Dose Rate Evaluation of a $^{244}$Cm alpha source for cell irradiation

L. Sarchiapone, D. Zafiropoulos

INFN, Laboratori Nazionali di Legnaro, Legnaro (Padova), Italy.

INTRODUCTION

In this paper a description of the characteristics of a $^{244}$Cm alpha source, available at the LNL, is given. Being the source used as an irradiator for cells in a dedicated stainless steel Petri dish 0, it is extremely important the determination of the fluence and the energy of the alpha particles as they impinge on the cell.

The calculations have been done using the FLUKA Monte Carlo code for radiation/particles transport through matter 00.

MATERIALS AND METHODS

Curium-244 has half-life of 18.11 years. It decays 100% by alpha transitions to Pu-240 ($T_{1/2}$ 6561 years) and by spontaneous fission with branching fraction of $1.36 \times 10^{-4}$%.

The major alpha particles are emitted with energy $5804.77$ keV (probability 76.7 %) and $5762.65$ keV (probability 23.3%).

The radioactive source used for the present study is a planar source, covered by a gold foil of thickness 50 micrograms per cm$^2$. The source active diameter is 20 mm.

The initial activity (February 2005) was 370 kBq (10 $\mu$Ci) and at the date of the present study (January 2016) it is 243 kBq.

In order to determine the dose rate released to the cells at a certain distance, the following relation has been used

$$D = F \cdot \text{LET} \cdot \rho^{-1} \cdot 1.6 \times 10^{-9}$$

where

- $D$ = dose rate [Gray per second]
- $F$ = alpha particles’ fluence [cm$^2$ per second]
- $\text{LET}$ = Linear Energy Transfer [keV per $\mu$m]
- $\rho$ = density [grams per cm$^3$]

The LET of alpha particles on the target depends on the energy of the particles at the interaction with matter.

A plastic holder, realized at the Laboratory, has been used both to support the Petri dish and to avoid the direct contact with the source, as schematically shown in Errorre. L'origine riferimento non è stata trovata.

The distance between the gold foil and the mylar support, where cells were located, is 4.45 mm and the mylar thickness is 6 $\mu$m.

It has been calculated that alpha particles cross the mylar surface towards the cell layer with a LET of 92 keV/µm, as represented in Errorre. L'origine riferimento non è stata trovata.

RESULTS

In the FLUKA Monte Carlo code the radioactive source has been described through the BEAM card, as an isotropic source of alpha particles of energy 5.805 MeV. The definition of an isotropic emission is essential to normalize the fluence with the source radioactivity. The evaluation of the fraction of alpha particles emitted by the source in the solid angle subtended by the cell layer (or the plastic support holder) is thus statistically computed by the Monte Carlo code.

Table 1 Materials between the alpha source and the cell layer, their thicknesses and the energy lost.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
<th>Energy loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>50 $\mu$g/cm$^2$</td>
<td>40 keV</td>
</tr>
<tr>
<td>Air</td>
<td>4.45 mm</td>
<td>427 keV</td>
</tr>
<tr>
<td>Mylar</td>
<td>6 $\mu$m</td>
<td>680 keV</td>
</tr>
</tbody>
</table>
Fig. 3 Yield of alpha particles as function of the Linear Energy Transfer in the cell layer. The graph shows a LET of 92.3 keV/μm.

Fig. 4 Fluence of alpha particles in each of the materials in the experimental set up. Blue - particles from gold layer to air; green - particles from air to mylar; magenta - from mylar to cells.

Fig. 5 Spectrum of alpha particles measured with the SOLOIST alpha spectrometer (Ortec).

In Errore. L’origine riferimento non è stata trovata. It is represented the fluence of particles crossing the boundary between various materials, averaged over the full solid angle (2π). The mean energy of particles leaving the gold protection layer is 5.78 MeV, after the attenuation in the air gap it becomes 5.38 MeV to finally impinge on the cell layer with mean energy 4.70 MeV. These results, obtained with FLUKA simulations, have been confirmed by TRIM simulations 0, used to evaluate the energy of alpha particles transmitted through gold, air and mylar.

The alpha source has been measured with the alpha spectrometer SOLOIST (Ortec), the spectrum obtained is presented in Errore. L’origine riferimento non è stata trovata. The source to detector distance is about 5 mm and the measure has been done in air (being the spectrometer calibrated in energy using an Am-Cm source under vacuum).

According to the measurements the energy of the alpha particles emitted by the source is 5.23 MeV and after crossing a mylar foil of thickness 6 μm it is 4.37 MeV. The difference of about 330 keV with respect to the calculated energy (4.7 MeV) is due to the air gap, being the mylar surface-to-detector distance about 3 mm (the stopping power of air is about 110 keV/μm).

The average fluence in the cell layer, obtained with the FLUKA simulation, is 0.103 cm⁻² per source particle. Multiplying by the source intensity we obtain 2.5 × 10⁴ cm⁻² per second.

The dose rate according to the equation (1) is then 3.7 × 10⁻³ Gy per second, and the time needed to expose the cells to a dose of 1 Gray is 270 seconds, 4.5 minutes.

The calculations here presented have been compared, as a reference, with the calculation of Esposito et al. [5]. The dose rate, in that report has been evaluated for a ²⁴⁴Cm source with activity 148 kBq, 4 mm distance source to sample, similarly to the irradiation conditions described in this paper. The reference dose rate was 1.9 × 10⁻³ Gy per second, with LET at cell entrance of 98 keV/μm.

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