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科研費
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科学研究費助成事業　　研究成果報告書

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研究課題名（和文）A direct range visualization method by C-10 3-gamma Compton-PETfor C-ion therapy

研究課題名（英文）A direct range visualization method by C-10 3-gamma Compton-PETfor C-ion therapy

研究代表者
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交付決定額（研究期間全体）：（直接経費）　　3,700,000円

研究成果の概要（和文）：照射技術の進化が目覚しい粒子線がん治療において、患者体内飛程をその場で検証する技術は、重要課題の一つである。本研究では、我々のグループにて二次ビームとして試行実績のある10C が、陽電子放出以外に単一のガンマ線を同時に出すことに着眼して、PET とCompton カメラの方法を組み合わせた新しい核種分布画像化法を提案した。本研究では、シミュレーションによるフィージビリティ検証後、小規模な装置試作を行って、HIMAC 二次ビームポートにて実証実験を行った。

研究成果の学術的意義や社会的意義
The major advantage of heavy ion therapy is a good dose localization and it is desirable to reduce range ambiguities in treatment planning for making full use of the major advantage. We developed a range verification system using C-10 beams to verify the ranges in patients directly.

研究成果の概要（英文）：In heavy ion therapy, where the cancer treatment using heavy ions has significant advantages, verification of the ion rage inside the patient’s body is an important issue. In this study, we focused on detection of C-10 nuclide, which emits a positron and a single gamma ray at the same time, by combining the PET and Compton camera Methods. First the feasibility of proposed method was checked by performing Monte Carlo simulation and then we made a small-scale prototype of the device (whole-gamma imaging (WGI)) and conducted a demonstration experiment at the HIMAC secondary beam port.

研究分野：医歯薬学

キーワード：粒子線治療学　Compton PET　triple gamma-ray imaging　visualization of C-10

１．研究開始当初の背景

Heavy ion therapy is an effective method for cancer treatment without any surgery because of maximum dose localizing in a tumor even though for deep seated tumors inside the patients' body. The major advantage of heavy ion therapy is this maximum dose (Bragg peak) but the position of the dose peak should be matched the tumor position as planned. The method of confirming the position of the dose peak has not been implemented into practical use yet [Nucl. Instrum. Methods Phys. Res. Ap284, 2004]. If the Bragg peak position shifts due to the difference in the internal condition between the time of CT imaging and the time of treatment, the treatment may not be successful and strong side effects may occur. Therefore, a technique for imaging the position of the beam stop (Bragg peak) in the body has been eagerly desired. So far, attempts have been made to image positron emission nuclides generated by spallation reaction by positron emission tomography (PET), but the dose peak position and the peak position of the PET image do not match in principle. Therefore, clinical trials are limited to comparison of changes for each irradiation fraction (for example in national Cancer Center Hospital East) and comparison with the distribution of positron-emitting nuclides predicted by Monte Carlo simulation [Radiothe. Oncol. P218, 2013] has been done. In addition, the amount of positron emitting nuclides produced is as low as 1/100 to 1/1000 of the dose in a normal PET examination, and there is also attenuation due to biological washout. Therefore, in order to minimize the effect of physical and biological half-life, irradiation research and development of an in-beam PET dedicated device for on-site PET measurement is also in progress. The development of gamma camera [Phys. Med. Biol. P279, 1996, Med. Phys. P4190, 2006, etc.], which still has problems in 3D imaging performance, has also been considered for rage verification. We have already developed the original PET device (OpenPET), which is a full-ring type with excellent performance, and has an open space for the beam to pass through [Phys. Med. Biol. P1795, 2016]. We are planning to use OpenPET for clinical trials in near future.

２．研究の目的

In advanced ion therapy, the visualization of the range of incident ions in a patient's body is important for exploiting the advantages of this type of therapy. The technology to verify the range inside the patient' body on the dose spot is one of the important issues that has not been solved yet. In this study ^{10}C, which has been tried as a secondary beam in our group and emits a single gamma of 711 keV and a positron at the same time, was considered for range verification using triple-gamma-ray detection method. The method combines the PET and Compton camera methods by detecting the annihilation photons of 511 keV (from positron) and the 718 keV gamma-ray at the same time. We proposed a three-gamma imaging system (WGI). In this study, after verifying the feasibility of proposed WGI system by simulation, we constructed a large-scale prototype of the device (WGI) and conduct a demonstration experiment at the Heavy Ion Medical Accelerator in Chiba (HIMAC) secondary beam port.

３．研究の方法

The WGI prototype consists of a ring of scatterers for detection of Compton scattering of single gamma-rays and a ring of absorbers for detection of coincidence events of 511 keV from positron annihilation as shown in Fig. 1 (a). The scatterer detector is a 24×24 array GAGG crystals and the absorber detector is a 16×16×4 DOI array of GSOZ crystals.

