SUN, SOLAR ACTIVITY, SOLAR-TERRESTRIAL RELATIONS AND ASTROBIOLOGY

https://doi.org/10.18524/1810-4215.2024.37.312685

THE EXISTENCE OF SIMPLEST BIOLOGICAL STRUCTURES IN THE FIELD OF HARD RADIATIONS

Doikov D.M.[1,2], Doikova E.M.[3], Jerdev M.[4]

[1] Dept. of Physics, Medical laboratory of the North Medical Center, Poria, Israel

[2] Dept. of Mathematics, Physics and Astronomy, Odesa National Maritime University, Ukraine *dmitro.doikov@gmail.com*

[3] Dept. of Radiology, of the North Medical Center, Poria, Israel, *doikovaekaterin@gmail.com*

[4] Dept. of Radiology, of the North Medical Center, Poria, Israel, *jerdev.michael@gmail.com*

ABSTRACT. The paper deals with the application of biophysics in astrobiology and space medicine. The interaction between cells, bacteria, and hard radiation in near-Earth space is calculated. We studied role of photons on the destruction of elementary biological structures. Depending of the spectra and intensity of X-rays and soft γ-radiation we declared, that calculations of photon energy deposition has been practical interest from the point of view of space flight safety and the survival of various forms in space. It was found how radiation energy transfer processes in cells and bacteria, changes their spectrum. This is leads to changing the cross sections of interaction between quanta and biological structures, i.e., membranes and organelles of cells and bacteria. We considered only structure of this interaction, percentage contribution in total extinction of the photon component of solar radiation in the standard biological structure named “Soft Tissue”. The main standards of biological tissues and anatomical structures were used for calculations and their interpretation. Different biological objects are stored in specialized standards. In particular, in the National Institute of Standards and Technology (NIST). Radiation field in determine survivability of some types of microorganisms from ionizing radiation is significantly increased by drying and freezing. Drying and freezing significantly increases the radiation survival of microorganisms when used separately, and the combination of excision and freezing significantly increases radiation survival. Within the framework of Astrobiology, the study of the conditions proposed for consideration helps to understand the possibility of transporting multi-atomic structures (sugars, amino acids, etc.), primary bacteria in comets and some types of meteorites. It is noted that these cosmic bodies provide sufficient shielding from external exposure to cosmic rays during such transportation.

Keywords: astrobiology, energy deposition in bacteria, radiology and space medicine, cell damage.

АНОТАЦІЯ. У роботі розглянуто застосування радіаційної біології в астробіології та космічній медицині. Зроблено розрахунки взаємодії між клітинами, бактеріями та жорстким випромінюванням у навколоземному просторі. Нами отримано, що вплив фотонів на руйнування елементарних біологічних структур залежить від інтенсивності та довжини хвилі рентгенівського та м’якого γ-випромінювання. Згідно результатам розрахунків виникає практичний інтерес з точки зору безпеки космічних польотів і виживання різних примітивних біологічних форм у космосі. Отримано, що у процесі переносу радіаційної енергії в клітинках та бактеріях її спектр змінюється, що доводить до змін перерізів взаємодії квантів з біологічними структурами. Це стосується мембран та органел клітинок та бактерій. Ми розглядали лише структуру взаємодії між фотонним компонентом сонячного випромінювання та біологічною структурою яка моделювалася вигляді параметру «М’яка тканина». Для розрахунків та їх інтерпретація були використані головні стандарти біологічних тканин та анатомічних структур. Різни біологічні об'єкті зберігаються в спеціалізованих стандартах. Зокрема в Національному інституті стандартів і технологій США (NIST). Головні пункти, які розглянуто у роботі підтверджують раніше отримані експериментальні висновки. Тобто – що живучість деяких типів мікроорганізмів від іонізуючого випромінювання значно підвищується при висушуванні та заморожуванні. Одночасне висушування та заморожування значно збільшує радіаційну виживаність мікроорганізмів при окремому застосуванні. В межах Астробіології вивчення запропонованих для розгляду умов допомагає зрозуміти можливість транспорту багатоатомних структур (сахари, амінокислоти та інші), первинних бактерій у кометах та деяких типах метеоритів. Зазначено, що ці космічні тіла забезпечують достатнє екранування від зовнішнього опромінення космічними променями під час такого транспортування.

Ключові слова: астробіологія, депонування енергії в бактеріях, радіологія та космічна медицина, пошкодження клітин.

