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# Spectral emission properties of some blue light-emitting diodes

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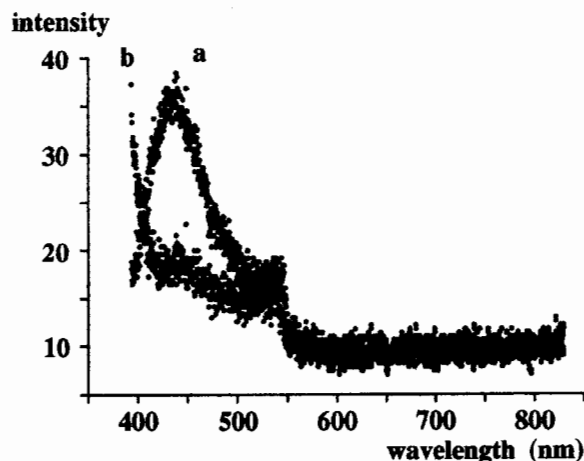
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The emission spectrum of light-emitting diodes used for stimulation of luminescence is important because of the need to separate the luminescence from scattered stimulating light by use of optical filters (for example as discussed by Huntley *et al.*, 1985; Galloway *et al.*, 1997; Bøtter-Jensen, 1997) and also because the efficiency of stimulation of luminescence is wavelength dependent (Spooner, 1994; Bøtter-Jensen *et al.*, 1994; Huntley *et al.*, 1996). We report here on the properties of three blue light-emitting diodes (LEDs) which have peak emission at wavelengths of 430, 450, and 470 nm (table 1) and which show contrasting behaviour in their emission spectra. The Nichia NSPB500S with peak emission at 470 nm is the brightest of the three and is in use for luminescence stimulation in this laboratory and elsewhere (Bøtter-Jensen, 1997). Optical spectra were measured with the same spectrophotometer as used by Galloway and Neal (1998) in the study of green LEDs. The spectrometer is based on a 700 lines/mm holographic grating with the diffraction spectrum captured by a CCD camera and displayed by a PC microcomputer; the wavelength range covered is 393 - 830 nm.

The results from spectral measurements on the blue LEDs are summarised in table 1, in terms of both the wavelength of the emitted light and the corresponding photon energy. Otherwise the results are presented and discussed in terms of emitted wavelength for ease of comparison with the data provided by manufacturers of optical filters. At a current of 20 mA, the 430 nm LED showed an emission peak with a width at half maximum of 65 nm, the 450 nm LED width was 78 nm, while the 470 nm LED had the narrowest width at half maximum, 28 nm. The mean wavelength of maximum emission for 7 of the 430 nm LEDs was  $430 \pm 2$  nm while that for 6 of the 470 nm LEDs was  $467 \pm 7$  nm, i.e. the wavelength of maximum emission varied more from diode to diode for the 470 nm LEDs. (Only one 450 nm LED was available for testing.) For all the LEDs,

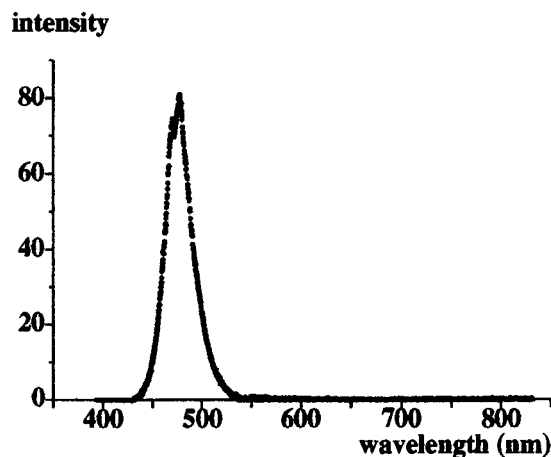
the shape of the emission spectrum was unchanged over the current range 10 - 30 mA. Indeed for the 430 and 450 nm LEDs the shape remained unchanged down to 4 mA, while for the 470 nm LED the wavelength of maximum emission moved upwards by about 4 nm as the current was reduced from 10 mA to 2 mA.



**Figure 1.**  
Spectra from a 430 nm LED with the current in pulses of 50 ms duration at a repetition rate of 1 kHz, (a) for 20 mA pulses and (b) for 400 mA pulses. (The intensity is in photons  $s^{-1} nm^{-1}$  on an arbitrary scale.)

Constancy of emission with time is also important for luminescence stimulation. Spectra were collected for all three types of diode, operated at 20 mA, at switch on and at frequent intervals over a 30 minute period without any detectable change in shape of the emission band. Commonly the intensity of light from an LED shows an overshoot at switch on (Poolton and Bailiff, 1989; Galloway *et al.*, 1997; Galloway and Neal, 1998). The brightest of the three types of LED (470 nm) was investigated in this regard by using a photomultiplier (preceded by neutral density filters) to count the number of photons detected in

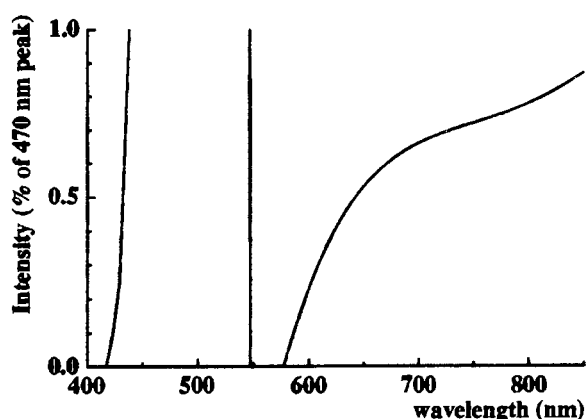
250 successive 1 s intervals from switch on of a constant current supply. After the initial overshoot of intensity, which depends on the current as detailed in table 2, the intensity was constant within better than  $\pm 1\%$ .



**Figure 2.**  
The spectrum from a 470 nm LED with 50 mA current pulsed at 5% duty cycle. (The intensity is in photons  $s^{-1} nm^{-1}$  on an arbitrary scale.)

The behaviour of the 430 nm and 470 nm LEDs was also investigated when the maximum recommended current (30 mA dc or 100 mA pulsed at 10% duty cycle) was exceeded. For the 430 nm LED, increasing the current beyond the recommended maximum of 30 mA up to 50 mA produced no noticeable change in the emitted spectrum. Pulsing the LED on for 50 ms at a repetition rate of 1 kHz (5% duty cycle) showed for current pulses above 100 mA, a reduction in the 430 nm emission and the occurrence of significant emission at wavelengths shorter than 400 nm. Fig. 1 compares the emission spectra for current pulses of 20 mA and 400 mA; this change of emission from a peak at 430 nm to a peak in the ultraviolet has been reported for a Nichia type NLPB500 LED by Sato *et al.* (1996). A typical spectrum for a 470 nm LED is shown in fig. 2; however, increasing the dc current above the recommended maximum of 30 mA introduced emission at the long wavelength end of the spectrum, as exemplified in fig. 3. The magnitude of this effect ( $< 2\%$  of the main 470 nm peak) and the range of wavelengths of the emitted photons varied with current and from diode to diode of the same type. Once induced by exceeding 30 mA dc current, the effect persisted to a lesser extent even if the current was reduced well below 30 mA; it remained detectable down to 10 mA with one diode. However

if the diode is pulsed at 50 mA at 5% duty cycle, the spectrum, fig. 2, is no different from the spectra associated with dc currents of less than 30 mA. Indeed pulsing the LED at currents up to 400 mA at 5% duty cycle does not introduce the long wavelength emission, but simply broadens the 470 nm peak (to 46 nm full width at half maximum). The long wavelength emission thus appears to be associated with overheating the diode rather than with the magnitude of the current passing through it. However, the shape of the spectrum in fig. 2 is not that of incandescence. All the diodes tested recovered their normal behaviour, that is no long wavelength emission for dc currents less than 30 mA, after being switched off. No such effect of long wavelength emission could be observed for the 525 nm (2.37 eV) green LED (Nichia type NSPG500) discussed by Galloway and Neal (1998) by increasing the dc current to 50 mA or by pulsing at 400 mA (5% duty cycle). The effect of pulsing at 400 mA was to increase the full width at half maximum to 64 nm (from 42 nm at 20 mA dc) and to reduce the wavelength of the peak in the emission spectrum by 10 nm.



**Figure 3.**  
An example of long wavelength emission from a 470 nm LED operated at a current greater than recommended maximum of 30 mA. The current was 50 mA and the intensity is a percentage of the amplitude of the 470 nm peak.

The 470 nm Nichia type NSPB500S LED shows a constancy of emission spectrum and light intensity when the recommended maximum current (30 mA dc) is not exceeded, which makes it suitable for luminescence stimulation. However exceeding the maximum current may induce unexpected emission at

long wavelengths, in the region of the resonance in the photostimulation of potassium feldspars (Hutt *et al.*, 1988).

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### Reviewer

D.J. Huntley

### Comments

It is very useful to know the properties of the blue LED's available. I had expected that they would not be particularly useful for dating because a significant

fraction of the blue photons would be Raman scattered into the UV measurement window. Apparently I was wrong. I would caution those planning to use blue LED's particularly those of the shorter wavelengths, that this may yet be a problem in some instances, and will become more so if measurements are performed above room temperature.

**Table 1**

Properties of the blue LEDs measured.

Type no.	110121*	110039*	NSPB500S**
<b>Specification:</b>			
Peak wavelength (nm)	430	450	470
(photon energy eV)	(2.89)	(2.76)	(2.64)
Mcd at 20 mA	~300	500 – 1000	2000
Max. current (mA)	30	30	30
<b>Measured (for 20 mA):</b>			
<i>One LED as example of</i>			
<i>type, peak wavelength (nm)</i>	$430 \pm 2$	$449 \pm 2$	$461 \pm 2, 489 \pm 2$
(photon energy eV)	$(2.89 \pm 0.01)$	$(2.75 \pm 0.01)$	$(2.70, 2.54)$
50% of peak intensity (nm)	$402 \pm 2, 467 \pm 2$	$419 \pm 2, 497 \pm 2$	$450 \pm 2, 511 \pm 2$
(eV $\pm 0.01$ eV)	$(3.09, 2.66)$	$(2.97, 2.50)$	$(2.76, 2.43)$
10% of peak intensity (nm)	$<390, 512 \pm 2$	$398 \pm 2, 550 \pm 2$	$438 \pm 2, 530 \pm 2$
(eV $\pm 0.01$ eV)	$(>3.19, 2.43)$	$(3.12, 2.26)$	$(2.76, 2.43)$
1% of peak intensity (nm)	$<390, 550 \pm 2$	$<390, 596 \pm 2$	$438 \pm 2, 530 \pm 2$
(eV $\pm 0.01$ eV)	$(>3.19, 2.26)$	$(>3.19, 2.09)$	$(2.84, 2.35)$
<i>mean of several LEDs,</i>			
mean peak wavelength (nm)	$430 \pm 2$		$467 \pm 7$
(photon energy eV)	$(2.89 \pm 0.01)$		$(2.66 \pm 0.04)$
number of LEDs measured	7	1	6

\*\* Nichia Chemical Company, Japan

\* M.I. Cables Ltd., Inverness IV3 6EX, Scotland.

**Table 2.**

The initial overshoot in photon counting rate from one 470 nm Nichia type NSPB500S LED at switch on of a constant current power supply.

current (mA)	10	20	30	40	50
amplitude (%)	$0 \pm 0.8$	$0.9 \pm 0.6$	$1.6 \pm 0.5$	$2.4 \pm 0.5$	$4.1 \pm 0.5$
duration at half amplitude (s)	$0 \pm 2$	$2 \pm 2$	$8 \pm 3$	$8 \pm 3$	$8 \pm 3$

## Further comments on decay kinetics of isotropic radicals in carbonates

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**Abstract :** This work is a continuation of previous investigations on decay kinetics of isotropic radicals in carbonates (Ancient TL, 1997, 15, 30-35). It rules out a model implying only chemical reactions between  $\text{CO}_2^-$  and  $\text{CO}_3^-$  radicals, questions the use of a sum of first-order kinetics and supports the dispersive second-order equal concentration kinetics with a time-dependent rate constant.

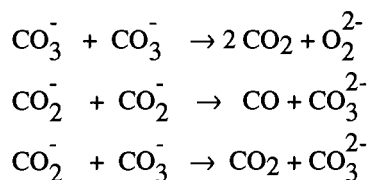
### Introduction

Recently, we studied the decay kinetics of isotropic radicals ( $\text{CO}_2^-$ ,  $\text{CO}_3^-$ ,  $\text{SO}_2^-$ ), located in a disordered environment of protons of the occluded water (Callens *et al.*, 1994; Idrissi *et al.*, 1996), in synthetic monohydrocalcite and natural carbonates (Debuyst *et al.*, 1995, 1997). We considered various kinetic approaches including diffusion-controlled mechanisms and dispersive kinetics with a time-dependent reaction rate of the form  $k(t) = Bt^{\alpha-1}$  ( $B$  and  $0 < \alpha \leq 1$  are constants). The best decay description was found to be the second-order equal concentrations dispersive equation (Plonka, 1991), as, with only two parameters, it could satisfactorily fit all the kinetic data (provided that the annealing temperature is lower than that of the water departure). The radicals are supposed to diffuse and recombine together ( $2 \text{CO}_2^-$  or  $2 \text{CO}_3^-$ ), as was previously proposed (Hisatsume *et al.*, 1970) or react with an equal number of complementary centers (electron center + hole center,  $\text{CO}_2^- + \text{CO}_3^-$ ) (Ikeya, 1993), but with an in-time-decreasing reaction rate. Dispersive models have been successfully applied to reaction kinetics of radiation produced species in condensed media (i.a. ice, polymers, drugs) (Plonka, 1990; Kantoglu *et al.*, 1995; Miyazaki *et al.*, 1994). A distribution of reaction rates or activation energies may indeed be expected in disordered, non-homogeneous systems.

