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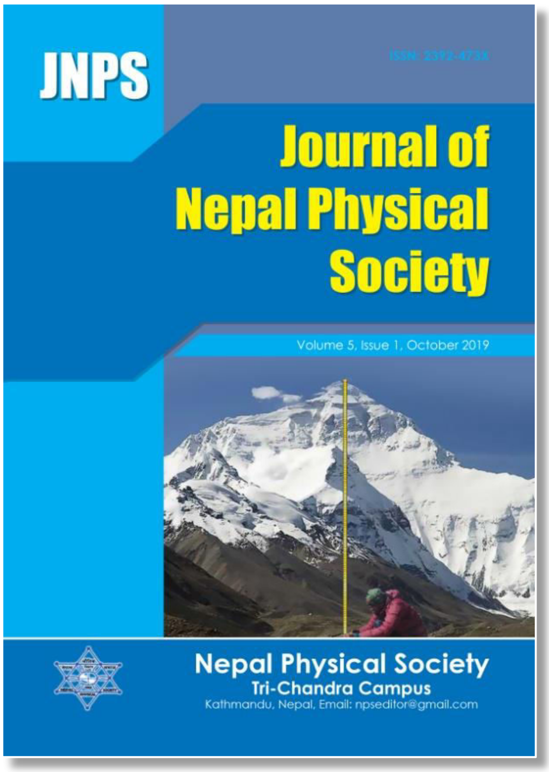

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Research Article

ENERGY LOSS OF PROTON BEAM ON OVARY TUMOR

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ABSTRACT

Proton beam therapy is more effective method than most common radiation (x-rays or photons) therapy and is a new type of irradiation that destroys the tumor or cancer cells in the human body. In the proton therapy, the beam consists of charged nuclei of hydrogen atoms i.e. hydrogen ions or protons. The beam of proton loses the most of its energy to the targeted tissue like ovary tumor cells, with less impact of healthy tissues and organs. This property of a proton beam makes it ideal for clinical applications. When organ safekeeping is our priority then proton beam therapy is the most effective tool to damage nearby affected tissues. For efficient treatment planning in ovary tumor, the maximal energy loss of proton beam in its tissues must be exactly calculated. The method of computer simulation, SRIM is employed for the calculation of energy loss by energized proton beam irradiation on ovary tumor at a depth of 43.3 mm. The stopping power and range data agrees with standard reference data. 65 Mev energy loss is caused by ionization and the energy loss in various layers viz. skin, adipose tissue, soft muscle and ovary are approximately 2.6 MeV, 15 MeV, 7 MeV and 40 MeV respectively, ensuring less injury to healthy cells.

Key words: Proton, Ovary, Tumor, Therapy, Ionization

INTRODUCTION

Radiation is naturally present in our environment and artificially in hospitals interact with human body that may cause harm to the tissue [1]. A beam of heavy charged particles, especially protons and ${}^{6}C_{12}$ ions, have now become instruments of clinical applications in radiotherapy [2]. A branch of radiology, mainly proton beam therapy hire for the treatment of oncological treatment. Proton therapy is an established type of radiation therapy that uses energy from positively charged particles called protons. It is a proven treatment option for a wide range of cancers, and is particularly effective for treating irregularly shaped tumors, hard to reach tumors, tumors near vital organs and critical structures, and localized tumors that have not spread to other area. Protons, on the other hand, are energized to specific velocities. These energies determine how deeply in the body protons will deposit their maximum energy. As the protons move through the body, they slow down, causing increased interaction with orbiting electrons. Maximum interaction with electrons occurs as the protons approach their targeted stopping point. Thus, maximum energy is released within the designated cancer volume. The surrounding healthy cells receive significantly less injury than the cells in the designated volume [3]. Because of ionization of the proton these charged particles lose their energy to target tissue causing damage to the DNA of cells, ultimately killing them or stopping their reproduction. Cancerous cells are particularly susceptible to attacks on DNA because of their high rate of division and their reduced abilities to repair DNA damage. Some cancers with specific defects in DNA repair may be more sensitive to proton radiation [4]. Experiments on animals or humans tissues are rather complicated; we need to create a simple model or theoretical program that could be used to calculate the dose distributions in biological matter [5]. For this purpose, a computer program, SRIM is employed, which is usually used in the calculation of energy loss by nuclear physicist [6].

