

---

# 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 I*. Ancient TL 4(1): 3-9.

<https://doi.org/10.26034/la.atl.1980.031>

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 UTILIZATION OF THE GAMMA IRRADIATION OF QUARTZ AND OTHER PHOSPHORS

## PART I

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

### INTRODUCTION - PART I

The problem of beta source calibration has been discussed in some detail recently (Wintle and Aitken, 1977; Wintle and Murray, 1977; Murray and Wintle, 1979) and the methods suggested for calibration have usually been based on the use of a TL phosphor such as calcium fluoride for intercomparing the beta source with a well-calibrated gamma source. Aitken (1979) proposed the inter-laboratory calibration of beta sources using 100  $\mu\text{m}$  grains of natural fluorite and then calculation of the equivalent dose-rate to quartz. He did suggest, however, that quartz itself would be a better phosphor to use if sufficient quantities possessing satisfactory TL characteristics were available. Pernicka and Wagner (1979) described the use of commercially available Merck quartz for beta source calibration and proposed that irradiated samples of this quartz could be distributed for interlaboratory calibration. Although the use of quartz for calibration purposes excludes the uncertainty involved in the calculation of the dose-rate to quartz from the measured dose-rate to the TL phosphor, care must still be applied to every detail of the procedure in order that the most accurate result possible may be attained.

This paper has been prompted partly by the lack of adherence to this latter principle by Pernicka and Wagner (1979) - resulting in a minor uncertainty in their source calibration - and partly by the desire to recount some other complicating factors associated with the transparency of the quartz grains themselves which can also have important effects for TL dating. In Part I, given here, the effects of the gamma irradiation of matter in general and in particular the problems which arise when an interface divides two different media being irradiated by gamma rays are described. In Part II, which will be published in the next issue of this newsletter (No. 11, June 1980), the irradiation of quartz grains for beta source calibration purposes is discussed and some unwelcome phenomena associated with the transparency of the quartz grains are described.

### THE EFFECTS OF GAMMA IRRADIATION OF MATTER

In the energy range and for the materials of interest to us, the primary interaction of the gamma rays (photons) with absorber atoms is via three quite distinctive processes: -

- (i) The photoelectric effect: a photon gives up all of its energy to a bound electron (usually from the K or L shell) which is then ejected from the atom with a kinetic energy equal to the incident photon energy minus the binding energy of the electron in the atom. This effect is particularly important at low photon energies, i.e. less than 100 KeV, and for high atomic number absorbers. The photoelectric absorption coefficient varies rapidly with atomic number Z, approximately as  $Z^4$ .

(ii) The Compton effect: a photon is scattered from its original direction of motion by a collision with an atomic electron. This results in a Compton scattered photon and a Compton recoil electron. The Compton electrons will have a range of energies distributed around a mean value. Compton scattering is important for photon energies around 1 MeV and for low and medium value atomic number materials. The Compton scattering coefficient is almost independent of  $Z$ .

(iii) Pair production: a photon travelling in the field of a nucleus, and to some degree the field of an electron, can be completely annihilated giving rise to an electron-positron pair. Pair production predominates at high photon energies and for high atomic number materials. A minimum threshold photon energy of 1.02 MeV is required for pair production in the field of a nucleus, and a threshold of 2.04 MeV is required in the field of an atomic electron.

These three effects are described in detail by Evans (1958, 1968) and Davisson (1968).

