TL \;\; per \;\; unit \;\; absorbed \;\; beta \; energy} \times \frac{1}{density} \qquad (3)$$

In the SI system the unit of b is Gy m^2.

We now derive the alpha equivalent dose term in the age equation for the case where thick-source alpha counting measurements are to be used. We define λ to be the total surface alpha emission rate per unit area and time. This is related to the activities (disintegrations per unit mass and time), A_i, of the isotopes, and their corresponding alpha particle ranges, $R_i\rho$ (length x density), by

$$\lambda = \frac{1}{4} \sum_i A_i R_i \rho \qquad (4)$$

The rate at which alpha track length is generated per unit volume is $\sum_i A_i R_i \rho = 4\lambda$. Thus for a sample of age T, the beta equivalent dose due to the alpha particles is

$$ED_\alpha = 4\lambda b T \qquad (5)$$

To this equation two minor modifications are required. The first is due to the observation that the TL per unit track length may not be constant for alpha particles with energies less than about 2 MeV. To allow for this the right hand side of (5) must be multiplied by a dimensionless factor η (defined by equation 7 of Aitken and Bowman) for which the best estimate is still 0.90 ± 0.05 (see below).

The second modification arises because in practice it is conventional in thick-source alpha counting to count 82% of the alpha particles from the uranium chain and 85% from the thorium chain. Denoting these measured count rates by λ_U and λ_{Th} respectively we obtain finally

$$ED_\alpha = 4\eta \left\{ \frac{\lambda_U}{0.82} + \frac{\lambda_{Th}}{0.85} \right\} bT \tag{6}$$

In practice then, one uses equation (2) to determine 'b' and equation (6) for the alpha term in the age equation.

We now relate the above 'b-value' to the 'a-value' of Aitken and Bowman. We must first note that in all the above equations one can adopt any system of units one wishes. The 'a-value', on the other hand, is defined by

$$a = \frac{x}{1300S} \tag{7}$$

where x is the number of rads of beta irradiation that produce the same TL as 1 minute of alpha irradiation from a source of strength S μm^{-2} min^{-1}. For the same measurements equation (2) yields b (in rads μm^2) = x/S. Thus we have

$$b \ (in \ Gy \ \mu m^2) = 13a \quad . \tag{8}$$

Thus, for example, if a = 0.1 then b = 1.3 Gy μm^2, meaning that a beta dose of 1.3 Gy yields the same TL as one normally incident alpha particle per square micrometre.

Apart from presenting the track length system in a form that we believe to be easier to assimilate, there are two significant advantages to the new proposal. The first is the absence of the arbitrary value of 1300 introduced by Aitken to make the a-value numerically the same as the old K-value at an energy of 3.7 MeV. This avoids any confusion of the track length system with that based on absorbed alpha dose. The second advantage relates to the definition of the a-value. Although the a-value is dimensionless, as defined above its evaluation requires the use of specific units i.e. μm and rads, the latter of which is not an SI unit. Only by changing the definition of the a-value could the use of grays be achieved, even so it would still be necessary to use the units specified in the new definition. The b-value, on the other hand, allows freedom of choice of units and, in particular, consistency with the SI system.

POSTSCRIPT

To this note we would like to add the following points related to the application of the b-value system.

(1) When equal uranium and thorium parent activities and full chain equilibrium are assumed, 52% of the alpha count-rate above the threshold is due to uranium and 48% to thorium. Equation (6) then becomes

$$ED_\alpha = 4.80\eta\lambda bT \tag{9}$$

and taking $\eta = 0.9$, we have

$$ED_\alpha = 4.32\lambda bT \tag{10}$$

(2) It has been assumed throughout that η is independent of which series predominates. Strictly equation (6) should be

$$ED_{\alpha} = 4\left\{\frac{\eta_U \lambda_U}{0.82} + \frac{\eta_{Th} \lambda_{Th}}{0.85}\right\} bT \qquad (11)$$

For full chain equilibrium, however, η_{Th} is only 1.5% higher than η_U and the average value of 0.90 has been used when the two chains are of approximately equal activities (Bowman, 1976).

If one chain predominates, as for example uranium in flint (Bowman et al., 1982), the small spectrum dependence of η which appears to exist, partially balances that of the threshold factor. The equivalent alpha dose for the individual series are then:

	U	*Th*
full chain	4.36λbT	4.28λbT
pre-Rn	4.44λbT	4.44λbT

The dependence on which series is dominant and on gas escape is therefore small, and for all practical purposes can be ignored (see also Aitken, 1983) when the error on η is considered. The value of η recommended for use in dating is 0.90 ± 0.05 (Bowman, 1976). This value is based on measurements on a variety of materials of TL versus alpha energy for energies up to 7.3 MeV. The error on η, considered to be systematic, relates to the variation in results for the different minerals and to the uncertainty regarding the reason for the rapid fall in TL observed in some samples for energies less than 2 MeV. This fall-off could be a genuine effect caused by decrease in energy or be due to agglomeration of grains during deposition which produce a sample thickness that exceeds the alpha particle range.

(3) In deriving the equations for the alpha equivalent dose it was implicitly assumed that in the b-value measurement all alpha particles used were sufficiently energetic that the TL was proportional to the alpha track length. The fall in TL per track length for energies below about 2 MeV necessitates the use of a source and geometry such that all alpha particles have at least 2 MeV after passing through the sample. Singhvi and Aitken (1978) showed that their alpha irradiator, in which ^{241}Am sources are used in vacuum, is satisfactory in this respect when used with one of the type AMM.7 10 μCi foil sources from the Radiochemical Centre, Amersham, UK, and provided the source to sample distance was at least 10 mm. The energy of the alpha particles from this source was 4.9 MeV. Another, stronger, source of type AMM.3 from the same company, and as normally used in the Singhvi and Aitken six-seater irradiator, emitted alphas of only 4.2 MeV and Aitken (personal communication) has pointed out that the typical energy shown for ^{241}Am foil sources in the Radiochemical catalogue is only 4 MeV. For these the 2 MeV requirement will not be satisfied by oblique alpha particles from a source at a distance of 10 mm from a sample assumed to be 8 μm thick.

ACKNOWLEDGEMENTS

We would like to thank Dr. M. J. Aitken and Dr. M. S. Tite for reading the manuscript and making helpful suggestions.

REFERENCES

Aitken, M. J., 1983, PACT, *9*, 69-71.

Aitken, M. J. and Bowman, S. G. E., 1975, Archaeometry, *17*, 132-138.

Bowman, S. G. E., 1976, Unpublished D. Phil. Thesis, Oxford University.

Bowman, S. G. E., 1982, PACT, *6*, 61-66.

Bowman, S. G. E., Loosemore, R. P. W., Sieveking, G de G, and Bordes, F., 1982, PACT, *6*, 362-369.

Singhvi, A. K. and Aitken, M. J., 1978, Ancient TL, *3*, 2-9.

Zimmerman, D. W., 1971, Archaeometry *13*, 29-52.