Ovary

The ovaries are the female pelvic reproductive organs, one of the important parts of the female reproductive system. Each ovary is a solid, ovoid structure about the size and shapes of an almond, about 3.5 cm long, 2 cm wide, and 1 cm thick. The ovaries are located in shallow depressions, called ovarian fosse, one on each side of the uterus, in the lateral walls of the pelvic cavity. They are held loosely in place by peritoneal ligaments.

Stopping Power and Range

Stopping power of a medium is defined as the average unit of energy loss suffered by the charge particles per unit path length in the medium under consideration. The charged particles interact with matter mainly in two ways it is either electronic interaction or nuclear interaction. Electronic interaction is when the projectile particle interacts with the electrons of the atoms in the target medium that leads ionization. And the nuclear interaction causes production of secondary particles or simply the vibration. In both interaction certain amount of energy is lost and causes the particles to slow down.

The energy loss per unit length of the medium ($\frac{dE}{dx}$); energy gradient is known as stopping power of the medium. It can be calculated by using Bethe Bloch formula;

$$-\frac{dE}{dx} = \left(\frac{e^2}{4\pi\epsilon_o}\right)^2 \frac{4\pi N_A Z\rho}{mc^2\beta^2 A}\left[ln\left(\frac{2mc^2\beta^2}{I}\right) - ln(1-\beta^2) - \beta^2\right] \cdots\cdots (1)$$

Here, the minus sign signifies the energy loss, $\boldsymbol{\varepsilon_0}$ is the vacuum permittivity is electron charge, m is rest mass, N_A is Avogadro number, Z is atomic number, A is atomic mass number, ρ is density of the medium, I is excitation potential and $\beta = \frac{v}{c}$, v being velocity of particle, c the velocity of light.

The distance "x" is not always expressed in meters, but often in units of mass per square meter. The distance travelled by the charged particle before it loses its all energy is known as its range. As the energy loss is a statistical phenomenon there are certain variations in the range which we call the range straggling. Range can be determined from the stopping power provided that we know the form of S from zero energy up to the initial energy of the particles in the incident beam [6].

$$R(E) = \int_0^E \left(\frac{dE}{dx}\right)^{-1} dE' \approx \sum_0^E \left(\frac{dE'}{dx}\right)^{-1} \Delta E \cdots\cdots (2)$$

Here, E is the ion's initial kinetic energy and the summation denotes that the continuous transport is approximated by calculations of discrete steps.

MATERIAL AND METHOD

Computer simulation software SRIM 2013 is used to calculate the energy required along with the stopping and range table for water sample. We take water sample because density of water is nearly equal to human body muscles. Simulation was run for 1 hundred thousand protons. SRIM is adopted when woman abdominal is exposed to proton beam targeting ovarian cancerous cells 43.3 mm from skin. And then a multilayer target was built on the TRIM section. Simulation was run for 100000 protons. From the data obtained from TRIM calculation, various aspects of energy loss such as energy loss in ionization and phonon and energy loss in different layers and final distribution of protons in the target were calculated. After a simulation data various graphs are plotted by using MATLAB.

Table 1: Layer properties.

Layer	Layer name	Layer width (mm)	Layer density (g/cm^3)
1	skin	2.2	1.09
2	adipose	13.4	0.92
3	skeletal muscles	4.8	1.07
4	ovary	22.5	1.05

RESULT AND DISCUSSION

The energy as calculated from stopping power and range table was found to be 65 MeV. We also compared the energy versus range data from SRIM with that from PSTAR for water.

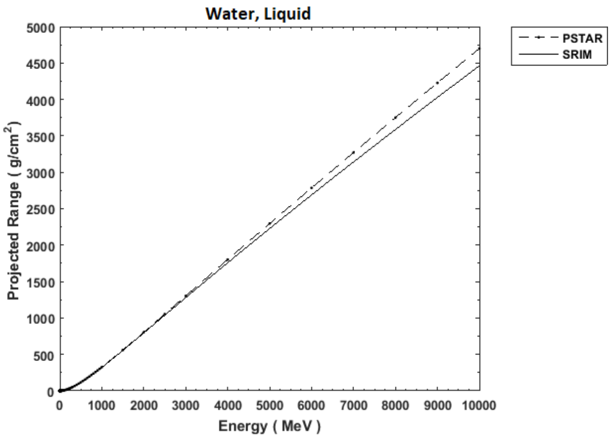

Fig.1: *Energy Vs Projected Range.*

The range versus energy plot is consistent with the standard reference data obtained from PSTAR. For depth of 43.3 mm the appropriate energy was found to be 65 MeV.

