NON-LINEAR GROWTH:
ALLOWANCE FOR ALPHA PARTICLE CONTRIBUTION

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This note points out that when there has been an appreciable alpha particle contribution to the natural TL, techniques for dealing with some types of non-linear growth of TL with dose may need to be more complex than those presently employed. This need arises because the non-linearity observed for beta or gamma dosage does not represent the behaviour for alpha dosage. The familiar supralinearity observed in the low dose region for beta or gamma irradiation is absent for alpha irradiation, and, as regards the non-linearity associated with the onset of saturation it has been reported by Zimmerman (1972, figs. 6-9) that for the five substances investigated the departure from linearity occurred at an order of magnitude lower dose for beta irradiation than for alpha irradiation.

The reason for these differences in response is that whereas beta or gamma irradiation results in an effectively uniform dosage of the whole volume of the sample (except at doses low enough for the particle tracks not to be fully overlapping), for alpha irradiation the dosage is contained in discrete cylinders along the track of the ~~particle and~~ within the central portion of these cylinders the dosage is so high that the TL is in saturation. This is the accepted explanation for the low TL effectiveness of alpha radiation (Aitken, Tite and Fleming, 1967), firmly established by Zimmerman (1972). Thus for alpha particles the observed TL is equal to the product of the (TL per track) x (number of tracks in the sample); since each track is in virgin territory and therefore not influenced by earlier irradiation, the TL is simply proportional to the number of tracks and hence the growth of TL with dose is linear - until the level of irradiation is so heavy that there is appreciable overlap of tracks. With lightly ionizing particles, overlap begins much earlier so that the TL per track changes because of the earlier dosage received by the volume of sample concerned.

Consequences

This difference in behaviour needs to be considered whenever there is non-linear growth and an appreciable alpha contribution to the natural TL (as may be the case not only for the fine-grain technique but also for coarse grains when there is alpha activity within the grain - as in flint and calcite dating). A curve fitted to the growth characteristic obtained for beta or gamma dosage does not then give a valid representation of the growth during antiquity. Similarly when using the regeneration technique in sediment dating (method *a* of Wintle and Huntley, 1980) the paleodose derived by finding the beta (or gamma) dose needed to induce TL equal to the level of the natural TL is liable to lead to an erroneous age - as illustrated shortly by a worked example.

Supralinearity correction

First, however, a recapitulation is given of the basis for correction for supralinearity in the low dose region. As long as the growth characteristic consists of an initial upward curving portion followed by a linear portion, and the level of the natural TL is on the latter, the correction is exact.

The growth of alpha induced TL may be represented by

$$G_{\alpha} = \chi_{\alpha} D_{\alpha} \qquad (1)$$

where χ and D represent (TL per unit dose) and dose respectively. As regards the growth of TL induced by beta, gamma and cosmic radiation the linear portion of the characteristic may be represented by

$$G_\beta = \chi_\beta (D_\beta - I) \tag{2}$$

where the suffix β is to be taken as referring to all these three types of lightly-ionizing radiation, and, I is the intercept of the straight line on the dose axis. Obviously this representation of the characteristic is not correct other than for TL levels which lie on the linear portion.

The natural TL may be written as

$$G_N = \chi_\alpha \dot{D}_\alpha A + \chi_\beta (\dot{D}_\beta A - I) \tag{3}$$

where $\dot{D}$ represents annual dose, and A represents age. If we now introduce Q_β as the beta dose equivalent to G_N, then

$$\chi_\beta Q_\beta = G_N \tag{4}$$

In practice Q_β is obtained as the intercept of the first-glow growth line obtained by measuring the TL from undrained portions which have been given additional beta doses. As so defined Q_β does not have any physical meaning unless there is linearity in this growth. Further we define the relative alpha effectiveness as

$$k = \chi_\alpha / \chi_\beta \tag{5}$$

From (3), (4) and (5), we have

$$A = \frac{Q_\beta + I}{k\dot{D}_\alpha + \dot{D}_\beta} \tag{6}$$

This follows *exactly* and does not involve any approximation in respect of the alpha growth as is sometimes thought. The condition of applicability is that all the TL levels concerned lie on the linear portion of the growth characteristic. We may note incidentally that the analysis applies also in the case of I being negative so that (6) can be used in the case of a growth characteristic consisting of a concave-down initial curve followed by a linear portion such as might be given by two component growth in which one component saturates early.

