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Investigations of Residual Nuclei on Lung Cancer Treatment By Using FLUKA Monte Carlo Code

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Abstract: *In addition to developments in the field of nuclear medicine and studies in the field of nuclear physics, this work is important for the research of many scientists working in the field of hadron therapy around the world.*
Additionally, this study will provide scientists interested in particle physics with a different perspective in their research. Particle physics is utilized in expressing a nuclear study. Studies have shown that particle physics aids research in the field of nuclear medicine. This study has been prepared within the framework of existing literature and research, and it will help to make the name of hadron therapy, a type of radiotherapy, more well-known in the future.
In this study, a sample design for an adult male was created using the Monte Carlo simulation and the Fluka Program through a server system. For the design, a tumor area with a radius of 1 cm was defined on the lung organ of the adult male. The inputs for the design were created using Fluka manual source information. In the simulation study, for the sample design on the lung organ, the target (tumor) area identified was irradiated with carbon-12 in the simulation.The target area was irradiated with a C12 beam at 200 MeV for 1 hour. After the expected cooling periods, the residual nuclei formed were examined.The selected cooling periods were determined as 10 seconds, 3600 seconds, 7200 seconds, 86400 seconds and 259200 seconds respectively..For these selected durations, the activity (Bq/g) values at the tumor target point, depending on the Z/A value of the residual nuclei, were calculated in the simulation environment, and graphs showing the nuclear changes over time were drawn. Additionally, the Bragg peak curve was obtained by calculating the energy deposition density according to depth on the X-Y-Z Cartesian coordinate system.
***Keywords**: Monte Carlo, Fluka,Hadron Theraphy,Lung Cancer*

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I. INTRODUCTION

The aim of this study is to provide a new perspective on particle physics, nuclear physics, and developments in the field of nuclear medicine worldwide. Particle accelerators are extremely important for contributing to studies in nuclear physics and particle physics. Therefore, studies conducted in particle physics will also significantly contribute to the field of nuclear medicine

In addition to developments in the field of nuclear medicine and studies in the field of nuclear physics, this work is important for the research of many scientists working in the field of hadron therapy around the world. Additionally, this study will provide scientists interested in particle physics with a different perspective in their research. Particle physics is utilized in expressing a nuclear study. Studies have shown that particle physics aids research in the field of nuclear medicine. This study has been prepared within the framework of existing literature and research, and it will help to make the name of hadron therapy, a type of radiotherapy, more well-known in the future.

In addition to radiation therapies such as X-rays and gamma rays, hadron therapy also has its advantages. Proton particles are generally preferred in hadron therapy. However, in many European countries, hadron therapy is now being applied using carbon beams as well[4,16].

Due to the sharp increase in Relative Biological Effectiveness (RBE), it is said that carbon ions are more effective than protons in achieving the desired outcome in the radioactive treatment of tumor areas [8].

Technological advancements today have enabled the creation of new treatment types as alternatives to existing treatment preferences. Chemotherapy, radiotherapy, and surgical treatment methods, along with vaccines, biological and hormonal therapies, and gene therapies, are now more widely used. For an individual seeking a cure for cancer and wanting to learn more about this topic, there are endless resources consisting of various treatment methods, different approaches, and scientific publications.

It is believed that experimental studies from these works may cause harmful effects. To keep these effects to a minimum, it is necessary to write the conditions and geometry data required for the experiment into Monte Carlo simulation programs before the experiment, and then prepare a preparatory study to determine the experiment results. The Monte Carlo Simulation technique uses programs such as PHITS, MCNP, FLUKA, GEANT4, and MARS. These programs are similar to each other in terms of their working methods.

The data on the interaction probabilities (cross sections) between different radiations of elements are defined in programs in the form of ready-made libraries (such as ENDIF, JNDL, ENEA, CLES, etc.). To run these programs, important input commands are required. In another sub-program within the main program, parameters such as the radiation to be used (gamma, neutron, X-ray, etc.), the experimental geometry, and the material to be used in the interaction are entered. After the simulation is created, the results are read in output files, and graphs are generated from the results to calculate error margins.

The Fluka program, a Monte Carlo program, serves as a resource for calculating the interactions particles with matter. This program operates on the Linux operating system and its programming language is Fortran. It has various applications, including the design of detectors, neutron physics calculations, and radiotherapy.