The parameter  $\alpha$  is a measure of the dispersion of reactivity due to spatial, temporal or energetic disorder of the system. So, the model has also a well-founded physical basis and seems to be suitable to an occluded water environment.

In the present note, we further investigated kinetics for the following reasons. First, some colleagues (chemists) criticized us for not having explicitly considered the chemical reactions between  $\text{CO}_2^-$

and  $\text{CO}_3^-$  which are the only radicals observed in the ESR spectra of irradiated synthetic monohydrocalcite. The following reactions may be proposed (Hisatsume *et al.*, 1970) :



The corresponding differential equations for both **coupled** radicals can be solved **numerically**. In case of satisfactory fitting, this model based on chemical reactions and constant reaction rates may be an alternative to the dispersive model.

Second, we reconsider also the possibility that each kinetic curve is a sum of exponential functions. This is the model generally used in dating : several first-

order reactions occurring simultaneously and independently of each other with different rates. Çetin *et al.*, 1993, e.g., proposed for their data a sum of three exponentials. Using their data, we demonstrated that dispersive kinetics explained just as easily the entire decay curves with fewer parameters (Debuyst *et al.*, 1995). The number of localization sites (three) seemed to us also quite arbitrary in the multi-exponential model. Different environments with different activation energies for the radical can, however, be considered e.g. in the bulk or at the surface of the constituents of the material (here, the occluded water). A similar situation is encountered e.g. in tooth enamel, where two types of anisotropic  $\text{CO}_2^-$  radicals with very similar g-values are produced and are difficult to distinguish in EPR powder spectra (Callens, 1997). The multi-exponential model is thus again reconsidered here by means of the "spectral analysis" used by one of us (M.B.) in another research field (Cunningham and Jones, 1993).

As will be seen in the Results, the dispersive model seems to us still the most satisfactory one. Kinetic curves exhibiting an initial increase are here also analysed within the framework of this model. An initial increase is indeed quite common to both laboratory- irradiated synthetic and natural carbonates. Moreover,  $\alpha$  values for the radicals in monohydrocalcite in a wide range of temperature (303-443 K) are also presented.

### Experimental data

The following experimental data were used in this work :

a) the data for  $\text{CO}_2^-$  and  $\text{CO}_3^-$  of Debuyst *et al.*, 1995, where  $\gamma$ -irradiated (2700 Gy) synthetic monohydrocalcite was thermally annealed at 371, 391, 417 and 443 K ; new experimental data at 303, 333 and 403 K (for the last temperature at 3000 and 9000 Gy) were added ;

b) the data of Çetin *et al.*, 1993, concerning  $\text{CO}_2^-$  in a fossil mollusc annealed at 493, 513 and 522 K.

### Theory

For both following methods, the parameters of the models were fitted to the data using the Levenberg-Marquardt algorithm (Press *et al.*, 1990).

#### Differential equations for connected kinetics

The decay of both  $\text{CO}_2^-$  and  $\text{CO}_3^-$  can be described by the following equations (1) :

$$\frac{d[\text{CO}_2^-]}{dt} = -p_1[\text{CO}_2^-]^2 - p_2[\text{CO}_2^-][\text{CO}_3^-] - p_4[\text{CO}_2^-]$$

$$\frac{d[\text{CO}_3^-]}{dt} = -p_2[\text{CO}_2^-][\text{CO}_3^-] - p_3[\text{CO}_3^-]^2$$

where  $p_1$ ,  $p_2$ ,  $p_3$  and  $p_4$  are the parameters to be fitted to the data. The first three parameters correspond to the chemical reactions presented in the Introduction, whereas the fourth is a supplementary one describing a possible first-order reaction mechanism for  $\text{CO}_2^-$ . Equations (1) (with and without parameter  $p_4$ ) were numerically solved by ordinary differential equations method implemented as ODE 23 in Matlab software. The fitting procedure can be applied to the data of each radical separately.

#### Exponential functions

Because the number of exponential functions is initially not known and only some functions are retained from as much as 50 functions used to fit the data, this method is called spectral analysis (Cunningham and Jones, 1993). The data of the radical were assumed to be a combination of  $n$  exponential functions (2) :

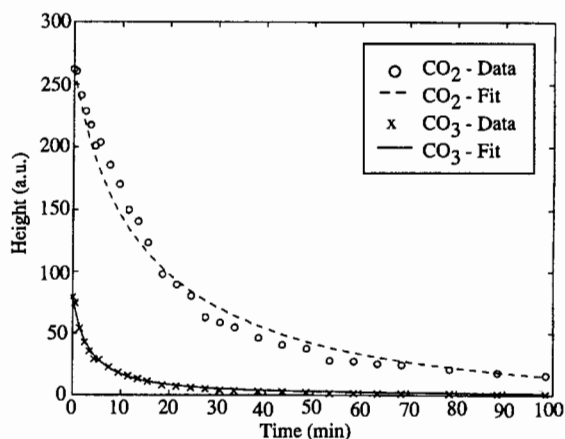
$$f(t) = c_1 \exp(-b_1 t) + c_2 \exp(-b_2 t) + \dots + c_n \exp(-b_n t)$$

where the coefficients  $c_i$  ( $i = 1, n$ ) are non-negative constants.  $t$  is the sampling time of the curve and is a column vector of size  $m$ . The number of terms  $n$  is initially arbitrarily chosen to be large enough to explore the range of physical true constants ( $n = 50$ ). The exponents  $b_i$  sequentially take the  $n$  values from an arbitrarily small value ( $b = 10^{-5}$ ) to  $b = 1$ . Equation 2 can be written in a matrix form:

$$[E] \cdot [C] = [F_2] \quad (3)$$

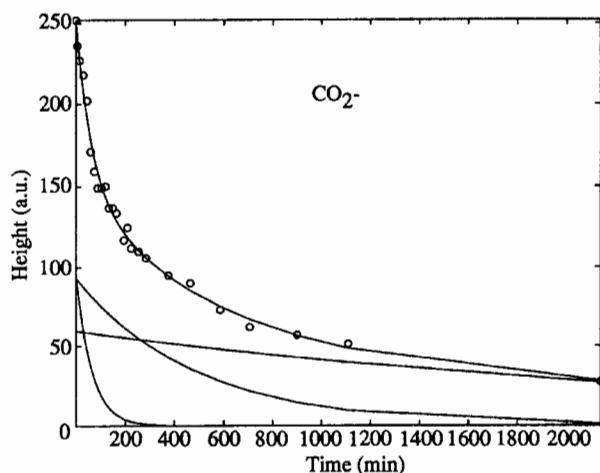
where the  $m \times n$  matrix  $[E]$  is formed by the exponential functions,  $[C]$  is the  $n$  elements vector of coefficients and  $[F_2]$  is the  $m$  data points to be fitted. The coefficients  $c_i$  can be obtained by solving equation (3) using the non-negative least square (nnls) algorithm (Lawson and Hanson, 1974). The few  $c$  values satisfying both equation 3 and the non-negativity constraint, together with their corresponding  $b$  values, form the requested exponential functions (in general, only 2 to 6 terms are obtained from the initial 50). This technique

generally gives some parameters split in two values and this effect is due to the finite sampling of the  $b$  values. These two values can be averaged to form one exponential function and these parameters are further fitted to more precisely adjust the data.



**Figure 1.**

Fitting  $\text{CO}_3^-$  data of monohydrocalcite annealed at  $T=443\text{ K}$  as described by eq 1 without parameter  $p_4$ , followed by fitting  $\text{CO}_2^-$  data with  $p_4$  (see text).



**Figure 2.**

Decomposition of  $\text{CO}_2^-$  radicals in monohydrocalcite in their exponential functions for data at  $417\text{ K}$ . Here, the decomposition was constrained to 3 components. Their sum is shown to accurately fit the data.

Spectral analysis provides all the exponential functions giving the best approximation to the data. However, statistical fluctuations in the data can generate one or more components recognisable by their shape, which can be omitted and the remaining

parameters are fitted to the data, thus constraining the decomposition to physical components.

## Results

### A. Kinetics

The kinetic data of  $\text{CO}_2^-$  and  $\text{CO}_3^-$  in monohydrocalcite are connected in Equations (1). These equations, without parameter  $p_4$ , were not able to fit both kinetic curves. The best results were obtained by fitting first, satisfactorily, the curve of  $\text{CO}_3^-$ , and afterwards, but badly, that of  $\text{CO}_2^-$ . Figure 1 shows the data at  $443\text{ K}$  with a good fit for  $\text{CO}_3^-$  ( $p_3/p_2 \cong 8$ )

The calculated values for  $\text{CO}_2^-$  are however already too high after about ten minutes heating time (not shown on the figure). Keeping these values of  $p_1$ ,  $p_2$  and  $p_3$ , a better but insufficient fit for  $\text{CO}_2^-$  was obtained by adding the fourth parameter  $p_4$  ( $p_4 \gg p_1, p_2$ ) (shown on figure 1). Similar or worse results are obtained for the other data of Debuyst *et al.*, 1995 plus the new ones at  $403\text{ K}$ . This model should thus be abandoned.

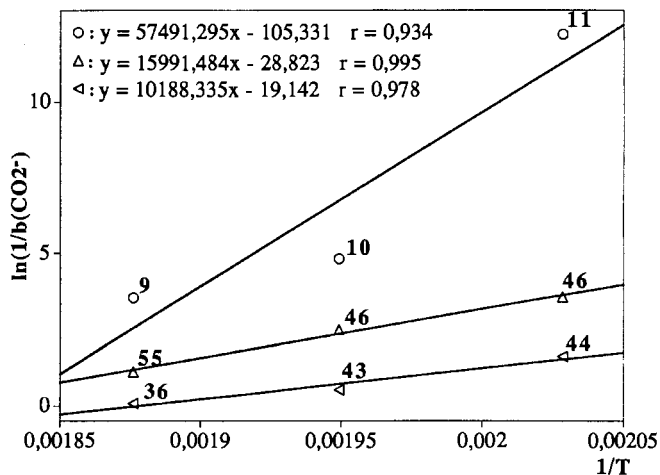
### B. Sum of exponentials

The program of spectral analysis was used with the experimental data of both monohydrocalcite and fossil mollusc. Two options were chosen: no constraint at all for the number of components and elimination of too small components followed by a new fit with a fixed number of components. Even with no constraint, only three components were found for the data of the fossil mollusc, whereas, in the case of monohydrocalcite, up to six components appeared that could be reduced to three or two after elimination of small contributions (see Fig. 2 as an example). Figures 3 and 4 show the Arrhenius plots

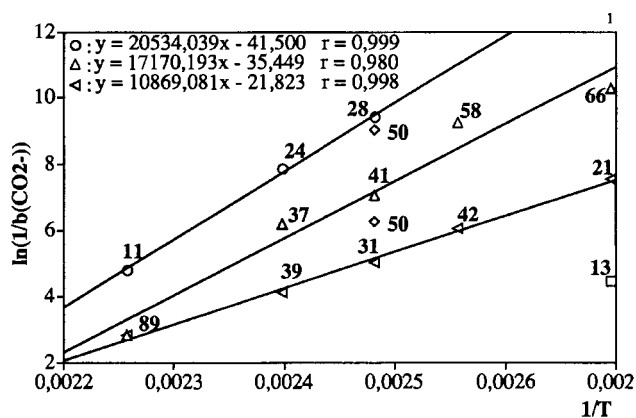
obtained for  $\text{CO}_2^-$  in both compounds. The values indicated in these figures are those of the coefficients  $c$  expressed in %. At  $403\text{ K}$ , the data for  $3000\text{ Gy}$  yielded two components (noted  $\diamond$  in figure 4), whereas those for  $9000\text{ Gy}$  had three components. The results for the fossil mollusc are better than those for monohydrocalcite: the corresponding  $c$  values at different temperatures are close to each other. Those of monohydrocalcite ( $\text{CO}_3^-$  included,



whose results are not shown) are definitely less conclusive.



**Figure 3.**  
Arrhenius plots for the three exponential functions (symbols : circle, triangle up and triangle left) of  $\text{CO}_2^-$  in fossil mollusc annealed at  $T = 493, 513$  and  $533$  K. The numbers beside the symbols represent the coefficients of the exponentials.

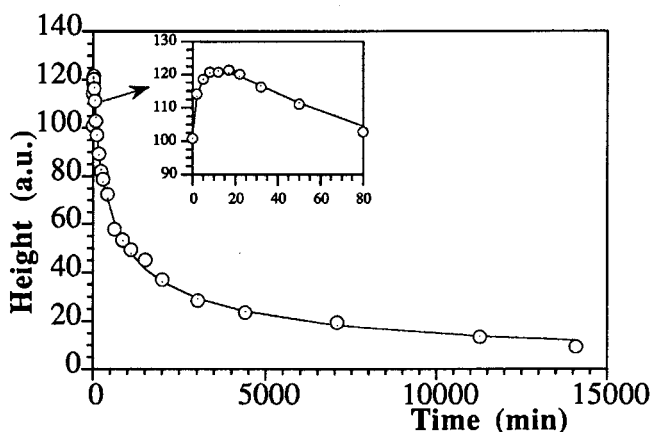


**Figure 4.**  
Arrhenius plots for the three or two exponential functions of  $\text{CO}_2^-$  in synthetic monohydrocalcite annealed at  $T = 371, 388, 403, 417$  and  $443$  K.