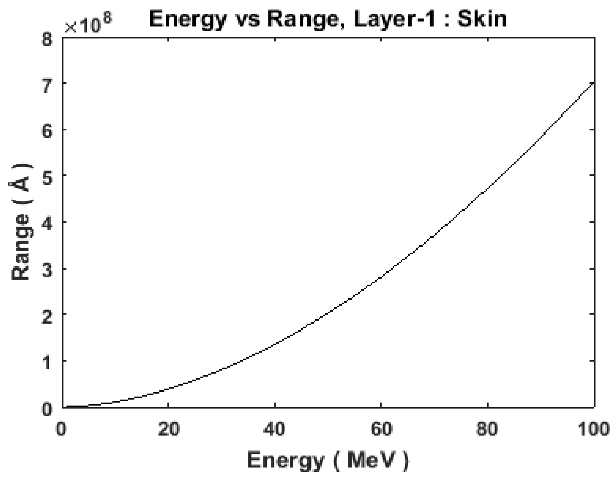

Fig.2: *Energy Vs Range.*

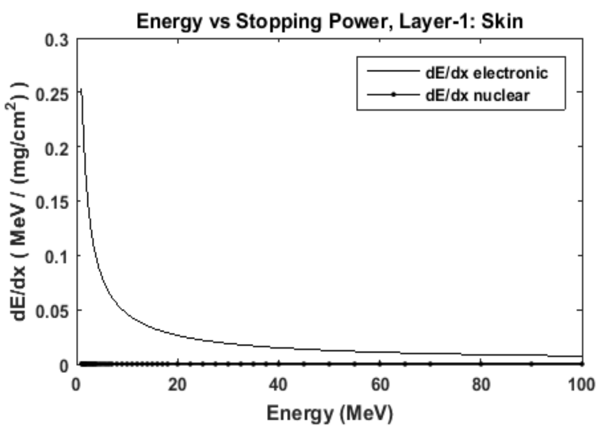

Fig.3: *Energy Vs Stopping Power.*

Graphs of stopping power versus energy reveal that the nuclear interaction have insignificant contribution on total stopping power of the medium, it is in fact almost 1/10000 times less than that due to electronic interaction. The major loss of energy is caused by electronic interaction of proton i.e. ionization. This is due to the smaller size of proton than the target atoms and a positive charge on it which attracts the electron out of its orbit. The stopping power seems to decrease as energy increases since high energy particle have high velocity which provide less time for interaction. The range versus energy graph is similar for various layers which show that the range of proton in biological target is a function of target density.

