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Alpha particle effectiveness: numerical relationship between systems

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There are now four systems: the original k-value system formalized by Zimmerman (1971), the a-value system of Aitken and Bowman (1975), the b-value system of Bowman and Huntley (1984), and the omnidirectional flux system in use at Gif-sur-Yvette (Guerin and Valladas 1980; Valladas and Valladas, 1982; Guerin 1982; Valladas 1985); the latter system deals also with response of coarse grains to an external alpha flux. The purpose of this note is to collate, for convenience, numerical relationships between the various coefficients.

In the k-value system (though Zimmerman used the symbol ε in place of k) the basic definition is:

$$k_{3.7} = \frac{\text{TL/gray for 3.7-MeV alpha particles}}{\text{TL/gray for beta irradiation}}$$

The alpha particles received during antiquity have a spectrum that spreads from 8.8 MeV to zero and to make allowance for this Zimmerman introduced k_{eff}, which for a sample having equal thorium and uranium activities is equal to 0.83 $k_{3.7}$. The drawback to this system is that the value obtained is strongly dependent on particle energy, as also is the absorbed dose. The other three systems are based on the approximation that the TL per unit length of alpha particle is independent of particle energy. This was implicit in the work of Zimmerman and was demonstrated explicitly by Bowman (1976) for a variety of TL phosphors.

The first of these systems was based on the definition

$$a = x'/1300S \qquad (1)$$

where x' rads is the beta (or gamma) dose necessary to induce the same level of TL as 1 minute's irradiation by an alpha source of strength S micron^{-2} minute^{-1}; this latter represents the rate at which track length is delivered to unit volume of the sample. If grays are used instead rads then the definition becomes

$$a = x/13S \quad (2)$$

The numerical factor is equal to the energy loss per micron for a 3.7 MeV alpha particle in quartz divided by the density, i.e. (13S) is the dose-rate for an alpha source delivering 3.7 MeV alpha particles to a thin sample of quartz. Hence a, like k, is dimensionless and the value obtained for quartz, measured on the basis of equation (2), is by definition equal to $k_{3.7}$; the value obtained for a is only weakly dependent on particle energy (to the extent that the TL per unit length of track does have some dependence on particle energy) whereas to measure (or use) k the particle energy must be specified. For a sample having an alpha stopping power ratio r relative to quartz,

$$a = r\, k_{3.7} = r.k_{eff}/0.83 \quad (3)$$

The b-value system avoids any numerical factor in the definition of b, which is,

$$b = \frac{\text{TL per unit alpha track length per unit volume}}{\text{TL per unit absorbed beta dose}} \quad (4)$$

Unlike a, b is not dimensionless and if it is expressed in terms of (gray micron^2),

$$b = 13\, a \quad (5)$$

The Gif system if similar to the b-value system except that the units used are (rad cm^2), so that

$$S_\alpha = 10^{-6} b \quad (6)$$

where S_α represents the beta rads necessary to match the TL level due to a perpendicular alpha flux of 1 particle per cm^2.

<u>Coarse grains</u>

In the quartz inclusion technique (Fleming, 1970) the skin of material irradiated by alpha particles from the clay matrix is removed by etching with hydrofluoric acid. An alternative approach, stimulated by uncertainties in the etching process (Valladas and Valladas, 1982), is to dispense with etching and to make direct experimental measurement of the alpha response of the grains. An important 'theorem' here is that the irradiation situation for a spherical grain exposed to an omnidirectional flux, Φ is identical to that of the grain when it is exposed to a parallel flux of the same value, both fluxes haing the same energy distribution (loc. cit., p. 176); the omnidirectional flux corresponds to the alpha dose received by the grain during antiquity and the parallel flux to laboratory irradiation (the grains are placed on a vibrating pan during measurement so as to minimize error due to grains which are non-spherical). The value of the omnidirectional flux for a sample is equal to four times the particles incident on unit area exposed to 2π steradians of the sample, i.e. the flux rate equals four times the alpha count rate (for zero threshold) per unit area.

It may be useful to note incidentally (see Aitken, 1985, p. 318) that the 'true' effectiveness as obtained by irradiation of fine grains is related to the 'apparent' alpha effectiveness as obtained by irradiation of coarse spherical grains by the ratio

$$\frac{2D}{3\eta' R} \qquad (7)$$

where D is the grain diameter, R is the alpha range and η' is the ratio, for the alpha energy used, between the average TL per unit track length for total absorption and that for a thin layer of fine grains. Guerin (1982) reports an experimental value of 6.11 ± 0.55 for this ratio using 3.5 MeV particles and grains of diameter 100 microns. This is consistent with the value of 6.3 obtained for the above ratio on substituting $R = 13$ microns and $\eta' = 0.81$ as appropriate to 3.5 MeV, the value for η' being obtained using the representative energy dependence of TL per unit track length given by Aitken and Bowman (1975); this latter consists of a constant level for energies above 2 MeV with a linear rise between 0 and 2 MeV from 25% of that constant level.

Reviewed by G. Valladas

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