Ancient TL

www.ancienttl.org · ISSN: 2693-0935

Bell, W., 1980. *Beta source calibration: some problems associated with the utilization of the gamma irradiation of quartz and other phosphors, part II.* Ancient TL 4(2): 2-6.
https://doi.org/10.26034/la.atl.1980.034

This article is published under a *Creative Commons Attribution 4.0 International* (CC BY):
https://creativecommons.org/licenses/by/4.0

© The Author(s), 1980

BETA SOURCE CALIBRATION: SOME PROBLEMS ASSOCIATED WITH THE UTILISATION OF THE GAMMA IRRADIATION OF QUARTZ AND OTHER PHOSPHORS

PART II

W. T. Bell
Archaeometry Project, Risø National Laboratory
DK-4000 Roskilde, Denmark

INTRODUCTION - PART II

In Part I of this paper, given in the last issue of this newsletter (No. 10, March 1980), the interaction of gamma radiation with matter was described and the particular problems which arise when an interface separates two media under gamma irradiation were discussed. It was shown that the motion of the secondary electrons created by the initial photon interactions must be taken into account when the dose distribution in the vicinity of an interface is to be assessed. Three particular cases were considered:

(i) the dimensions of the irradiated material are large compared to the secondary electron range;

(ii) the dimensions are small compared to this range; and

(iii) the dimensions are comparable to this range.

Equations were given to describe the dose, D, deposited in a phosphor by a gamma beam for each of the three cases given above. These equations will be used in this second Part and hence they are repeated here for convenience. The symbols have all been defined in Part I.

$$\text{(i)} \qquad D = 0.869 \times \frac{(\mu_{en}/\rho)_{phosphor}}{(\mu_{en}/\rho)_{air}} \times X \qquad (1)$$

$$\text{(ii)} \qquad D = 0.869 \times \frac{(\mu_{en}/\rho)_{medium}}{(\mu_{en}/\rho)_{air}} \times \frac{{}^{S}m_{phosphor}}{{}^{S}m_{medium}} \times X \qquad (2)$$

$$\text{(iii)} \qquad D(x) = 0.869 \times \left[\frac{(\mu_{en}/\rho)_{medium}}{(\mu_{en}/\rho)_{air}} \times \frac{{}^{S}m_{phosphor}}{{}^{S}m_{medium}} \times G(x) + \frac{(\mu_{en}/\rho)_{phosphor}}{(\mu_{en}/\rho)_{air}} \times \{1 - G(x)\} \right] \times X \qquad (3)$$

THE USE OF QUARTZ FOR BETA SOURCE CALIBRATION

As mentioned in Part I of this paper, Pernicka and Wagner (1979) have proposed the interlaboratory calibration of beta sources using quartz as the TL phosphor. They suggest that some quartz samples should be irradiated by them with a gamma dose from an accurately calibrated Co-60 source and then be distributed to various TL laboratories for the beta source calibrations. Because of the fundamental importance of such a source calibration it is necessary to discuss here a small error in Pernicka and Wagner's irradiation procedures.

The quartz grains, in the size range 70-150 μm after etching in HF, were prepared for gamma irradiation by packing approximately 100 mg of the grains into small polyethylene bags so that the sample thickness was less than 1 mm, or alternatively 2 mg was placed in small polyethylene containers. The irradiations took place behind 0.5 cm of perspex in order to "achieve secondary electron equilibrium conditions". They then calculated the dose to the quartz according to

$$D = 0.869 \times \frac{(\mu_{en}/\rho)_{quartz}}{(\mu_{en}/\rho)_{air}} \times X \qquad (4)$$

It can be seen immediately that equation (4) is directly equivalent to equation (1). However, equation (1) was valid only for the case where the dimensions of the phosphor were large compared to the range of the electrons set in motion by the photon collisions. For Co-60 gamma rays ($\bar{E}$ = 1.25 MeV) the average range of these electrons is approximately 2 mm in quartz. The thickness of the quartz samples is less than 1 mm and as the samples are packages of much smaller quartz grains, then the actual thickness of solid quartz will be considerably less than 1 mm. Hence the dimensions of the phosphor are not large compared to the secondary electron range and equation (4) is not valid for this situation.

