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ALPHA DOSE ATTENUATION IN QUARTZ GRAINS FOR THERMOLUMINESCENCE DATING

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Fleming (1969) has calculated the attenuation of the alpha dose from the uranium and thorium series in quartz grains of certain sizes. Aitken and Fleming (1972) used these calculations to predict that the attenuation of the alpha dose in the fine-grain technique of Zimmerman (1971) would be about 6%. As the alpha dose contributes typically only about 40% of the total radiation dose to the fine grains, this implied that there would be a decrease of only about 2.5% in the overall effective dose. It has become quite usual for users of the fine-grain dating method to regard this attenuation factor as negligible when compared to other possible sources of error in the method and hence not to correct for it in the TL age determination (Aitken, 1978). The purpose of this paper is to present the results of the calculation of the alpha dose attenuation in quartz grains in the size range 1 μm - 1 mm using more sophisticated computer techniques than were available to Fleming (1969) and thus give a more exact and detailed description of the attenuation in quartz over a wider grain size range.

Method of Calculation

The calculation of the alpha dose attenuation was based on the mathematical formalism developed by Charlton and Cormack (1962), which was also the basis for Fleming's (1969) calculations. The calculations essentially involve the development of a geometrical factor, $S_\alpha(x)$, which describes the dose at a point within a non-radioactive sphere, at a distance x from the interface with a surrounding radioactive matrix. The theory makes two simplifying assumptions:

a) the ionising particles are emitted isotropically within the surrounding medium, and

b) the emitted particles travel in straight lines.

Both of these assumptions are valid for the alpha particles emitted by an homogeneous distribution of the uranium and thorium series in a clay matrix. It is further assumed that the quartz grains constitute non-radioactive spheres within the radioactive clay matrix. The actual mathematical expressions for $S_\alpha(x)$ are given by Charlton and Cormack (1962), but Howarth (1965) has reduced these to a more convenient form for numerical evaluation. The values of $S_\alpha(x)$ required here were taken from Howarth's tables for a spherical interface.

In order to assess the mean absorbed dose in a quartz grain, the values of $S_\alpha(x)$ were integrated numerically over the grain volume for diameters from 1 μm up to 1 mm. This integration was performed by a computer programme for numerical integration on a Univac 1100 series computer and the results are shown graphically in Figure 1 for the uranium and thorium series. $\overline{S}_\alpha$ is the mean absorbed dose in a quartz grain of given diameter expressed as a fraction of the dose which would be absorbed by an infinitesimally small grain. The numerical values for $\overline{S}_\alpha$ for each grain diameter are given in Table 1.

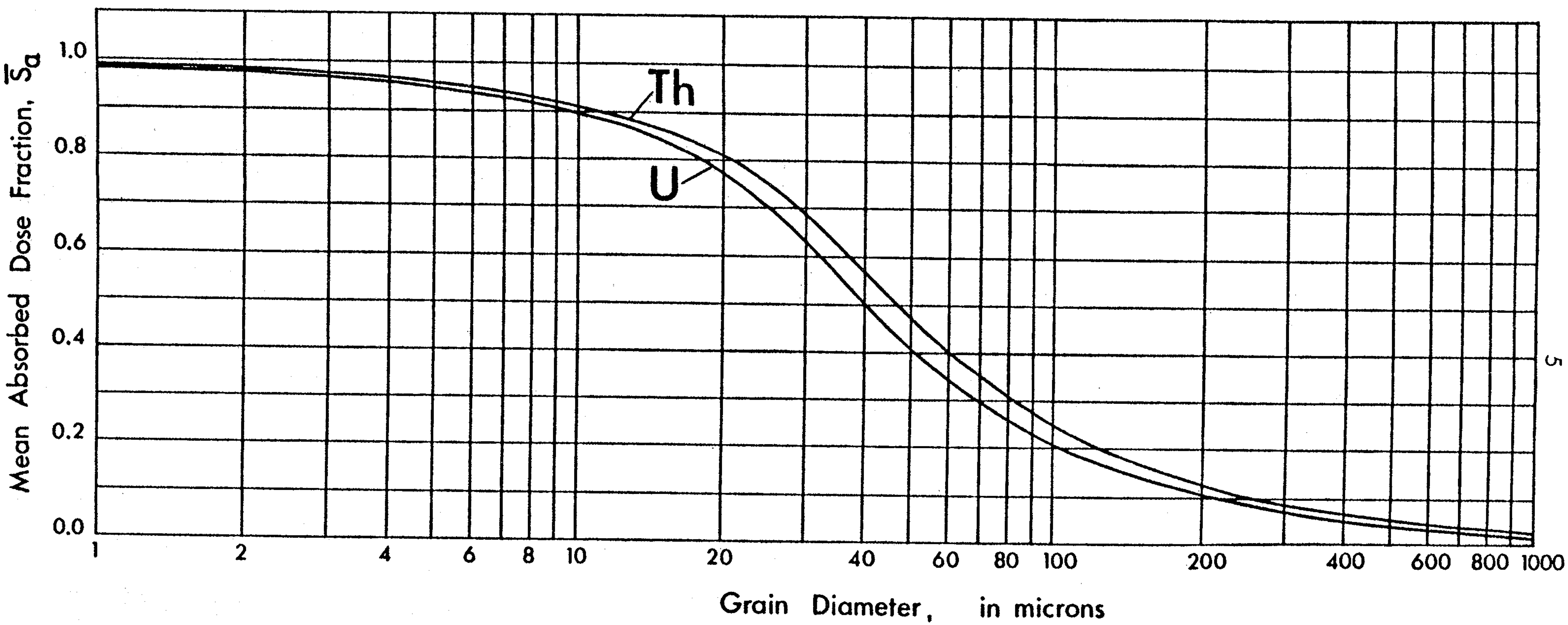

FIGURE 1. The Mean Absorbed Dose Fraction, $\overline{S}_\alpha$, for Alpha Particles from the Uranium (U) and Thorium (Th) Series in Quartz Grains Plotted as a Logarithmic Function of the Grain Diameter from 1 μm up to 1 mm.