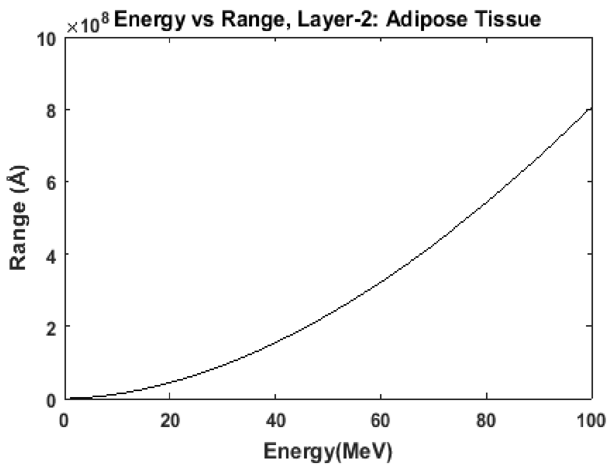

Fig.4: *Energy Vs Range.*

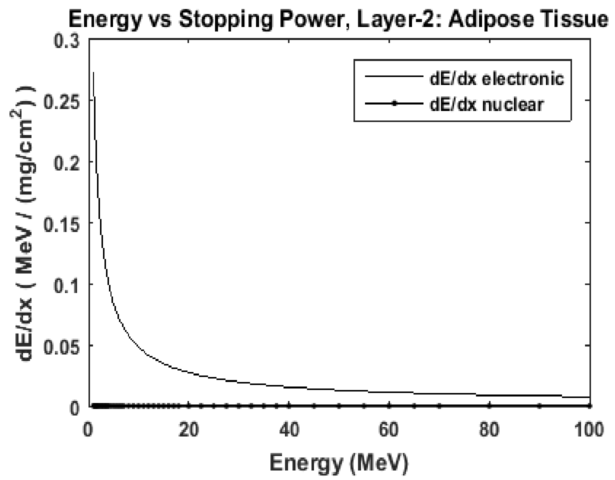

Fig.5: *Energy Vs Stopping Power.*

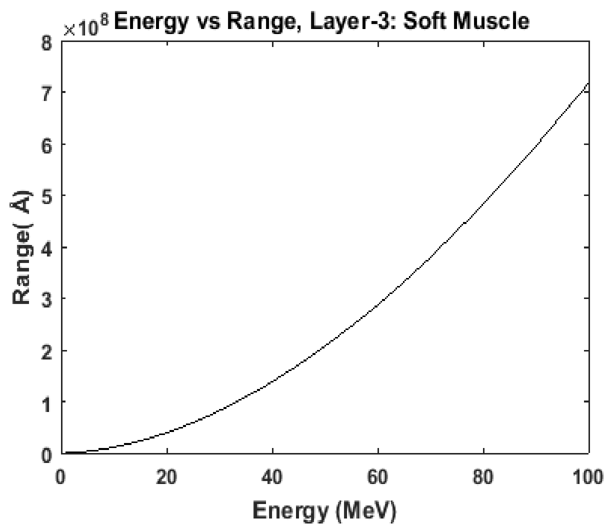

Fig. 6: *Energy Vs Range.*

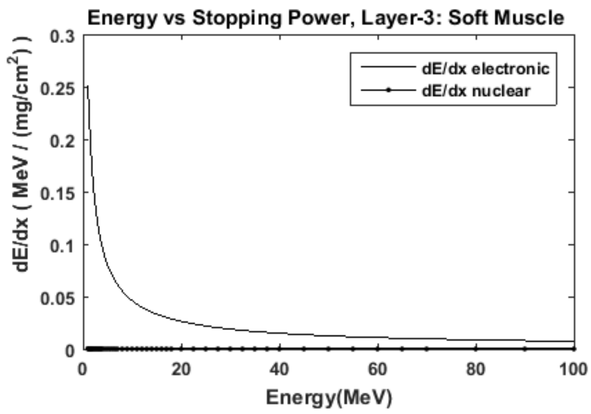

Fig.7: *Energy Vs Stopping Power.*

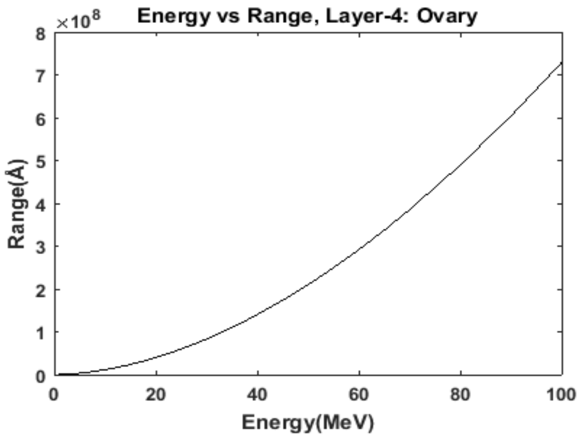

Fig.8: *Energy Vs Range.*

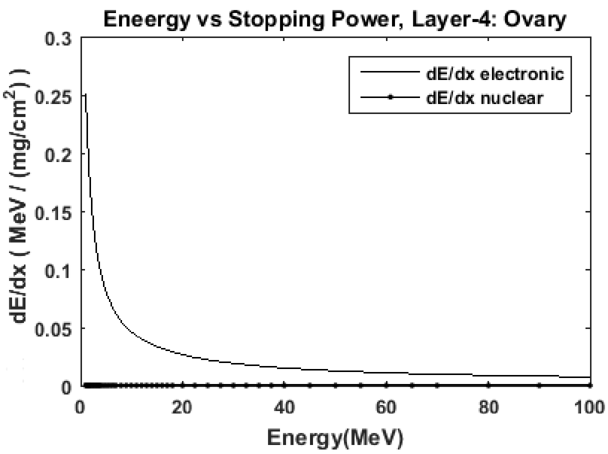

Fig.9: *Energy Vs Stopping Power.*

Energy loss due to Ionization

This plot contains the energy given up to the target electrons. The data relating to 'Ions' the direct energy transferred from the protons to target electrons. The data relating to 'Recoils' is the energy transferred from recoiling target atoms to the target electrons. This is also known as Bragg peak. In figure it is seen at 35.5mm which is maximum energy loss. Area under the curve between any two points on x-axis gives the energy loss in that region.

