

I-1. PROJECT RESEARCHES

Project 2

Estimation for 3D Distribution of Biological and Chemical Doses for BNCT

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BACKGROUNDS AND PURPOSES: For the further advancement of BNCT, it is important to improve the estimation for biological effect due to neutrons. At Heavy Water Neutron Irradiation Facility of Kyoto University Reactor (KUR-HWNIF), the fundamental studies for BNCT in the fields of medicine, biology, chemistry and pharmacology, etc., have been performed. Through these studies, the difficulty in the estimation for neutron biological effects is being acutely realized. In the BNCT irradiation field, it is difficult to monochromatically generate neutrons with a specific energy, and neutrons with the various energy ranges such as thermal, epi-thermal and fast neutrons, and also gamma rays are mixed. Furthermore, the neutron energies and the types and energies of secondary charged particles due to the nuclear reactions in living body are different. The biological effect estimation for BNCT is being studied by multiple groups in the world, but the consistent estimations have not been possible due to the difficulty of estimation for the biological effects, particularly regarding neutrons. The final goal of this project research is to develop a consistent estimation method of the biological effects for BNCT. In the third year of this research project, 2025, the developments of the estimation method for the 3D dose distribution, focused on the biological and chemical effects were continued. For the biological dose estimation, the estimation methods using three-dimensional co-culture, which can model the structure of living tissues and organs, were mainly studied. For the chemical dose estimation, the estimation methods using chemical dosimeters such as gel dosimeters were studied.

RESEARCH SUBJECTS: The collaboration and allotted research subjects (ARS) were organized as follows;

ARS-1 (R7P2-1): “Establishment of beam-quality estimation method in BNCT irradiation field using dual phantom technique (IX)”, Y. Sakurai, et al..

ARS-3 (R7P2-3): “Development of a BNCT evaluation system using a three-dimensional model”, K. Igawa, et al..

ARS-4 (R7P2-4): “Verification of BNCT effect on hematological cancer cells and dosimetry for expansion of BNCT case”, S. Yoshihashi, et al..

ARS-5 (R7P2-5): “Development and evaluation of 3D gel dosimeter for the measurement of dose distribution in BNCT”, S. Hayashi, et al..

ARS-6 (R7P2-6): “Establishment of three-dimensional dose distribution estimation method for BNCT using radiochromic gel dosimeter (III)”, Y. Sakurai, et al..

ARS-7 (R7P2-7): “Evaluation of boron dose and dosimetric performance of NC-RFG for BNCT”, J. Shimbo, et al..

ARS-9 (R7P2-9): “Development of an epithermal neutron spectrometer for boron neutron capture therapy”, Y. Ota, et al..

ARS-10 (R7P2-10): “Measurement of wavelength-dependent luminescence of BaFBr:Eu for beam quality assurance of BNCT”, K. Tanaka, et al..

ARS-12 (R7P2-12): “Experiments for boron dose measurement with glass dosimeter in BNCT”, Y. Morizane, et al..

For ARS-2 (R7P2-2) and ARS-11 (R7P2-11), the experiments continued until April 2026, and these subjects were not completed by the end of fiscal year 2025. ARS-8 (R7P2-8) could not be performed due to the scheduling and preparation issues. So, the reports of these subjects do not appear.

Establishment of Beam-quality Estimation Method in BNCT Irradiation Field using Dual Phantom Technique (IX)

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INTRODUCTION: Before the start of treatment with BNCT, the relative biological effectiveness (RBE) for the fast neutrons incident to the irradiation field must be estimated. Measurements of RBE are typically performed by biological experiments with a phantom. Although the dose deposition due to secondary gamma rays is dominant, the relative contributions of thermal and fast neutrons are virtually equivalent in a water and/or acrylic phantom. Uniform contributions to the dose deposited from thermal and fast neutrons are based in part on relatively inaccurate dose information for fast neutrons. The aim of this study is to establish the accurate beam-quality estimation method mainly for fast neutrons by using two phantoms made of different materials [1]. In 2025, verification experiments for the dual phantom technique were continued using Heavy Water Neutron Irradiation Facility installed in Kyoto University Reactor (KUR-HWNIF) [2].