This study offers an alternative solution for patients battling cancer. Unlike radiotherapy, hadron therapy treats malignant cancer cells with minimal damage to existing healthy tissue and cells. Hadron therapy is applied in the form of proton or carbon therapy

The FLUKA program, which operates on a FORTRAN infrastructure, was developed in 1954. The development of the FLUKA program began in 1962 with J. Ranft and H. Geibel using Monte Carlo simulation for high-energy protons. The name FLUKA comes from a thermodynamic-based study in 1970 (FLUktuierendeKAskade). From the early 1970s, J. Routti and P. Aarnio, along with G.R. Stevenson and A. Fasso from CERN, contributed to the program's development. The modern code systems of the program can be listed as follows: GEANT-FLUKA interface (1993), MCNPX (high-energy hadronic FLUKA generator - 1990), FLUGG (GEANT4 interface - 1994), INFN project (2001), INFN-CERN project (2003). The FLUKA program, which operates on a FORTRAN infrastructure, is effectively used in the design of shielding for electron and proton accelerator systems, the interactions and transitions of particles with matter, detector design, radiotherapy, neutron physics, dosimetry, and space physics research[14,15].

Research conducted in socioeconomically disadvantaged and undernourished low-income and low-education environments highlights the protective effects of vaccines. However, studies conducted in societies above a certain level of education and income show that such vaccines are not as effective as stated [9].

Lung cancer ranks first among cancer-related deaths. Radiotherapy is widely used to treat cancer patients. Proton therapy is a highly suitable form of radiation treatment for tumors around critical tissues such as the lungs due to the unique properties of protons.

According to global data records from 2018, lung and breast cancer are the most common types of cancer. In 2018, a total of 210,537 new cases and 116,710 deaths were reported for all cancers in Turkey. Of these new cases, 34,703 (16.5%) were reported as lung cancer [17].

As of 2024, approximately 125,070 lung cancer patients have died. This represents about 20.4% of all cancer patients. Approximately 234,580 new cancer cases have been observed. The proportion of all new cancer cases is 11.7%.

When looking at the new case and death rates per 100,000 people, the rate of new lung and bronchus cancer cases per year is 49.0 per 100,000 men and women, while the death rate is 32.4 per 100,000 men and women per year. These rates are age-adjusted and based on cases from 2017-2021 and deaths from 2018-2022[17].

Hadron therapy is a radiation treatment method that uses particles interacting with nuclear forces (strong force). These particles include protons, neutrons and various ions (such as alpha particles, Ne, C, etc.). The difference between hadron therapy and conventional radiation therapy is that it uses heavy particles as projectiles to bombard cancerous cells. In radiation therapy, photons (known as light) are used. Photons are massless particles that are the force carriers of electromagnetic interactions. However, the 'hadrons' used in hadron therapy are, as the name suggests, 'heavy' particles. For example, a proton has a mass of 1 billion eV (2000 times the mass of an electron). Using heavy particles has several advantages: protons can distribute the radiation dose effectively and focus on the desired area; neutrons are excellent tumor killers.

In hadron therapy, particles such as helium, neutrons, protons, and ions (lithium, carbon, oxygen, silicon, etc.) are used. The most important advantage of particle therapy in hadron therapy is minimizing damage to critical areas[5].

In some treatments using photons, the target dose cannot be delivered to the cancerous part due to limited doses for critical organs. In particle radiotherapy, however, more appropriate doses can be administered. In particle therapy, higher doses can be delivered to the tumor [1,2,3,6,7,10].

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In recent years, the popularity of Monte Carlo (MC) techniques in the field of health physics has rapidly increased, especially for proton therapy. MC simulations are important tools in the design and commissioning of clinical facilities, providing detailed solutions in beamline and progress, and can be preferred to simulate the entire Proton Therapy System.

MC uses fundamental physics principles to adjust the probability distributions of individual interactions of photons and particles. As the number of simulated particles increases, the accuracy of predicting their distributions improves, but the computation time extends significantly. Dose distribution is calculated by the accumulation of ionizing events that cause energy deposition in the medium. Despite uncertainties during computation, MC is the most accurate method for calculating dose distribution in a patient. Sample plans with MC simulation have shown improvements in dose calculation accuracy, especially at the interfaces of heterogeneous tissues and in the lungs where particle disequilibrium may occur under certain conditions [11].
Additionally, beam data simulated with MC can be used as input data for clinical commercial treatment planning systems.

