THICKNESS RESPONSE OF β DOSE-RATE IN TL DATING OF POTTERY FRAGMENTS*

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ABSTRACT

Generally, the walls of ceramic ware are thin and the sample to be used for TL dating has to be collected from 1~2mm under the surface. This can introduce significant error into the dating method. Therefore, the results of a series of simulated experiments are reported on the build-up effect of the internal β dose response in different thicknesses of pottery fragments (involving tile and brick). Correction factors, corresponding to different thicknesses, and correction "depths" are proposed in terms of the experimental findings which may be incorporatd into the dating methods.
Keywords TL dating, Thickness response, Ancient pottery, China

1 INTRODUCTION

In the application of TL dating, the objects of interest are pottery fragments which involve a variety of shapes and pattern. The thickness of the shards can be widely different as they can come from different pottery utensils, figureens and models of all sizes and taken from varying parts of the sample. From measurements over many years at Shanghai Museum, for example, the shard thickness can vary from 2~3 mm to 10~15 mm, and even in some cases up to 20~30 mm.

The thickness response of the β dose in the pottery will differ for different shard thicknesses, β dose is the major portion of the total dose in quartz inclusion dating techniques, with typical ratios of β-ray, γ-ray and cosmic ray dose being 56%, 39% and 5%, respectively[1] (these values corresponding to pottery and soil having radionuclide abundance of 1% K, 50μg/g Rb, 10μg/g Th and 3μg/g U). Therefore, the uncertainty of β dose measurement resulting from varying shard thickness will directly influence the dating accuracy. Methods of determining the internal β irradiation dose rate in pottery are given in many books and articles[1−3,6], but the thickness response effect of the β dose rate has not yet been systematically studied experimentally. Normally, the β dose rate is obtained either by the α counting method, calculated in terms of the abundance of radionuclides in the sample, or by directly measuring TL from TLD inserts irradiated inside the sample powder. Both results correspond to a whole dose contribution for the radionuclides.

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In fact, in thin shards, the β dose accumulated over the lifetime by quartz inclusions inside the pottery is less than the total β dose obtained by the above methods. To match these predictions experimentally, thick shards have to be selected and sample powder taken deep inside the shard. Unfortunately much archaeological pottery does not have the required thickness and, in addition, when authenticating ancient ceramics only a minimal amount of sample powder is allowed to be taken and is usually collected from the surface, or at most 1 or 2 mm below. This introduces a significant uncertainty in the dating.

In this paper an experimental study is reported of the build-up effect of the internal β dose response in different thicknesses of pottery fragments (involving tile and brick). Correction factors, corresponding to different thicknesses, and correction "depths" are obtained in terms of the experimental findings.

2 MEASUREMENTS OF β DOSE RATE FOR INTERNAL AND EXTERNAL IRRADIATIONS

The surface area of the sample pieces was designed to cover six TLD inserts. Suitable thickness intervals from 1 to 12 mm were chosen. Below 1 mm the sample integrity could not be maintained and so no results are given.

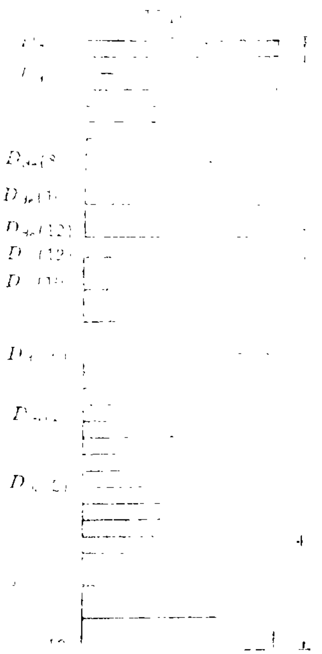

Fig.1 Internal and external irradiation sample design

Three pieces of a given sample (2 for internal, 1 for external irradiation) with constant thickness were taken as a parallel group. In total 10 groups with thickness varying from 1 to 12 mm were studied (see Fig.1).

The six $CaSO_4$:Tm TLD components (diameter 8 mm and thickness 2mg/cm^2) were packed in a plastic film (thickness 8mg/cm^2), to shield from α-rays and then put between two samples of the same thickness. The resulting piece was packed in more plastic film and stored. Another six TLD components were again packed in plastic film and the positive surface placed against the third piece with the given thickness. Again the composite was packed in plastic film and stored. Two to four weeks later the TLD inserts of the two sets of samples are taken out and measured. This procedure was repeated for all ten groups of samples.

The first set of the samples corresponds to 4π "internal" irradiation (β dose rate $D_{\beta i}$[3~5], the second set is 2π "external" irradiation (β dose rate D_{β_e})

$$D_{\beta\text{i}}(2x) = (D_\text{i}(2x)/t) - D_\text{c} \tag{1}$$

$$D_{\beta\text{e}}(x) = (D_\text{e}(x)/t) - D_\text{c} \tag{2}$$

where D_i and D_e are the average β dose rates of the six TLD components in 4π and 2π geometry, respectively; t is the storing time; D_c is the background dose rate inside the storing room.

