SYSTEMATIC ERROR FROM Th/U RATIO IN LUMINESCENCE AND ESR DATING

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ABSTRACT

In luminescence and ESR dating methods, total count rate from thick source alpha counting is commonly used for estimating annual dose with assumption of equal activities for both uranium and thorium decay chains. This is equal to a Th/U weight ratio of 3.2. The systematic error in total dose rate due to uncertainty of the ratio is calculated. It is found that the error is insignificant for uniformly distributed samples such as sediment, but can be significant for some extreme circumstances.

Keywords Luminescence and ESR dating, Th/U ratio, Systematic error, Infinite matrix

1 INTRODUCTION

Thick source alpha counting technique has been widely used in determining U and Th contents for estimating their contributions to the annual dose in luminescence and ESR dating methods[1]. The alpha count of the Th (or U) content can be separated from the total alpha count by using "pair technique". However, this requires a prolonged counting time in order to have statistically enough 'slow' or 'fast' pairs being measured and may be impossible in practice if small screen, e.g. ϕ15 mm, is used in routine dating practice. Total alpha counting rate is often converted into annual dose under the assumption of equal activity of Th and U equaling a 3.2 of Th/U ratio in weight[1].

For the same amount of radioactivity, the α or β dose rate is higher and the γ dose rate is lower for the U-series than that for the Th series. Hence, a systematic error is introduced in estimating the annual dose using the whole alpha counting rate without consideration of the Th/U ratio. The error is largely contributed by the β and γ portions. This was analyzed by Sasidharan et al.[2], and recently by Leung et al.[3]. Because the luminescence signals induced by γ rays are in fact through secondary electrons, the β and γ doses can be treated identically for dry materials. As the error contributed from β dose rate is in opposite sense with the γ dose rate, both errors will compensate each other if both dose rates are considered as a whole. In this paper, we explore in more details about the systematic error from the Th/U ratio and its effect on dating results for sediment, pottery and thin section samples in luminescence and ESR dating.

2 CONVERSION FACTORS AND UNCERTAINTY

Conversion factors have been introduced in calculating dose rates from whole alpha counting rates[4]. For a whole alpha count rate $\dot{\alpha}$ [c/(ks·cm^2)], the annual α, β and γ dose rates (mGy/a) are given by[3]

Manuscript received date: 1994-12-20

$$D_\alpha = F_\alpha \dot{\alpha}, \quad D_\beta = F_\beta \dot{\alpha}, \quad D_\gamma = F_\gamma \dot{\alpha}$$

where F_α, F_β and F_γ (mGy·a^{-1}·C^{-1}·ks·cm^2) are the conversion factors, can be defined as

$$F_\alpha = (20.50R + 22.78)/(R + 1)$$

$$F_\beta = (0.795R + 1.187)/(R + 1)$$

$$F_\gamma = (1.426R + 0.935)/(R + 1)$$

where R is the alpha counting rate ratio of Th series to U series (normally regarded as the activity ratio too).

If β and γ dose rates are considered together, one has

$$D_{\beta+\gamma} = D_\beta + D_\gamma = F_{\beta+\gamma}\dot{\alpha} \qquad \text{(mGy/a)}$$

where $F_{\beta+\gamma}$ is a conversion factor for β plus γ dose rates and can be obtained as follows:

$$F_{\beta+\gamma} = (2.221R + 2.122)/(R + 1) \qquad (\text{mGy·a}^{-1}\text{·C}^{-1}\text{·ks·cm}^2)$$

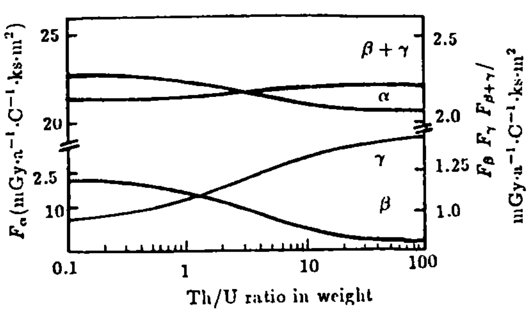

Fig.1 Variation of dose rate conversion factors with Th and U ratio in weight

Assuming that the members of Th and U series are in equilibrium conditions, the conversion factors, as well as the dose rates, will vary with the ratio of Th to U as illustrated in Fig.1. The curves at both ends are close to the maximum values corresponding to Th/U=0 and ∞. For dating practices, equal activity (R = 1) is assumed in calculating the dose rates. This has brought error in the conversion factors if the Th/U ratio is unknown. The conversion factors and their maximum errors are $D_\alpha = 21.64\dot{\alpha}\pm5\%$, $D_\beta = 1.982\dot{\alpha}\pm20\%$, $D_\gamma = 1.182\dot{\alpha}\pm20\%$, $D_{\beta+\gamma} = 2.172\dot{\alpha}\pm2\%$, all in mGy/a. As can be seen, the error in $D_{\beta+\gamma}$ is significantly smaller than those for β or γ dose rates because of compensation.