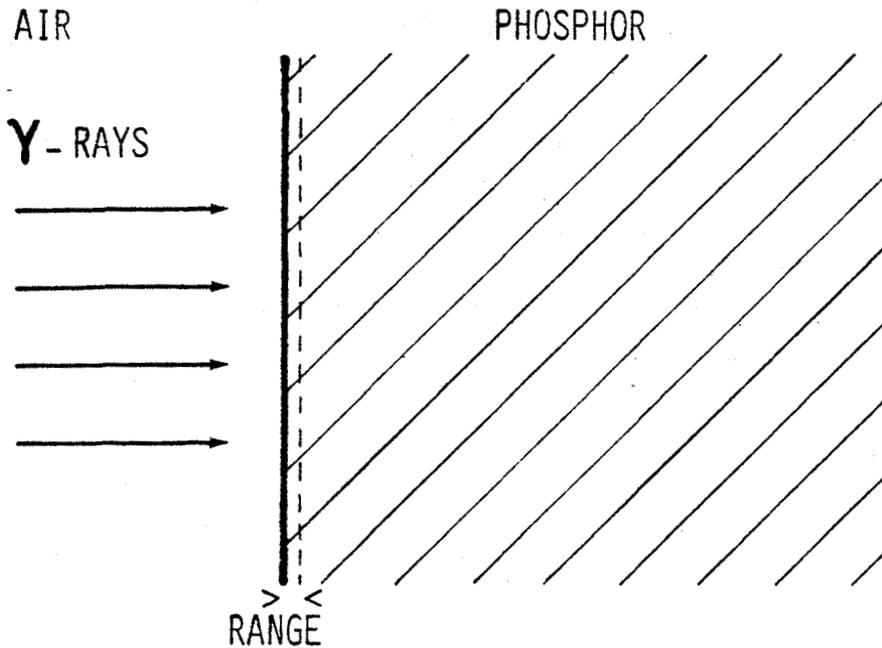
Thus the interaction of gamma rays with matter usually involves the production of energetic secondary electrons and it is the interaction of these secondary electrons which accounts predominantly for the ionization and excitation of the absorber atoms. For example, the interaction of a 1 MeV gamma ray travelling in quartz-like material will produce a secondary electron whose most probable energy will be 440 KeV. This electron can then go on to ionize over 10,000 further atoms before being brought to rest. The electrons liberated in these ionizations can themselves go on to produce further showers of lower energy electrons and this process continues until all of the energy imparted by the initial photon collision is dissipated within the material.

Within the bulk of a gamma-irradiated material there will exist an equilibrium fluence of electrons where the number of electrons produced within a small volume is balanced by the number absorbed. At the surface of a material exposed to a gamma ray beam, however, this equilibrium will not exist because there will have been no electrons produced before the surface. As we move into the material, the increase in the production of electrons initially outweighs the increase in absorption, so that the electron fluence builds up until eventually the production and absorption rates become equal and the equilibrium value is attained. This secondary electron equilibrium is achieved at a distance from the surface of the material equal to the average range of the initial photon collision electrons. Thus there will be a thin surface layer of the material in which the equilibrium value of the electron fluence is being built up and the relative importance of this layer will depend on the actual dimensions of the material being irradiated.

The following three cases will now be 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 the range.

Figure 1 shows the gamma irradiation in air of a TL phosphor whose dimensions are large compared to the average secondary electron range, so that the surface layer in which secondary equilibrium is being built up will be very small compared to the total phosphor volume. Thus the build-up layer can be neglected and it can be assumed that secondary equilibrium exists



**FIGURE 1:** The Gamma Irradiation in Air of a TL Phosphor whose Dimensions are Large compared to the Average Secondary Electron Range (Range). Secondary electron equilibrium exists within the bulk of the phosphor except for the thin surface layer in which it is being built up.

throughout the phosphor volume. However two additional, although relatively small, effects are neglected in this assumption - (i) the attenuation of the primary gamma beam (less than 1% attenuation per mm quartz), and (ii) the build-up of secondary, scattered photons. These effects work in opposite directions though, and for the situations considered here they will tend to be self-cancelling. The dose deposited in the phosphor by the gamma beam is given by,

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

where D is the dose to the phosphor in rads (1 Gray = 100 rads),

X is the gamma exposure in Röntgen,

0.869 is the number of rads deposited in air by an exposure of one Röntgen,

and  $(\mu_{en}/\rho)_{\text{phosphor,air}}$  are the photon mass-energy <sup>absorption</sup> attenuation coefficients for the phosphor and air respectively, in  $\text{cm}^2/\text{gm}$  at the energy of the gamma rays.

When, on the other hand, the dimensions of the phosphor are small compared to the secondary electron range and some other medium is used to build up secondary electron equilibrium, the probability that any photon collisions will occur within the phosphor itself will be small. But even if there were any collisions, the electrons thus produced would most probably escape from the phosphor volume and deposit a negligible part of their energy therein.

