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RADIOBIOLOGICAL RESEARCH AND DOSIMETRY USING A FLAT ALPHA SOURCE

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Abstract. *The irradiation system consisting of an α-source and disc holder has been developed in the Heavy Ion Laboratory, University of Warsaw. A simple exposure system for irradiation of biological samples consists of the Am-241 disc source, source holder and biological samples cultured in special Petri dishes. The irradiation system has been investigated to determine the alpha spectrum and dose distribution in irradiated single cell layer attached to the Mylar foil. Commercial Am-241 disc source of 50 mm in diameter, with a radioactive element embedded into a substrate layer was examined to established the uniformity of surface radioactivity over the disc source. The experimental device is equipped with cell dishes of 40 mm in diameter and a 6 µm thick Mylar foil bottom. Care was taken for homogenous irradiation of the cells. Dose calibration for the irradiation system was calculated taking into account source-to-target geometry.*

Keywords: *Activity distribution, alpha particle irradiator, Am-241 disc source, cell irradiation system, dose distribution*

1. Introduction

Research in the field of the biological response induced by heavy charged particles is of great importance for radiotherapy and space radiation biology [1]. The main reason for using protons and heavier ions in tumor therapy is their depth-dose distribution in tissue, characterized by a small dose at the entrance and distinct maximum called the Bragg peak at the end of the range [2]-[3]. Heavy charged particles like those emitted by an α-source introduce DNA damages and particularly DNA double-strand breaks (DSB) in cells. Cell irradiation studies with α-particles have an important role in understanding the biological effects produced by high LET radiation. DNA damage is induced in cells as a consequence of dose deposition by radiation interacting with biological material.

Dosimetry of ionizing radiation is essential in the interpretation of radiation effects. In studies concerning radiobiological effects initiated by α-particles, it is important to determine the energy spectrum of particles reaching the biological samples and their fluence. Due to the ability of cells to form monolayers of small thickness, all α-particles with a range lower than the cell diameter deposit their energy in a cell layer.

Here we describe a simple experimental device (apparatus) consisting of a flat Am-241 disc source and Petri dish holder. Also, special Petri-dishes of 41 mm in diameter were made. The bottom of the dish forms a 6 µm thick Mylar foil. The layers of the Mylar foil and air between the surface of the source and Mylar reduces the energy of α-particles. The distance between the source and bottom of the Petri dish can be modified according to the demand of the experiment. The system utilizes α-particles from Am-241 source covered by a 1 µm layer of gold. Similar exposure apparatus for in vitro irradiation using Am-241 α-source were constructed previously [4]. Irradiation systems with collimators providing an almost parallel α- particle beam and to provide a perpendicular angle of incidence to the cell layer are also being built [5].

2. Materials and Methods

2.1 Alpha source

The α-particle source used as an irradiator in radiobiological experiments in the Heavy Ion Laboratory, University of Warsaw is Am-241 disc source. The source model AM1AP1 0053U with activity 1.96 MBq (53 µCi) was manufactured by Eckert & Ziegler. The active layer of the disc has a diameter of Φ=50 mm and thickness of d=0.4 µm. According to the certificate, the source has the surface activity of 100 kBq/cm^2 and is protected by a 1 µm gold layer. We have investigated activity distribution on the surface of the source. The uniformity of the surface activity was checked in a series of measurements with Si-charged particle detector (ORTEC - implanted boron N-type Si with active area 300 mm^2) indicating that surface activity has an uncertainty of 3.5%.

2.2 Irradiation device

The main parts of the irradiation device are shown in Fig. 1. The source emitting the α-particles is 5 mm away from the bottom of the Petri dish. The α-particles of the average energy of E=4.92 MeV emitted at 0°

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(perpendicular to the surface) while reaching the cells in a Petri dish have the energy of 3.6 MeV reduced due to the losses in the air and Mylar foil. It should be noted that α-particles emitted at non-zero angles have lower energies because their trajectories in the source, gold layer, air and Mylar foil increase in accordance with the expression

$$d' = \frac{d}{\cos\theta} \quad (1)$$

The energy loss suffered by the α-particles passing through all devices (Am-disc, gold layer, air gap between the source and Petri dish and Petri dish bottom) since its emission until reaching the biological target was calculated using the Monte Carlo modeling program SRIM [6]. The SRIM software is publicly available [7]. The calculated energy shifts and spreads match perfectly those obtained from the measurements.