In the preceeding χ refers to first-glow growth. In order to evaluate the intercept I it is necessary to use second-glow growth measurements. It has to be assumed that I is the same for both but it does not matter if there has been a change in slope between first-glow and second-glow. The validity of evaluating the supralinearity correction by means of a second-glow measurements is a matter of *ad hoc* test for the type of sample concerned; data relevant to this have been reported, for instance by Bowman (1975), by Fleming (1975), and by Huxtable and Murray (1980).

The regenerative technique: a worked example

To illustrate that appreciable error can arise in the case of non-linear beta (or gamma) growth we take the form of that growth to be a saturating exponential, *i.e.*, instead of equation (2) the growth is given by

$$G_\beta = \chi_\beta D_o \ (1 - \exp(-D_\beta / D_o)) \tag{7}$$

where χ_β is now the (TL per unit dose) for $D_\beta << D_o$, and D_o is a constant indicative of the dose level at which saturation effects become serious. The natural TL is now given by

$$G_N = \chi_\alpha \dot{D}_\alpha A + \chi_\beta D_o \ \{1 - \exp(-\dot{D}_\beta A / D_o)\} \tag{8}$$

In the regenerative technique the paleodose is evaluated by finding the beta (or gamma) dose necessary to induce in a bleached sample a level of TL equal to the natural TL, *i.e.*, it is the value of D_β which on substitution into (7) makes $G_\beta = G_N$. We are taking these levels of TL to be the levels above any residual unbleachable component.

For the example we take

$$\dot{D}_\beta A = \frac{1}{2} D_o \tag{9}$$

and

$$\chi_\alpha \dot{D}_\alpha = \frac{1}{2} \chi_\beta \dot{D}_\beta \tag{10}$$

These conditions give the paleodose, P_β, as

$$P_\beta = 2.06 \dot{D}_\beta A \tag{11}$$

If we now derive the age as

$$A_1 = \frac{P_\beta}{k_1 \dot{D}_\alpha + \dot{D}_\beta} \tag{12}$$

where $k_1 = \chi_\alpha / \chi_\beta$, we obtain

$$A_1 = 1.38 A \tag{13}$$

i.e., and overestimate by 38%.

An alternative way of introducing the reduced alpha effectiveness is to use $k_2 = P_\beta / P_\alpha$ where P_α is the value of D_α which when substituted into (1) gives $G_\alpha = G_N$, the latter being as in (8). For the same conditions (9) and (10) as before we find

$$P_\alpha = 1.29 \chi_\beta \dot{D}_\beta A / \chi_\alpha \tag{14}$$

and if the age is derived on the basis of

$$A_2 = \frac{P_\beta}{k_2 \dot{D}_\alpha + \dot{D}_\beta} \tag{15}$$

we obtain

$$A_1 = 1.15 A \tag{16}$$

i.e., the overestimate is less but still significant.

On the other hand if the non-linearity in the beta growth is a form of low-dose supralinearity as described by equation (2) then the age is given correctly by

$$A = \frac{P_\beta}{k \dot{D}_\alpha + \dot{D}_\beta} \tag{17}$$

where P_β is the value of D_β which on substitution into (2) makes G_β equal to the natural TL, and $k = \chi_\alpha / \chi_\beta$. Unlike correction for supralinearity in the additive dose technique it is now necessary that the TL sensitivities, as well as *I*, for regenerated TL are the same as during antiquity.

Conclusion

When there is appreciable non-linearity in the beta growth, as in the worked example, then except in the simple case described by equation (2), using this beta non-linearity to infer the form of the growth during antiquity is likely to give rise to a significant overestimate of the age if the alpha contribution to the TL is sizeable. At any rate in the case of the regeneration technique used in sediment dating the error is reduced by using the ratio of beta paleodose to the alpha paleodose for the relative alpha effectiveness, as in equation (15).

The preferred procedure is of course to construct a combined alpha and beta growth characteristic, the components being in proportion to the respective annual doses.

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