3 ERROR IN DATING

The systematic error in dose rate from the uncertainty of Th/U ratio relates to whether the β and γ dose rates can be considered as a whole. Although samples dated by luminescence and ESR dating methods vary considerably in their dose rate estimations, they, as far as the systematic error is concerned, can be separated into two categories.

3.1 Dating object as part of infinite matrix

The β and γ dose rates can be considered as a whole dose rate for samples in this category. Sediment samples are the best example in this category. It may also be extended to corals and some pottery with the assumption that the pottery has the same Th/U ratio and radioactivity as the soil where it was buried.

For the fine grain (4~ 11μm) samples, the α, β and γ dose rates from U and Th chains were estimated to contribute 45%, 14% and 17% of the total dose rate respectively[1,3]. The maximum systematic error in total dose rate due to the uncertainty of Th/U ratio (0 to ∞ range), E_f, is

$$E_f = [(0.05 \times 0.45)^2 + (0.02 \times 0.31)^2]^{1/2} = 2.3\%$$

For radionuclide free coarse grains (around 100 μm), e.g. quartz inclusion, embedded in infinite matrix, the β and γ dose rates from U, Th chains were estimated to contribute 26% and 31% of the total dose rate respectively[1,3], the maximum error E_c is

$$E_c = 0.02 \times 0.57 = 1.1\%$$

The systematic errors for fine grain and coarse grain methods are smaller than those given elsewhere[2,3,5], and will become smaller if Th/U ratio is defined in a particular range. An even smaller error is expected for K-feldspar grains (similar size), as less dose rate is contributed by the Th and U chains because of high β dose rate contributed from K content of the grain itself. For zircon grains, we also expect a smaller error than quartz because of high uranium and thorium concentrations in these grains. The Th/U ratio in zircon grains will not affect the total error because alpha counting is unlikely to be used for measuring uranium and thorium contents in zircon. The systematic error due to Th/U ratio is negligible for samples in this category as compared with the errors from other sources such as equivalent dose determination. The systematic error due to the difference in water attenuation factor between β and γ dose rates is also negligible.

3.2 Dating objects buried in infinite matrix

Pottery, bone and flint buried in sediment belong to this category. The Th/U ratio and the radioactivity of the objects are likely to be different from the surrounding materials. Although laboratory treatments, e.g. etching or crushing, can eliminate the external β dose contribution from the surroundings, the external γ dose has to be included in dose rate estimation. Hence, the external β and γ dose rates cannot be considered as a whole. The systematic error is related to the percentage of the external γ dose from Th and U chains (P) in the whole dose rate.

For the coarse grain method, assuming that the internal β and γ dose rates from U and Th chains make Q percent of the total dose rate, the maximum error due to Th/U ratio in the total dose rate, E_p, as shown below

$$E_p = [(Q \times 0.02)^2 + (P \times 0.2)^2]^{1/2}$$

The error depends on the values of Q and P. For an object with high radioactivity buried in a U and Th poor material like chalk, the systemic error due to Th/U ratio is quite small. Assuming $Q = 80\%$ and $P = 5\%$, we have $E_p = 1.8\%$. Whereas for a low radioactivity object, such as calcite, buried in a U and Th rich material like sediment, the error will be relatively large. Assuming $Q = 1\%$ and $P = 50\%$, we have $E_f = 10\%$, which is significantly larger than 1.8%.

4 CONCLUSIONS

Estimating the annual dose by the total alpha counting result, the systematic error due to uncertainty of the Th/U ratio is smaller than that calculated previously and therefore is insignificant for dating object which is part of infinite matrix surrounding, such as sediment. For these samples, the β and γ dose rates from U and Th decay chains can be considered as a whole. For a sample with normal radionuclide content, the maximum error is found to be only 2.3% for the fine grain method and 1.1% for the coarse grain method. For dating object buried in infinite matrix, the error depends on the radionuclide contents of the object and its surrounding.

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