Highlights:

1. Ionizing radiation survivability of some type micro-organisms is greatly increased by desiccation and freezing.
2. Desiccation and freezing greatly increased radiation survival of microorganisms when applied separately,

and when combined, desiccation and freezing increased radiation survival even more so.

1. Introduction

As a first approximation, we consider the interaction of cosmic rays (therefore CRs) with soft tissues, referred to as "Soft-Tissue" in the NIST standard. The CR consists is energetic particles and quanta. It was considered only the radiation component. The pattern of exposure to ionizing radiation depends on the shape of the radiation component of solar flares. A significant fraction of soft X-ray radiation mainly falls in the energy intervals 0.2 – 10 keV In motion of X-ray quanta in "Soft-Tissue" we observe photo absorption, Compton and Rayleigh scattering. In the spectral interval between 0.2 keV and 10 keV the energy transfer of X-rays is determined by strong photo absorption. Here the striking power of the radiation is maximal. In the interval 10 keV – 60 keV, in the given figures one can trace also the geometrical effect. Namely, the dependence of the calculations results of the spectrum coming out of the absorber on the effective sizes of cells or tissues. An increase in the percentage of scattered radiation as the size of biological systems increases is observed. The sizes of cells and bacteria are limited to 150 nm, This results are presented in Fig. 1.

2. X-ray energy transport in Astrobiology

By the mid of1970-s, a number of papers by (Hoyle & Wickramasinghe, 1983; Wallis et al., 1992; Dayal et al., 2019; Stancheva et al., 2002) with therein reference had raised the question of surface reactions for the synthesis of complex molecules on ultracold particles within gas-dust conglomerates. Typical reaction times of macromolecule synthesis τ_{reac} are much shorter than the lifetime of gas-dust nebulae τ_{cloud}. In 1970s, radio astronomy began the pursuit of recording complex molecules down to sugars, amino acids, etc. At the same time, even small doses of hard radiations cause the appearance of surface charge of dust particles, which further reduces the values of the τ_{reac} On the other hand, the survival of macromolecules strongly depends on the spectrum of cosmic rays crossing these conglomerates. The question about the cross sections of cosmic ray interactions with macromolecules is reduced to their interactions with the atoms composing the molecule. The high-energy part of the CR distribution mainly penetrates into gas-dust nebulae. And the interaction of these particles gives very small cross sections in the interaction with atomic electron shells of the considered molecules and do not significantly affect the formation of macromolecules. Moreover, when solving such a class of problems and the energy ratio, we can consider these molecules with their constituent electrons as quiescent. To solve the above problem, it is necessary to calculate the total energy losses for dust particles and molecular atoms separately.

3. Direct and Non-Direct, Internal

3.1. Direct interaction

Numerical calculations of macromolecule survival in the field of hard radiation are gained prominence and relevance after the publication of the articles (Kyriakou et al., 2022), and (Imserti et al., 2018). In this source the open code version is now in widespread use Giant4-DNA 11.2. The simplified version of these codes is G. Weber X-Ray calculator (see link). The various model studies of protozoan bacteria in media with standard dimension 150 nm presented in Fig. 1. A main component of deposit energy's is E_{dep} for photon field includes only photo absorption. From Fig. 1 we may get the upper limit of the energy absorbed by the proto-bacterium has $E_{dep} = 0.12\ eV$. The presented in Fig. 1. results define only direct interaction of quanta with bacterial and cellular structures. It is important to note that E_{dep} energy is sufficient to excite the fluorescence of a certain type of bacteria exposed directly to the X-ray radiation presented in Fig. 1.

3.2. Non-Direct interaction

If bacteria live in water or liquid biological substrate to the direct effects of X-ray and γ-ray radiation is added the mechanism of radiolysis in these liquids. The general scheme of the hard-radiation interaction processes was consistent with the solutions adopted in open code Giant4-DNA 11.2. Taking into account characteristic times, we divide the chain of processes into stages: ionization → radiolysis + free radicals → reactions between free radicals and bacterial membranes and organelles. The given scheme was necessary for comparative characterization of prediction of bacteria existence in biological environment and without it. This algorithm begin from estimation of energy deposition in "Soft-Tissue".

3.3. Internal interaction

Internal interaction refers to the process of penetration of radioactive isotopes from the environment surrounding a bacterium or cell. These may be the free radicals described in the previous section but containing a radioactive isotope. These events are depends from the nuclear transformations inducing their appearance. This issue has not attracted the attention of researchers because of its low probability relative to other events. There is a non-zero probability that a radioactive isotope is present in a transport molecule that participates in metabolic processes.