MATERIALS AND METHODS: One of the dual solid phantoms was made of polyethylene with natural lithium fluoride for 30 weight percent (LiF-polyethylene phantom), and the other phantom was made of polyethylene with 95%-enriched lithium-6 fluoride for 30 weight percent (⁶LiF-polyethylene phantom). Cells were divided in two groups. One was treated group using p-boronophenylalanine (BPA, containing B-10), and the other was non-treated group. In addition to the conventional cell suspension, the cell in collagen gel was also prepared. These cell samples were placed at the depths of 0 cm, 2 cm, 5 cm and 8 cm in the phantoms. Figure 1 shows one of the experimental geometries. The depth dose distributions for the thermal neutron, fast neutron and gamma-ray components were determined based on the simulation calculation results normalized referring to the measured values. The epi-thermal neutron irradiation mode was used for the phantom experiments.



Fig. 1. One of the experimental geometries.

RESULTS: It was confirmed that the survival fraction became smaller as the thermal neutron flux became larger in the LiF-polyethylene phantom. The survival fraction for the non-treated cell was higher than that in BPA-treated cell. In the ⁶LiF-polyethylene phantom, the survival fraction showed no difference between non-treated and BPA-treated cells. These confirm the results from the previous years, with the same trends observed for the cells in suspension and gel. Incidentally, the differences were observed in the slopes of the dose-survival curves between these cell sample types.

ACKNOWLEDGMENT: This work was supported by JSPS KAKENHI Grant Number JP 24K03082.

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Development of a BNCT Evaluation System Using a Three-Dimensional Model

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INTRODUCTION: Accurate assessment of neutron-induced biological effects is essential for optimizing boron neutron capture therapy (BNCT). Conventional two-dimensional (2D) culture systems fail to reproduce the structural and microenvironmental complexity of living tissues, including cell–cell and cell–extracellular matrix interactions. Recent advances in three-dimensional (3D) models have demonstrated that radiation responses are strongly influenced by tissue architecture, suggesting limitations in 2D-based evaluations [1].

This study aims to develop a BNCT evaluation system using physiologically relevant 3D culture models by comparing neutron-induced responses between 2D and 3D systems, thereby improving the accuracy of radiosensitivity and RBE assessment.

EXPERIMENTS: Human cancer cell lines, endothelial cells, and patient-derived fibroblasts were cultured in both 2D and 3D collagen-based systems. The samples were exposed to neutron irradiation at the Kyoto University Research Reactor (KUR). Dosimetry was verified using gold foil and thermoluminescent detectors. Following irradiation, cells were incubated for 72 hours. Cell viability was assessed by trypan blue exclusion following enzymatic dissociation (trypsin for 2D, collagenase for 3D), with automated cell counting used to quantify total and viable cells. In 3D models, histological analysis and image-based quantification were performed. Statistical analysis evaluated the effects of dose, cell type, and culture dimensionality.

RESULTS: Neutron irradiation induced a dose-dependent decrease in cell viability in both 2D and 3D cultures, however, the magnitude of this effect differed significantly between the two systems. In 2D cultures, survival decreased markedly with increasing doses across all cell types, with endothelial and osteosarcoma cells exhibiting particularly high radiosensitivity. In contrast, 3D models showed an attenuated response, characterized by increased radioresistance, especially in stromal cells, and reduced variability among cell lines. Direct comparison between 2D and 3D cultures revealed consistently higher survival in 3D systems across all dose levels (0–25.8 Gy), underscoring the critical influence of tissue architecture on neutron response. Notably, patient-derived cells such as normal fibroblasts and cancer-associated fibroblasts demonstrated stable resistance irrespective of culture conditions. Histological analysis of the 3D models revealed dose-dependent matrix contraction and reduced tissue thickness, accompanied by a gradual decline in cell number. Methodological validation showed strong agreement between histology-based analysis and live-cell counting, confirming the robustness of 3D quantification.

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Verification of BNCT Effect on Hematological Cancer Cells and Dosimetry for Expansion of BNCT Case

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INTRODUCTION: The number of newly diagnosed patients with major hematologic cancers (malignant lymphoma, multiple myeloma, and leukemia) in Japan was 58,547 in 2019 [1], and 5,853 hematopoietic stem cell transplants were performed in FY2022 as the last treatment option for these refractory hematologic cancer patients [2]. While autologous transplantation is a desirable medical technique for patients because it does not require long-term administration of immunosuppressive drugs and prevents immune reactions (GVHD) caused by HLA incompatibility, the grafts contain tumor cells, which must be removed and treated with chemotherapy and radiotherapy, which are pre-treatment procedures. We are now conducting basic research to remove tumor cells in grafts by Ex Vivo BNCT. In this study, the response of PVA-GTA-I gel dosimeter to thermal neutrons, fast neutrons, and gamma-ray was evaluated to use the gel dosimeters for dose assessment in cell bags.

