The dose rate of beta sources for optical dating applications: A comparison between fine silt and fine sand quartz

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(Received 11 January 2005; in final form 18 January 2005)

Abstract

This note reports on the determination of the dose rates of beta sources used for optical dating. Equipment and targets used for the experiments were chosen according to dating application requirements: sand-sized and silt-sized quartz mounted on aluminium and stainless-steel discs were measured in two Risø readers using a single aliquot regeneration dose protocol.

The experiments show that backscattering due to disc substrate accounts for ~ 16% of the dose rate. Charge build-up and attenuation associated with the grain size of the target accounts for ~ 11% of the dose rate. The total uncertainty of the dose rates is ~ 2% or less depending on the accuracy of the primary gamma-source. The excellent agreement between our values and those reported by Armitage and Bailey (2005) indicate that factors determined can be adopted by other laboratories.

Introduction

One of the most crucial laboratory parameters for optical dating applications is the dose rate of the beta source used to reconstruct the environmental dose experienced by a sample. The dose given to quartz during laboratory beta irradiation depends on charge build-up, attenuation and backscattering (Aitken, 1985). While charge build-up and attenuation depends on the mineral and its grain size, backscattering is a function of the sample carrier (disc). Maintaining backscattering constant, Wintle and Aitken (1977) reported a ~ 25% lower dose rate for 4-11µm samples than for ~ 100 µm samples. Armitage and Bailey (2005) show that ~ 12% of the beta dose rate is derived from the grain size of the target. The enormous difference between ~ 25% and 12% is due to differences in measurement protocols and geometry. The sample-to-source distance decreased from ~ 16 mm (Wintle and Aitken, 1977) to ~ 7 mm (Markey et al., 1997) and, thus, the maximum angle at which the beta particles hit the sample and the build-up effect are changed.

The purpose of this note is to describe our approach of assessing beta source dose rates and to compare our results with those of Armitage and Bailey (2005).

Experimental details

Materials, discs and aliquot sizes:

1. Sand-sized quartz (150-250 µm) provided by the Risø National Laboratory. The sample has the laboratory number 914807 and was irradiated on 16.08.1999. The grains were mounted on aluminium and stainless-steel discs using silicone oil. Each aliquot contained ~1500 grains. These grains covered the inner 7-7.5 mm of discs of 9.7±1 mm diameter.

2. Silt-sized quartz (10-20 µm) provided by the Liverpool Luminescence Laboratory. The material was settled on aluminium discs using acetone. Each aliquot contained 2.5 mg material, which covered the entire 9.7±1 mm diameter discs.

The silt-sized quartz was extracted from loess sediment originating from the "Nussloch-site" in southern Germany. The loess sample was treated using the conventional procedures for fine grain samples, etched in 20% hydrofluoric acid for several tens of minutes until tests (Mauz and Lang, 2004) showed its quartz purity. The material was then washed in acetone, dried and settled in acetone onto aluminium discs. The aliquots were then annealed at 500°C for 1 hour and subsequently sensitized in the Risø reader by alternating irradiation (~5 Gy) and OSL read-out (40 s at 125°C) 18 times. The sensitized material was subsequently washed off the discs and sent to the National Physical Laboratory (NPL) for gamma-irradiation. After gamma-irradiation the sample was again settled onto aluminium discs and stored for around 6 weeks at room temperature before measurement.