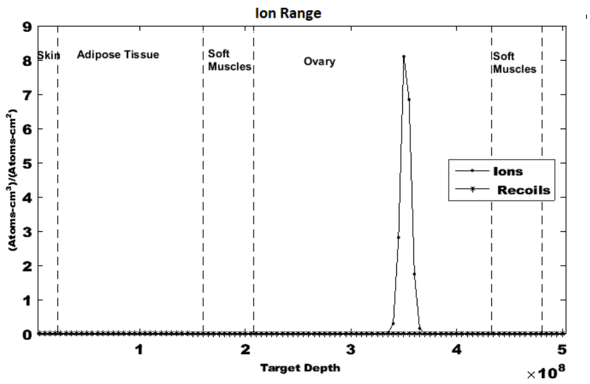

Fig.10: *Target Depth Vs Energy Loss.*

Table 2: Energy loss with depth.

Depth (mm)	Energy Loss (MeV)
Skin (0-2.2)	2.500258
Adipose tissue (2.3-16.0)	14.9027
Skeletal Muscles Equivalent (16.0-20.8)	7.38011
Ovary (20.8- 43.3)	40.190819

Energy Loss due to Phonon

Phonons are created on nuclear interaction. The energy loss to target phonons consists of the direct creation of phonons by the protons and the additional energy loss by target recoil atoms to phonons. The plot shows the energy loss on phonon by ions and recoils.

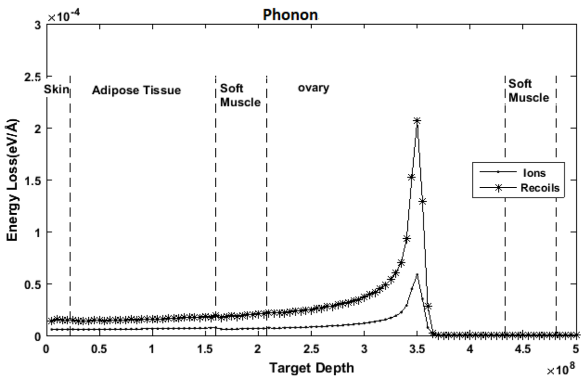

Fig.11: *Energy Loss vs. Target Depth.*

The energy loss due to the phonon is negligible in comparison to energy loss due to ionization. The total energy loss due to the phonon is 3.54 KeV by ions and10.159 KeV due to the recoils. It infers that production of phonon is mainly due to the recoil atoms rather than the proton itself. As seen from graph maximum energy is lost in ovary part. The energy deposition peak by phonon occurs at 35.5 mm comparatively, energy loss due to ionization is inundating than energy loss due to phonon.

Final Distribution of Proton

This graph represents the final distribution of protons on the target. Although the unit in the ordinate appears weird but when we multiply it by implantation dose we get concentration versus depth graph.

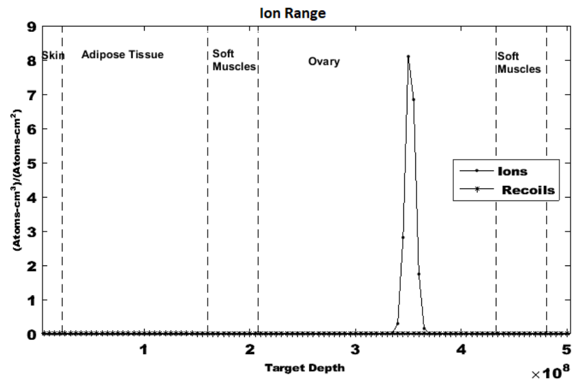

Fig.12: *Ion Range Vs Target Depth.*

Proton average range = 349279000 Å

Straggling = 4851980 Å

The average range is taken over the ensemble of protons and the straggling is because the energy loss is a statistical phenomenon. Comparing the average range with projected range from SRIM the error in calculation is 0.63%.

