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Design of cylinderical discharge type fusion neutron beam for medical application

医療応用を目的とした円筒放電型核融合中性子ビーム装置の検討

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Charged particles shuttle between tube shaped cathode and two axially-aligned anodes in cylinderical discharge type fusion neutron beam source. Mainly on the cathode of this source, neutrons are generated by nuclear fusion reaction with glow discharge. Neutron beam which has arbitrary energy spectrum can be obtained by appropriate placing reflector and moderator around the source. We evaluated the neutron beam equipment designed to a new minimally-invasive cancer therapy method by using of BNCT (Boron Neutron Cancer Therapy) in low dose rate fractionated repetitive irradiation. By MCNP5 (Monte Carlo Neutron Particle code version 5) simulation, we can hope enough curative effect under the order of 10^6 neutrons/cm^{2}s epithermal neutrons. We also evaluated discharge equipment, composition of reflector in addition moderator and geometric condition under that situation.

1. Introduction

The cylindrical discharge type fusion neutron beam source equipment developed by authors [1, 2] is enough small, light-weight, and low-cost to install it to small-scale hospital. And also, this equipment can irradiate to free direction with boarding on robot arm. In this research, we aimed to reveal the possibility of cancer therapy in low dose rate fractionated repetitive irradiation with hospital admission. To evaluate the possibility of cancer therapy in low dose rate fractionated repetitive irradiation, we assumed BNCT with arbitrarily placed affected part and analyzed neutron transportation in each energy spectra.

At present, fission reactor BNCT medical treatment is promoted by only KUR (Kyoto University Reactor) [3]. This fact indicates not to be sufficient to treat all cancer patients in Japan. In addition, accelerator BNCT whose clinical application research is promoted now, is the project for some large institute or university. This project doesn’t target to efficient number of patients.

To tackle now society that one of third Japanese people affect with various type cancers, we need to target for every general hospital with inpatient faculty of normal cancer therapy.

Also, we are planning to broaden out the range of application for cancer therapy by combining to chemotherapy, surgical operation or other type of radiotherapy in contrast with stand-alone treatment as assumed in fission reactor and accelerator BNCT. To realize that, it is necessary to set up not only therapy plan but also parameters of neutron beam source equipment as follows; shape of neutron beam, energy spectra of neutrons (includes composition of reflector in addition moderator and geometric condition), irradiation field and plasma characteristic. In these points, we aimed to optimize in all aspects.

2. Method

We used MCNP5 for neutron transportation simulation. Plasma is generated in the vacuum vessel (10 cm diameter, 40 cm length) with glow discharge in the simulation. Titanium vapor-deposited cathode (4 cm diameter, 10 cm length) as neutron source is placed the center of vacuum vessel. Reflector A (20 cm diameter, 45 cm length, in other words 5 cm thickness) is placed on the outer and back region of vacuum vessel. Reflector B (70 cm diameter, 70 cm length, in other words 25 cm thickness) is placed on the outer and back region of reflector A. Arbitral moderator is placed on the exit of vacuum vessel. Under various conditions, shape of neutron beams and energy spectra are calculated.

Human head phantom is placed nearby exit of neutron beam. Curative properties by neutron beam are calculated. This phantom includes 1 cm thickness skin, 1cm thickness skull, 16 cm diameter brain and cancer affected part with arbitral position in the brain. Abundance ratio of boron-10 between affected part and healthy brain is 65 ppm: 18 ppm. Based on the result of calculation, we evaluated irradiation method which reduces exposure effect and keeps dose to affected part.

3. Results and discussion

Calculation result represents that D-D reaction neutrons (2.45 MeV) are adequately beam-shaped and shielded by use of heavy water as reflector A and polyethylene as reflector B. And if 1×10^7 neutrons/s generate on the cathode, 9.76×10^3 neutrons/cm^{2}s flux of neutron beam is obtained on the exit of vacuum vessel. If D-T reaction is changed to D-T reaction, we will be able to obtain over hundredfold neutron generation, but more shielding will be needed because D-T reaction neutrons have higher energy (14 MeV) than D-D.

We have already accomplished neutron generation as 2.5×10^6 neutrons/s in D-D reaction under follow conditions; time of titanium vapor-deposition: 120 min, voltage: 45 kV, current: 10 mA, gas pressure: 4Pa. We expect to obtain enough intensity neutron beam by changing to D-T reaction, optimization of equipment shape and adjustment of several parameters.

We evaluated neutron absorption in each sections of phantom with every energy spectrum on neutron source. The results indicates that over 1 MeV neutrons pass through affected part, under 1 keV neutrons don't reach to affected part and figure 1 shows that around 100 keV neutrons can cause objective thermal neutron capture by boron-10 in affected part. This result changes depend on the depth of affected part [4].

In the BNCT, required thermal neutron fluence is 5×10^{13} neutrons/cm^2 to cancer cell. If we suppose to achieve that fluence by 10 direction crossfire irradiation, 120 times fractionation and 3 months hospitalization, 5×10^6 neutrons/cm^{2}s flux of neutron beam makes it possible. In this situation, maximum effective dose that epithermal neutron gives to healthy brain cells is under 0.5 micro Sv/s in ICRP 2007 equivalent.

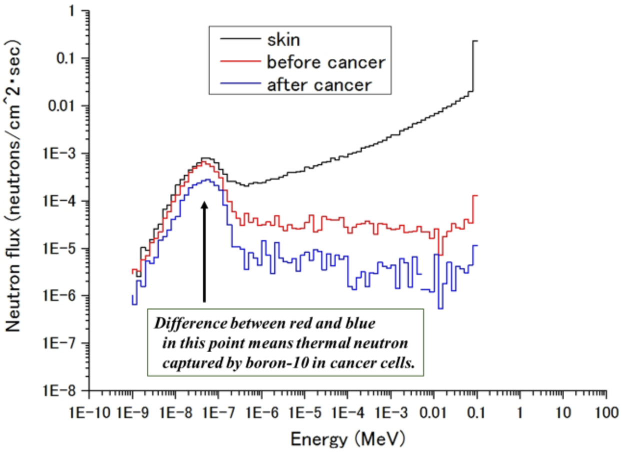

Fig. 1. Energy spectra analysis in 100 kV irradiation

According to curative curve on linear-quadratic model [5], damage to normal cell recuperate 6 hours approximately and damage to cancer cells accumulate [6]. BNCT focuses exposure to affected part, but normal cells' exposure in the pathway to affected part is not ignorable. While from the results, it become clear that we can keep normal cells' exposure to a recoverable level.

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