On the other hand, the dimensions of the phosphor are not small compared to the secondary electron range so that equation (2) is not valid either. The true situation lies somewhere between the two cases with the dose absorbed by the quartz delivered partly by the electrons generated within the perspex absorbers and partly from electrons generated within the quartz grains themselves. Thus some form of equation (3) would need to be used to calculate the dose to the quartz grains but the evaluation of the geometrical function G would be an exceedingly complex, if not impossible, problem. This is firstly because there is not a plane interface between two solid materials as on one side there are polyethylene bags packed with grains, and the density of packing of the grains will have an influence on the absorbed dose. Secondly, the spatial characteristics of the electron field generated in the perspex would have to be taken into account because perspex is a low atomic number material exposed to high energy photons and hence the electrons will be biased in the forward direction as described above. It is not thought that the electron scattering phenomenon of Dutreix and Bernard (1966) will have much influence here due to the small volume of back-scattering material.

The problems associated with evaluating the dose to Pernicka and Wagner's quartz grains would not exist if quartz absorbers were used instead of perspex. The secondary equilibrium electron fluence generated within the absorbers would then be that of quartz and the dose to the grains would be given by equation (1). If we put values in equation (1) we find that the dose D_1 is given by

$$D_1 = 0.867 \times X \quad (5)$$

Substituting values in equation (2) is rather more complex because it requires the ratio of the mass stopping powers of quartz and perspex. These figures are slightly energy dependent, so the problem of deciding at which energy to take the ratio arises. Dutreix et al. (1962) found that for Co-60 gamma rays the secondary electron fluence penetrating an ionisation chamber from wall materials of different atomic numbers behaved as though the mean energy of the electrons was in the order of 0.01 MeV. Taking the ratio of the stopping powers at this energy and using equation (2), gives

$$D_2 = 0.757 \times X \quad (6)$$

The difference between equations (5) and (6) is seen to be quite considerable and as mentioned above, the true figure for Pernicka and Wagner's irradiation should lie somewhere between these limits. This was investigated experimentally here by irradiating simultaneously in a Co-60 gamma beam some quartz grains behind 0.5 cm thick quartz absorbers and some grains behind the same thickness of perspex absorbers. Both samples of grains were packed in polyethylene bags to a thickness of approximately 1 mm. It was found that the dose to the quartz grains irradiated behind the perspex was (5.0 ± 0.3)% lower than the dose to the grains behind quartz implying that for this irradiation procedure equation (3) gives

$$D_3 = 0.826 \times X \quad (7)$$

It is not possible, however, to say that this value in equation (7) should apply to Pernicka and Wagner's irradiations since the density of packing of the grains could have been somewhat different.

It is strongly recommended, therefore, that if quartz grains are to be used for calibration purposes, the gamma irradiations should take place behind quartz absorbers in order to circumvent the problems and uncertainties in the dose assessment as described above.

THE EFFECT OF GRAIN TRANSPARENCY ON BETA SOURCE CALIBRATION

A limiting factor in using one type of quartz grains, or any other phosphor, for a "once-and-for-all" beta source calibration is the dependency of the measured dose-rate of the beta source on the transparency of the particular quartz grains as was first described by Bell (1979). Further studies have now been completed however the results, described below, are still somewhat preliminary. A detailed account of this transparency phenomenon will be published soon.

The dependency on grain transparency is thought to arise from the comparison of the non-homogeneous dose distribution to the grains from the beta source, with the homogeneous dose distribution from the gamma source. The non-homogeneous beta dose distribution is a result of two effects. The first is the dose build-up with depth described by Wintle and Aitken (1977) which is due to the increased obliquity of the electron paths caused by multiple

scattering as the electrons penetrate the sample. Thus the path length per unit thickness, and hence the energy loss, increases with depth until it reaches a maximum (at about 40 mg/cm^2 for a Sr-90 source and aluminium absorbers) after which attenuation effects predominate and the dose decreases. For 100 μm quartz grains the dose will increase through the grains so that the lower regions will receive a higher dose than the upper regions.

The second effect, which probably has a greater influence on the dose distribution, is the back-scattering of electrons from the high atomic number material on which the grains are resting during beta irradiation. Murray and Wintle (1979) showed that 100 μm grains of CaF_2 receive a 40% higher dose when irradiated on nichrome instead of perspex and for lead the increase is over 60%. These back-scattered electrons will have energies very much less than the initial source energy and will not penetrate very far into the quartz grains, thus depositing most of their energy in the lower regions of the grains.