3 MEASUREMENTS OF β DOSE RATE IN SIMULATED EXPERIMENTAL SAMPLES

In practice, sample powder for dating is usually collected from 2 mm deep below the sample surface (1 mm deep for thin pottery). To study the thickness effect for this case, another two sets of simulated experiments were designed with TLD inserts being put 1 mm and 2 mm deep inside different thickness sample shards. That is the TLD components were sandwiched between the 1 mm (or 2 mm) shard and a second piece of thickness from 1 mm (or 2 mm) up to 9 mm (see Fig.2). Plastic film packing and storing are the same as mentioned above.

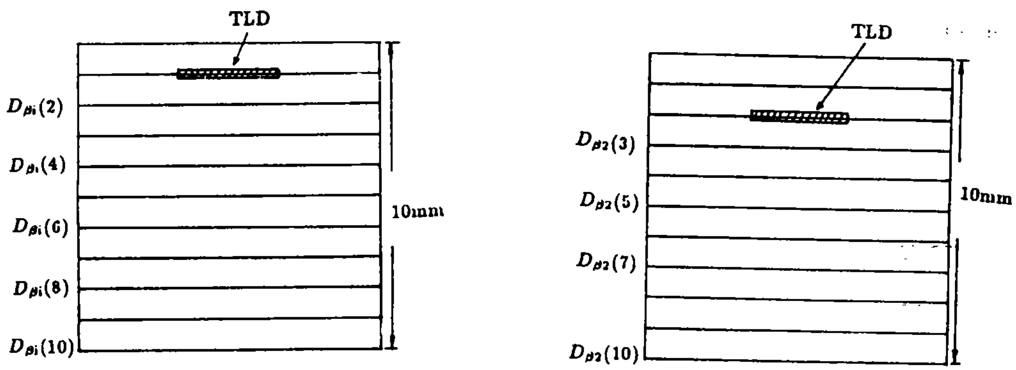

Fig.2 Simulated collection sample irradiation design

Then the corresponding β dose rate is

$$D_{\beta 1}(x) = (D_1(x)/t) - D_\text{c} \tag{3}$$

$$D_{\beta 2}(x) = (D_2(x)/t) - D_\text{c} \tag{4}$$

where $D_1(x)$ and $D_2(x)$ are the average β dose rates of the six TLD components set in 1 mm and 2 mm depths in a total x mm thickness, respectively.

4 RESULTS AND DISCUSSION

Table 1 shows the experimental results for the β dose rate for internal and external irradiation for varying thicknesses. Table 2 shows the experimental results for the β dose rate for the simulated practical samples from different thicknesses of pottery.

Table 1

β dose rates for internal and external irradiations

Shard thickness x/mm	$D_{\beta i}(2x)$ /mGy·a^{-1}	$D_{\beta e}(x)$ /mGy·a^{-1}
1	5.821±0.066	2.112±0.044
2	6.662±0.058	2.627±0.035
3	6.915±0.062	2.843±0.068
4	7.150±0.098	2.988±0.065
5	6.901±0.147	3.013±0.055
6	7.100±0.158	3.091±0.034
7	7.317±0.113	3.353±0.089
8	7.310±0.124	3.381±0.066
10	7.251±0.146	3.349±0.055
12	7.391±0.093	3.410±0.040

Table 2

β dose rates for simulated collected sample

Shard thickness x/mm	$D_{\beta 1}(2x)$ /mGy·a^{-1}	$D_{\beta 2}(x)$ /mGy·a^{-1}
2	5.716±0.091	—
3	6.411±0.075	6.412±0.112
4	6.690±0.070	6.631±0.087
5	6.823±0.089	6,857±0.055
6	6.805±1.141	6.734±0.101
7	6.958±0.097	7.040±0.081
8	7.165±0.079	7.068±0.114
9	7.176±0.124	7.261±0.080
10	7.087±0.103	7.224±0.094

4.1 From the data for internal $D_{\beta i}$ in Table 1, it is clear that the maximum range for β-irradiation in pottery fragments is about 7 mm, the internal β dose becomes saturated at this point. The average value $\overline{D}_{\beta i}$ of the $D_{\beta i}$ of the 7, 8, 10 and 12 mm thick shards is 7.317±0.241 mGy/a which can be used as a saturation value. Between 2 and 7 mm thickness the actual β dose rate can be calibrated using a factor F_i (see Table 3) to convert to the saturation β dose rate, where:

$$F_i(2x) = D_{\beta i}(2x)/\overline{D}_{\beta i} \tag{5}$$

Table 3

Correction factors for internal and external β dose rate response

Shard thickness x/mm	$F_i(2x)$	$F_e(x)$	$[D_{\beta e}(x)/D_{\beta i}(2x)]$ /%
1	0.796±0.028	2.756±0.065	36.3±6.5
2	0.910±0.031	2.536±0.040	39.4±4.0
3	0.945±0.032	2.432±0.062	41.1±6.2
4	0.977±0.035	2.392±0.062	41.8±6.2
5	0.943±0.037	2.290±0.064	43.7±6.4
6	0.970±0.039	2.297±0.063	43.5±6.3
7	1.000±0.036	2.181±0.067	45.8±6.7
8	0.999±0.037	2.162±0.056	46.3±5.6
10	0.991±0.038	2.165±0.056	46.2±5.6
12	1.010±0.36	2.168±0.037	46.1±3.7