3.4. Radiology and space medicine

The new opportunities now study the effects of radioactive isotopes penetrating across cell membranes and decaying inside cells and bacteria. The advent of PET CT led to the use of the decaying isotope $^{18}_{9}F$, which is part of the transport radiopharmaceuticals molecule (hereinafter RFP)-Fluorodeoxyglucose (hereinafter FDG), a biological analog of glucose. Its full name is 2-fluoro-2-deoxy-D-glucose. When $^{18}_{9}F$ atom is introduced into the preparation, the names are supplemented with its mention,

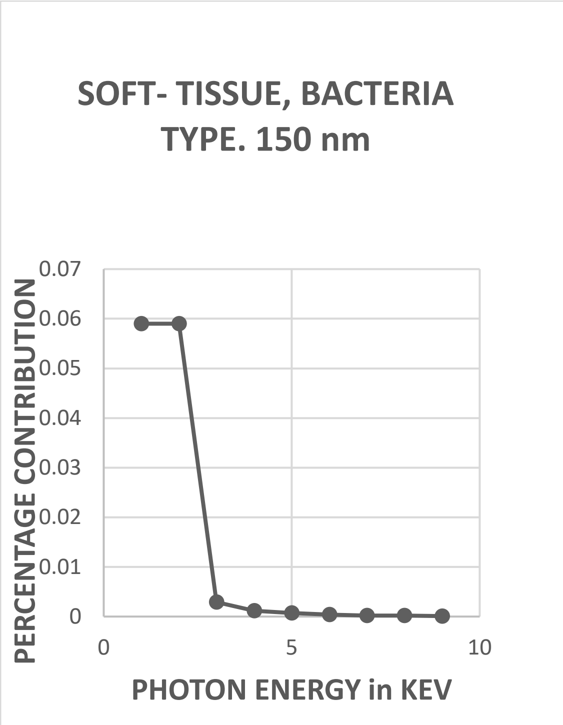

Figure 1: Attenuation in 150 nm bacteria wth size 150 mm

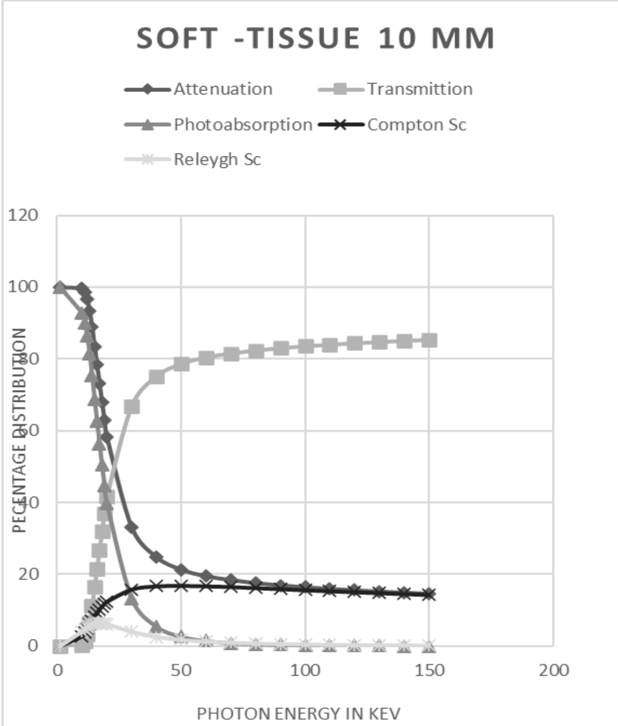

Figure 2: Extinction in Soft Tissue. Layer size is 10 mm

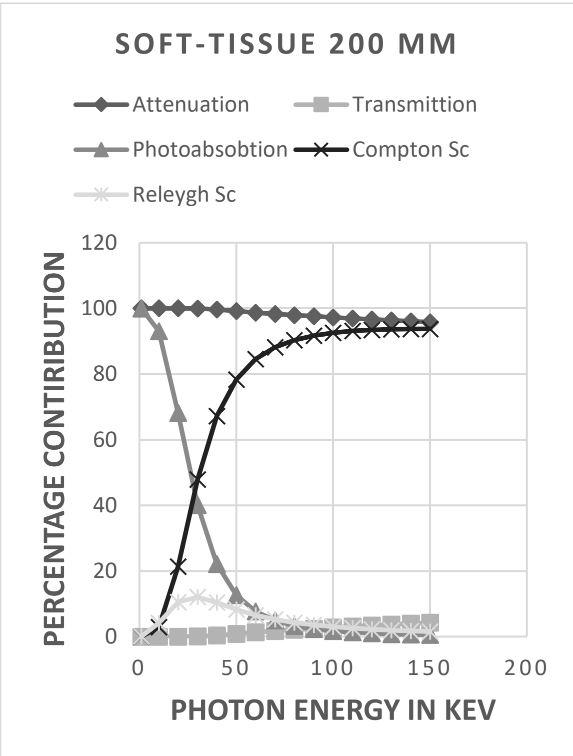

Figure 3: Ibid for Soft-Tissue size 200 mm

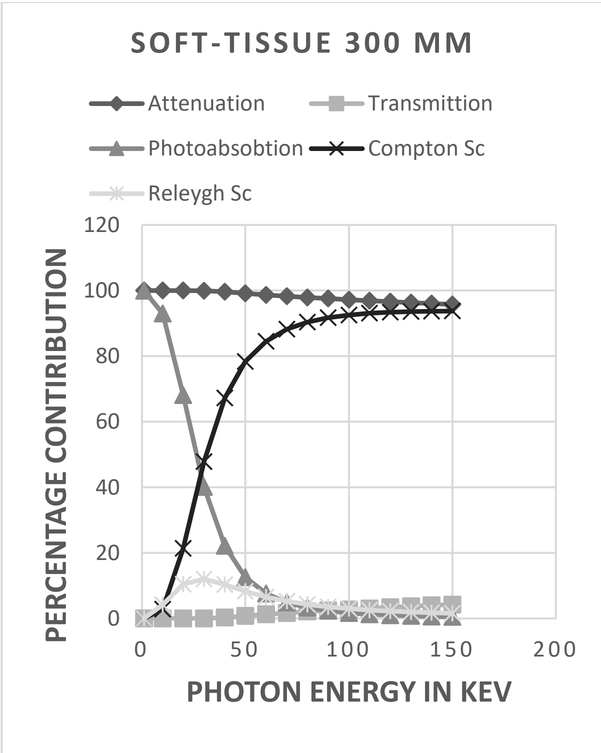

Figure 4: Ibid for Soft-Tissue size 300 mm

e.g. ${}^{18}_{9}F$ -FDG. For the model experiment the medium conventionally called "living environment" (hereinafter referred to as LE) is chosen. The LE experiences the direct effect of positrons and gamma-quanta formed by decay in the RFP. The calculations of the various model studies of protozoan bacteria in media filled with radiopharmaceuticals (hereinafter RFP)-Fluorodeoxyglucose (hereinafter FDG). In this case a biological analog of glucose, were carried out. Its full name is 2-fluoro-2-deoxy-D-glucose. When ${}^{18}_{9}F$ atom is introduced into the preparation, the names are supplemented with its mention, e.g. ${}^{18}_{9}F$-FDG. For the model experiment the medium conventionally called "living environment" (hereinafter referred to as