EXPERIMENTAL AND COMPUTATIONAL INVESTIGATION ON THE LOW DOSE RADIATION ABSORPTION IN SOME LIVING TISSUES

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KEYWORDS: Cobalt radiation, Monte Carlo technique, nucleic acids, biosynthesis, pork tissues

An investigation of low dose radiation absorption effects in liver, muscle and lung has been done using a low activity laboratory gamma radiation source ($^{60}$Co). Tissue samples size and irradiation times have been determined using a theoretical approach based on computer simulation techniques in which organic materials substitutes for the studied living tissues were used. The disruptive effects of ionizing radiation in macromolecules as well as the cell ability of repair some of damaged molecules have been revealed.

1. INTRODUCTION

The interest for low radiation dose effects in the last decades was determined by the increased number of artificial radiation sources that are generating permanent exposure of Earth biosphere (Kuzin et al [1-3]). The rabio-biological knowledge at the present time allows to evidence that, beside the disruptive effects of radiation absorption, some restoration effects at the level of cell nucleus could occur. The cellular complex biochemistry has led to another interesting issue, i.e. the possibility of cell metabolism stimulation by low radiation doses.

The aim of the present study was to investigate the low dose radiation absorption effects in some living tissues. The biological effects such as the average content of DNA and RNA in the irradiated tissue samples are closely related to the absorbed dose values in these samples. The accurate experimental determination of the absorbed dose in living tissues being for the moment beyond our capabilities, due to the lack of the measurement devices, we have used a theoretical approach based on Monte Carlo radiation transport techniques. It is well known that Monte Carlo techniques have become popular in different areas of radiobiological applications, with the advantage of powerful computing systems. In particular, they have been

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extensively applied to simulate processes involving random behavior and to quantify physical parameters that are difficult or even impossible to calculate by experimental measurements.

Taking into account the source characteristics and the irradiation geometry, the tissue samples size has been optimized and the irradiation times required to reach the expected absorbed dose values have been obtained.

2. MATERIALS AND METHOD

2.1 Experimental set-up

Tissues samples (liver, muscle and lung) have been placed on Petri dishes and irradiated with photons emitted by a $^{60}$Co gamma radiation source (185 Bq activity) like in the Figure 1. The studied tissues have been provided by commercial sources (pork tissues): liver, muscle, lung, freshly withdrawn. Spectrophotometric assay JASCO V type spectrophotometer provided with quartz cells was used to measure light extinctions in ultraviolet absorption spectra. The standard assay method for the average content of nucleic acids in diluted perchloric acid extract [4] was applied to the exposed samples 24 hours after the irradiation. The average level of DNA and RNA is computed by taking into account the sample mass and the extraction solvent volume. Statistical analysis: average values as well as standard deviations (corresponding to repeated measurements in identical irradiation conditions) have been used to plot the experimental data.

2.2 Monte Carlo simulations

In order to calculate the irradiation times, closely related by the source characteristics and the source-to-sample geometry, the $^{60}$Co gamma radiation sources, including the lead protection (Fig. 1), have been modeled using BEAMnrc [5], an EGSnrc [6] user code. EGSnrc is a general purpose package for the Monte Carlo simulation of the coupled transport of electrons and photons in an arbitrary geometry for particles with energies above a few keV up to several hundreds of GeV. The physics in EGSnrc [6] is very complex including the most important particle interactions processes.

The EGSnrc system is a structured set of subroutines that handles all of the physics in the simulation in a manner which allows users to write their own geometry and scoring routines without actually touching the EGS system itself. One of the most important design features of the BEAMnrc is the possibility of defining a certain
number of scoring planes between two consecutive CMs or at the end of the last CM. These planes are always perpendicular on the z axis.

The complete information (charge, energy, position, direction, history) of each particle crossing an user defined scoring plane is recorded in a phase space data file that can be re-used in BEAMnrc or as an input in other Monte Carlo codes (like BEAMDP or DOSXYZ) in order to determine the particles characteristics (fluence, angular distributions or energy spectra) or to calculate dose distributions in phantoms.

In this work we have used the BEAMnrc Monte Carlo code to simulate the radiation beams provided by the $^{60}$Co and $^{137}$Cs gamma ray sources that are incident on the Petri dishes containing the tissue samples (Fig. 1).

The sources were built from a series of component modules centered on the z axis. An uniform mono-energetic radiating cylindrical isotropic source routine have been used to model the $^{137}$Cs sources emitting gamma photons with 0.662 MeV. The cross section data for the materials from which the sources are made (cesium, lead), and further for the tissue substitutes materials, have been prepared using PEGS4 code [6].

In order to calculate the absorbed dose distributions in different living tissues under investigation, cylindrical phantoms made from substitutes of these tissues have been modeled with DOSRZnrc [7], a Monte Carlo code that simulates the passage of an electron or photon beam in a finite, right cylindrical geometry. The phantoms were divided in cylindrical voxels determined by radii and depths (Fig. 2), dose being scored in every voxel. The phase space files obtained with BEAMnrc at the reference plane (i.e. immediately before Petri dishes) have been used as input in DOSRZnrc. The elemental composition, mass fraction, nominal density and mean atomic number of tissue substitutes [8] are taken from ICRU [9]. The mean atomic numbers $\bar{Z}$, used for mixtures and/or compounds, were calculated using the following formula [9],

$$\bar{Z} = \frac{\sum_i p_i Z_i^2}{\sum_i p_i Z_i}$$

where $p_i$ is the mass fraction, $Z_i$ is the atomic number, and $M_{A_i}$ is the molar mass of element $i$. 