Hence the dose to the phosphor will be delivered by the secondary electrons entering the phosphor volume from the build-up medium. If the thickness of this build-up medium is sufficient to give secondary electron equilibrium then the dose to the phosphor is given by,

$$D = 0.869 \times \frac{(\mu_{en}/\rho)_{\text{medium}}}{(\mu_{en}/\rho)_{\text{air}}} \times \frac{m_{\text{phosphor}} S_{\text{phosphor}}}{m_{\text{medium}} S_{\text{medium}}} \times X \quad (2)$$

where  $m_{\text{phosphor}}, m_{\text{medium}}$  are the mass electron stopping powers for the phosphor and medium respectively, in MeV. cm<sup>2</sup>/gm, at the mean secondary electron energy.

In the intermediary situation, the phosphor dimensions comparable to the secondary electron range, the dose to the phosphor will come partly from electrons generated in the build-up medium and partly from electrons produced within the phosphor itself. In this case, Charlton and Cormack (1962) have shown that, assuming the electrons are generated isotropically, the dose at any point  $x$  within the phosphor,  $D(x)$ , will be given by,

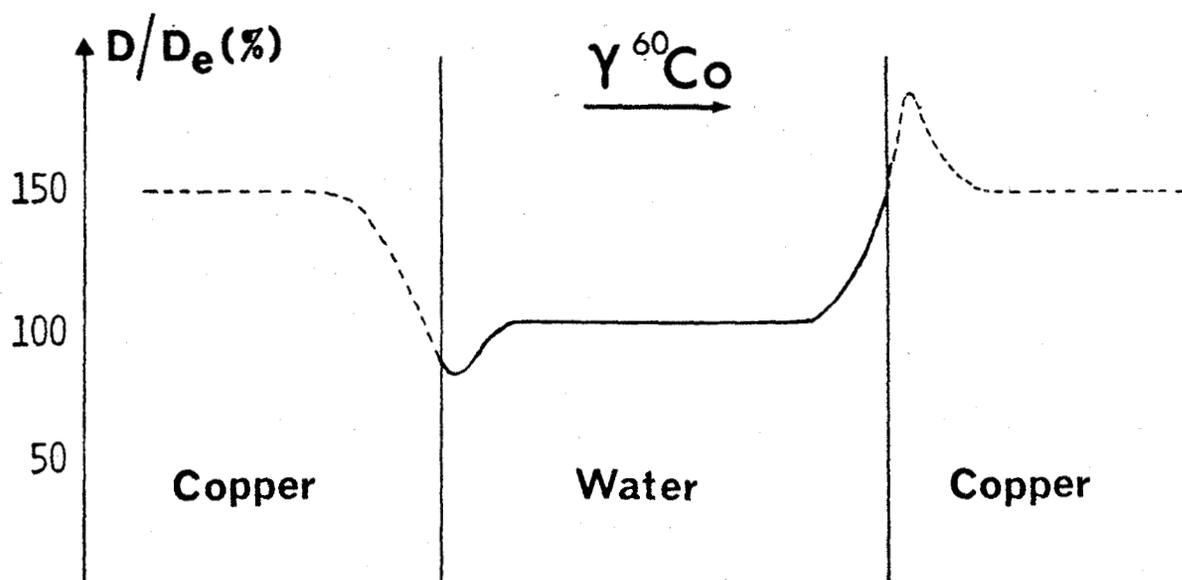
$$D(x) = 0.869 \times \left[ \frac{(\mu_{en}/\rho)_{\text{medium}}}{(\mu_{en}/\rho)_{\text{air}}} \times \frac{m_{\text{phosphor}} S_{\text{phosphor}}}{m_{\text{medium}} S_{\text{medium}}} \times G(x) + \frac{(\mu_{en}/\rho)_{\text{phosphor}}}{(\mu_{en}/\rho)_{\text{air}}} \times \{1 - G(x)\} \right]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

where  $G(x)$  is the geometrical function for a plane interface defined by Charlton and Cormack (1962).