EXPERIMENTS: PVA-GTA-I gel is prepared by adding PVA as the main component, KI as the reactant, Fructose as the reducing agent, GTA as the gelling agent, and GDL as the gelation promoter by adding GTA. In this study, 100 mM of B-(OH)₃ was added to PVA-GTA-I gel to make it sensitive to thermal neutron beams. The prepared gels were sealed in a 2D-case with a thickness of 4 mm. A sample was prepared consisting of 10 stacked 2D-cases. The sample was placed inside a water phantom, and half of the sample was covered with a ⁶LiF Teflon plate which absorbs thermal neutrons. The ⁶LiF Teflon plate enabled a difference in the ¹⁰B(n, a)⁷Li reaction rate, allowing for a comparison of the thermal neutron response. Neutron irradiation was performed using the KUR heavy water irradiation facility, and the irradiation time was 60 minutes. The color reaction of each 2D case was measured using scanner, and the absorbance was evaluated from the pixel values.

RESULTS: Fig. 1 shows a scam image of the 2D case after neutron irradiation. The sample on the side not shielded by the ⁶LiF Teflon plate exhibited stronger color reaction. In other words, it was demonstrated that the PVA-GTA-I gel to which B-(OH)₃ had been added exhibits high sensitivity to thermal neutrons.

The total dose was defined as the sum of the boron dose, hydrogen dose and gamma dose, and was calculated using the following method. The response to the boron dose was determined using the difference in sensitivity resulting from the presence or absence of the ⁶LiF Teflon plate. Furthermore, the response to gamma dose was calculated by combining gamma-ray measurements using BeO-TL, simulation results and the results of gamma-ray calibration experiment using ⁶⁰Co source. Fig. 2 shows the results of the evaluation of the response of each dose component.



Fig. 1 Response of the irradiated sample (left: overall view, right: first layer)

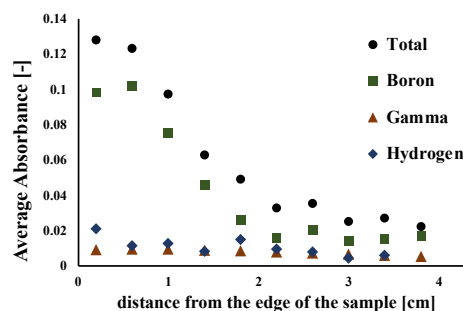


Fig. 2 Absorbance response distributions

Development and evaluation of 3D gel dosimeter for the measurement of dose distribution in BNCT

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INTRODUCTION: Three-dimensional (3D) gel dosimeters have been developed to facilitate the volumetric verification of complex conformal dose distributions in radiotherapy [1]. These dosimeters consist of radiosensitive chemical species dispersed within an aqueous gel matrix to preserve the spatial information of the absorbed dose. The 3D dose distribution is reconstructed from the amount of reaction products, typically measured via imaging modalities such as MRI or optical computed tomography (OCT). We previously reported a PVA-GTA-I radiochromic gel dosimeter that utilizes red color development resulting from the formation of a polyvinyl alcohol (PVA)-iodine complex [2, 3]. In a recent study, as a preliminary step toward 3D evaluation using optical CT, we assessed the pseudo-depth dose distribution of a reactor-based neutron beam by arranging small gel dosimeters containing ¹⁰B and ⁶Li in a block-like configuration [4]. In the present work, for comparison with these prior results, we fabricated similar small-scale dosimeters sensitized with gadolinium, which possesses a significantly larger thermal neutron absorption cross-section, and evaluated their performance.

EXPERIMENTS: The PVA-GTA-I gel dosimeter comprises partially saponified PVA, potassium iodide (KI), glutaraldehyde, fructose, glucono- δ -lactone, and distilled water. To enhance thermal neutron sensitivity, gadolinium chloride (GdCl₃, 50 mM), containing natural abundances of ¹⁵⁷Gd (15.7%), was added to the gel formulation. The resulting solution was dispensed into PMMA cuvettes (4.5 mL, 1 cm path length). Neutron irradiations were conducted at the Heavy Water Neutron Irradiation Facility (HWNIF) of the Kyoto University Research Reactor (KURR, 1 MW) in air at room temperature. Three distinct beam modes (thermal neutron-rich, fast neutron-rich, and mixed) were generated using a heavy water spectrum shifter and cadmium thermal-neutron filters.

