Dose Rate Calibration of Sr-90 for Thermoluminescence Dating Using the Additive Dose Method

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Abstract

This article describes the procedure of calibrating Sr-90, which is used as a beta source for luminescence dating in faculty of Archaeology and Anthropology labs at Yarmouk University. The beta source is contained within a 770 beta irradiator manufactured by Daybreak Nuclear and Medical Inc. combined with automated Thermoluminescence reader system model 1100. The nominal activity of the source is 100 mCi (3.7×10⁹ Bq) as reported by AEA Technology on June the 29th 2005. On the 22nd of December 2005, the dose rate for the high position of the elevator was determined as 0.0586 (Gy/s). On the 6th May 2008, the source was calibrated for the second time using fine grains of quartz as a thermoluminescence phosphor material with size 4-11μm extracted from pottery shreds taken from Bedieh site, Jordan. Co-60 gamma ray facility in Al-Bashir hospital was used to deliver three doses to three different samples of quartz; 9, 6 and 3Gy to be used as a reference doses for the calibration process. The Additive Dose method is performed in order to determine the beta dose in unit of time and finally comparing between the gamma and the beta dose in order to define the beta dose rate in unit (Gy/s).

Keywords: Thermoluminescence; Additive dose; Dose rate; Sr-90; Co-60.

Introduction

Using Sr-90 as beta source in luminescence dating requires an accurate calibration for the dose rate. The accuracy of calibration process depends on defining the dose delivered from gamma facility to quarts. There are number of factors that should be considered during the irradiation with gamma beam. This has been discussed by Bell (1980) [2], where he introduced the interactions of gamma beam with matter and factors associated with it, while using gamma irradiation to deliver specified dose to quartz material do not induce directly thermoluminescence energy into the quartz material [1]. It is known that the interaction of gamma beam with matter occurs via three forms; the photoelectric effect, Pair Production and Compton Effect. These three interactions are responsible for producing energetic secondary electrons which in turns collide with atoms loosing part of its energy at each collision to be transferred to further secondary electrons released from the atoms. This process creates a large number of low energetic secondary electrons in the matter that have the probability of being captured by electron

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traps inducing thermoluminescence energy. The creation of low energetic electrons take place in the matter gradually, as photon energy enters the matter and passes through it; a build up for the secondary electrons begins, after few millimeters the electron flux reach an equilibrium state “charge particle equilibrium”, in which the number of electron produced equals to the number of electron absorbed. The charge particle equilibrium attained after a distance from the surface in the range of the initial electron energy produced by the collision with gamma beam [1, 2, 7]. In this region the absorbed dose by the material is calculated and where the sample should be fixed to be used as thermoluminescence dosimetric material for calibration process.

Finally calculating the dose delivered to quartz sample by gamma beam from Co-60 depends on the geometry and the dimension of the quartz container and mass energy absorption coefficient ($\mu_{en}$) that is used to describe the total reduction of gamma radiation in quartz [2]. In addition, it is important to consider that Co-60 facility is calibrated according to the dose absorbed by water or equivalent tissue that has similar composition to human tissue where water represents 75% of it, and so has the same mass energy absorption coefficient.

Experiment

Quartz grains with size 4-11μm were extracted by crushing pottery shreds and sieving via mesh of size 45 μm. The sieved material was cleaned by 7% of HCL overnight to remove calcites and 6% H$_2$O$_2$ overnight to remove organic materials. In each step of cleaning deionised water was used repetitively for washing and removing residues from the cleaning process. After that quartz was deposited for 20 minutes in 50 cm tall cylinder tube, the suspended material represented quartz grains less than 11μm were extracted, and the process was repeated for another 50 minutes to discard grains less than 4 μm that located in the first 5 cm of the tube. At the end, the extracted quartz grains were within the size of four and 11μm, this size was chosen for calibrating beta source since it is the same size that is used for pottery dating with the TL reader. Quartz was annealed to 500°C for 3 hours to remove any TL signals in quartz crystals.