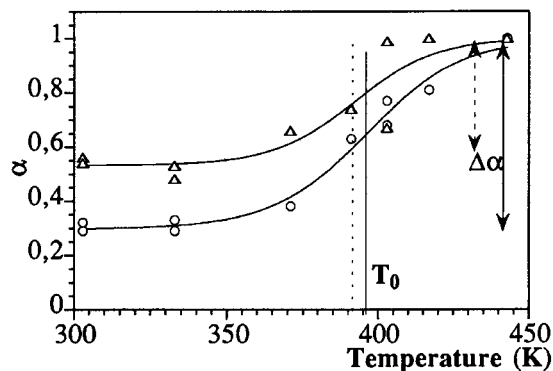
#### C. Dispersive model

Satisfactory fits with the dispersive model for radicals in synthetic monohydrocalcite, fossil mollusc and coral have already been presented in Debuyst *et al.* (1995, 1997). This model remains our

favourite one. The previous works, however, did not consider the presence of an initial increase in the isothermal data. To our knowledge, this increase does not exist in non-laboratory-irradiated fossil samples ; in the case of synthetic monohydrocalcite, it lasts some minutes for  $\text{CO}_3^-$  and some tens of minutes for  $\text{CO}_2^-$ , and has been removed in the previous analyses.



**Figure 5.**  
Curve fitting with the dispersive model for  $\text{CO}_2^-$  in 9000 Gy-monohydrocalcite annealed at 403 K.



**Figure 6.**  
 $\alpha$ -values for  $\text{CO}_2^-$  (o) and  $\text{CO}_3^-$  ( $\Delta$ ) radicals in irradiated monohydrocalcite as a function of the annealing temperature

This initial increase can be explained by the presence of a precursor feeding the radical in the first step of the thermal annealing. As this phenomenon is common to both radicals, we believe that this increase is due to anisotropic radicals which, following their diffusion or the diffusion of nearby

partners, rotate more and more easily and become isotropic. In fossil samples, this diffusion is achieved nowadays and no increase is observed. Figure 5 shows a complete curve

for  $\text{CO}_2^-$  at 403 K using the following equations solved numerically with Matlab software :

$$\begin{aligned} dr/dt &= -Bt^{\alpha-1} r^2 + Ct^{\alpha-1} p \\ dp/dt &= -Ct^{\alpha-1} p \end{aligned} \quad (4)$$

where  $r$  and  $p$  represent the concentrations of the radical and the precursor,  $\alpha$  is supposed to have the same value for both species. A first-order reaction for the precursor yielded a slightly better fit than a second-order one.

Two experiments at low temperatures (303 and 333 K, during around 45 weeks) were also performed in order to have a broader field of  $\alpha$  values. At these low temperatures, the initial increase is weak or hardly visible and the intensity of the ESR signal only decreases after some time (several hours at 333 K and a hundred hours at 303 K). The values of  $\alpha$  at 303, 333 and 403 K obtained using equations (4) are presented in figure 6 together with the values at the other temperatures obtained previously. The experimental data show a sigmoid behaviour : below nearly 353 K,  $\alpha$  remains constant for both species, but with a lower value for the more stable  $\text{CO}_2^-$

radical (0.3 compared to 0.5 for  $\text{CO}_3^-$  and reaches the value of 1 (i.e. the classical second-order) at around 413 K for  $\text{CO}_3^-$  and 443 K for  $\text{CO}_2^-$ . A function of the form  $\alpha = 1 - (\Delta\alpha(1 + \exp m(T - T_0)))$ , where  $\Delta\alpha$  is the total difference in the  $\alpha$ -values,  $T$  is the temperature,  $T_0$  the temperature at which a mean value of  $\alpha$  is obtained and  $m$  is a parameter related to the slope of the curve, was used to fit the data. The experiments were duplicated at 303 and 333 K with the same dose (3000 Gy), whereas at 403 K the dose was 3000 for one of the samples and 9000 Gy for the other. The experimental uncertainties are larger for the less stable  $\text{CO}_3^-$ . A sigmoid behaviour also appears, in the dispersive model, for the distribution function of the activation energy at a given temperature (Plonka, 1991).

## Conclusions

The present work rules out a model implying only chemical reactions between  $\text{CO}_2^-$  and  $\text{CO}_3^-$  radicals.

The distribution of rates for a given decay reaction proposed in dispersive kinetics seems, in disordered systems, more logical than a superposition of a limited number of exponential decays. The reason for having a precise number of first-order reactions is not clear, the Arrhenius plots (specially in figure 4) are not convincing and the number of parameters used in the fits is quite high. Nevertheless, the experimental uncertainties are larger for unstable compounds (monohydrocalcite compared to natural carbonates) and less stable radicals ( $\text{CO}_3^-$

compared to  $\text{CO}_2^-$ ). In this respect, the Arrhenius plots for the more stable fossil mollusc (figure 3) could be considered as not too bad. It is hoped that this work will incite colleagues to utilize both multi-exponential and dispersive models. As for dose response curves, multiple samples and repeated measurements should improve the quality of the data and make the choice of an appropriate model easier.

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#### Reviewer

H. Schwarcz

# Bleaching characteristics of some optically stimulated luminescence signals

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## Introduction

When dating sediments by luminescence, zeroing of the signal prior to deposition is essential since incomplete bleaching will result in age overestimation. Therefore when dating sediments undergoing rapid transportation like fluvial deposits, resetting of the luminescence signal prior to deposition needs to be verified. One possibility to do so is the comparison of luminescence emissions with different bleaching characteristics. As demonstrated by Godfrey-Smith et al. (1988), optically stimulated luminescence (OSL) is more rapidly bleached in comparison to thermoluminescence (TL). Hence, obtaining similar OSL and TL ages indicates zeroing of both signals prior to deposition (Duller 1994). However, for many sediments from fluvial environments complete bleaching of the TL signal is not very likely. Thus, the approach of comparing OSL and TL ages will be limited to well bleached sediments and negates the advantage of OSL, the easy-to-bleach nature of the signal. It has been suggested that the comparison of OSL from quartz and feldspars should be an appropriate method to confirm complete bleaching prior to deposition (Fuller et al. 1994). Furthermore, different IRSL emissions have been used for verifying the zeroing of feldspars gathered from lake deposits from Antarctica (Krause et al. 1997). However, only a few studies focusing on the bleaching characteristics of different OSL signals have been published so far. Therefore, it was the aim of this study to investigate whether these methods are indeed suitable for testing complete bleaching of the OSL signal prior to deposition.

## Experimental details

Experiments were carried out to define the bleaching characteristics of different OSL emissions from polymineral fine grains (4-11 µm) and coarse grained (100-200 µm) potassium rich feldspar and quartz samples. The fine grained fraction was enriched using

the technique described by Frechen et al. (1996). Coarse grains were separated by wet sieving and heavy liquids (Mejdahl 1985). The quartz fraction was furthermore etched in concentrated HF for 60 minutes. The etched and dried samples were subsequently sieved again to remove remaining feldspar grains. Purity of the quartz samples was verified by the lack of luminescence under infrared stimulation (Smith et al. 1990).

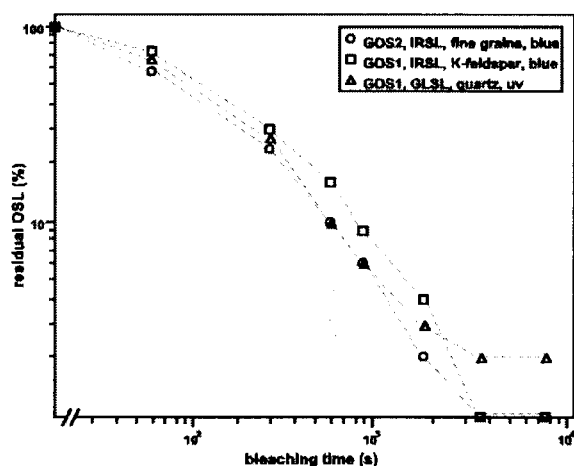
Bleaching was carried out using an Osram Ultra-Vitalux UV lamp (300 W) and a Schott GG475 filter. The filter cuts off any light with wavelengths < 475 nm (UV - blue) and thus will give a rough simulation of shallow water conditions. However, an authentic simulation of a natural fluvial transport is nearly impossible because of the complexity of the environment. Former work has shown that turbidity and turbulence within the water column will severely decrease the light intensity (Ditlefsen 1992), yet turbidity and turbulence are highly variable both spatially and temporally.

The samples were taken from sections at Gossau (GOS) and Zell (ZEL), Switzerland. The delta sediments at Gossau (GOS1, GOS2) and the fluvial deposits at Zell (ZEL5) have OSL ages of approximately 100 ka. Sample GOS3 was gathered from an overbank deposit with an age of approximately 50 ka (Preusser 1999 a, b).

A Risø reader DA 12 has been used for the OSL measurements (Bøtter-Jensen et al. 1991). GLSL was measured using the apparatus described by Bøtter-Jensen & Duller (1992) with a Hoya U340 detection filter. The IRSL signal was detected in the broad band (Schott BG39), yellow (Schott BG39, Schott OG530), blue (Schott BG39, Corning 7-79, Schott GG400) and UV (Hoya U340) emission bands.

The multiple aliquot technique was applied for the fine grained samples GOS2 and GOS3 recording the emitted luminescence during a 60 second measurement with IR diodes. Five aliquots were

measured for each step without any normalisation and the integral 50-60 seconds was subtracted as late light (Aitken and Xie 1992). All other measurements were carried out using a single aliquot protocol. Here, the natural luminescence intensity was measured by a 0.5 sec exposure to infrared stimulation (IRSL) or green light stimulation (GLSL), respectively. The aliquots were then bleached for 60 seconds using the filtered light of the UV lamp and measured again. Subsequently, the samples were bleached for a further 240 seconds resulting in an entire bleaching time of 300 seconds. This procedure was repeated using different bleaching intervals up to the maximum entire bleaching time of 7200 seconds when no further depletion of the OSL signal has been recognised.

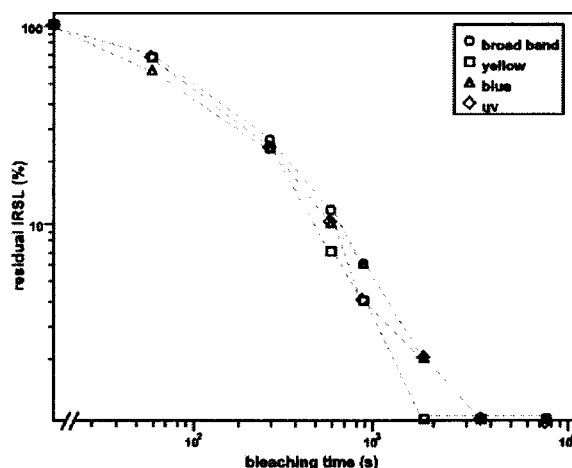


**Figure 1.**

*Comparison of the bleaching characteristics of GLSL from quartz and blue IRSL emissions from polyminerale fine grains and feldspar samples gathered from early weichselian delta sediments at Gossau, Switzerland.*

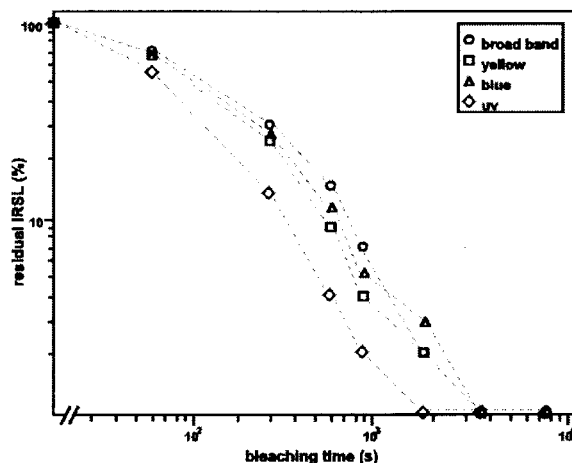
## Results

The results of the bleaching experiments are presented in figures 1-5. For comparison the remaining OSL after bleaching is stated as the percentage of the original signal intensity. Typical scatter within the single bleaching steps is about 5-10 % for the multiple aliquot and about 2-3 % for the single aliquot measurements. After 60 seconds of bleaching the signal depleted to about two-thirds of the original level. 300 seconds bleaching resulted in residual levels of about 20-30 %. After 3600 seconds the remaining IRSL intensity was about 1-2 %.



**Figure 2.**

*Comparison of the bleaching characteristics of different IRSL emissions from polyminerale fine grains (sample GOS2).*

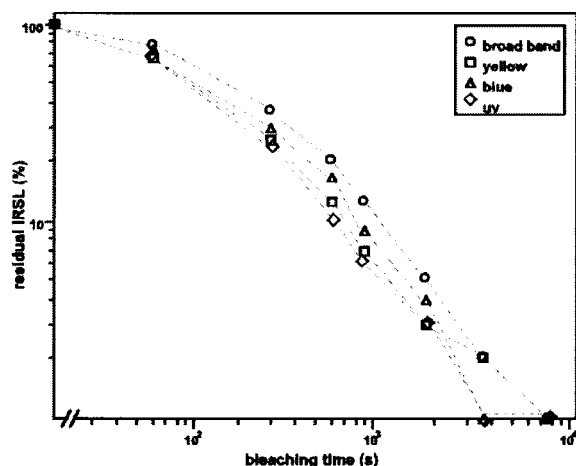


**Figure 3.**

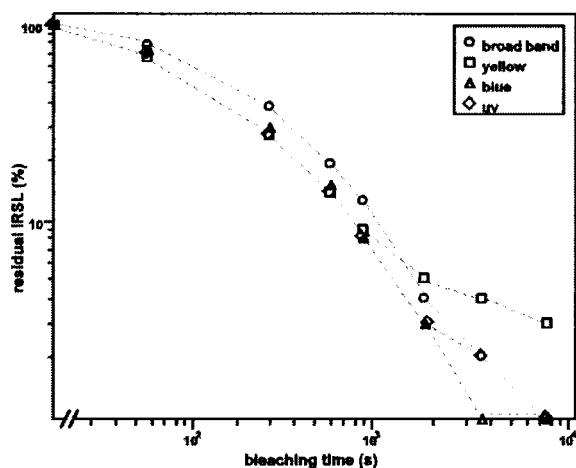
*Comparison of the bleaching characteristics of different IRSL emissions from polyminerale fine grains (sample GOS3).*

Figure 1 compares the results of the bleaching experiments for GLSL from quartz and the blue IRSL emissions from K-feldspars and polyminerale fine grains of two samples (GOS1 and GOS2) from the delta sediments at Gossau. All dosimeters show nearly identical bleaching characteristics except for a higher residual level for the quartz measurements caused by scattered light from the stimulation source. The results of the bleaching experiments on different IRSL emissions for fine grains are plotted in figure 2 and figure 3. Both samples show nearly corresponding bleaching characteristics of the single IRSL emissions but a more rapid zeroing of the yellow emission (GOS2; Fig. 2) and UV emissions (GOS3; Fig. 3), respectively. The K-feldspar samples (Fig. 4 and Fig. 5) show also only small differences

in the resetting of the IRSL. However, for both samples the broad band emissions seem to be bleached less rapidly. The apparent higher residual level for the yellow emissions of sample ZEL5 (Fig. 5) is due to the weak IRSL signal emitted in that range and, hence, caused by a low signal/background ratio.