Lateral Distribution of Protons

This plot summarizes the lateral and radial spread of ions within the target window. The lateral projected range is defined as the average of the absolute values of the projected displacements from the x-axis.

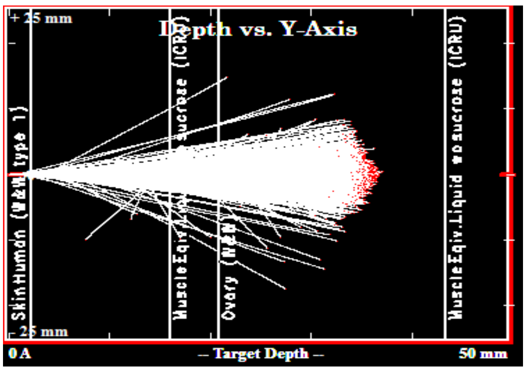

Fig.13: *Target Window.*

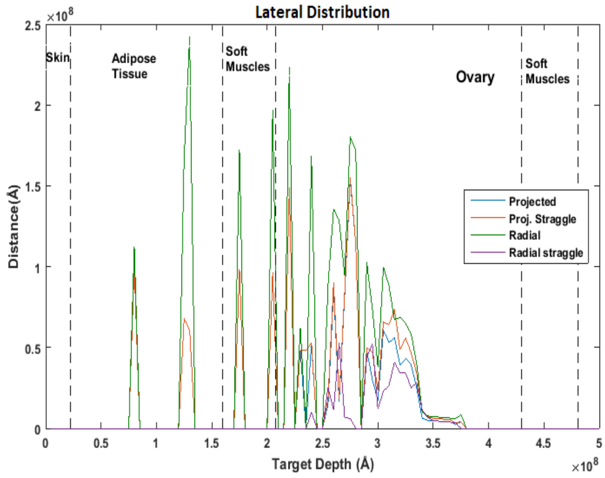

Fig.14: *Lateral Range Distribution.*

Whereas, the radial range is the mean radial displacements range from the x-axis assuming cylindrical symmetry. The lateral and radial ranges and corresponding straggling are

Proton lateral range = 463640 Å

Straggling = 6654350 Å

Proton radial range = 7284350 Å

Straggling = 6081750 Å

CONCLUSION

We successfully determined the energy in biological medium by using stopping and range table for liquid water. This shows the trustworthy of SRIM software for this kind of research and for treatment planning.

TRIM data shows that 99.54% of the energy of proton is lost in the process of ionization by ion and 0.188% in ionization by recoils and only 0.0054% energy is lost by production of phonon by ion and 0.0166% by recoils. 65 MeV of the energy deposited on various layers viz. skin, adipose tissue, smooth muscles and ovary are approximately 3.84%, 22.93%, 11.36%, and 61.86% respectively and 0.01% is the calculation error. This concludes that proton beam therapy can damage the cancerous cell effectively and does not harm the other healthy tissue as well. Therefore it is clear that side effect after the proton beam therapy is less than the other radiological treatment.

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REFERENCES

[1] Ghossain, M. O. El. Calculations of stopping power, and range of ions radiation (alpha particles) interaction with different materials and human body parts. *International Journal of Physics*, **5**(3), 92-98 (2017).

[2] Khoroshkov, V. S. Radiation beam therapy evolution: from x-rays to hadrons. *Physics of Atomic Nuclei*, **69**, 1724–1742 (2006).

[3] Debus, Jurgen Proton Therapy and Carbon Ion Therapy High Precision Cancer Treatment Department of Radiation Oncology/Heidelberg Ion Beam Therapy Center.

[4] Liu, Q.; et al. Lung cancer cell line screen links fanconi anemia/BRCA pathway defects to increased relative biological effectiveness of proton radiation. International Journal of Radiation Oncology, Biology, Physics. **91** (5), 1081-1089 (2015).

[5] Weronika M.; et al. Application of instruments of nuclear physics to the calculation of theoretical dose distribution in various organs of the human body for beams used in hadron therapy, *Nukleonika*, **61** (1), 19-22. Doi: 10.1515/nuka-2016-0008 (2016).

[6] Wayne, D. and Rui, Z. The physics of proton therapy. *Physics in Medicine and Biology*, **60**,8. Doi: 10.1088/0031-9155/60/8/R155 (2015).