Three samples were prepared for gamma irradiation, each sample composed of 250 mg of quartz, each contained in a 4 mm quartz tube with inner radius of 4mm and wall thickness equals to 0.5 mm. The quartz tubes were intended to be used in order to ensure that the gamma beam will travel within the container medium and the dosimetric material that have the same mass energy absorption coefficient.

To avoid the buildup region in the quartz sample and guarantee that it will be only within the charged particle equilibrium region; and by knowing that the electron equilibrium for Co-60 gamma ray (\(E = 1.25\) MeV) occurs after 2 mm [2], another quartz tube was used, with inner radius of 6 mm and wall thickness also equals to 0.5 mm to surround the original tube as shown in figure 1. The space between the two tubes is now 1mm which is also filled with the same quartz material prepared for calibration. In this geometry the distance that the gamma beam will pass through to reach the inner tube is 2 mm where the buildup of secondary electrons will take place.
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![Diagram of quartz sample container]

Figure 1: A profile of the quartz sample container; the dashed lines represent the inner tube which hold the principle quartz that will be used in the calibration; the continues line represents the outer tube; the space between the two tubes is 1mm filled with quartz.

The gamma irradiation was performed in Al-Bashir Hospital, Radio Therapy Department, Amman-Jordan, where Co-60 facility used as gamma beam source ($\bar{E} = 1.25$ MeV) to deliver 9, 6 and 3Gy to the samples, in order to specify the exact dose deposited in the sample; the same conditions that are used in calibrating the dose rate of Co-60 were applied in irradiating the quartz samples, the quartz tube was fixed at a distance 80cm from the source, and enclosed within an equivalent tissue used as an alternative of human tissue during calibrating and determining the dose rate of Co-60 facility. Now the dose received by the quartz material is calculated using the mass energy absorption coefficient of water and quartz by the formula [3]:

$$D = \left[ \frac{\mu_{en}/\rho_{\text{quartz}}}{\mu_{en}/\rho_{\text{water}}} \right] * X,$$

where $D$ is the absorbed dose delivered to quartz, $\frac{\mu_{en}/\rho_{\text{quartz}}}{\mu_{en}/\rho_{\text{water}}}$, are the mass absorption coefficients (cm$^2$/g) for quartz and water and $X$ is the exposure of gamma beam.

For gamma ray ($\bar{E} = 1.25$ MeV), the $\frac{\mu_{en}/\rho_{\text{water}}}{\mu_{en}/\rho_{\text{water}}}$ is 2.965×10⁻² (cm$^2$/g) from NIST database and 2.66×10⁻² (cm$^2$/g) for quartz [4]. By considering these two factors and irradiating with 9, 6 and 3 Gy, the absorbed dose to the quartz is 8.074, 5.383 and 2.6914 Gy respectively.

Now each sample of the irradiated fine grains was suspended in ethanol and allowed to deposit over 20 aluminum discs of 0.4 mm thickness and 10 mm diameter to be loaded in the TL reader for reading TL signals.

The Additive Dose method was performed to determine the dose delivered to quartz with Sr-90 in unit of time(s), the measurements were applied separately for each sample. For each sample the first four measurements represented the TL energy produced by the gamma irradiation of Co-60, the next group of measurements are taken after irradiating quartz with different doses by Sr-90, the irradiation time for the three samples are 136, 273, 436 and 573 seconds for sample with dose 8.074 Gy, 85, 170, 255 and 341 seconds for sample with dose 5.383 Gy and the last sample that carry 2.69 Gy was irradiated for 51, 102, 153 and 205 seconds.
Results and Conclusions

To obtain the beta dose deposited in quartz using Sr-90, a curve was plotted that represents the growth of TL energy with the increase of beta irradiation time for each 5°C temperature intervals as illustrated in Figure 2. Interpolation of these curves to zero TL intensity (TL = 0) gives the equivalent beta irradiation time (D_{\beta}). A plot of (D_{\beta}) values versus temperature was created, as shown in figure 3; D_{\beta} values rise from zero for temperatures below 200°C till it reach a plateau in the region of 350-370°C, this represents the actual beta irradiation time D_{\beta} that created electron traps in quartz crystal [1].