**Figure 4.**  
Comparison of the bleaching characteristics of different IRSL emissions from coarse grained potassium rich feldspars (sample GOS1).



**Figure 5.**  
Comparison of the bleaching characteristics of different IRSL emissions from coarse grained potassium rich feldspars (sample ZEL5).

### Discussion

Considering scatter and reproducibility, only trifling differences in the resetting characteristics of the single OSL signals have been recognised in the recent

study. Furthermore, these small differences seem to show no systematic pattern.

The bleaching experiments by Krause et al. (1997) were performed under similar experimental conditions but on a different mineral (plagioclase). In contrast to the original interpretation by the authors, these experiments show actually also only small differences in the bleachability between the single IRSL emissions (see Krause et al. 1997: Fig. 7; consider the logarithmic scale). Consequently, it has to be questioned if the higher IRSL ages obtained for the emissions at 330 nm and 410 nm are really caused by differences in the resetting characteristics of the single emissions, as suggested by the authors.

### Conclusions

No significant differences in the bleachability of the single OSL signals have been found so far. Therefore, comparing different OSL emissions is no appropriate method for verifying zeroing of the OSL prior to deposition until clear evidence for variations in the resetting characteristics is given. However, even if some systematic patterns could be confirmed, the differences in resetting of the single OSL emissions are likely too small to give a reliable verification considering the reproducibility of multiple aliquot dating.

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#### Reviewer

G. Duller

## Notices

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### Community News

Although most of us believe that peer approval of an individual's research is adequate accolade it is nevertheless satisfying to know that from time to time there is external recognition of our field. Early this year Henry Schwarcz was honoured with the Fryxell Award of the Society for American Archaeology, and a couple of years ago Martin Aitken received the Pomerance Science Medal of the Archaeological Institute of America.

[The Editor apologizes for any omissions in the above and would be glad to include them in the next issue, as well as news of any fresh awards.]

### Back copies of Ancient TL

Copies of some back issues are available but not of all. Since a library is more amenable to taking a periodical if a complete set can be obtained we are investigating the practicalities, and cost, of the necessary reprinting to make this possible. It would be helpful to hear from anyone who might be interested. Quite apart from the library aspect there are some interesting precursors in the early issues.

Back issues presently available are:

1985, Vol. 3, No.2  
 1985, Vol. 3, No.3  
 1986, Vol. 4, No.1  
 1986, Vol. 4, No.2  
 1986, Vol. 4, No.3  
 1987, Vol. 5, No.3  
 1988, Vol. 6, No.1  
 Supplement date list  
 1988, Vol. 6, No.3  
 1990, Vol. 8, No.3  
 1991, Vol. 9, No.1  
 1991, Vol. 9, No.3  
 1992, Vol. 10, No.1  
 1992, Vol. 10, No.3  
 1993, Vol. 11, No.1  
 1993, Vol. 11, No.2  
 1994, Vol. 12, No.1  
 1994, Vol. 12, No.2  
 1995, Vol. 13, No.2  
 1996, Vol. 14 No.1  
 1996, Vol. 14 No.2  
 1996, Vol. 14 No.3  
 1997, Vol. 15 No 1  
 1997, Vol. 15, No2/3  
 1998, Vol.16, No.1  
 1998, Vol.16, No.2

Contents : see Vol. 14 No.2 ; for details and prices, please apply the Editor.



## Meeting announcement

### 31st International Geological Congress

The next great get-together of the International Geological Congress will take place during next year, at Rio de Janeiro from August 6 to 17. Those of you who received the first circular may have noted that sub-Symposium 18-1 on Geochronology was entitled "Fission track, Thermoluminescence and Cathodoluminescence". This title has now been corrected and will appear in the second circular as "Fission track, Thermoluminescence, Electron Spin Resonance and Optical dating", with three conveners, Gérard Poupeau and Alexandre M. Rossi for TL, ESR and optical dating, Gérard Poupeau and Ariadne do Carmo Fonseca for fission-track dating.

There will be one half-day poster session and another one for a few selected talks and round tables. We remind you that abstracts, no more than 250 words, must be submitted before September 1st. We encourage you to participate.

Rio de Janeiro and the Guanabara bay are one of the world most fantastic sights. We hope we shall have the pleasure of seeing you there. Remember also that Brazil has a rich and varied geology and that many field trips are proposed in the framework of the Congress.

General information on IGC31 can be found on the Congress web site :

<http://www.31igc.org>

You can also consult the conveners at:

[poupeau@ujf-grenoble.fr](mailto:poupeau@ujf-grenoble.fr) ; [ariadne@ufc.br](mailto:ariadne@ufc.br) or [ariadne@degeo.ufc.br](mailto:ariadne@degeo.ufc.br) ; [rossi@cbpf.br](mailto:rossi@cbpf.br)

Gérard Poupeau  
ESA-CNRS, Université Joseph Fourier  
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## Obituary

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### Miro Ivanovich

We mourn the loss of a dear research colleague, Miro Ivanovich, who died tragically in a motoring accident in January. Through his career Miro contributed widely to our understanding of uranium-series disequilibrium in the natural environment, and there was also his extensive work on the use of these methods in the study of radioactive waste disposal sites. He will be well remembered for his co-editing (with Russ Harmon) of the definitive treatise on uranium-series geochemistry. Moreover, he was a marvellous person to have known, a man who radiated friendship and warmth. He will be sadly missed. He is survived by his son, Alex.

H.P. Schwarcz

## Thesis Abstract

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**Thesis title :** Luminescence stimulated from quartz by green light : developments relevant to dating

**Author :** Duk-Geun Hong

**Date :** 1998

**Supervisor :** Dr. R.B. Galloway

**University :** The University of Edinburgh, Dept. of Physics and Astronomy

Since the introduction, in 1985, of optically stimulated luminescence (OSL) for age determination, the technique has become increasingly common as a method of dating.

Light emitting diodes (LEDs) are a convenient and economical light source for the optical stimulation of luminescence. However for work with quartz, green light stimulation with an argon ion laser as light source is usual, particularly because of the low light intensity of light emitting diodes. Replacement of the original green light emitting diodes by newly developed high intensity green light emitting diodes allowed this limitation to be overcome. The new arrangement was shown to be of comparable sensitivity to the traditionally used argon ion laser system.

The optically stimulated luminescence dating method has been advanced with the introduction of the "single aliquot method", which uses one disc prepared from the sample to carry out all the measurements to determine the equivalent dose. A method based on a single aliquot has the advantages of avoiding normalization problems and reducing effort. The original version of this method concerned the infrared stimulation of feldspar and showed success with an additive dose method, in which correction was made for loss of luminescence signal due to repeated preheating and reading of the same aliquot. A similar single aliquot approach has been applied to the stimulation of quartz by green light, involving an alternative method of analysis of single aliquot data. This approach provides comparable accuracy to conventional equivalent dose determination by the multiple aliquot technique.

# Date list

## Ancient TL supplement issue 6

Since over seven years have elapsed since the last Date List (AnTL 9, 1991) we have taken the opportunity to make a number of revisions to the format, primarily to make it less rigid in structure and also to accommodate the results of larger dating programmes of the type that have been submitted by Sarah Barnett of the Durham Laboratory. I am grateful to Martin Aitken for acting as a reviewer of this issue and for making constructive suggestions concerning the simplification of the format. The main departure from previous lists is the provision of a prologue in which the dating results are placed into an archaeological context and more detail of the laboratory procedures employed is given. Since the terminology used has changed substantially since the last date list, the prologue also provides a more flexible format in which to describe new

techniques and procedures. The original aim of the Date List to provide a full technical specification of luminescence ages remains however. We hope that other laboratories will take the opportunity to submit their dating results for inclusion in future Date Lists. Since all previous entries have been for heated materials, the next development needed is a general formulation for sediment ages and if you have any suggestions please send them to me or the Editor.

An outline of the modified structure of the Date List entry for this issue (ceramic materials) is given below.

I.K. Bailiff

### Details to be given in the prologue

The prologue should contain in concise form:

- Background to dating work;
- Nature of site(s) and samples;
- Experimental set up;
- Dose evaluation and total dose-rate measurement procedures (with schematic if necessary);
- Method of uncertainty analysis;
- Overall conclusions of dating results;
- Acknowledgements;
- References;
- Essential figures.

### HEADER

**1. Site:** [*Name* ]

Grid Reference to be given here if not in preamble.

**2. Site reference:**

**3. Location:** [*Region, country* ]

**4. Excavation:**

[Name of Director or organisation conducting excavation]

**5. Technique**

[Name] [mineral and grain size range ( $\mu\text{m}$ ) if all in tabulation are similar; otherwise details given in table for each sample]

## Tabulated data

---

### 1. Date/Age

luminescence

Single Date/Age      900 BC   ± 100   ±200  
    |     |  
    [Rand. error]   [Overall error]

### 2. Laboratory reference

(Dur95TLqi)      100-1/6  
                          |     |  
                          [Lab code]     [Sample code]  
                          [Test year]     |  
    [Technique]

3. **P** = [value] ± s.e. Gy

4. **I/P** = [value]

A measure of the proportion of the palaeodose due to an empirical correction for low dose supralinearity, defined here in the context of a TL procedure based on the measurement of high temperature TL

5. **m2/m1** = [value] ± s.e.

A measure of the change in dose response following the first measurement, in this case defined for TL, representing the ratio of slopes of 2nd/1st dose response curves; as specified in prologue.

### 6. Procedure

Defines certain components of the luminescence procedure employed, the pre-heating protocol; (TL) the peak temperature or the temperature range of the plateau region or (OSL) the sample temperature during stimulation.

Other aspects of the procedure may be clarified in the prologue.

7. **Total Effective Dose-Rate** = [value] ± s.e. mGy/a

[The a or b value would be given in the next column in the case of results obtained using the fine-grain technique.]

### 8. Dose-rate Components %

[  $\alpha$  = [value]% [method ];  $\beta$  = [value]% ;  $\gamma$  = [value] % ; cos(mic) = [value] % ]

Methods used indicated at base of column.

The measurement of and corrections to the dose-rate for disequilibrium in the U and Th decay series to be discussed in the prologue.

### 9. Moisture content

**W<sub>s</sub>** [Sample ( [value] ± s.e. %)]; **W<sub>e</sub>** = [Burial medium ( [value] ± s.e. %) ]

Defined here for ceramics

10. Notes to Table, e.g.:

## KEY TO ABBREVIATIONS

## STANDARD METHODS/TECHNIQUES/PROCEDURES

i	Inclusion	fg	Fine-grain		
TSAC	Thick source alpha counting		FPh	Flame Photometry	
AAS	Atomic absorption		NAA	Neutron Activation Analysis	
XRF	X-ray fluorescence		PXE	PIXIE	
BetaC	Beta counting		SPEC	Spectrometer (SPEC = portable)	
CAP	Capsule		$\beta$ -TLD	Beta Thermoluminescence Dosimetry	

## MINERALS &amp; ETC.

ft	Flint		p	Polymineral	-	Not applicable
f	Feldspar	q	Quartz		e	Equivalent to
Af	cal Calcite		Nf	Sodium feldspar	*	Other
Unsep.	alkali feldspar	z	Zircon			(used as prefix)
Kf	Potassium feldspar		por	Porcelain	a	Year
<b>Terms:</b> I, P, <i>a</i> , <i>b</i> , A, S <sub>N</sub> , S <sub>O</sub> , TAC: as defined in the literature.						



## Date List 6: Luminescence dates for Late Bronze Age and Iron Age pottery assemblages in eastern and northern Britain

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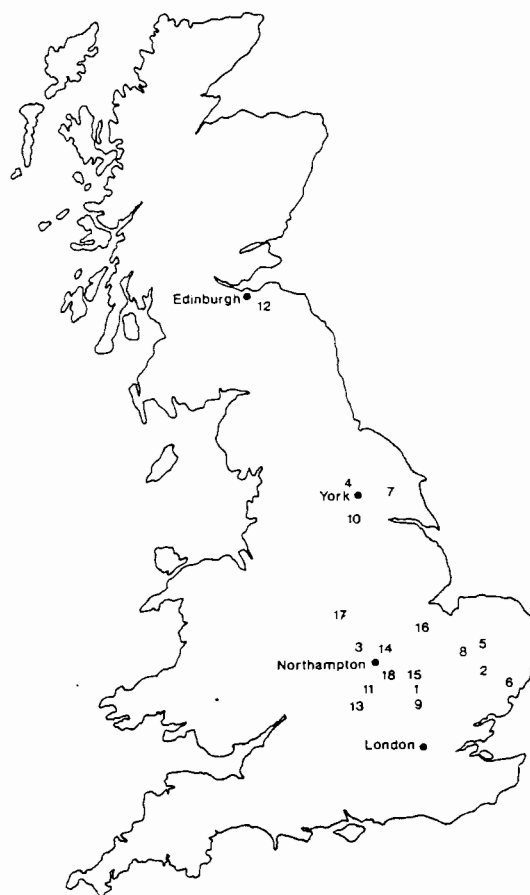
(Received 15 February 1999; in final form 4 May 1999)

### Introduction

This Date List presents a corpus of over 160 dates for Later Prehistoric pottery from Britain which were obtained as part of a single research project. Given the size of the dataset, the form of the Date List entries departs from earlier lists by providing additional technical details and archaeological background in this prologue.