γ-dose (Gy)	Grain size range (μm)	Position in wheel	Disc	$D_{eß}$ (s)	Recycling ratio
$^{90}Sr/^{90}Y$ source mounted on Risø DA 15B/C					
4.59±0.07	150-250	1	ss	34.68±2.76	1.00±0.003
4.59±0.07	150-250	8	ss	34.86±2.13	0.996±0.002
4.59±0.07	150-250	20	ss	34.58±1.83	1.004±0.002
4.59±0.07	150-250	32	ss	34.65±2.77	1.003±0.007
4.59±0.07	150-250	43	ss	34.65±2.35	1.009±0.003
4.59±0.07	150-250	1	al	40.11±2.80	0.989±0.003
4.59±0.07	150-250	8	al	40.54±2.70	0.988±0.003
4.59±0.07	150-250	20	al	39.76±2.92	1.021±0.004
4.59±0.07	150-250	32	al	41.05±2.98	1.008±0.003
4.59±0.07	150-250	43	al	41.83±3.51	1.016±0.002
8.92±0.18	10-20	1	al	88.13±4.35	1.0184±0.0005
8.92±0.18	10-20	8	al	89.27±5.04	1.0274±0.0003
8.92±0.18	10-20	20	al	88.59±3.99	1.0143±0.0003
8.92±0.18	10-20	32	al	89.41±5.71	1.0307±0.0003
8.92±0.18	10-20	43	al	89.37±4.10	1.0169±0.0003
$^{90}Sr/^{90}Y$ source mounted on Risø DA15					
4.59±0.07	150-250	1	ss	45.00±2.12	1.001±0.003
4.59±0.07	150-250	8	ss	45.32±3.10	0.972±0.007
4.59±0.07	150-250	20	ss	45.52±3.63	0.97±0.02
4.59±0.07	150-250	32	ss	44.92±2.36	0.99±0.01
4.59±0.07	150-250	43	ss	45.91±3.51	0.998±0.001
4.59±0.07	150-250	1	al	53.93±4.23	1.006±0.003
4.59±0.07	150-250	8	al	51.71±2.28	0.991±0.002
4.59±0.07	150-250	20	al	51.49±4.15	1.016±0.010
4.59±0.07	150-250	32	al	51.86±3.95	1.010±0.006
4.59±0.07	150-250	43	al	52.51±2.80	1.030±0.002
8.92±0.18	10-20	1	al	114.56±7.57	1.007±0.005
8.92±0.18	10-20	8	al	113.51±9.00	1.008±0.006
8.92±0.18	10-20	20	al	115.43±7.91	1.000±0.005
8.92±0.18	10-20	32	al	110.80±13.29	1.006±0.005
8.92±0.18	10-20	43	al	113.54±12.46	1.003±0.005

Table 1 : *Beta equivalent doses ($D_{eß}$ ± standard error, in seconds irradiation time) of individual aliquots and parameters associated. ss stands for stainless-steel and al for aluminium; recycling ratio is the ratio of the first regenerated dose and the repeated first regenerated dose at the end of the SAR protocol. All errors are quoted at* 1σ.

Risø reader	Grain size range (μm)	Disc	Dose rate (Gy s^{-1})	Uncertainty (%)	Normalized dose rate
DA15	150-250	stainless-steel	0.101±0.002	1.6	1.00
DA15	150-250	aluminium	0.088±0.001	1.6	0.87
DA15	10-20	aluminium	0.0785±0.002	2.1	0.78
DA15B/C	150-250	stainless-steel	0.132±0.002	1.5	1.00
DA15B/C	150-250	aluminium	0.113±0.002	1.5	0.86
DA15B/C	10-20	aluminium	0.100±0.002	2.0	0.76

Table 2: *Dose rates of the beta sources examined and their dependence on grain size and substrate of disc. Normalised dose rates were normalised to the stainless steel values to facilitate comparison. All errors are quoted at 1σ.*

Gamma sources and given γ-doses
Risø used a ^{137}Cs source (662 keV in air) delivering 0.1013±0.0012 Gy $hour^{-1}$ (20/5/98), while NPL used a ^{60}Co source (1.25 MeV in water) delivering 0.949 Gy min^{-1} (7/9/2004). The sand-sized quartz received a dose of 4.59±0.07 Gy. The silt-sized quartz received a dose of 8.92±0.18 Gy.

Measurement equipment
One reader is a Risø DA-15 equipped with 41 blue LEDs (Nichia NSPB 500S) emitting 470Δ30 nm and an EMI 9235QB photomultiplier. The ß-source mounted on this reader is a ~4 years old 40 mCi $^{90}Sr/^{90}Y$ source and the source-to-sample distance is 7.4 mm. The second reader is a Risø DA-15B/C equipped with 27 blue LEDs (Nichia NSPB 500S) emitting 470Δ30 nm. In terms of construction and housing its ß-source is identical to the first one (Markey et al., 1997 and Bøtter-Jensen et al., 2000); it is around one year old and the source-to-sample distance is 5 mm (Bøtter-Jensen et al., 2000). The optical stimulation units of both readers deliver ~ 30 mW cm^{-2} at 90% power. For detection a 7.5 mm Hoya U340 filter transmitting 290-380 nm was used in each reader.