II. RESULTS

In this study, a sample design was created for an adult male individual using the Monte Carlo simulation and the Fluka Program with a server system. For the design, a tumor region with a radius of 1 cm was defined on the lung organ of an adult male individual as the target. The inputs for the design were created using Fluka manual source information. For the sample design in the simulation study, the target (tumor) region identified on the lung organ was irradiated with carbon-12 in the simulation environment. The target area was irradiated with a C12 beam at 200 MeV for 1 hour. After the expected cooling periods, the residual nuclei formed were examined. The selected cooling periods were determined as 10 seconds, 3600 seconds, 7200 seconds, 86400 seconds and 259200 seconds respectivelyFor these selected durations, the activity (Bq/g) values of residual nuclei in the tumor target point were calculated in the simulation environment based on the Z/A ratio and graphs showing the changes in nuclei over time were plotted. Additionally, the Bragg peak curve was obtained by calculating the energy deposition density according to depth on the X-Y-Z Cartesian coordinate system.

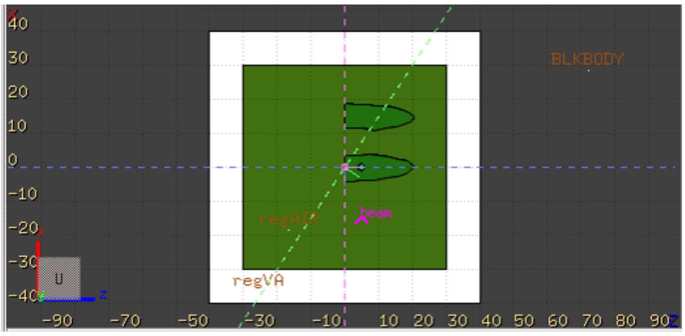

Fig. 1. Geometry of the lung tumor region

In this paper,for Fig.1 shows the geometry of the lung cancer tumor target region for an adult man.By sending a C12 atom to the target in this region,the target was irradiated for different times and at different energy values.Then ,in order to see results of the brag effect on the tumor target for different energy values,Bragg peak curves were drawn according to the MeV energy levels per particle.

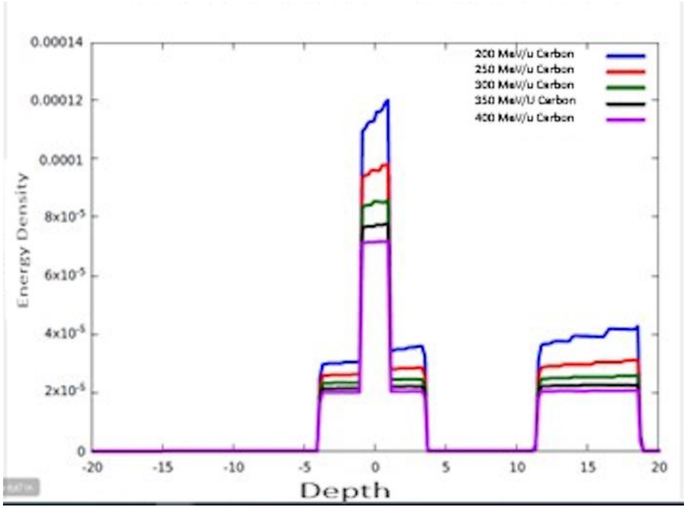

Fig. 2. Bragg peak curve formed by irradiating the lung tumor target region with C12 at different energy levels.

As can be easily seen from Fig.2 that the Bragg peak curve formed by irradiating the lung target region with C12 at different energy levels(200 MeV/u,250 MeV/u,300 MeV/u,350 MeV/u,400 MeV/u)
Additionally,residual nuclei formed in the tumor target area were investigated.For this calculation,the target point was irradiated by sending C12 to the tumor target for different cooling periodsin the simulation environment and graphs of the results were drawn
In this paper ,In order to last 5 figures from Fig.3 to Fig.7,those are shows residual nuclei forms. The target area was irradiated with a C12 beam at 200 MeV for 1 hour. After the expected cooling periods, the residual nuclei formed were examined. The selected cooling periods were determined as 10 seconds, 3600 seconds, 7200 seconds, 86400 seconds and 259200 seconds in tumor respectively We wanted to see for these selected durations, the activity (Bq/g) values of residual nuclei in the tumor target point were calculated in the simulation environment based on the Z/A ratio and graphs showing the changes in nuclei over time were plotted.