Table 1

Mean Absorbed Dose Fractions, $\overline{S}_\alpha$, in Quartz Grains of Various Diameters for the Uranium and Thorium Radioactive Decay Series.

Grain Diameter (μm)	Uranium series	Thorium series
1.0	0.990	0.991
2.0	0.979	0.982
3.0	0.969	0.973
4.0	0.958	0.964
5.0	0.947	0.955
6.0	0.936	0.945
7.0	0.925	0.936
8.0	0.914	0.926
9.0	0.903	0.917
10	0.892	0.907
15	0.834	0.859
20	0.772	0.807
30	0.628	0.690
40	0.502	0.567
50	0.414	0.471
60	0.350	0.402
70	0.303	0.349
80	0.266	0.308
90	0.238	0.275
100	0.215	0.248
150	0.144	0.167
200	0.108	0.126
250	0.087	0.101
300	0.073	0.084
400	0.054	0.063
500	0.043	0.050
1000	0.022	0.025

Use of the Attenuation Factors

It must be stressed that the data given in Table 1 apply only to the case of non-radioactive quartz grains embedded in a clay matrix having an homogeneous distribution of the uranium and thorium series. Singhvi and Zimmerman (1979) have shown, however, that in many fine-grain samples feldspars can be the dominant TL minerals. Therefore the mean absorbed dose fractions for 1-8 μm grains of potassium feldspar were calculated and compared to those for quartz in the same size range. They were found to be less than 1% different from each other. The same calculations were performed for 100 μm grains but here the difference between the quartz and feldspar factors was found to be about 7%, due to the fact that the alpha particles have a greater range in the feldspar which in turn results in a smaller attenuation of the dose. Hence, the data given in Table 1 can safely be applied to most fine-grain samples, but for larger grain sizes the data should only be used for quartz.

There will be certain samples, however, for which the radioactivity content of the TL grains themselves, feldspar or quartz, will not be negligible. In these cases the above data will still be valid for the matrix alpha dose to the grains but account will also have to be taken of the small internal dose from any radioactivity within the grains.

It is worth noting here that there are certain other factors, in addition to the grain size attenuation, which must be included in the determination of the alpha dose to a particular grain size range. The most important of these is the alpha efficiency factor which describes the relatively low efficiency of alpha particles at producing TL compared to that of beta and gamma radiation. This phenomenon has been described in detail elsewhere by Zimmerman (1971, 1972) and by Aitken and Bowman (1975), but it should be remembered that for larger grains at least, the alpha efficiency may vary radially within the grain due to the diffusion of impurities into the outer layers as mentioned by Bell and Zimmerman (1978). Other factors which must also be taken into account in the alpha dose determination are the effect of ground water on the dose-rate (Zimmerman, 1971) and the possible escape of radon from the sample (Zimmerman, 1971; Desai and Aitken, 1974).

Although the data of Table 1 may be used for all grain sizes in the range 1 µm - 1 mm, the two principal TL dating methods employed today utilise grains either in the fine-grain range of 1-8 µm or quartz inclusions of approximately 100 µm diameter. The attenuation of the alpha dose in 100 µm quartz inclusions has already been specifically dealt with by Bell (1979), so let us look here in a little more detail at the fine-grain size range.

Zimmerman (1971) has shown that the separation techniques used in the fine-grain dating method give grains in the size range 1-8 µm and, assuming equal numbers of all sizes in the initial distribution, this results in an average grain diameter of 5 µm. From Table 1 this predicts a mean absorbed dose fraction for fine grains of 0.947 for the uranium series and 0.955 for the thorium series. For typical concentrations of the two series this implies an average attenuation of the alpha dose in fine grains of 5%, in good agreement with the figure of 6% given earlier by Aitken and Fleming (1972). As mentioned above, because of the low efficiency of alpha particles at inducing TL (efficiency factors are of the order of 0.1), the alpha dose contributes typically only about 40% of the total radiation dose, with the remainder coming from the beta, gamma and cosmic ray doses. Hence a 5% attenuation in the alpha dose will normally result in only a 2% decrease in the total dose and thus only a 2% increase in the TL age.

Nevertheless, now that the attenuation factor is accurately known for the fine-grain method and unless any other complications (such as significant internal radioactivity within the grains) are suspected, there appears to be no reason to neglect the correction even though the error in doing so would probably be much smaller than other possible errors in the dating method.

There can, however, be certain circumstances (such as an exceptionally high alpha efficiency factor and/or a very low potassium contribution) which would imply that the alpha dose would contribute greater than 40% of the total dose and hence the alpha dose attenuation would be more significant. This can be illustrated to some degree by the TL dating of a deep-sea sediment core as described by Wintle and Huntley (1979). These authors used fine grains in the size range 4-11 µm and found the grains to consist mostly of clay minerals. Using the data presented here for quartz gives an alpha dose attenuation of 10% for this size range. The potassium content of the core is low and, for the younger samples at least, the radiation dose comes predominantly from precipitated thorium-230. Hence for this particular dating programme, the alpha contribution to the overall radiation dose is greater than 50% and neglect of the alpha dose attenuation factors will result in TL ages which are more than 5% too young, assuming negligible internal radioactivity within the grains.

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