### Archaeological background

The dating of Later Prehistoric (c. 1000 BC - AD 50) sites in Britain relies heavily on pottery typologies and yet the pottery in some regions is notoriously difficult to date stylistically (Willis, 1999). In southern Britain, although there are distinct regional styles, most show little development over several centuries and there is uncertainty concerning the duration of use of each and the chronological relationships between styles of different regions. In northern Britain, the pottery is sparse and predominantly undecorated throughout this important period and typologies cannot be established. The little absolute dating that has been performed to test individual typologies relies almost exclusively on radiocarbon dates and only a small proportion of the 700 published dates can be directly associated with individual pottery styles. With this background, luminescence dating was applied directly to the pottery in order to both verify existing typologies and to provide individual site chronologies. A full discussion of the technical aspects and archaeological implications of this work is to be given elsewhere.



**Figure 1.**

*Locations of sites studied, 1: Broom Quarry, 2: County Farm, 3: DIRFT East, 4: Easingwold, 5: Fornham St Genevieve, 6: Foxhall, 7: Hayton, 8: Landwade Road, 9: Lobs Hole, 10: Methley, 11: Piddington, 12: Port Seton, 13: Slade Farm, 14: Sywell, 15: Warren Villas Quarry, 16: Welland Bank Pit, 17: Willington Hill Farm, 18: Wollaston Quarry and Hardwater Road.*



## Sites and sampling

Over 200 pottery samples were obtained from 18 recent excavations of Late Bronze Age and Iron Age settlements with important ceramic assemblages, see Figure 1 and Table 1. Many of the excavations were necessitated by the extensive gravel extraction and development in the East Midlands and East Anglia; the number of sites of this period excavated recently in northern Britain is much less. All the ceramics were examined by pottery specialists and fabric type, form and decoration recorded; details of the pottery reports are available from the author. Each sherd was cut in such a way as to retain any profile or decoration and a portion retained for reference.

## Experimental details

### Luminescence

Measurements were performed on 90-150  $\mu\text{m}$  quartz inclusions (~1 mg aliquots) which were extracted following a modification of the quartz inclusion technique (Aitken, 1985). Heavy liquid separation with solutions of sodium polytungstate was used to isolate the fraction of density 2.62 - 2.68  $\text{g cm}^{-3}$ . A typical multiple aliquot measurement sequence is shown in Table 2. Eight aliquots were used for measurement of the natural signal and additive measurements were typically made with a further twelve, usually divided into five groups. Regenerative measurements were performed with the aliquots which had not received additional laboratory dose so as to minimise the potential effect of sensitisation during measurements. Aliquot-to-aliquot normalisation was achieved by sample weight or by measurement of the response to a final beta dose. In general, palaeodoses determined by weight and by beta normalisation were in agreement, but, in several cases, sensitivity changes dictated that only the former could be used. For three samples, it was possible to employ a single aliquot regeneration procedure (see Table 2). Integrations were performed with a single resolved peak and therefore a plateau test was not performed routinely; otherwise, the range of the plateau is indicated in the 'Procedure' column of the Date List.

Luminescence measurements were made in Risø TL/OSL-DA-12 and TL/OSL-DA-15 automated readers. The detection window for TL measurements was defined by a Kopp 5-60 filter (blue/violet); for some samples a Kopp 7-51 filter (uv/violet) improved the signal to noise ratio.

Approximately eighteen sherds were also dated by OSL (stimulation range 420-560 nm) with a detection window defined by Hoya U340 filters. Both multiple and single aliquot procedures were used; these are summarised in Table 3. In procedure C, following Murray and Mejdahl (1999), a test dose was employed to monitor, and ultimately to correct for, sensitivity changes resulting from successive dosing/heating cycles. The ratio of the final regenerative to first (post-natural) test dose response has been specified in the Date List following the precedent set by Roberts *et al.* (1998). In these samples, the ratio is high due to the stringent preheats used, varying from 1.26 to 1.78, indicating that the calculated OSL date should be viewed with caution.

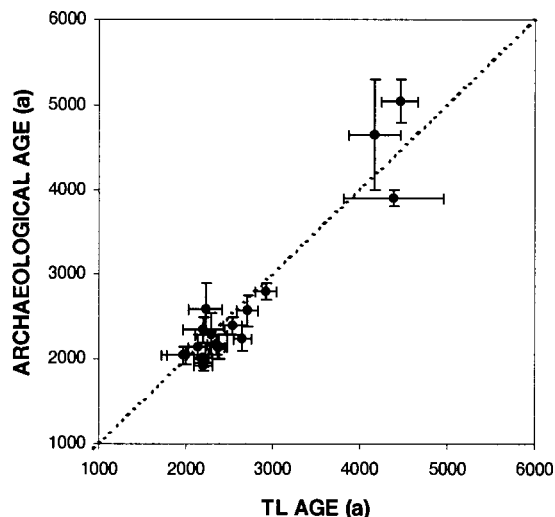
### Dose Rate Determination

The beta dose rate within the pottery was determined by  $\beta$ -TLD (Bailiff, 1982). General determinations of the gamma activity were performed on-site using a Harwell gamma ray spectrometer, but it was seldom possible to make direct measurements within the fills yielding the pottery which was subsequently dated. The gamma dose rate for the sample environment was calculated on the basis of U, Th and K concentrations (derived from  $\beta$ -TLD and TSAC), taking into account the geometry of the burial context, the position of the sherd and the general gamma ray spectrometer measurements. Because of the limited duration of the excavations,  $\gamma$ -TLD was not performed. No radon loss was detected by comparison of sealed and unsealed TSAC, and secular equilibrium has been assumed in all samples.

### Summary of dating evidence

1. The luminescence dates were compared with archaeological dating of the pottery based on form and fabric; 18 sherds were dated by characteristic profile or decoration and a further 54 by fabric type, the remainder were undiagnostic. Figure 2 shows a generally good correlation between the luminescence and archaeological dates based on profile and surface decoration (gradient  $0.99 \pm 0.02$ ,  $R^2 = 0.90$ ). Correlation with dating based on fabric type is, however, poor, suggesting that fabric alone is not a reliable chronological indicator. This is of significance since many sites lack pottery with diagnostic profile or decoration and the chronology may rest entirely on fabric typologies. This study shows that if dating of the ubiquitous, undiagnostic, coarse wares is based on fabric alone, the dates are likely to be in

error. This conclusion was accepted by a meeting in October 1998 of the UK Prehistoric Ceramics Research Group.



**Figure 2.**  
*Comparison of luminescence ages with archaeological dating (profile and decoration) of diagnostic pottery sherds. Two of the ages included were determined using OSL procedure A, while the majority were determined by TL using the additive dose procedure outlined in the text.*

2. From the perspective of dosimetry, the sampling of large features with uniform fills previously advocated for luminescence dating is reasonable. However, this study has shown that for Later Prehistoric period in Britain, the pottery from large features such as enclosure ditches and animal pens is often residual, probably due to persistent use and continual reworking. Thus smaller features of shorter lifetime are preferable although for such contexts the assessment of the gamma dose rate requires a more detailed approach. In dating pottery from Sywell, Northamptonshire (lab ref. 194), for example, shallow features were sampled and a simple modelling procedure for the gamma dose rate gave a set of dates consistent with the typological dating.
3. By averaging luminescence ages to obtain higher precision, examination of the relationship between individual features was possible on certain sites. For example, pooled means were calculated based on the luminescence ages for samples from features within three spatially related groups at Willington Hill Farm,

Derbyshire (lab ref. 202). The pooled mean dates of  $2420 \text{ BC} \pm 160 \pm 320$  (samples 202-1,4,7,11,12) and  $2220 \text{ BC} \pm 240 \pm 360$  (samples 202-3,9,14) show that two of the groups are contemporaneous while the third is significantly later with a pooled mean date of  $560 \text{ BC} \pm 300 \pm 340$  (samples 202-216).

4. It is worth noting that as a result of the completion of such a large programme of dating, several professional field archaeology units now routinely distribute sampling requirements for luminescence dating, and one large archaeological service has adopted luminescence as the preferred technique for dating Later Prehistoric sites in Britain.

#### Acknowledgements

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**Reviewer**  
M. Aitken

**Table 1:** Gazetteer of sites.

Site Name	Location	National Grid Ref.	Publications
Broom Quarry	Biggleswade, Bedfordshire	TL 175440	Mortimer, 1996
County Farm	Chilton, Sudbury, Suffolk	TL 423888	Abbott, 1998
DIRFT East	Crick, Northamptonshire	SP 572734	Chapman, 1994; Hughes, 1998
Easingwold	North Yorkshire	SE 521683	
Fornham St Genevieve	Ingham, Suffolk	TL 847686	
Foxhall	Ipswich, Suffolk	TM 235436	Newman, 1992; Martin, 1999
Hayton	Humberside	SE 8246	Halkon and Millett, 1997; Halkon <i>et al.</i> , 1998
Landwade Road	Fordham, Cambridgeshire	TL 631683	Barnett, 1999
Lobs Hole	Stevenage, Hertfordshire	TL 263263	
Methley	West Yorkshire	SE 417270	
Piddington	Northamptonshire	SP 8154	
Port Seton	Lothian	NT 409754	Haselgrove and Lowther, 1999
Slade Farm	Bicester, Oxfordshire	SP 580240	Hughes and Jones, 1997
Sywell	Northamptonshire	SP 825675	Webster, 1997
Warren Villas Quarry	Sandy, Bedfordshire	TL 181472	Dawson and Maull, 1996
Welland Bank Pit	Deeping St James, Lincolnshire	TF 184082	
Willington Hill Farm	Willington, Derbyshire	SK 299295	Barnett, 1999
Wollaston Quarry and Hardwater Road	Wollaston, Northamptonshire	SP 895641	

**Table 2.** TL measurement procedure. The beta doses are chosen such that the dose range for additive and regenerative measurements is ~3 times and ~4 times the estimated natural dose respectively. Normalisation by both aliquot weight and response to a beta dose were used. In run 4, doses are chosen such that aliquots 7 and 8 receive a dose equal to the dose used in the normalisation of aliquots 9-20 (and hence this measurement is used for normalisation of aliquots 7 and 8 in the additive dose, beta normalised, growth characteristic). The beta dose for the normalisation measurement was chosen to be equal to the estimated natural dose.

	TLA		TLR
	Aliquots 1-8	Aliquots 9-20	
Step 1		additive beta doses	
2	PH: heat to 180°C @ 2°C/s		PH: heat to 180°C @ 2°C/s
3	TL: heat to 450°C @ 5°C/s		TL: heat to 450°C @ 5°C/s
4	beta doses	beta dose for normalisation	beta dose
5	PH: heat to 180°C @ 2°C/s		PH: heat to 180°C @ 2°C/s
6	TL: heat to 450°C @ 5°C/s		TL: heat to 450°C @ 5°C/s
7	beta normalisation dose		repeat steps 4-6
8	PH: heat to 180°C @ 2°C/s		
9	TL: heat to 450°C @ 5°C/s		

**Table 3.** OSL measurement procedures. The range of the doses administered was determined as for TL measurements (Table 2). Procedure A is based on that proposed by Duller (1991) and procedure C on that of Murray and Mejdahl (1999) with the same preheat treatment throughout. The procedure, preheat and measurement temperatures used are specified in the 'Procedure' column of the Date List entries. Several different preheat treatments were used, denoted by 1-5 respectively in the Date List: (1) heat to 180°C at 2°C/s; (2) heat to 220°C at 2°C/s; heat to 220°C and hold for (3) 10s, (4) 300s or (5) 600s. OSL measurements were performed while holding the sample at 50°C, 110°C or 125°C.