RESULTS: Figure 1 illustrates the results obtained in the mixed mode as a representative case, where position numbers correspond to depth. In all experimental sets, the color intensity attenuated from the surface (left) to the deeper positions (right). Samples containing gadolinium exhibited localized increases in coloration, a trend qualitatively similar to that observed with ¹⁰B and ⁶Li. However, the change in absorbance (proportional to the absorbed dose) for the gadolinium-doped samples was comparable to those of ¹⁰B and ⁶Li, despite the vastly large thermal neutron capture cross-section of ¹⁵⁷Gd (240,000 barns) relative to ¹⁰B (3,850 barns) and ⁶Li (870 barns). This discrepancy suggests that gadolinium ions significantly inhibit the oxidation of iodide ions. Consequently, these results indicate that gadolinium is unsuitable as a thermal neutron sensitizer for PVA-iodine-based gel dosimeters.

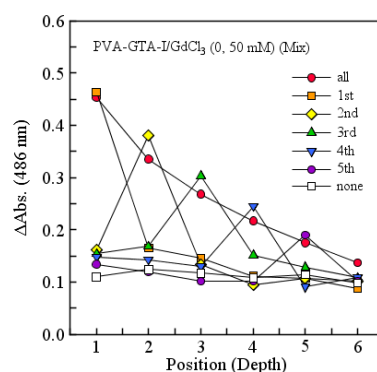


Fig. 1. The change of absorbances in depth (corresponding to relative depth dose distribution) in mixed mode, and the irradiated PVA-GTA-I radiochromic gel dosimeters.

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Establishment of Three-dimensional Dose Distribution Estimation Method for BNCT using Radiochromic Gel Dosimeter (III)

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INTRODUCTION: Development in accelerator-based irradiation systems for BNCT is underway. BNCT using newly developed accelerator systems is being implemented at multiple facilities around the world. However, there are still issues that need to be improved for further advancement of BNCT. The advancement of dose estimation is one of these, and the estimation of biological dose is particularly important. As part of the advancement of biological dose estimation for BNCT, we focus on chemical effects, which are the precursor to biological effects. We are studying on the estimation method using chemical dosimeters, especially gel dosimeters. Gel dosimeters are made of materials similar to living tissue and can be formed into any shape. Using a phantom made from gel dosimeter that models human body, three-dimensional dose distribution estimation becomes possible. Among the various types of gel dosimeters, we are especially focusing on “radiochromic gel dosimeters” that can be read out using optical CT, etc.. The purpose of this study is to establish three-dimensional dose distribution estimation method for BNCT using multiple types of radiochromic gel dosimeters. In 2025, the characterization for micellar gel dosimeters was continued [1].

MATERIALS AND METHODS: Leucocrystal violet (LCV) was selected as dye of micelle gel dosimeters, because it is extremely clear before irradiation, based on our previous study [2]. The micelle gel dosimeters were prepared based on 1 mM of LCV in the 96% water and 4% gelatin according to the method of Babic et al. [3]. For dose rate independency and temporal coloration reduction, the type and concentration of surfactant and sensitizer were changed. In addition, boric acid or urea was added for the estimation of boron or nitrogen dose components, referring to Gambarini et al. [4]. Furthermore, a dosimeter in which heavy water was replaced with light water was also prepared to estimate hydrogen dose component. The amount of additives was based on our previous study. The characterization experiments were mainly performed using Heavy Water Neutron Irradiation Facility of Kyoto University Reactor (KUR-HWNIF) [5].



Fig. 1. An example of color change before and after the irradiation using the LCV micelle gel dosimeters.

RESULTS: From the experiment results, it was confirmed that the dose response of each gel dosimeter depended on the linear energy transfers (LETs) of the particles produced in each dosimeter. Using these results, the factors for dose-component discrimination method were determined and verified for different energy spectra, and the validity was confirmed.

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Evaluation of Boron Dose and Dosimetric Performance of NC-RFG for BNCT

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INTRODUCTION: To establish a dose evaluation method for boron neutron capture therapy (BNCT), we investigated the applicability of a novel nanoclay-based radiofluorescent gel dosimeter (NC-RFG) with LET-independent characteristics (LET: linear energy transfer) using the Heavy Water Neutron Irradiation Facility (HWNIF) at the Kyoto University Research Reactor (KUR).