LE) is chosen. The LE experiences the direct effect of positrons and gamma-quanta formed by decay in the RFP. Bacteria or cell are placed inside the LE. Having the results of measurements of hard radiation fluxes on the PET CT, we set the field of gamma rays and diffusely moving particles – decay products in the form of positrons and recoil nuclei. As a result, we have two reactions channels: ${}^{18}_{9}F \rightarrow {}^{18}_{8}O + e^{+}$ and $e^{+} + e^{-} \rightarrow 2\gamma$.

The second case is applied to space conditions. Here the field of hard radiations interacts directly with the microorganism. The participation of RFP – Glucose Fluorine in the processes of metabolism and synthesis was considered in the form of different variants of their placement in space. The effects of the decay products of the isotope ${}^{18}_{9}F$ in RFP on protozoan organisms and cells are considered in the following cases:

– Free radicals during radiolysis arise in the bio-solution around the bacterium and enter the intracellular space (Kyriakou et al., 2022), and (Imserti et al., 2018).

– Decaying within the bacterium.

– Direct interaction of the cell membrane, organelle and macromolecule with radioactive decay products.

The role of the RFP decay product ${}^{18}_{8}O$ inside the bacterium or cell as a result of ionization and direct destruction of components of the internal structure of the bacterium or cell is important because he mean free path is drastically shorter. In consequences of this presence of ${}^{18}_{8}O$ as a decay product of ${}^{18}_{9}F \rightarrow {}^{18}_{8}O + e^{+}$ and involved in the damage of complex organic molecules were specificities.