It can be seen that equation (3) is a combination of equations (1) and (2) together with the geometrical function  $G(x)$ . It must be remembered, however, that the assumption of isotropic electron generation will not always be valid particularly for low atomic number materials and high photon energies. This is because in low atomic number materials the scattering of the high energy electrons generated by the high energy photons is not very pronounced. Hence the electrons remain biased in their original direction of motion, i.e. in the direction of the photons, and the spatial characteristics of the electron field should be taken into account when determining the dose to the phosphor, although this will not always be possible. Another particularly complex effect, the differential scattering of electrons across the interface between two media, must also be taken into account when the atomic numbers of the two media are significantly different and this is described below.

#### Electron scattering at an interface.

Dutreix and Bernard (1966) have shown that for high energy X-rays and gamma rays passing through an interface separating media of different atomic compositions, electron scattering can have a significant effect on the dose to the material in the vicinity of the interface. Figure 2 is taken from Dutreix and Bernard's (1966) work and it shows the dose distribution at the interfaces between copper and water irradiated by Co-60 gamma rays. The equilibrium electron fluence generated by the photons within the copper region is composed of electrons moving in the forward direction, i.e. the same general direction as the photon beam, and electrons which have been scattered so that they are moving in the backward direction. Within the



**FIGURE 2:** The Dose Distribution in Water in the Vicinity of an Interface with Copper. The ordinates correspond to the ratio of the absorbed dose  $D$  to the dose  $D_e$  in water under electronic equilibrium conditions. The dotted curve corresponds to the dose in an infinitely small mass of water located in the copper and the arrow shows the direction of the Co-60 gamma rays. There is an underdosage in the vicinity of the copper-water interface and an overdosage in the vicinity of the water-copper interface.

water region the electrons are assumed to be moving predominantly in the forward direction as scattering is very much less pronounced than in copper and hence there is negligible back-scattered electron fluence.

As the copper-water interface is approached (Figure 2), the backward component of the electron fluence begins to decrease as the amount of back-scattering material decreases, so that at the interface only the forward component of the electrons from the copper exists. In the water behind the interface, the electrons from the copper progressively vanish, but at the same time the electron fluence in water is generated and builds up to the equilibrium value. The attenuation of the copper electrons is more rapid than the build-up of the water electrons and hence the dose distribution curve passes through a minimum.

As the water-copper interface is approached the number of back-scattered electrons from the copper begins to increase so that the dose at the interface is considerably higher than the equilibrium dose in water. In the copper behind the interface the dose distribution passes through a maximum as the forward component of the electrons from the copper builds up, while the water component is simultaneously attenuated. The transition zones of underdosage or overdosage are approximately 2-3 mm thick which in certain circumstances can have important dosimetric consequences (Dutreix and Bernard, 1966).

Carlsson (1973) showed that electron scattering must be taken into consideration for much lower photon energies (100 and 200 KeV) when a high atomic number material forms an interface with a low atomic number material. She showed that at a plane interface between lead and mylar the measured dose in the mylar was about a factor of two less than the dose calculated neglecting electron scattering, i.e. a calculation based on a form of equation (3). This is because at the interface the electrons created in the lead and crossing the interface for the first time are not nearly so effectively back-scattered as from the high atomic number material, which results in a reduced electron fluence at the interface. The transition zones on either side of the interface are, however, only a fraction of a millimetre thick because of the short range of the low energy secondary electrons and hence this effect will be of minor importance in most situations.

It is worth noting here the results of Wintle and Aitken (1977), who showed that electron back-scatter is also important for beta source irradiations. They irradiated a 350  $\mu\text{m}$  thick slice of the TL phosphor  $\text{CaF}_2:\text{Dy}$  with a Sr-90 beta source on a nichrome plate and on perspex. By measuring the TL from the slice they found that the average dose to the 350  $\mu\text{m}$  slice irradiated on the nichrome plate was 17% higher than when irradiated on perspex. The increase is entirely due to back-scattered electrons from the nichrome.