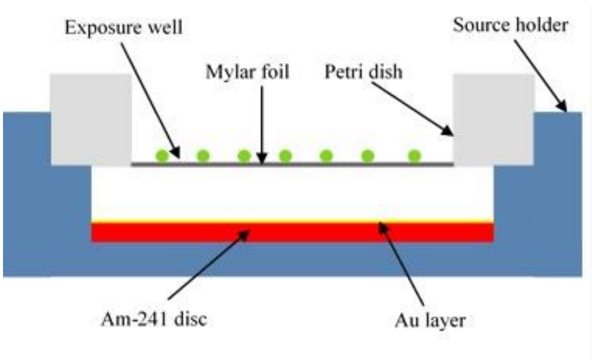

Figure 1. Schematic view of the irradiation device. The Petri dish bottom made of Mylar foil is located 5mm from the source surface. The distance between the source and Petri dish can be changed.

The irradiation system allows for the irradiation of cells in special 10 mm-high Petri dishes and with the inner diameter of Φ=41 mm. The bottom of the dish is a 6 μm thick Mylar foil. The Petri dish was fixed in a holder to keep the established distance from the source (Fig.1).

3. Results

3.1 Alpha energy spectrometry

Radiobiological experiments - due to the use of live cells - will be conducted in atmospheric conditions. These cells will also be placed in Petri dishes with their bottom made of Mylar. Measurements were made to determine the change in alpha spectra after passing through subsequent absorbents. Fig. 2 presents four energy spectra of a Am-241 disc source. The first shows the energy of particles when no absorbents are placed. The second and third were obtained after placing 6 μm Mylar and 17 mm air, respectively. The fourth energy spectrum arose as a result of the simultaneous placement of both mentioned absorbents - 6 μm Mylar and 17 mm air. Under the interaction of radiation with matter, the average energy of particles decreases. This can be seen in Fig. 2, where the maximum energy spectra for the subsequent absorbents are shifting to lower energy values. In addition, the FWHM of the distribution increases.

The incremented path in the absorbent increases energy loss. In the considered experimental system, such elongation is caused by a change in the angle of emission, according to formula (1). One can calculate the energy of the particles emitted from individual parts of the source and reaching a cell located 5 mm above its center. Such particles lose part of the energy they carry, in gold, air and Mylar layers, and then deposit the dose in the cell.

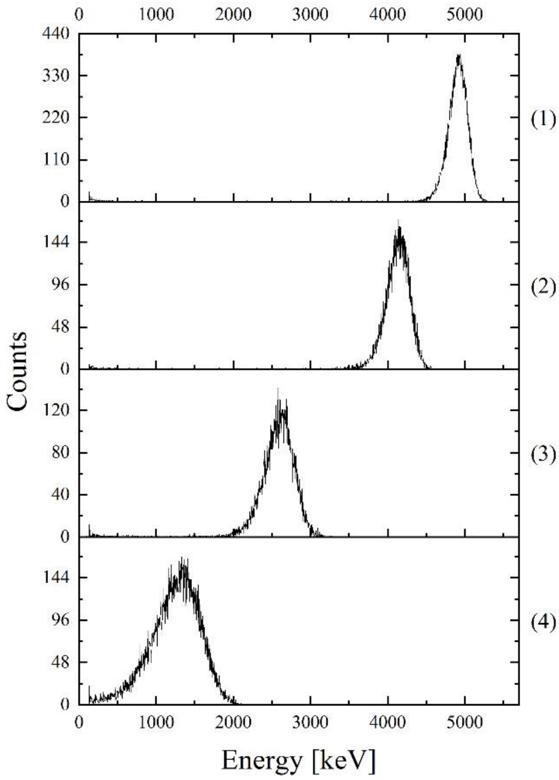

Figure 2. The measured α-energy distribution functions measured by Si-detector at angle θ=0°. (1) - spectrum measured in vacuum, (2) – spectrum in vacuum after passing 6μm of Mylar, (3) – spectrum in air at distance from the source of 17 mm, (4) – spectrum in 17 mm of air and 6μm of Mylar.