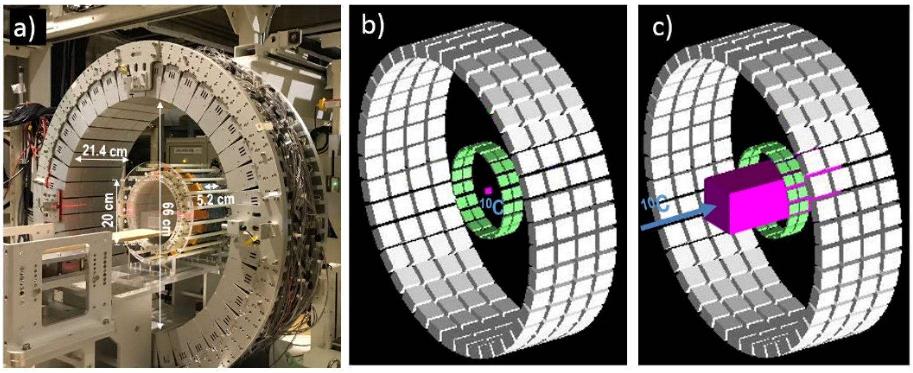

Fig.1. A photo of our WGI prototype, a). The simulated geometry of the WGI for a ^{10}C point source b) and for ^{10}C ion beam c).

The concept of the WGI for three radionuclides of ^{18}F, ^{44}Sc and ^{22}Na was investigated [2017 IEEE NSS & MIC, M-21-2, 2017]. The system can work in three modes; 1) only PET imaging, 2) single gamma-ray imaging, and 3) triple gamma-ray imaging.

Our study was performed in three steps:

1) Feasibility of the WGI system for ^{10}C nuclide was investigated for all three modes by simulations.

2) Performance of the scatterer regarding radiation hardness was investigated for one scatterer detector

3) We conducted a demonstration experiment at HIMAC secondary beam port.

４．研究成果

1) Simulation results

The WGI consists of two rings of scatterer detectors for detection of Compton scattering of single gamma-rays and four rings of absorbers for detection of coincidence events of 511 keV from positron annihilation. The scatterer detector is a 24×24 array GAGG crystals mounted on an 8×8 array TSV MPPCs (muli-pixel photo counters) with pixel pitch of 3.2 mm. The absorber detector is a 16×16×4 DOI array of GSOZ crystals mounted on a 64 ch SBA PMT (photo-multiplier tube). The inner dimeter of absorber and scatterer rings are 66 cm and 20 cm, respectively. The total number of 160 and 40 detectors are placed within four rings of absorber and 2 rings of scatterer.

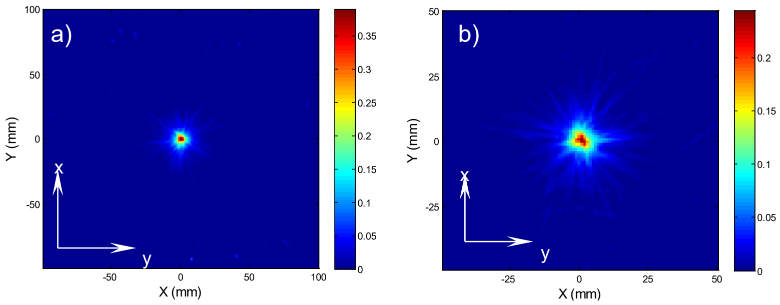

Fig.2. 2D images (using simple back projection) at the center of FOV for a point source of ^{10}C, a), and a PMMA phantom irradiated by ^{10}C ion beam of 350 MeV/u, b). The images obtained for triple-gamma ray imaging.

Geant4 code was used for the simulation of the performance of the WGI. A photo of the WGI and the schematic drawings are given in fig. 1. A point source of ^{10}C nuclide was simulated at the center of field of view (FOV), fig.1b), and a PMMA phantom (10cm × 10cm × 30cm) was irradiated with ^{10}C ion beams of

350 MeV/u, fig. 1c). Detected single events were recorded as list mode data and coincidence events were selected using a software. The events were selected based on energy of each event and the images were obtained using simple back projection.

2D images at the center of FOV for the point source and ion beam of ^{10}C are shown in Fig. 2. The spatial resolution of 12.5 mm was obtained from the image for the point source.