Thus we have seen how the motion of the secondary electrons plays a vital role in the energy deposition by gamma rays in two media separated by an interface. In Part II of this paper it will be shown how this effect must be taken into account when quartz grains are irradiated by a gamma source for the purpose of beta source calibration. In addition, Part II describes the problems which can arise due to differences in grain transparency between different quartz samples.

#### REFERENCES

- Aitken, M.J., 1979. Interlaboratory calibration of alpha and beta sources, Proceedings of a Specialist Seminar on Thermoluminescence Dating, Oxford, July 1978, PACT Journal No 3, 443.
- Carlsson, G.A., 1973. Dosimetry at Interfaces, Acta Radiologica, Supplementum 332.
- Carlton, D.E. and Cormack, D.V., 1962. Energy dissipation in finite cavities, Radiation Research, 17, 34.
- Davisson, C.M., 1968. Interaction of  $\gamma$ -radiation with matter. In "Alpha-, Beta- and Gamma-ray Spectroscopy, Vol. 1", ed. K. Seigbahn, 2nd edition, North-Holland Pub. Co., Amsterdam, 37.
- Dutreix, J. and Bernard, M., 1966. Dosimetry at interfaces for high energy X and gamma rays, Br. J. Radiol., 39, 205.
- Evans, R.D., 1958. Compton Effect. In "Handbuch der Physik", 34, ed. S. Flügge, 218.
- Evans, R.D., 1968. X-ray and  $\gamma$ -ray interactions. In "Radiation Dosimetry, Vol. 1", eds. F.H. Attix and W.C. Roesch, 2nd edition, Academic Press, New York, 93.

- 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.
- Wintle, A.G. and Murray, A.S., 1977. Thermoluminescence dating: reassessment of the fine grain dose rate, Archaeometry, 19 (1), 95.

## THERMOLUMINESCENT DATING OF ANCIENT TOCONCE POTTERIES

G. Concha, A. Román, O. Brito and A. Deza  
 Thermoluminiscent Laboratory  
 Catholic University  
 P. O. Box 114-D, Santiago, Chile

**SUMMARY:** The dating of five samples from different depth levels of the same archaeological "site" Toconce was made by TL measurements. These results agreed with the estimated values obtained by the archaeological context and the radiocarbon method.

**INTRODUCTION:** The study of the natural thermoluminescence (NTL) and the artificial thermoluminescence (ATL) produced by irradiation with the beta source was made on five pottery samples from the archaeological "site" Toconce at Antofagasta in the north of Chile. The pieces of pottery were chemically washed and sieved in order to get the quartz grains with a diameter of 100 microns. The radiation dose received by each sample, after its original firing, was determined by the "plateau" and the "pre-dose" methods. The annual dose was calculated from the concentration of radioactive trace elements of the sample and the burial soil. An analysis of the TL glow showed that the light emission is proportional to the dose received by the sample. The calculated ages of the five samples differ by about 10% from the values given by the radiocarbon and context methods.

**METHODS AND MATERIALS:** The quartz grains, were poured onto a stainless steel sample holder, and placed on a heater plate. The heating rate of 20°C/sec was controlled electronically and measured with a chromel-alumel thermocouple welded to the heating plate. The luminescent emission was detected with a photomultiplier (Phillips 56-AVP) connected to a high tension source (Keithley 246). The signal from the photomultiplier was amplified with an electrometer (Keithley 610 c), and recorded through channel Y of a Hewlett-Packard 7004-B recorder. The signal from the thermocouple was recorded through channel X of the same recorder giving the glow curve. The quartz grains were irradiated with a 85 rad/min dose rate from a fixed position Sr-90, 10 mCi source.

**SAMPLE PREPARATION:** The pottery samples were crushed and washed with "Aqua regia" and 1% HF solution. The quartz inclusions were sieved to obtain grains with 100-200 microns diameter in order to use the quartz inclusion technique (1).

**THE EQUIVALENT DOSE (ED):** The dose received by the sample after its original firing, the equivalent dose (ED), was calculated by the "plateau" and the "pre-dose" methods. In the plateau method the curves of NTL and ATL, for 850 rad  $\beta$  dose, were recorded.