Procedure A: Single aliquot additive	Procedure B: multiple aliquot additive and regenerative		Procedure C: single aliquot regenerative
Aliquots 1-10	Aliquots 1-8	Aliquots 9-20	Aliquots 1-8
PH 1s OSL	1s OSL normaliser   additive beta doses PH 100s OSL 16 h halogen lamp bleach		PH 100s OSL test dose (0.7 Gy) PH 100s OSL
Additive doses $\beta_n$ PH 1s OSL	regenerative doses $\beta_n$ PH 100s OSL		regenerative doses $\beta_n$ PH 100s OSL test dose (0.7 Gy) PH 100s OSL

## Date List 6: Luminescence dates for late Bronze Age and Iron Age pottery assemblages in eastern and northern Britain

Sarah M. Barnett

### Notes (see also preceding Tables 2 and 3)

1. Dates and errors have been rounded to the nearest 20 years reflecting the precision of the date obtained and the precision with which the errors are estimated.
2. Error formulation follows Aitken, M.J. (1976) *Archaeometry* 18 233-238. Dates are quoted  $\pm$  random error  $\pm$  overall error at 68% level of confidence.
3. temper are abbreviated as follows:

Do dolerite  
 Fl flint  
 Gn granite  
 Grgrog (=crushed pottery)  
 Ir ironstone  
 Li limestone  
 Qu quartz  
 Sh shell  
 Vesicular (=organic)  
 P palaeodose  
 I/P fractional contribution of the

supralinearity correction to the palaeodose

m2/ml	ratio of slopes regenerative : additive
TD ratio	ratio of final regenerative to first
(post-natural) test dose in OSL procedure C.	
TLA	multiple aliquot additive and regenerative dose TL
TLR	single aliquot regenerative TL
DR	dose rate
c	cosmic
W <sub>s</sub>	saturation water uptake of pottery, $\pm$ 10%
W <sub>e</sub>	'as-dug' water content of burial medium, $\pm$ 10%
5.	Information given in 'Procedure' column comprises procedure; preheat; TL peak/OSL measurement temperature. Preheats are denoted as follows:
1 -	preheat to 180°C at 2°C/s
2 -	preheat to 220°C at 2°C/s
3 -	preheat at 220°C for 10s
4 -	preheat at 220°C for 300s
5 -	preheat at 220°C for 600s

Site name: Broom Quarry

Site ref.: BRQ 96

Location: Biggleswade, Bedfordshire

Excavation: Cambridge Archaeology Unit

Laboratory: Durham

Technique: quartz inclusion (90-150µm)

Entry: 49

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components % β γ ε	W <sub>s</sub> %	W <sub>e</sub> %
920 BC ± 120 ± 280	Dur98TLq1 198-2	Sh	F15 ring ditch ; 182 0669	5.55 ± 0.15	0.11 ± 0.07	0.71 ± 0.06	TLR; 1; 325°C	1.91 ± 0.06	57 35 8	31	36
1040 BC ± 300 ± 380	Dur98TLq1 198-4	"	" ; "	7.14 ± 0.67			TLA; 1; 380°C	2.35 ± 0.08	65 28 7	20	36
960 BC ± 260 ± 360	Dur98OSLq1 198-7	"	" ; 511/241	5.24 ± 0.42			OSLA; 1; 50°C	1.78 ± 0.06	54 38 8	28	36
1380 BC ± 400 ± 460	Dur98TLq1 198-12	"	F210 pit ; 576 0045	6.14 ± 0.71	0.59 ± 0.11	0.74 ± 0.06	OSLA; 1; 125°C	1.82 ± 0.06	52 40 8	17	15
540 BC ± 180 ± 240	Dur98TLq1 198-17	Qu	F210 pit ; 576 0052	5.56 ± 0.35	0.05 ± 0.04	0.99 ± 0.05	TLA; 1; 380°C	2.20 ± 0.07	61 33 6	13	15
820 BC ± 320 ± 360	" -18	"	" ; "	6.42 ± 0.70	0.06 ± 0.02	0.97 ± 0.07	"	2.28 ± 0.08	62 31 7	13	15
1700 BC ± 360 ± 440	" -19	Sh	" ; "	7.06 ± 0.65	0.13 ± 0.07	1.06 ± 0.14	"	1.91 ± 0.06	55 38 7	21	15
1180 BC ± 180 ± 260	" -26	Qu	F174 well ; 591B	7.55 ± 0.32	0.08 ± 0.07	0.86 ± 0.03	"	2.38 ± 0.08	69 25 6	14	19
760 BC ± 240 ± 320	" -27	"	" ; "	8.39 ± 0.35	0.09 ± 0.02	0.89 ± 0.01	"	2.17 ± 0.07	66 27 7	24	19
1020 BC ± 240 ± 300	Dur98OSLq1 198-28	Sh	F174 well ; 701 0182	5.33 ± 0.39	0.22 ± 0.06	0.67 ± 0.09	OSLB; 1; 125°C	1.77 ± 0.06	58 34 8	21	15
840 BC ± 180 ± 300	Dur98TLq1 198-30	"	F15 ring ditch ; 511/241	5.97 ± 0.30	0.03 ± 0.04	0.65 ± 0.06	TLA; 1; 380°C	2.10 ± 0.07	61 32 7	29	36
									β-TLD TSAC β-TLD β-SpEC		

Site name: County Farm

Site ref.: CHT009

Location: Chilton, Sudbury, Suffolk

Excavation: Suffolk County Council Archaeological Services

Laboratory: Durham

Technique: quartz inclusion (90-150µm)

Entry: 50

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components % β γ ε	W <sub>s</sub> %	W <sub>e</sub> %
320 BC ± 120 ± 200	Dur98TLq1 231-1		0124	5.32 ± 0.23	0.32 ± 0.05	0.95 ± 0.04	TLA; 1; 325°C	2.29 ± 0.08	54 39 7	25	18
1120 BC ± 100 ± 220	" -3		"	7.42 ± 0.04	0.32 ± 0.09	0.74 ± 0.05	"	2.37 ± 0.08	56 38 6	19	18
2500 BC ± 160 ± 320	Dur98OSLq1 231-4		"	10.31 ± 0.10		(1.31 ± 0.01)	OSLC; 2; 110°C	2.30 ± 0.08	54 39 7	17	18
1640 BC ± 160 ± 280	" -5		0140	10.68 ± 0.23		(1.28 ± 0.01)	"	2.93 ± 0.11	66 29 5	18	20
2220 BC ± 160 ± 340	" -6		"	10.84 ± 0.09		(1.27 ± 0.01)	"	2.57 ± 0.09	61 34 5	22	20
2320 BC ± 160 ± 320	Dur98TL/OSLq1 231-7		"	9.93 ± 0.10	0.18 ± 0.02	0.94 ± 0.04	TLA; 1; 300-430°C	2.31 ± 0.08	56 37 7	20	20
2460 BC ± 180 ± 360	Dur98OSLq1 231-8		"	10.11 ± 0.19		(1.26 ± 0.04)	OSLC; 2; 110°C	"			
1720 BC ± 160 ± 300	Dur98TL/OSLq1 231-9		0310	11.51 ± 0.25	0.01 ± 0.01	(1.69 ± 0.04)	TLA; 1; 330°C	2.58 ± 0.09	61 33 6	22	20
				9.27 ± 2.00		0.87 ± 0.15	OSLC; 2; 110°C	2.92 ± 0.10	65 30 5	15	19
1700 BC ± 140 ± 280	Dur98OSLq1 231-13		"	10.91 ± 0.29		(1.62 ± 0.04)	"	2.44 ± 0.08	58 36 6	22	19
				9.04 ± 0.08		(1.69 ± 0.05)			β-TLD TSAC β-TLD β-TLD		

Site name: DIRFT East

Site ref.: DRE97/98

Location: Crick, Northamptonshire

Excavation: Birmingham University Field Archaeology Unit

Laboratory: Durham

Technique: quartz inclusion (90-150µm)

Entry: 51

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/α)	DR components % β γ c	W <sub>s</sub> %	W <sub>e</sub> %
600 BC ± 100 ± 220	Dur98TLq1 229-1	Qu/Gr; scored	F180 ditch ; 1123	11.04 ± 0.12	0.03 ± 0.01	1.08 ± 0.05	TLA; 1; 270-400°C	4.24 ± 0.16	72 25 3	23	18
200 BC ± 100 ± 220	-2	Qu	F191 ditch ; 1143	5.88 ± 0.20	0.19 ± 0.07	0.93 ± 0.07	TLA; 1; 330°C	2.67 ± 0.09	61 33 6	34	31
360 BC ± 120 ± 220	-4	Qu/Gr/Ir; scored	F210 ditch ; 1171	9.54 ± 0.32	0.09 ± 0.05	0.85 ± 0.03	TLA; 1; 250-350°C	4.06 ± 0.16	77 20 3	25	25
380 BC ± 80 ± 180	-5	Qu	F207 gully ; 1163	5.54 ± 0.07	0.14 ± 0.02	0.95 ± 0.03	TLA; 1; 325°C	2.34 ± 0.08	54 39 7	16	27
340 BC ± 100 ± 320	-7	Ve	F223 ditch ; 1191	5.58 ± 0.16	0.12 ± 0.04	0.93 ± 0.05	TLA; 1; 330°C	2.39 ± 0.08	59 35 6	60	34
400 BC ± 100 ± 240	Dur98TL/OSLq1 229-9	Qu/Li	F230 ring ditch ; 1203	6.41 ± 0.13	0.06 ± 0.04	0.93 ± 0.03	"	2.73 ± 0.09	61 33 6	35	29
840 BC ± 180 ± 320	Dur98TLq1 229-11	Ve	F500 ditch ; 3340	7.85 ± 0.44	0.16 ± 0.14	1.01 ± 0.13	OSLB; 1; 50°C	2.91 ± 0.10	58 37 5	39	25
1040 BC ± 120 ± 280	-14	Qu/Ve	F286 ditch ; 1279	8.28 ± 0.41	0.12 ± 0.06	1.03 ± 0.11	TLA; 1; 330°C	2.45 ± 0.08	59 35 6	31	29
620 BC ± 120 ± 200	-17	Qu	F295 gully ; 1290	7.45 ± 0.17	0.08 ± 0.02	1.03 ± 0.05	"	3.94 ± 0.15	74 22 4	11	28
240 BC ± 140 ± 300	-18A	Qu/Gr; scored	F291 gully ; 1287	10.32 ± 0.17	0.02 ± 0.01	0.90 ± 0.04	TLA; 1; 260-410°C	3.08 ± 0.11	66 29 5	27	32
680 BC ± 100 ± 240	-19	Qu/Ve	F296 ring ditch ; 1292	6.91 ± 0.69	0.15 ± 0.18	0.89 ± 0.20	TLA; 1; 240-380°C	2.80 ± 0.10	58 36 6	25	29
AD 240 ± 80 ± 160	-21	Ve	F162 gully ; 1296	7.52 ± 0.10	0.01 ± 0.02	0.91 ± 0.02	TLA; 1; 320°C	3.21 ± 0.11	63 32 5	33	23
160 BC ± 60 ± 220	-23	Qu/Gr; scored	F663 hearth ; 1315	8.23 ± 0.50	0.12 ± 0.03	0.82 ± 0.02	TLA; 1; 330°C	3.82 ± 0.14	71 25 4	16	27
760 BC ± 100 ± 240	-24	Qu/Ve; scored	F207 gully ; 1163	6.52 ± 0.07	0.04 ± 0.02	0.89 ± 0.02	TLA; 1; 320°C	2.37 ± 0.08	56 38 6	31	25
620 BC ± 100 ± 280	-25	Qu	F668 ditch ; 1320	6.91 ± 0.16	0.13 ± 0.03	0.90 ± 0.06	TLA; 1; 330°C	2.64 ± 0.09	61 33 6	42	29
AD 540 ± 340 ± 360	-32	Qu/Ve	F610 ; 1387	4.86 ± 1.11	0.23 ± 0.22	0.84 ± 0.09	TLA; 1; 340°C	3.35 ± 0.12	65 31 5	29	37
380 BC ± 100 ± 200	-33	Qu/Ve	F615 ditch ; 1440	5.51 ± 0.09	0.13 ± 0.03	0.88 ± 0.03	"	2.32 ± 0.08	56 37 7	18	42
880 BC ± 120 ± 300	-34	Gr	F851 ditch ; 3646	7.04 ± 0.14	0.08 ± 0.01	1.00 ± 0.02	"	2.44 ± 0.08	55 39 6	47	20
760 BC ± 120 ± 240	-35	Sh	F820/3 ditch ; 2031	5.99 ± 0.16	0.08 ± 0.03	0.94 ± 0.02	"	2.17 ± 0.07	48 45 7	29	27
320 BC ± 120 +	-40	Gr	F559 pit ; 3592	6.85 ± 0.28	0.27 ± 0.05	0.98 ± 0.05	TLA; 1; 360-400°C	2.96 ± 0.10	58 37 5	26	22
760 BC ± 100 ± 280	-42	Gr/Ve	F556 pit ; 3594	8.39 ± 0.05	0.25 ± 0.12	0.75 ± 0.14	TLA; 1; 330°C	3.04 ± 0.10	58 37 5	45	20
AD 140 ± 120 ± 180	Dur99TLq1 229-45	Li/Gr; scored	F985 gully ; 2385	8.31 ± 0.41	0.14 ± 0.04	0.84 ± 0.03	TLA; 1; 320°C	4.47 ± 0.17	69 27 4	19	15
360 BC ± 140 ± 220	-47	Sh; scored ware	F981 ditch ; 2316	6.33 ± 0.30	0.23 ± 0.06	0.94 ± 0.04	TLA; 1; 330°C	2.68 ± 0.09	47 47 6	22	23
900 BC ± 180 ± 400	Dur99OSLq1 229-52	Sh	F1290 ditch ; 2679	6.86 ± 0.37		(1.76 ± 0.02)	OSLC; 3; 125°C	2.36 ± 0.08	50 44 6	70	22
820 BC ± 380 ± 420	-55	Li	F1414.2 ring ditch ; 2879	7.04 ± 0.90		(1.78 ± 0.04)	"	2.50 ± 0.08	54 40 6	25	23
420 BC ± 180 ± 260	Dur99TLq1 229-58	"	F1129 ring ditch ; 3237	6.58 ± 0.44	0.01 ± 0.08	1.06 ± 0.07	TLA; 1; 325°C	2.72 ± 0.09	44 51 5	29	24
240 BC ± 120 ± 200	-59	Gn/Gr; scored	F1453 ditch ; 4180	9.26 ± 0.31	0.03 ± 0.03	0.84 ± 0.03	TLA; 1; 330°C	4.14 ± 0.16	74 23 3	19	15
260 BC ± 160 ± 220	-61	Qu/Gr/Li; scored	F1418.2 ring gully ; 4207	9.32 ± 0.56	0.12 ± 0.08	0.84 ± 0.04	TLA; 1; 320°C	4.11 ± 0.15	67 30 3	21	21
360 BC ± 120 ± 200	-62A	Gn	F1598 ; 4299	10.34 ± 0.40	0.04 ± 0.02	0.92 ± 0.04	"	4.40 ± 0.16	70 27 3	17	24
AD 80 ± 180 ± 220	-62B	"	F1598 ; 4299	8.29 ± 0.74	0.19 ± 0.04	0.69 ± 0.06	"	4.34 ± 0.16	69 27 4	17	24
									β-TLD TSAC β-TLD gSpEC		