In contrast, the gamma irradiation of quartz grains will result in a homogeneous distribution of the dose throughtout the grain volume. Hence the TL measured after a beta irradiation will come more from the lower regions of the grains than the TL measured after a gamma irradiation. Therefore the beta induced TL will be more attenuated than the gamma TL if the grains are not very transparent; whereas there will be little difference in the attenuation if the grains are very transparent.

We have measured a large number of different quartz samples using a Co-60 gamma source and a Sr-90 beta source (20 mg of grains resting in platinum cups of area 52 mm^2 for this latter irradiation) and the results for the apparent dose-rate values of the beta source were found to vary over a wide range - approximately 20%. Optical inspection of the quartz grains from the two extremes showed that the sample whose grains had a very transparent, "shiny" (Bell and Zimmerman, 1978) appearance gave a high dose-rate figure for the beta source, indicating that little difference in the attenuation of the beta and gamma induced TL had occured. By comparison the grains from the other sample which had a less transparent, "frosty" appearance gave a 20% lower dose-rate figure for the beta source, implying a greater attenuation of the beta TL than the gamma TL.

As a result of this phenomenon a beta source calibration is now performed for each individual archaeological sample dated by this laboratory. In this context it is interesting to report that the two extreme samples mentioned above both give very good results for the ages when the individual source calibration figures are used, but if a mean calibration figure is used then the dates obtained fall outside the known age limits for the archaeological samples. The same effect is also true, to a lesser extent, for many other samples studied.

Furthermore, preliminary investigations tend to show that there is perhaps a correlation between firing temperature of the sample and the degree of transparency after etching in HF acid. Quartz grains from a geological sand were divided into two fractions - one fraction heated to 1000^o C for four hours and the other remaining unheated. The two fractions were then etched in HF for one hour and it was quite noticeable that the unheated grains had a slightly more "frosty" appearance than the heated grains. We hope to publish full details of the experimental methods we use and a full account of the effects of grain transparency in the near future.

It is recommended here that individual TL dating laboratories should pay attention to this transparency effect and that whenever possible beta source calibration experiments should be performed for each archaeological sample studied. This is particularly important when the quartz grains under consideration have either a very "frosty" or very "shiny" appearance.

REFERENCES

Bell, W.T., 1979. Problems and uncertainties in the dose and dose-rate evaluation for TL dating. A paper presented at the Annual Symposium on Archaeometry and Archaeological Prospection, London, March 1979.

Bell, W.T. and Zimmerman, D.W., 1978. The effect of HF acid etching on the morphology of quartz inclusions for thermoluminescence dating, Archaeometry, 20 (1), 63.

Dutreix, J. and Bernard, M., 1966. Dosimetry at interfaces for high energy X and gamma rays, Br. J. Radiol., 39, 205.

Dutreix, J., Dutreix, A. and Bernard, M., 1962. Étude de la dose au voisinage de l'interface entre deux milieux de composition atomique différente exposés aux rayonnement γ du Co-60, Phys. Med. Biol., 7, 69.

Murray, A.S. and Wintle, A.G., 1979. Beta source calibration, Proceedings of a specialist Seminar on Thermoluminescence Dating, Oxford, July 1978, PACT Journal No 3, 419.

Pernicka, E. and Wagner, G.A., 1979. Primary and interlaboratory calibration of beta sources using quartz as thermoluminescent phosphor, Ancient TL, No 6, 2.

Wintle, A.G. and Aitken, M.J., 1977. Absorbed dose from a beta source as shown by thermoluminescence dosimetry, Int. J. App. Rad. Isotopes, 28, 625.

110°C QUARTZ PEAK: A NEW NORMALIZATION FACTOR

Y. Liritzis*
Physics Department
Edinburgh University, Scotland

It is well known that in our attempt to measure the total archaeological dose a pottery sample has received since the last firing, we follow the "additive procedure" which simulates the natural TL acquisition. The construction of the first built up curve is usually made by using the following normalization procedures:

*Present address: Physics Laboratory II, University of Patras, Patras, Greece