4.2 From the data for external $D_{\beta e}$ in Table 1, it is found that the values for 2π irradiation are less than half that from 4π irradiation $D_{\beta i}$. The maximum (or saturated) ratio $D_{\beta e}/D_{\beta i}$ is 0.46 where the shard thickness is equal to or larger than 7 mm. This ratio becomes smaller when the thickness decreases below 7 mm (see Table 3). This means that, for a certain thickness pottery shard, the internal β dose rate $D_{\beta i}$ can be obtained by measuring the surface (2π solid angle) β dose rate $D_{\beta e}$ and multiplying this by a thickness correct factor F_e (see Table 3) where:

$$F_e(x) = D_{\beta i}(2x)/D_{\beta e}(x) \quad (6)$$

then

$$D_{\beta i}(2x) = F_e(x)(D_e(x)/t - D_c) \quad (7)$$

The environmental β dose effects from the surroundings have not be considered in this calculation.

4.3 In this way a nondestructive measure of the β dose rate to the pottery may be obtained by measuring the TLD components irradiated on the its surface (i.e. the external $D_{\beta e}(x)$) and converting this to the saturated value $\overline{D}_{\beta i}$ using the two correction factors F_i and F_e. That is:

$$\overline{D}_{\beta i} = D_{\beta i}(2x)/F_i(2x) = (F_e(x)/F_i(2x)) \cdot D_{\beta e}(x) \quad (8)$$

for thicknesses less than 7 mm and

$$\overline{D}_{\beta i} = D_{\beta i}(2x) = F_e(x) \cdot D_{\beta e}(x) \quad \text{for the thickness} \geq 7\,\text{mm} \quad (9)$$

This seems a simpler and more useful mehod of finding the saturated β dose rate and/or the annual dose compared with the more usual methods.

Provided the effects from sunlight and the surroundings can be ignored, this might suggest that TL dating can be carried out by taking sample powder from the surface of the pottery.

4.4 In practical dating the effects of the natural environment (eg weather and the radionuclide contents of surrounding soil), osmosis at the surface of the pottery and material exchange means that the environmental absorbed β dose is always uncertain. In order to minimize these effects it is the usual practice to discard 1~2 mm of the surface depth and then collect a powder sample.

Again using the internal irradiation saturated β dose rate value $\overline{D}_{\beta i}$ as a reference value, and taking the results shown in Table 4, the correction factors here should be:

$$F_1(x) = D_{\beta 1}(x)/\overline{D}_{\beta i}; \quad F_2(x) = D_{\beta 2}(x)/\overline{D}_{\beta i} \quad (10)$$

for 1 mm and 2 mm surface depth, respectively.

This means that whether the annual β dose is obtained from the radionuclide abundance by α counting, or from measuring the TL dose of the sample powder, or by directly using the characteristic value 5.5 mGy/a for Chinese pottery given by P.L.Leung *et al*[6], the actual β dose should be revised by using the correction factor F_1 or F_2.

4.5 From Table 4, it can be seen that the difference between F_1 and F_2 is only about 1% and is not really significant. However, comparing F_1 (or F_2) with the saturated internal values it can be seen that the proposed corrections are necessary. The uncertainties introduced are 2% ~ 3% for pottery thicknesses larger than 7 mm and 4% ~ 12% when

Table 4
Correction factors for simulated sample β dose rate response

Shard thickness x/mm	$F_1(x)$	$F_2(2x)$
2	0.781±0.029	—
3	0.876±0.031	0.876±0.033
4	0.914±0.032	0.906±0.032
5	0.933±0.033	0.937±0.032
6	0.930±0.159	0.920±0.033
7	0.951±0.034	0.962±0.034
8	0.979±0.034	0.966±0.035
9	0.981±0.037	0.992±0.035
10	0.969±0.035	0.987±0.035

the thickness is in the range 3~7 mm. The introduced uncertainty can be larger than 20% for thicknesses equal to or less than 2 mm.

Moreover, when taking the sample powder from the surface the correction is higher than 50% whatever the thickness of the object. Therefore, in fact, sample powder should not be taken from the surface of the object. not only because of the effects of environmental conditions but also the large "depth" correction, even though obtainable, must introduce a large uncertainty.

In the particular case of pottery buried over its history in soil with a radionuclide abundance similar to the pottery itself, the accumulated radiation dose (the equivalent dose) of the sample will be the same (i.e. $D_{\beta i}$) no matter at what depth the sample powder is taken. In other words the percentage values of the differences mentioned above, due to the different thicknesses of the pottery and the different sample collection depths, reflect the contribution of the surrounding material to the collected sample at that depth. So that the effects of the surrounding material not only depend on the surrounding material itself but also depend on the total thickness of the pottery and on the sample collection depth.

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