![Cylindrical phantom modeled with DOSRZnrc and used to calculate the depth doses and dose profiles in organic substitutes for liver, brain and bone.](image)
3. RESULTS AND DISCUSSION

Depth doses and dose profiles for liver (ICRU) irradiated with $^{60}$Co gamma rays are shown in Fig. 3a and 3b, respectively. Similar dose distributions have been obtained for brain and bone substitutes. The absorbed dose has a maximum in the central region of the radiation field, decreasing very fast with both dept and radius. In order to increase the irradiation efficiency, based on these absorbed dose distributions, we decided to use in our experiment cylindrical samples of tissues having 2 cm radius and 0.5 cm thickness centered on beam axis. The absorbed dose has a maximum in the central region of the radiation field, decreasing very fast with both dept and radius. In order to increase the irradiation efficiency, based on these absorbed dose distributions, we decided to use in our experiment cylindrical samples of tissues having 2 cm radius and 0.5 cm thickness centered on beam axis. The irradiation times calculated in these conditions – for the absorbed dose of 1 mGy - are shown in Table 1. The time durations corresponding to the doses ranging between 1 and 8 mGy have been adequately multiplied.

The graphical results regarding the nucleic acid content changes in the irradiated tissues (acute irradiation) are given in Figures 4 – 6. In Figure 4 the response

![Fig. 3: Depth dose distributions (a) and dose profiles (b) calculated in a liver substitute phantom irradiated with $^{60}$Co gamma radiation.](image)

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Dose (mGy)</th>
<th>Dose/particle (mGy)</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>liver</td>
<td>1</td>
<td>$2.544 \times 10^{-10}$</td>
<td>177.0</td>
</tr>
<tr>
<td>muscle</td>
<td>1</td>
<td>$2.539 \times 10^{-10}$</td>
<td>177.4</td>
</tr>
<tr>
<td>lung</td>
<td>1</td>
<td>$2.307 \times 10^{-10}$</td>
<td>195.2</td>
</tr>
</tbody>
</table>
The average nucleic acid content in the liver samples is presented in Figure 4. The main issue is that the average content of DNA and RNA in liver tissue is diminished in all exposed samples (up to 70%) in comparison to the control one (with a slight tendency of increasing for relatively long exposure time).

In Figure 5 the results obtained for muscle tissue (with lower content of lipid) are given. Generally, the exposed samples present lower level of nucleic acids than the control, except for the dose of 2 Gy where the nucleic acid content is increased. However the differences are non-significant from statistically viewpoint. In figure 6 the situation corresponding to lung tissue is presented. One can see that for all exposed samples the average content of DNA and RNA is significantly diminished in comparison to the control sample (up to 25%) with a tendency to recover toward longer exposure times (where the control value is almost totally recovered).

The discussion regarding these results need to take into account the possible effects of the exposure to low radiation doses as well as the putative peculiarities of the analyzed tissues. First one need to mention that the radiation effects in various types of living tissues have been much studied in the case of high radiation doses, when most of the biological structures are negatively affected. However for low radiation doses and especially for low dose rate the radiobiological issues provide the possibility of some molecular damage restoration – mainly in the case of nucleic acids [10]. The explanation should be related to other phenomena – specific cellular processes that could lead to the increase of the nucleic acid content – meaning the stimulatory effect of small radiation dose on the biosynthesis. We have to mention that in previous report [11] similar experiments carried out in some different radiation conditions revealed the diminution of the nucleic acid content for relatively short irradiation times followed by the partial recovering of this diminution in the case of longer exposure times. When compare the exposed tissue one can see that they have similar content of water with small differences in the lipid and protein levels. In all these tissues there is a large amount of water (more than 70%) so that the presence of the water molecules could be related to the indirect effect of radiation absorption in the living tissues. The water radiolysis results in the release of free radicals of hydrogen...
and oxydril that are able of destabilization of many biochemical reactions in the cellular structures. While in the case of high radiation doses both direct and indirect radiation effects result in nucleic acid destroying, in the case of low radiation doses it seems that the activation of recovering processes as well as the stimulation of nucleic acid biosynthesis need to be also considered. This could be taken as the cell ability to adapt to the low level stress induced by radiation absorption; in some cases the intensification of biosynthesis seems to be able to overrun the molecular loses determined by negative radiation influence.

In this experiment, damages induced by radiation exposure in liver and lung are the dominant effect, having higher amplitude in liver, known as rather radiosensitive. In the case of muscle, the radiation disruptive effects are small, in the limits of the standard deviation.

4. CONCLUSIONS

The response to low radiation doses of some tissue samples freshly withdrawn has been assessed, the average content of nucleic acid being diminished up to 70% in liver and, respectively 25% in lung. The overlapping of disruptive radiation effect as well as the stimulation of biosynthesis have been revealed. The study is important for practical reasons related to the behavior of fresh food of animal origin under low radiation impact.

REFERENCES