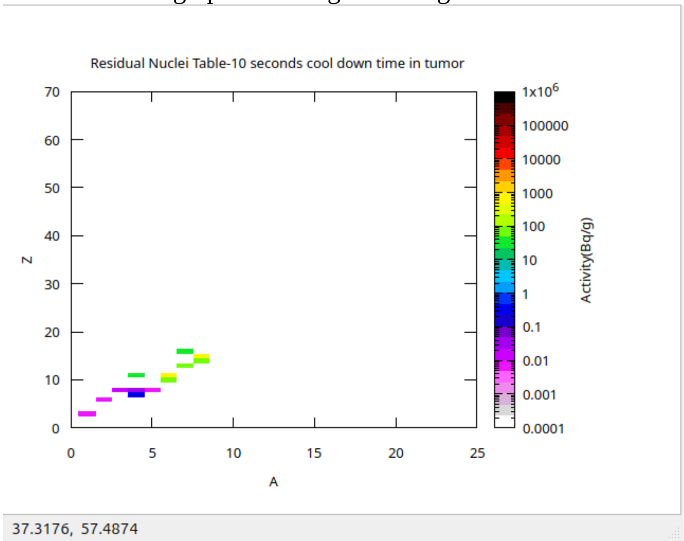

Fig. 3. Residual nuclei formed by cooling period for 10 secondsın tumor. In this paper for figure, the activity of the residual nuclei formed as a result of cooling period of the tumor target for 10 seconds was calculated according to Z/A value.

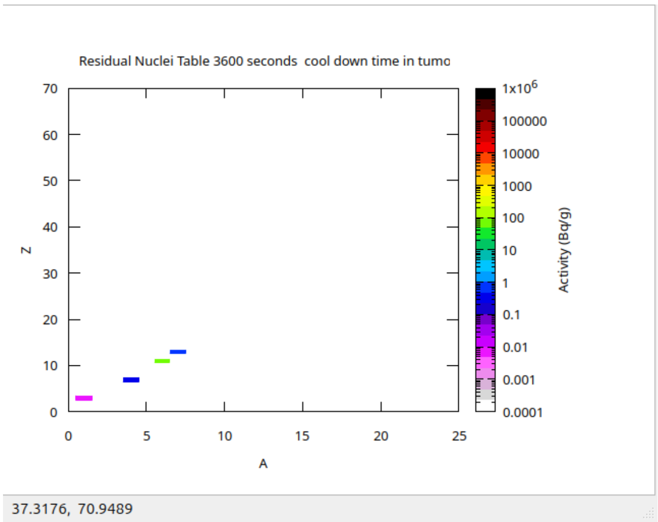

Fig. 4.Residual nuclei formed by cooling period for 3600 secondsın tumor. In this paper for figure, the activity of the residual nuclei formed as a result of cooling period of the tumor target for 3600 seconds was calculated according to Z/A value.

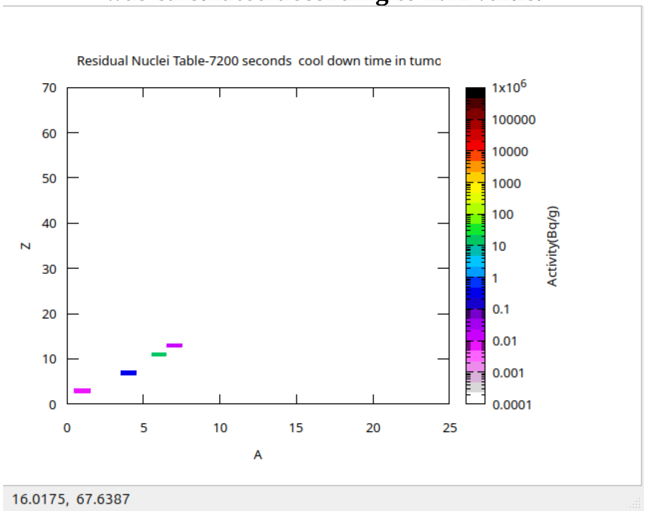

Fig.5.Residual nuclei formed by cooling period for 7200 secondsın tumor. In this paper for figure, the activity of the residual nuclei formed as a result of cooling period of the tumor target for 7200 seconds was calculated according to Z/A value.