2) Radiation hardness of scatterer

Performance of the scatterer regarding radiation hardness was investigated for one scatterer detector. A PMMA phantom was irradiated by ^{10}C beam of 350 MeV/u in the HIMAC and the detector was set at 10 cm from the Bragg peak position at 90 degrees as shown in Fig. 3a). After irradiation, the PMMA phantom was moved to another room and the performance of the scatterer was measured. The energy spectrum of the ^{22}Na point source was obtained before and after radiation 400 spills for all GAGG crystals. Fig. 3b compares the shift of photopeak values at 511 keV for a crystal at the center and corner of the MPPC.

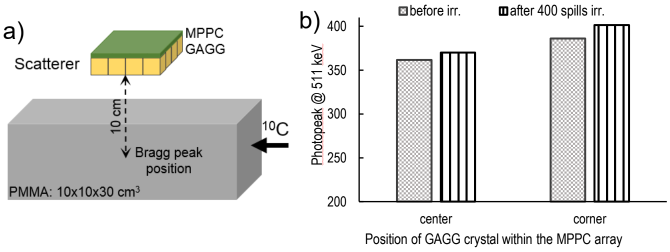

Fig.3. Schematic drawing of experimental setup for radiation hardness of the scatterer, a), comparison of photopeak values at 511 keV of a GAGG crystal at the center and corner of MPPC array before and after irradiations of 400 spills, b).

As the photpeak values at 511 keV did not decrease with increasing the number of spills it seemed that none of the microcells of MPPC were damaged during the irradiation and thus the MPPC could work normally without any irradiation damage.

3) Experiment in the HIMAC

A PMMA phantom (10cm × 10cm × 30cm) was irradiated with ^{10}C ion beams of 350 MeV/u. The phantom center was set at the FOV of the WGI. The 3D image of PET mode is shown in Fig. 4 and the data for reconstruction of triple-gamma image is still under investigation.

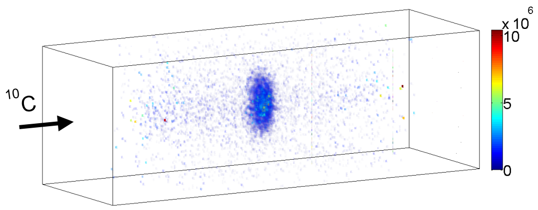

Fig.4. 3D PET image of an irradiated PMMA phantom with ^{10}C beam

５．主な発表論文等

〔雑誌論文〕　計2件（うち査読付論文　0件／うち国際共著　1件／うちオープンアクセス　0件）

１．著者名 Akram Mohammadi, Eiji Yoshida, Yusuke Okumura, Munetaka Nitta, Fumihiko Nishikido, Atsushi Kitagawa, Kei Kamada, Katia Parodi and Taiga Yamaya	４．巻 -
２．論文標題 Compton-PET Imaging of 10C for Range Verification of Carbon Ion Therapy	５．発行年 2019年
３．雑誌名 2018 IEEE Nuclear Science Symposium and Medical Imaging Conference Proceedings (NSS/MIC)	６．最初と最後の頁 1-3
掲載論文のDOI（デジタルオブジェクト識別子） 10.1109/NSSMIC.2018.8824325	査読の有無 無
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

１．著者名 Akram Mohammadi, Eiji Yoshida, Yusuke Okumura, Fumihiko Nishikido, Hideaki Tashima, Atsushi Kitagawa and Taiga Yamaya	４．巻 ３９
２．論文標題 Feasibility of Compton-PET to image C-10 distribution for range verification of carbon ion therapy	５．発行年 2019年
３．雑誌名 第11回日本医学物理学会学術大会会報文集	６．最初と最後の頁 １３４
掲載論文のDOI（デジタルオブジェクト識別子） なし	査読の有無 無
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 ―

〔学会発表〕　計4件（うち招待講演　0件／うち国際学会　3件）

１．発表者名 Akram Mohammadi
２．発表標題 Feasibility of Compton-PET to image C-10 distribution for range verification of carbon ion therapy
３．学会等名 第11回日本医学物理学会学術大会
４．発表年 2019年

１．発表者名 Akram Mohammadi
２．発表標題 Compton-PET imaging of 10C for Range Verification of Carbon Ion Therapy
３．学会等名 NSS-MIC 2018 (2018 IEEE Nuclear Science Symposium and Medical Imaging Conference)（国際学会）
４．発表年 2018年

1．発表者名 Mohammadi Akram
2．発表標題 Potential of Radioactive Ion Beams for Therapy and PET imaging
3．学会等名 NSS-MIC 2017 (2017 IEEE Nuclear Science Symposium and Medical Imaging Conference)（国際学会）
4．発表年 2017年

1．発表者名 Mohammadi Akram
2．発表標題 Range verification of O-15 beam using OpenPET
3．学会等名 PTCOG56 (56th Annual Conference of the Particle Therapy Co-Operative Group（国際学会）
4．発表年 2017年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

8．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関