![Figure 2: The growth of the TL energy with the increase in the irradiation time.](image)

The dose rate for the source is now determined by the comparison of the beta dose specified in unit of time and the gamma dose that corresponds to the beta dose by using the formula,

\[ \dot{D} (\text{Gy/s}) = \frac{D_\gamma (\text{Gy})}{D_{\beta} (s)}, \]

where \( \dot{D} \) represents the dose rate of the beta source, \( D_\gamma \) the gamma dose delivered to the sample by Co-60 and \( D_{\beta} \) is the derived equivalent irradiation time(s) from the Daybraek TL reader using the additive dose method [5, 6]. The average dose rate is found to be \( \dot{D} = 0.0532 \pm 0.00583 \text{(Gy/s)}. \) Table 1 illustrates the results obtained by the comparison of the gamma dose and the beta irradiation time.

The results of the three samples as represented in figure 4 show the effectiveness of the procedure followed in irradiating quartz with Co-60, using quartz tubes as containers and define the buildup region, and the area where TL energy will be created the interaction of gamma beam with matter helped in avoiding the miscomputation for the dose precipitated in the quartz sample that was used later in specifying the dose rate of Sr-90.
Figure 3: The plateau test of the irradiation time by Sr-90, the stability in the irradiation time values occurs between 350 and 470, the graphs a, b and c represent the results of the three samples that were irradiated with 3, 6, 9 Gy respectively.
Table 1: The dose rate of the three samples with different gamma doses

<table>
<thead>
<tr>
<th>$D_\text{r}$ (Gy)</th>
<th>Temp.(°C)</th>
<th>$D_\text{h}$ (s)</th>
<th>$u(D_\text{h})$</th>
<th>$\dot{D}$ (Gy/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.074</td>
<td>370-420</td>
<td>151.7440986</td>
<td>0.0059</td>
<td>0.050208</td>
</tr>
<tr>
<td>5.383</td>
<td>350-415</td>
<td>101.1651945</td>
<td>0.0063</td>
<td>0.056210</td>
</tr>
<tr>
<td>2.6914</td>
<td>380-450</td>
<td>50.58100309</td>
<td>0.0053</td>
<td>0.0532097</td>
</tr>
</tbody>
</table>

Figure 4: Dose rate results from Table 1, and the average value. The error bars represent the uncertainty in the dose rate value.
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معايرة الجرعة الإشعاعية للعنصر Sr-90 في عملية التاريخ بطريقة التأقلم الحاري

ملخص

يهدف هذا البحث إلى عرض مقترح لمعايرة المصدر المشع لجسيمات بيتا، العنصر Sr-90 ذات الجرعة الإشعاعية 100 ملي كوري المستخدم في التاريخ بطريقة التأقلم الحاري في مختبرات كلي الالات الأوروبية. المصدر، جزء من منظومة جهاز 1100 الأثاثولوجي، تم تثبيته في العيادة الإشعاعية للمرة الأولى. وتم إجراء تجربة معالجة الإلكترون البيني في 2-12-2000. تم تثبيت المصدر المشع للمرة الثانية باستخدام جهاز الكوارتز بحجم ارتفاع 11 ميكرومتر ونقطته النقطية عند موضع الجرعة. الأوروب، لتحديد مصدر إشعاع Sr-90 في العيادة الإشعاعية في مستشفى البيني-الإوروب من أجل إشعاع مصدر الكوارتز ثلاث مرات مختلفة بجرعات 6 و 9 و 11 ميكرومتر للجرعة الإشعاعية. وتم تحديد الكوارتز Sr-90 (جريان)، وتم تحديد الكوارتز Sr-90 (جريان) حيث تم قياس الكوارتز Sr-90 على جهاز الإلكترون البيني بالإضافة إلى مساحة الجسم نفس الكمية من المصدر Sr-90.

References