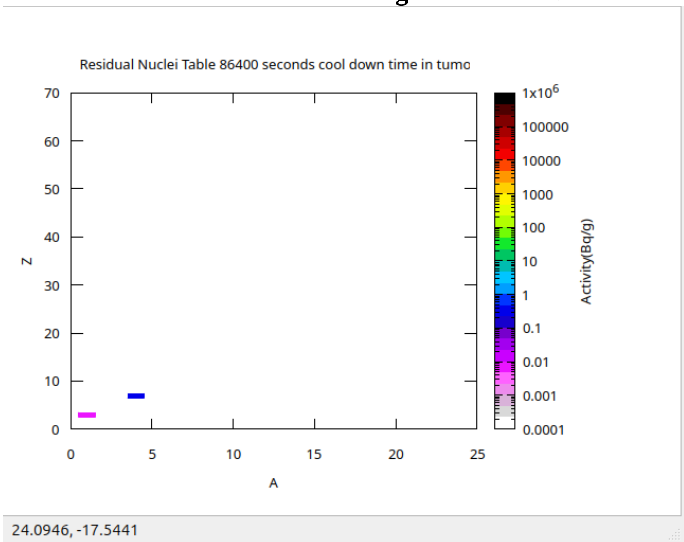

Fig.6.Residual nuclei formed by cooling period for 86400 secondsın tumor. In this paper for figure, the activity of the residual nuclei formed as a result of cooling period of the tumor target for 86400 seconds was calculated according to Z/A value.

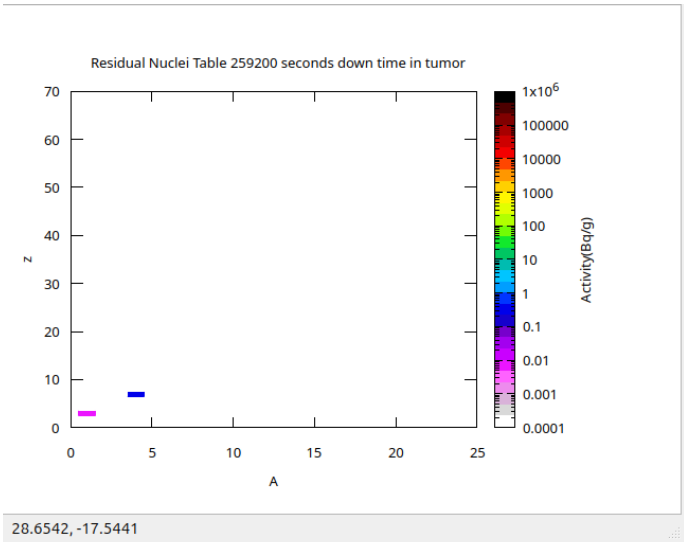

Fig.7.Residual nuclei formed by cooling period for 259200 secondsın tumor. In this paper for figure, the activity of the residual nuclei formed as a result of cooling period of the tumor target for 259200 seconds was calculated according to Z/A value.

III. CONCLUDING REMARKS

As a result, In the lung organ of an adult male individual, a tumor target with a radius of 1 cm was designed in the simulation environment, and this tumor target was irradiated with a C12 beam for an hour. Based on the decay in that region, an activity chart of the nuclei was created. In the graphs showing the activity of residual nuclei, as the cooling time increases, we observe fewer different colored curves according to the Z and A values. These colors indicate that, as the cooling time increases, fewer residual nuclei may be present in the target area. The target area was irradiated with a C12 beam at 200 MeV for 1 hour. After the expected cooling periods, the residual nuclei formed were examined. The selected cooling periods were determined as 10 seconds, 3600 seconds, 7200 seconds, 86400 seconds and 259200 seconds in tumor respectively.

Additionally, the target area was irradiated with a C12 beam for 1 hour, and this irradiation was carried out at different energy levels.

The energy density in the target area was calculated according to depth at different energy levels.Energy rangesfrom 200 MeV/u to 400 MeV/u was preferred for the calculation.According to this calculation, different Bragg peak curves were obtained at the same depth. It was observed that as the energy value increased, the effect of the Bragg peak curve in the target area was more intense.

Based on the calculations from this study, it is thought that it will contribute to scientists working in the fields of nuclear physics and nuclear medicine, particularly those involved in hadron therapy, in the future.

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