4. Discussion

The calculation of the survival rate of already formed complex molecules and possible simplest life forms is the basis of the present work The free path lengths of positrons $L_{e^{+}}$and ${}^{18}_{8}O$ atoms as $L_{{}^{18}_{8}O}$ are noticeably longer than the specified size of a bacterium or cell. Therefore, the localization of the decay point of the radioactive isotope in or outside the cell or bacterium is irrelevant. In this case it is necessary to solve the problem for the case of direct interactions taking into account chemical reactions of radiolysis.

In present time development of space technology requires new approaches to the study of biological aspects of prolonged stay of equipment and people in aggressive environment. In order to model the properties of biological systems, the program Geant4-DNA was extended and applied to solve new biomedical problems in the program Giant4-DNA 11.2 In some cases, Weber codes have been used for the sake of simplicity. The proposed codes are integrated into the NIST international databases, on proteins and their interaction cross-section with ionizing radiation.

The preliminary results allow us to construct inferred spectra of radiation passing through biological tissues. In present work, nanometer-sized volatiles and bacteria in the X-ray radiation field form specific induced emission in the form of classical fluorescence. The considered macroscopic biological structures almost completely transform the directed X-ray radiation into scattered Compton radiation. On the other hand, the obtained laboratory and model data are readily transferable to Astrobiology tasks (Lifshits et al., 2005), and (Horne et al., 2022). In particular, using Fig. 1, we can conclude that in dense gas-dust clouds cosmic rays do not destroy complex molecules and damage the simplest bacteria.

5. Conclusion

The calculations of X-ray and soft gamma radiation transfer through soft tissues, cells and bacteria in space and radiology have been carried out. Consideration has been given to all detailed processes of energy absorption and scattering between quanta in biological tissues are taken into account. The yield spectra of X-ray and γ-ray emission from Soft-Tissue tissues at different geometric sizes were determined. Percentage contribution of each mechanism to the formation of the spectral response of tissues is highlighted. Based on these data, conclusions are made regarding the role of photo absorption and incoherent Compton scattering in the formation of absorbed dose. The calculations showed that at soft tissue sizes larger than 10 mm these two processes compete. The absorbed dose at quantum energies up to 10 keV is formed exclusively due to photo absorption by atoms of biological medium. If the size of soft tissues exceeds 100 mm, we get an exclusive contribution of Compton scattering of X-ray and gamma-quanta on free and weakly bound electrons of atoms and molecules. In other words, initially directed ionizing radiation becomes completely scattered. Moreover, as it moves through soft tissues, the long-wave part of the X-ray spectrum is significantly amplified, reaching 10 keV and being completely absorbed by the substance.

Acknowledgements. The authors are grateful to the administration of Tsafon Medical Center for material assistance. D.D. thanks Prof. Avi Peretz for creating the conditions for this work and Dr. Natalia Volinski for constructive discussion of our work.

Contribution. The authors acknowledge the same contribution to the writing of the article and have no claims against each other.

Reference

Dayal N.C., Wickramasinghe·C. A. Tout·J.C., et al.: 2019, *A&ApSS*, **364**, 205.

Hoyle F., Wickramasinghe N.C.: 1983, *Nature*, **305**, Iss. 5930, 161; DOI: 10.1038/305161a0.

Horne W.H., Volpe R.P., Korza G. et al.: 2022, *Astrobiology*, **22**, Iss. 11, Nov., 1271-1375. https://doi.org/10.1089/ast.2022.0065.

Imserti S., Kyriakou M.A., Bernal M. et al.: 2018, *Medical Physics*, **45**, 772.

Kyriakou I., Sakata D., Tran H. N., Perrot Y., Shin W.-G., Lampe N., et al.: 2022, *Cancers*, **14**, 35.

Lifshits M.A., Chernetskii V.A., Mitrofanov I.G. et al.: 2005, *Astron. J.* (rus.), **82**, 11, 1025–1041.

Stantcheva T., Shematovich V.I., Herbst E.: 2002, *A&A*, **391**, 1069–1080.

Wallis M.K., Wickramasinghe N.C. and Hoyle F.: 1992, *Adv. in Space Res.*, **12**, 282–285.

Weber G. https://web-docs.gsi.de/~stoe_exp/web_programs/x_ray_absorption/index.php