EXPERIMENTS: Experiments were conducted to evaluate the sensitivity change due to boron addition (using the Irradiation Rail Device on December 10) and to investigate the applicability to two-dimensional dose measurement inside acrylic phantom (using the Large Sample Carrier on February 4). NaBH₄ was added to the NC-RFG, and the ¹⁰B concentration was varied from 0 to 10 or 22 ppm. After irradiation in the mixed neutron irradiation mode at KUR-HWNIF, sensitivity was evaluated using a fluorescence spectrophotometer (RF-6000, Shimadzu), and two-dimensional distributions were analyzed using a fluorescence image scanner (GELSCAN3, iMeasure).

RESULTS: Sensitivity increased linearly with boron concentration from 0 to 10 ppm (Fig. 1), while no increase was observed under X-ray irradiation, indicating that the response originates from ¹⁰B(n,α)⁷Li nuclear reaction. Using an X-ray calibration curve obtained at RIKEN, the boron dose coefficient was estimated to be $7.56 \times 10^{-14} \text{ Gy} \cdot \text{cm}^2 \cdot \text{n}^{-1} \cdot \text{ppm}^{-1}$, which agrees well with the theoretical value of 7.43×10^{-14} (Ref. 2). This demonstrates, for the first time, direct experimental quantification of boron dose and its validity. The depth-dose distribution measured with NC-RFG showed a similar attenuation trend to that obtained by gold wire measurements (Fig. 2). The NC-RFG (22 ppm ¹⁰B) data were corrected using the aerated data of the same sample, assuming that the response under aerated conditions represents the gamma-ray component in deoxygenated conditions, based on LET-dependent response differences due to dissolved oxygen. Although the correction is complex, NC-RFG reflects thermal neutron distribution and is effective for continuous evaluation of mixed radiation fields. Since this study demonstrated, for the first time, the feasibility of experimentally evaluating the boron dose coefficient, future work will focus on a more detailed assessment and extension to nitrogen dose coefficient evaluation. Furthermore, more advanced methods for separating mixed radiation components will be investigated to enhance the overall accuracy of dose evaluation.

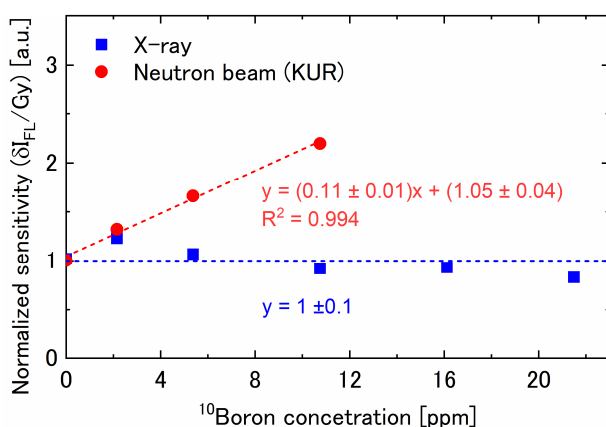


Fig. 1 Normalized sensitivity of the NC-RFG, using the value at 0 ppm boron concentration as the reference.

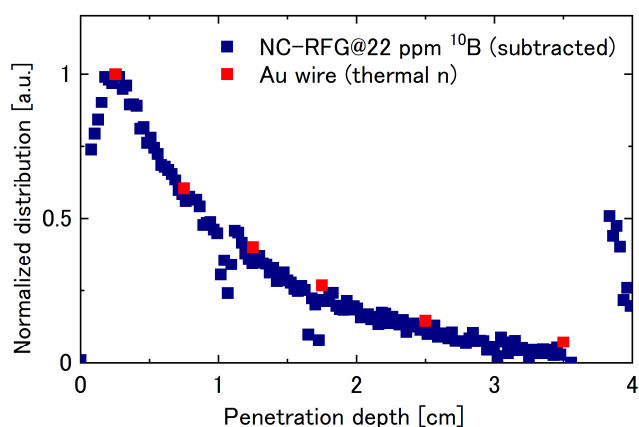


Fig. 2 Depth profiles of NC-RFG and Au wire.