The energy loss can be simulated using the SRIM program [5]. Calculations were made for three examples of the angle measured: 0°, 30° and 60°. The results are shown in Table 1. The quantification of the range values in cells were solved by means of the Monte Carlo modelling software – SRIM package [6].

Table 1. Energy values of particles after passing through subsequent absorbents placed in the irradiation system used for radiobiological exposures and the approximate range of these particles in the cells

Position of α-particle	Θ=0°	Θ=30°	Θ=60°
From the source [MeV]	4.92	4.83	4.37
After 5mm of air [MeV]	4.42	4.19	2.87
After Mylar foil [MeV]	3.60	3.22	0.79
Range in the cell [μm]	21.0	18.1	1.1

Energy losses increase with the length of the path the particles travel in the absorbent. As a consequence, they arrive with lower energy. Such an effect can be obtained in measurements when the collimator mounted in front of the Si-detector can change the angle at which particles are recorded. The measurements were carried out using a semiconductor detector in geometry ensuring the counting frequency at which the energy resolving power is optimal. Experimental results were collected for three different angles ($\theta=0^o$, $\theta=33^o$ and $\theta=52^o$). The angle was defined by two collimators $\Phi=3$ mm placed in a vacuum at a distance of 11 mm.

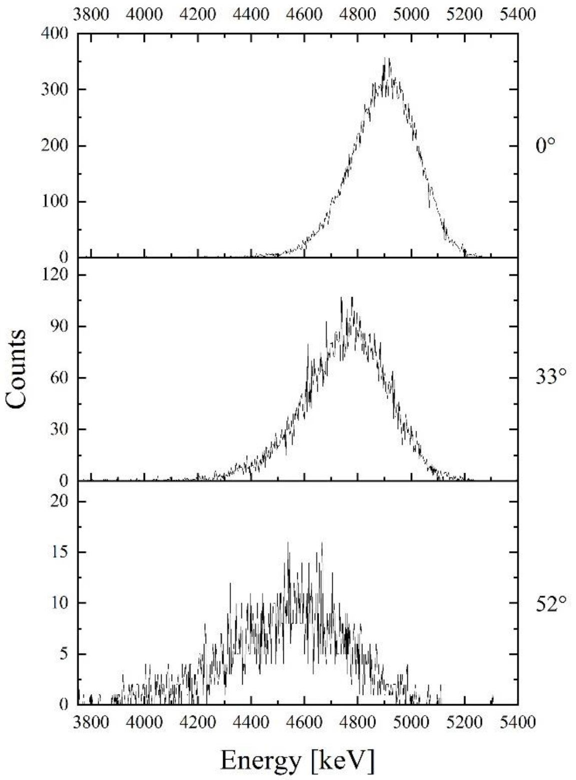

Figure 3. The energy spectrum of a flat source obtained for measurements showing different emission angles ($\theta=0^o$, $\theta=33^o$ and $\theta=52^o$)

The obtained spectra are presented in Fig. 3. It should be noted that the energy spectra presented in Fig. 3 are measured in vacuum and cannot be an indication for determining the energy values presented in Tab. 1. Increasing the angle and the average path that the particles travel in the source and absorbents leads to the reduction of the average radiation energy, as expected.

4. Discussion

The use of α-particles in radiobiological studies is of great interest because of their interaction effects which are not observed with low LET radiation. However, because the dimension of the cells is of the same value as the range of the particle, the deposition of the energy in the cell volume may not be uniform. Measurements of α-particle energy spectra for the subsequent layers of the materials that reduce particle energy as well as for different emission angles, allow to verify the results of the calculations of α-particle spectra carried out by the Monte Carlo method. Monte Carlo calculations allow to determine the shape and intensity of the particle spectrum for selected radiation geometry, and consequently the dose rate. Our device for the geometry indicated in Fig. 1 deposits a dose rate of 9 mGy/s.

5. Conclusion

The irradiation system consisting of an α-source Am-241 has been developed and installed in the Heavy Ion Laboratory, University of Warsaw for the studies of radiobiological effects in vitro. The components of the device were examined to ensure the uniform dose at target cells. The α-particle irradiator will be tested soon in the evaluation of survival fraction test in human cells.

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