Experimental design
The wheel used as an aliquot carrier in the Risø reader is a 6.0 mm to 6.1 mm thick aluminium ring. During manufacturing the wheel experiences stress which results in a slight bending of a regular pattern, shown by a dial-test indicator. With respect to the reference surface the wheel shows zero elevation at positions 1-5, 13-18, 23-28 and 36-42. At positions 19-22 and 43-48 a –40 μm depression was measured and at positions 6-12 and 30-35 a +60 μm and +40 μm height respectively was recorded using a depth micrometer. Thus, there is a height amplitude of maximum 100 μm between positions 6-12 and 19-22.

We have chosen the following positions on the wheel for our experiments: 1, 8, 20, 32, 43. A single aliquot regeneration dose protocol (SAR) was used to recover the given gamma dose with 260°C for 10 s as a preheat, heating to 200°C as a cut heat, and 40 s illumination with blue LEDs (90% power) at 125°C for OSL recording.

Experimental uncertainties
Uncertainties resulted from: (i) γ-irradiation: photon mass-energy absorption at 662 keV (Risø) and 1.25 MeV (NPL), photon fluence perturbation due to the sample carrier and mass absorption of quartz to air and water, respectively. The uncertainty of the dose to quartz provided by the Risø National Laboratory was 1.5% and that of the NPL was 2%. (ii) SAR protocol performed in Risø readers. We adopted a 1.5% systematic error (following Armitage et al., 2000) in addition to the standard error given by the arithmetical mean of 5 aliquots in each measurement. The shortest irradiation time was 32 s, which allows us to disregard a systematic error related to the irradiation time.

Results and discussion
The data resulting from the two experiments are shown in Table 1. Table 2 indicates the dose rates in dependence of grain size and sample carrier. The uncertainty of the beta equivalent doses resulting from the SAR protocol was ~ 6% per aliquot and, thus, obscured any differences between positions in the wheel. For sand-sized samples the factor between stainless-steel discs and aluminium discs is 1.16±0.01. Assuming that the difference in thickness between the two disc types is negligible, the disc material itself accounts for around 16% dose rate of the ß-source. This result confirms not only that steel discs produce higher backscattering and enhance the beta dose rate, it is also in agreement with the 14%

difference reported by Ingram et al. (2001) and the 16.6±0.2% published by Armitage and Bailey (2005). The factor between silt-sized and sand-sized quartz samples mounted on aluminium discs is 0.89±0.005 and thus, the grain size accounts for around 11% dose rate of the ß-source. This result again, confirms Armitage and Bailey (2005) who analysed the beta dose rate dependence on grain size. These authors report a maximum difference between sand- and silt-sized quartz of ~12%. Within the 1σ uncertainty level both Risø readers gave the same results indicating that a few millimetres difference in sample-to-source distances does not affect the factors determined.

The total uncertainty of the dose rates determined is ~1.6% for sand-sized quartz and ~2% for silt-sized quartz. The small difference of ~0.4% is due to the uncertainty derived from the γ-source.

The standard aliquot size used in this experiment is 7 mm. This size allows us to adopt the dose rate factors reported by Spooner and Allsop (2000) to correct the mean total dose rate received by the standard aliquot size to smaller and larger aliquot sizes.

Conclusion

While the effect of backscattering on beta source dose rates was known from previous studies, the dependence of the dose rate on grain sizes was only assumed when our study started. We now find an excellent agreement between our results and those of Armitage and Bailey (2005). This agreement indicates that the factors determined between aluminium and steel discs on the one hand and sand-sized and silt-sized quartz on the other can be adopted by other laboratories.

Acknowledgements

We thank Ian Stoker and James Manning from the National Physical Laboratory for performing the gamma irradiation and calculating the dose given to the silt-sized quartz sample. We further thank S. Packman for reviewing the manuscript.

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Reviewer

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