Site name: Easingwold

Site ref.: 1993-5000

Location: North Yorkshire

Excavation: York Archaeological Trust

Laboratory: Durham

Technique: quartz inclusion (90-150µm)

Entry: 52

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components %			W <sub>s</sub> %	W <sub>e</sub> %
									β	γ	ε		
AD 40 ± 160 ± 200	Dur95TLqi 173-4	Qu	1069	4.84 ± 0.37	0.24	0.82	TLA; 1; 380°C	2.47 ± 0.10	63	31	6	14	15
140 BC ± 280 ± 320		Do	1444	5.73 ± 0.74	0.33	1.13	"	2.68 ± 0.10	66	29	6	14	15
AD 180 ± 180 ± 200		Qu	1057	3.87 ± 0.35	0.21	0.83	"	2.13 ± 0.07	58	35	7	10	15
220 BC ± 280 ± 300		"	1103	5.20 ± 0.62	0.25	0.84	"	2.34 ± 0.09	68	25	7	13	16
AD 600 ± 160 ± 180		"	1240	3.41 ± 0.38	0.21	0.79	"	2.44 ± 0.11	64	30	6	10	15
200 BC ± 180 ± 240		"	1384	5.23 ± 0.39	0.29	0.92	"	2.37 ± 0.08	62	32	6	13	29
180 BC ± 180 ± 220		"	1443	5.26 ± 0.37	0.42	0.91	"	2.42 ± 0.08	60	33	7	16	18
100 BC ± 280 ± 300		Do	803	5.35 ± 0.69	0.28	0.80	"	2.55 ± 0.10	73	22	5	11	
AD 80 ± 180 ± 220		Qu	1444	4.56 ± 0.42	0.12	0.81	"	2.39 ± 0.08	62	32	6	13	15
AD 240 ± 160 ± 200		"	1240	4.58 ± 0.38	0.07	0.66	"	2.60 ± 0.12	66	28	6	13	15
AD 40 ± 200 ± 220		"	1444	5.57 ± 0.52	0.23	1.03	"	2.85 ± 0.10	68	27	5	11	15
180 BC ± 200 ± 240		"	1381	4.80 ± 0.42	0.33	0.77	"	2.21 ± 0.08	59	34	7	14	29
240 BC ± 240 ± 280		"	1384	5.25 ± 0.56	0.29	0.87	"	2.34 ± 0.08	62	32	6	19	29
AD 40 ± 240 ± 260		"	1240	4.35 ± 0.49	0.32	0.76	"	2.26 ± 0.10	61	33	7	16	15
AD 540 ± 340 ± 340		"	1220	3.70 ± 0.82	0.17	0.79	"	2.56 ± 0.12	65	29	6	15	15
									β-TLD	TSAC			
										β-TLD	gSpEC		

Site name: Fornham St Genevieve.

Site ref.: FSG013

Location: Ingham, Suffolk

Excavation: Suffolk County Council Archaeological Services

Laboratory: Durham

Technique: quartz inclusion (90-150µm)

Entry: 53

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components % β γ c	W <sub>s</sub> %	W <sub>e</sub> %
1160 BC ± 140 ± 240	Dur98TLqj 220-1	Qu	0022	5.48 ± 0.15	0.06 ± 0.03	0.82 ± 0.08	TLA; 1; 325°C	1.74 ± 0.06	58 33 9	24	7
860 BC ± 120 ± 220	-2	"	"	5.24 ± 0.14	0.10 ± 0.03	0.86 ± 0.02	"	1.84 ± 0.06	61 31 8	24	7
580 BC ± 100 ± 200	-3	"	"	4.54 ± 0.12	0.05 ± 0.04	0.79 ± 0.02	"	1.76 ± 0.06	59 33 8	24	7
900 BC ± 120 ± 220	-4	"	"	5.57 ± 0.09	0.06 ± 0.03	0.95 ± 0.10	"	1.92 ± 0.07	62 30 8	24	7
620 BC ± 160 ± 220	-5	Fl	0036	4.97 ± 0.26	0.15 ± 0.07	0.90 ± 0.05	"	1.89 ± 0.06	58 34 8	15	6
2000 BC ± 200 ± 300	-6	"	"	7.19 ± 0.27	0.06 ± 0.02	0.81 ± 0.04	"	1.80 ± 0.06	56 36 8	13	6
660 BC ± 120 ± 220	-8	"	0060	4.63 ± 0.15	0.27 ± 0.06	0.89 ± 0.02	"	1.74 ± 0.06	55 36 9	25	17
120 BC ± 140 ± 240	-9	"	"	6.09 ± 0.19	0.04 ± 0.03	0.95 ± 0.03	"	1.96 ± 0.07	60 32 8	17	17
900 BC ± 100 ± 200	-10	"	"	5.71 ± 0.04	0.09 ± 0.07	0.96 ± 0.04	"	1.97 ± 0.07	57 35 8	17	17
420 BC ± 120 ± 200	-11	Qu	0126	4.94 ± 0.20	0.08 ± 0.07	0.88 ± 0.04	"	2.04 ± 0.07	67 26 7	19	7
800 BC ± 140 ± 220	-12	"	"	5.54 ± 0.21	0.08 ± 0.05	0.86 ± 0.04	"	1.98 ± 0.07	66 27 7	17	7
180 BC ± 100 ± 160	-13	"	"	4.48 ± 0.11	0.23 ± 0.04	0.92 ± 0.02	"	2.06 ± 0.07	67 26 7	6	7
940 BC ± 100 ± 200	-14	"	"	5.81 ± 0.02	0.15 ± 0.01	0.95 ± 0.03	"	1.98 ± 0.07	66 27 7	18	7
1600 BC ± 280 ± 400	-15	Fl	0192	7.44 ± 0.52	0.01 ± 0.01	0.66 ± 0.06	"	2.07 ± 0.07	65 28 7	32	5
2040 BC ± 480 ± 520	-16	"	"	7.90 ± 0.88	0.06 ± 0.02	0.79 ± 0.04	"	1.95 ± 0.07	63 29 8	18	5
2180 BC ± 520 ± 620	-17	"	"	7.77 ± 0.94	0.10 ± 0.21	0.64 ± 0.13	"	1.86 ± 0.06	61 31 8	40	5
									β-TLD TSAC β-TLD gSpEC		

Site name: Foxhall

Site ref.: FXL013

Location: Suffolk

Excavation: Suffolk County Council Archaeological Services

Laboratory: Durham

Technique: quartz inclusion (90-150µm)

Entry: 54

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components %			W <sub>s</sub> %	W <sub>e</sub> %
280 BC ± 100 ± 200	Dur97TLqi 212-1	Qu	0386	3.82 ± 0.08	0.04 ± 0.04	0.87 ± 0.03	TLA; 1; 330°C	1.67 ± 0.06	β	γ	ε	28	8
1080 BC ± 180 ± 260	-2	"	"	5.87 ± 0.27	0.03 ± 0.08	0.93 ± 0.10	"	1.91 ± 0.07	71	21	8	15	8
300 BC ± 180 ± 260	-3	"	"	4.14 ± 0.27	0.06 ± 0.18	0.76 ± 0.08	"	1.80 ± 0.06	70	22	8	33	8
360 BC ± 120 ± 200	-4	"	"	4.27 ± 0.17	0.07 ± 0.06	0.86 ± 0.05	"	1.81 ± 0.07	70	22	8	24	8
560 BC ± 120 ± 220	-5	"	"	4.75 ± 0.12	0.08 ± 0.06	0.74 ± 0.06	"	1.85 ± 0.07	70	22	8	27	8
1060 BC ± 160 ± 240	-7	"	0274	5.47 ± 0.19	0.10 ± 0.03	0.88 ± 0.06	"	1.79 ± 0.06	65	27	8	21	8
400 BC ± 100 ± 180	-8	"	"	4.31 ± 0.09	0.14 ± 0.04	0.92 ± 0.03	"	1.80 ± 0.06	66	26	8	20	8
340 BC ± 80 ± 180	-9	"	"	4.89 ± 0.03			TLR; 1; 330°C	2.10 ± 0.08	β-TLD	TSAC	β-TLD	23	8

Site name: Hayton

Site ref.: KINCH 1995

Location: Humberside

Excavation: University of Durham

Laboratory: Durham

Technique: quartz inclusion (90-150µm)

Entry: 55

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components %			W <sub>s</sub> %	W <sub>e</sub> %
540 BC ± 140 ± 200	Dur97TLqi 191-17		1020/557	5.29 ± 0.24	0.17 ± 0.04	1.07 ± 0.03	TLA; 1; 340°C	2.08 ± 0.07	β	γ	ε	15	15
140 BC ± 180 ± 220	-18		"	4.76 ± 0.34	0.12 ± 0.06	0.98 ± 0.04	"	2.23 ± 0.08	58	35	7	15	15
AD 240 ± 100 ± 160	-19		"	3.92 ± 0.20	0.12 ± 0.03	1.10 ± 0.02	"	2.24 ± 0.08	60	33	6	15	15
AD 110 ± 120 ± 160	-20		"	4.07 ± 0.20	0.15 ± 0.03	0.97 ± 0.02	TLA; 1; 330°C	2.16 ± 0.07	59	34	7	15	15
									β-TLD	TSAC	β-TLD		

Site name: Landwade Road  
Site ref.: FORLR 96  
Laboratory: Durham  
Technique: quartz inclusion (90-150µm)

**Entry: 56**

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components % $\beta$ $\gamma$ $\epsilon$	W <sub>s</sub> %	W <sub>e</sub> %
1460 BC $\pm$ 180 $\pm$ 280	Dur97TLqi 206-2	Sh	592	4.96 $\pm$ 0.22			TLR; 1; 220°C	1.33 $\pm$ 0.04	58 30 11	16	15
180 BC $\pm$ 440 $\pm$ 460	-5	Fl	680	4.02 $\pm$ 0.78	0.08 $\pm$ 0.18	0.66 $\pm$ 0.06	TLA; 1; 350°C	1.85 $\pm$ 0.07	69 23 8	15	19
460 BC $\pm$ 120 $\pm$ 200	Dur97TL/OSLqi 206-6	"	"	4.66 $\pm$ 0.37	0.18 $\pm$ 0.06	0.82 $\pm$ 0.06	TLA; 1; 380°C	1.86 $\pm$ 0.07	69 23 8	14	19
				4.55 $\pm$ 0.17			OSLB; 1; 125°C				
460 BC $\pm$ 360 $\pm$ 400	Dur97TLqi 206-7	Qu	913	5.95 $\pm$ 0.86	0.02 $\pm$ 0.09	0.72 $\pm$ 0.08	TLA; 1; 350°C	2.43 $\pm$ 0.08	63 31 6	16	6
500 BC $\pm$ 260 $\pm$ 280	-8	Fl	1070	4.00 $\pm$ 0.38	0.19 $\pm$ 0.08	0.92 $\pm$ 0.07	TLA; 1; 380°C	1.61 $\pm$ 0.05	59 32 9	13	12
560 BC $\pm$ 200 $\pm$ 240	-9	"	"	4.00 $\pm$ 0.27	0.13 $\pm$ 0.04	0.94 $\pm$ 0.04	"	1.56 $\pm$ 0.05	57 33 10	13	12
1300 BC $\pm$ 220 $\pm$ 280	-10	"	1097	4.35 $\pm$ 0.25	0.02 $\pm$ 0.04	0.96 $\pm$ 0.04	"	1.32 $\pm$ 0.04	56 33 11	10	15
500 BC $\pm$ 360 $\pm$ 400	-11	"	"	5.63 $\pm$ 0.76	0.19 $\pm$ 0.12	0.90 $\pm$ 0.12	"	2.25 $\pm$ 0.09	74 19 7	12	15
400 BC $\pm$ 340 $\pm$ 380	-13	Sh	1763	5.90 $\pm$ 1.10	0.06 $\pm$ 0.13	1.02 $\pm$ 0.09	"	2.46 $\pm$ 0.09	69 25 6	20	10
720 BC $\pm$ 180 $\pm$ 240	-15	Fl	759	5.84 $\pm$ 0.31	0.06 $\pm$ 0.03	0.96 $\pm$ 0.03	"	2.15 $\pm$ 0.08	67 26 7	15	16
1540 BC $\pm$ 320 $\pm$ 400	-19	"	1097	4.58 $\pm$ 0.40	0.28 $\pm$ 0.04	0.90 $\pm$ 0.08	TLA; 1; 350°C	1.29 $\pm$ 0.04	55 33 12	17	15
920 BC $\pm$ 280 $\pm$ 340	-20	"	"	5.43 $\pm$ 0.49	0.26 $\pm$ 0.06	0.74 $\pm$ 0.06	"	1.86 $\pm$ 0.07	69 23 8	11	15
1800 BC $\pm$ 300 $\pm$ 360	-21	"	"	5.25 $\pm$ 0.38	0.24 $\pm$ 0.06	1.05 $\pm$ 0.06	"	1.38 $\pm$ 0.05	58 31 11	12	15
900 BC $\pm$ 160 $\pm$ 220	-22	"	"	3.88 $\pm$ 0.16	0.13 $\pm$ 0.04	0.92 $\pm$ 0.02	"	1.34 $\pm$ 0.04	57 32 11	14	15
920 BC $\pm$ 200 $\pm$ 260	-23	"	"	4.95 $\pm$ 0.06	0.26 $\pm$ 0.05	0.94 $\pm$ 0.05	"	1.69 $\pm$ 0.06	66 25 9	17	15
									$\beta$ -TLD		
									TSAC		
									$\beta$ -TLD eSpEC		