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Development of an epithermal neutron spectrometer for boron neutron capture therapy

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INTRODUCTION: The neutron spectrum is essential for accurate dose evaluation in boron neutron capture therapy (BNCT), where the epithermal neutron component is dominant. Multi-sphere neutron spectrometers are widely used to measure the epithermal neutron spectrum. The spectrum depends on initial spectrum because of its flat energy response ranging from 1 eV to 10 keV. To improve reliability of the results, we developed an epithermal spectrometer with a threshold-like energy response. The performance was validated at Kyoto University Institute for Integrated Radiation and Nuclear Science (KURNS).

EXPERIMENTS: The spectrometer is composed of a 0.1-mm thick copper plate sandwiched between 5-mm thick boron carbide (B₄C) neutron absorbers and acrylic plates. The B₄C neutron absorber is a mixture of 80% B₄C and 20% acrylic resin by weight. The neutron energy spectrum is measured via the copper plate activity produced by the neutrons passing through the acrylic and B₄C layers. The components of the spectrometer were stacked at the beam exit window. The copper plate was placed perpendicular to the surface of the beam exit window. The spectrometer with a 300 × 300 mm surface covers the 120-mm diameter aperture. All neutrons are incident on the spectrometer from the reactor through the collimator. Following a 50-minute irradiation of the neutron beam, the copper plate was exposed to an imaging plate after a 10-minute cooling time to measure the activity depth profile, which depends on the incident neutron energy. The response matrix was derived from the depth profile simulated by Particle and Heavy Ion Transport code System ver.3.34 for 16 incident neutron energy groups from 0.01 eV to 16 MeV. Using the measured depth profile and the response matrix, the neutron energy spectrum of the beam was derived with an iterative unfolding algorithm. As an initial guess spectrum, the multi-foil activation method was utilized for the unfolding procedure [1].

RESULTS: Figure 1 shows the neutron energy spectrum obtained using our spectrometer, compared with the KURNS reference spectrum. The experimental result reproduced the reference spectrum below 100 eV, while it shows an underestimation above 100 eV. This underestimation may be attributed to neutron detection at the different resonance peaks of the two natural isotopes of copper. The radioactive nuclides with different half-lives were produced on the copper plate. The time-dependence of the activity should be considered in the response matrix. Now we are improving the response matrix by accounting for the elapsed time.

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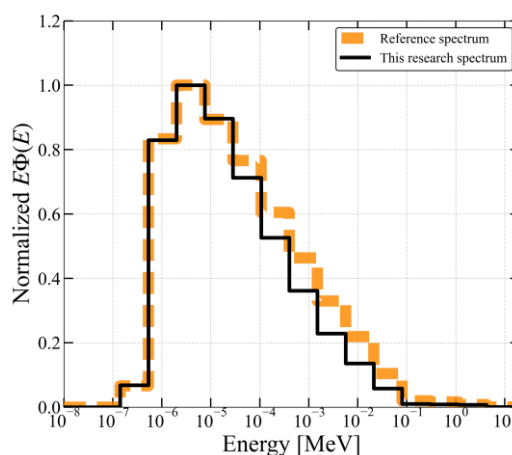


Fig. 1. Neutron energy spectrum obtained using the epithermal neutron spectrometer (black solid line), compared with the KURNS reference spectrum (orange dashed line).

Measurement of wavelength-dependent luminescence of BaFBr:Eu for beam quality assurance of BNCT

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INTRODUCTION: Beam fluence spatial distribution is required to be measured for quality assurance in the irradiation field, in boron neutron capture therapy. The imaging plate has been tested for usage in this purpose[1]. In imaging plate, the light for excitation and luminescence are investigated with respect to a single constant range of wavelength. However, BaFBr:Eu, *i.e.*, the luminescence material for imaging plate, has multiple peaks in its excitation spectrum[2]. Each peak corresponds to a excited state of electron and ion BaFBr:Eu. The efficacy in excitation to each level is expected to depend on the beam quality of the irradiated radiation, which deposits energy on the luminescence material. In this case, the dependence of the quantity of the luminescence on the wavelength of the excitation light, or possibly luminescence, will specify the beam quality. Also, the absorbed dose can be estimated from the quantity of the luminescence. This study investigated the use of the luminescence for measurement of both quantity and quality of the radiation.