**Site name:** Lobs Hole  
**Site ref.:** LHS-2-96  
**Laboratory:** Durham  
**Technique:** quartz inclusion (90-150µm)

Entry: 57

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components %			W <sub>s</sub> %	W <sub>c</sub> %
									β	γ	ε		
AD 380 ± 60 ± 120	Dur97TLq1	218-2	151	3.33 ± 0.74	0.62 ± 0.25	1.12 ± 0.17	TLA; 1; 350°C	2.14 ± 0.07	50	43	7	21	17
360 BC ± 200 ± 260	-4		308	5.04 ± 0.41	0.09 ± 0.07	0.54 ± 0.02	"	2.14 ± 0.07	51	42	7	18	23
1500 BC ± 240 ± 360	-5		"	7.72 ± 0.47	0.21 ± 0.02	0.74 ± 0.01	"	2.20 ± 0.07	52	41	7	24	23
680 BC ± 240 ± 280	-6		"	5.17 ± 0.41	0.30 ± 0.06	0.73 ± 0.03	"	1.93 ± 0.06	45	47	8	15	23
									β-TLD			TSAC	
									β-TLD				

Site name: Methley

Site ref.: METH 96

Location: Castleford, West Yorkshire

Excavation: MAP Archaeology

Laboratory: Durham

Technique: quartz inclusion (90-150µm)

Entry: 58

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components %			W <sub>s</sub> %	W <sub>e</sub> %
AD 380 ± 100 ± 140	Dur97TLqj 207-1	pottery	1008	3.32 ± 0.17	0.16 ± 0.07	0.70 ± 0.06	TLA; 1; 350°C	2.06 ± 0.07	β	γ	c	23	7
160 BC ± 140 ± 200	Dur97TLqj 207-1 -2	daub	1006	5.15 ± 0.26	0.02 ± 0.10	0.72 ± 0.12	"	2.39 ± 0.08	54	40	6	28	13
60 BC ± 100 ± 160	Dur97TL/OSLqj 207-4	burnt clay	1155	4.24 ± 0.14	0.09 ± 0.03	0.95 ± 0.03	TLA; 1; 350°C	2.06 ± 0.07	51	42	7	23	10
80 BC ± 80 ± 160	Dur97TLqj 207-4 S2	"	"	4.18 ± 0.10	0.15 ± 0.04	0.95 ± 0.03	OSLA; 4; 50°C						
260 BC ± 140 ± 200	-4 S3	"	"	4.27 ± 0.09	0.09 ± 0.02	0.85 ± 0.02	TLA; 1; 350°C						
AD 40 ± 100 ± 160	-4 S4	"	"	4.68 ± 0.22	0.05 ± 0.03	0.78 ± 0.02	"						
				4.04 ± 0.16					β-TLD	TSAC	β-TLD		

Site name: Piddington

Site ref.:

Location: Northamptonshire

Excavation: Upper Nene Archaeological Society

Laboratory: Durham

Technique: quartz inclusion (90-150µm)

Entry: 59

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components %			W <sub>s</sub> %	W <sub>e</sub> %
0 BC ± 240 ± 280	Dur97TLqj 208-5		Ditch F180 layer L4	5.69 ± 0.63	0.23 ± 0.10	1.18 ± 0.11	TLA; 1; 380°C	2.85 ± 0.11	β	γ	c	15	24
									β-TLD	TSAC	β-TLD		

Site name: Port Seton

Site ref.: PSE 95

Location: East Lothian

Excavation: University of Durham

Laboratory: Durham

Technique: quartz inclusion (90-150µm)

Entry: 60

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components % β γ c	W <sub>s</sub> %	W <sub>c</sub> %
AD 140 ± 160 ± 180	Dur96TLqi 192-1		1004	3.81 ± 0.28	0.21	0.94 ± 0.06	TLA; 1; 380°C	2.05 ± 0.07	0.56 0.37 0.07	18	15
									β-TLD TSAC β-TLD		

Site name: Slade Farm

Site ref.: SFB 96

Location: Bicester, Oxfordshire

Excavation: Birmingham University Field Archaeology Unit

Laboratory: Durham

Technique: quartz inclusion (90-150µm)

Entry: 61

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components % β γ c	W <sub>s</sub> %	W <sub>c</sub> %
340 BC ± 100 ± 180	Dur97OSLqi 219-1	Sh	F173 1049	4.93 ± 0.13			OSLA; 4; 50°C	2.11 ± 0.07	53 40 7	22	19
600 BC ± 620 ± 640	Dur97TLqi 219-2	Gr	F136.04 1036	5.88 ± 1.39	0.14 ± 0.21	0.74 ± 0.13	TLA; 1; 350°C	2.26 ± 0.08	57 36 7	15	15
									β-TLD TSAC β-TLD		

Site name: Sywell

Site ref.: SA 96/SAE 96

Location: Northamptonshire

Excavation: Northamptonshire Archaeology

Laboratory: Durham

Technique: quartz inclusion (90-150µm)

Entry: 62

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components % β γ c	W <sub>s</sub> %	W <sub>c</sub> %
AD 100 ± 180 ± 200	Dur96TLqi 194-5		TR2 2/15	4.04 ± 0.50	0.01 ± 0.04	1.05 ± 0.10	TLA; 1; 380°C	2.14 ± 0.07	56 39 5	23	15
AD 120 ± 220 ± 260			TR2 2/14	4.10 ± 0.54	0.17 ± 0.12	0.80 ± 0.07	"	2.20 ± 0.07	56 37 7	26	17
420 BC ± 280 ± 320		Sh/Qu	pit 22	5.20 ± 0.52	0.15 ± 0.09	0.91 ± 0.07	"	2.14 ± 0.08	48 45 7	19	13
280 BC ± 160 ± 220		Sh/ir	ditch 27	5.05 ± 0.33	0.14 ± 0.04	0.98 ± 0.07	"	2.21 ± 0.07	48 45 7	17	13
AD 40 ± 380 ± 400		"	"	4.35 ± 1.04	0.07 ± 0.20	1.02 ± 0.18	"	2.23 ± 0.07	54 40 6	21	14
200 BC ± 180 ± 240		"	ditch west 09	4.89 ± 0.35	0.11 ± 0.04	0.88 ± 0.05	"	2.21 ± 0.07	48 45 7	24	13
240 BC ± 220 ± 260		Sh	pit 54	4.92 ± 0.51	0.10 ± 0.06	0.91 ± 0.09	"	2.20 ± 0.08	49 44 7	24	11
									β-TLD TSAC β-TLD		

Site name: Warren Villas Quarry

Site ref.:

Location: Sandy, Bedfordshire

Excavation: Bedfordshire County Archaeology Service

Laboratory: Durham

Technique: quartz inclusion (90-150µm)

Entry: 63

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components %			W <sub>s</sub> %	W <sub>e</sub> %
20 BC ± 120 ± 200	Dur96TLqi 196-1 -2 -3		3160 / 847 3228 / 829 3295 / 898	4.25 ± 0.18	0.23 ± 0.11	0.80 ± 0.09	TLA; 1; 380°C	2.15 ± 0.07	β	γ	c	18	36
360 BC ± 100 ± 200				4.51 ± 0.10	0.24 ± 0.04	0.82 ± 0.05	"	1.92 ± 0.06	52	41	7	21	39
280 BC ± 140 ± 240				5.39 ± 0.27	0.21 ± 0.14	0.81 ± 0.08	"	2.36 ± 0.08	63	31	6	23	44
									β-TLD	TSAC			
									β-TLD	β-TLD			

Site name: Welland Bank Pit

Site ref.: WQE 96

Location: Deeping St James, Lincolnshire

Excavation: Heritage Lincolnshire

Laboratory: Durham

Technique: quartz inclusion (90-150µm)

Entry: 64

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components %			W <sub>s</sub> %	W <sub>e</sub> %
240 BC ± 160 ± 200	Dur97TL qi 201-2		1040	5.31 ± 0.32	0.16 ± 0.05	0.94 ± 0.04	TLA; 1; 360°C	2.38 ± 0.08	β	γ	c	19	79
									β-TLD	TSAC			
									β-TLD	β-TLD	gSpEC		





Site name: Hardwater Road  
 Site ref.: HWR 96  
 Location: Wollaston, Northamptonshire  
 Excavation: Northamptonshire Archaeology

Laboratory: Durham  
 Technique: quartz inclusion (90-150µm)

Luminescence Single Dates:	Lab ref.	Fabric	Archaeological Context	P (Gy)	I/P	m2/ml (TD ratio)	Procedure	total DR (mGy/a)	DR components % β γ c	W <sub>s</sub> %	W <sub>e</sub> %
480 BC ± 160 ± 220	Dur97TLqi 193-16	Sh; scored	301	6.06 ± 0.34	0.19 ± 0.08	0.96 ± 0.07	TLA; 1; 330°C	2.46 ± 0.09	62 32 6	20	9
AD 40 ± 120 ± 180		"	180	4.71 ± 0.25	0.10 ± 0.03	0.93 ± 0.02	"	2.40 ± 0.08	64 30 6	12	20
540 BC ± 200 ± 260	Dur97OSLqi 193-34	Sh/Ir	"	5.94 ± 0.41			OSLA; 5; 50°C	2.34 ± 0.08	62 31 6	18	20
540 BC ± 160 ± 240	Dur98TLqi 193-36	"	"	5.69 ± 0.30	0.23 ± 0.07	0.92 ± 0.06	TLA; 1; 330°C	2.24 ± 0.08	61 32 7	17	20
820 BC ± 120 ± 220	Dur97TLqi 193-37	Sh	"	5.88 ± 0.14	0.04 ± 0.02	0.89 ± 0.04	"	2.09 ± 0.07	59 34 7	18	20
240 BC ± 160 ± 220	Dur98TLqi 193-38	Sh/Qu	"	4.93 ± 0.30	0.39 ± 0.06	0.53 ± 0.05	TLA; 1; 330°C	2.20 ± 0.08	61 33 7	18	20
640 BC ± 120 ± 200	Dur97TLqi 193-39	Sh/Ir	"	6.19 ± 0.15	0.11 ± 0.02	0.86 ± 0.02	"	2.34 ± 0.07	63 31 6	16	20
320 BC ± 140 ± 200	Dur98TLqi 193-40	Sh	"	4.75 ± 0.25	0.17 ± 0.08	1.04 ± 0.06	"	2.05 ± 0.07	58 35 7	18	20
340 BC ± 100 ± 180		"	"	5.35 ± 0.17	0.14 ± 0.04	0.89 ± 0.03	"	2.30 ± 0.08	62 31 7	14	20
660 BC ± 300 ± 340		"	"	5.20 ± 0.55	0.08 ± 0.25	1.34 ± 0.25	"	1.96 ± 0.07	56 37 7	16	20
900 BC ± 140 ± 240		Sh; scored	"	5.97 ± 0.21	0.06 ± 0.05	0.95 ± 0.04	"	2.06 ± 0.07	58 35 7	19	20
20 BC ± 120 ± 180		Sh	105	4.43 ± 0.22	0.18 ± 0.04	0.94 ± 0.05	"	2.19 ± 0.07	52 41 7	24	10
720 BC ± 180 ± 240		"	"	5.27 ± 0.30	0.39 ± 0.22	0.99 ± 0.12	"	1.93 ± 0.06	46 47 7	18	10
1580 BC ± 200 ± 300	Dur97TLqi 193-55	"	24	7.49 ± 0.33	0.07 ± 0.02	1.01 ± 0.05	"	2.09 ± 0.07	57 36 7	18	12
220 BC ± 80 ± 160	Dur98TLqi 193-61	"	20	4.19 ± 0.09	0.06 ± 0.05	0.92 ± 0.03	"	1.88 ± 0.06	54 39 7	15	13
300 BC ± 140 ± 180	Dur97TLqi 193-62	"	"	3.91 ± 0.19	0.08 ± 0.04	0.83 ± 0.04	"	1.71 ± 0.06	49 42 9	15	13
260 BC ± 180 ± 220	Dur98TLqi 193-66	Sh/Ir	"	6.36 ± 0.45	0.20 ± 0.13	0.91 ± 0.18	"	2.83 ± 0.10	68 27 5	15	13
									β-TLD TSAC β-TLD gSpEC		

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Radtke, U. and Janotta, A. pages 1-18

Radtke, U., Czwiellung, K., Heidger, M. and Janotta, A. pages 19-45

Lang, M. and Fehrentz, M. pages 47-58

Radtke, U., Janotta, A. and Semmel, A. pages 59-64

Schündeln, M. and Radtke, U. pages 65-77

Radtke, U. and Janotta, A. pages 79-85

Brunotte, E., Gülicher, P. and Janotta, A. pages 87-93

Vogt, T. pages 95-102

Fehrentz, M. and Radtke, U. pages 103-115

Radtke, U. pages 117-124

Note also :

### ICRU Report 60

Fundamental Quantities and units for Ionizing Radiation  
ISBN 0-913394-59-9 (24pp)

Published 30 December 1998

The Commission has recently issued a short report that defines fundamental quantities and units of relevance to Luminescence and ESR dating research. Following a brief discussion of units and stochastic and non-stochastic quantities, the report contains sections on Radiometry, Interaction Coefficients, Dosimetry and Radioactivity. Each section contains concise definitions of relevant quantities and their units. Highly recommended for reference purposes. You may contact ICRU via email ([icru@icru.org](mailto:icru@icru.org)) or find further details on the WWW (<http://www.icru.org>). (Ian Bailiff)