EXPERIMENTS: In this study, BaFBr:Eu was fabricated and utilized as a sample, in case the blue film distort the influence of the beam quality of the dependence of the luminescence quantity of wavelength. This is based on the background that BaFBr:Eu in the imaging plate (Fujifilm Corporation, BAS-TR) is embed in blue-colored film. The samples were irradiated with gamma rays from ⁶⁰Co, and neutrons and gamma rays at the standard mixed neutron irradiation mode and standard thermal neutron irradiation mode of Kyoto University Reactor Heavy Water Neutron Irradiation Facility at 1 MW of the power [3]. In the latter, the samples were driven with Irradiation Rail Device. The fluorescence spectrofluorometer (Hitachi corporation, F-2700) was used to measure the dependence of the fluorescence quantity on the wavelength.

RESULTS: An example of the spectrum is shown in Fig. 1 for fabricated BaFBr:Eu. The ratio of the luminescence quantity by excitation at 630 nm to that at 650 nm is 1.13 for mix mode and 1.26 for thermal mode, 1.52 for Co. These aspects suggest that the dependence of the quantity of the luminescence on the wavelength is a promising indicator of the beam quality. The attempt to measure the beam quantity by using the luminescence dependence on wavelength is undergoing for usage of BAS-TR and fabricated BaFBr:Eu.

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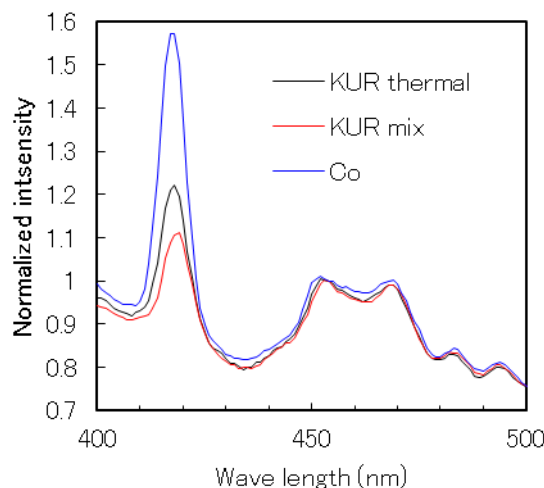


Fig. 1. Luminescence spectrum of fabricated BaFBr:Eu

Experiments for boron dose measurement with glass dosimeter in BNCT

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INTRODUCTION: The resulting reaction produces alpha particles and ${}^7\text{Li}$, which deposit energy within a range of approximately one cell diameter. This makes BNCT particularly promising for treating deep-seated tumors as a low-invasive cancer therapy, which are otherwise difficult to manage with conventional therapy [1]. Accurate evaluation of the individual dose is essential for the safe and effective planning of BNCT treatment. The total dose delivered to tissue consists of contributions from four components: the boron dose from the ${}^{10}\text{B}(n,\alpha){}^7\text{Li}$ reaction, the nitrogen dose, the hydrogen dose and the gamma dose. Of these, the boron dose is the main therapeutic component, yet it is challenging to measure accurately in clinical conditions. In this study, glass dosimeters were employed in combination with a ${}^6\text{Li}$ -based sensitivity approach to evaluate the boron dose component in a phantom. This dosimetry approach is expected to provide a practical accessible method of evaluating individual boron doses, which will ultimately contribute to optimizing patient-specific irradiation planning for deep-seated treatment in BNCT.

EXPERIMENTS: Glass dosimeters were encased in holders that were fabricated using a 3D printer. Two samples were prepared for each type; Dosimeters coated with about 2.0 g of ${}^6\text{Li}_2\text{CO}_3$ powder, and uncoated dosimeters. The prepared samples were irradiated within a phantom under two distinct conditions, thermal neutron and epithermal neutron. In a separate experiment, boric acid was homogeneously dissolved in the phantom water (1% ${}^{10}\text{B}$ concentration) to simulate a clinically relevant boron distribution and measured dose distribution between pure water and boric water.

RESULTS: As shown in Fig.1, A sufficient dose difference was observed between the ${}^6\text{Li}_2\text{CO}_3$ powder-coated dosimeters and the uncoated control dosimeters when exposed to thermal and epithermal neutrons. This demonstrates that the differential dosimetry approach using ${}^6\text{Li}_2\text{CO}_3$ powder can detect the thermal neutron-induced dose component with adequate sensitivity under these conditions. In contrast, no significant dose difference was detected when boric acid was dissolved homogeneously in the phantom water. This suggests that the method is less sensitive when boron is distributed in a dilute aqueous medium, probably because the local concentration of the neutron-reactive material near the dosimeter is insufficient.

Further investigation should be consider to establish the practical applicability of this approach and determine the minimum detectable concentration of ${}^6\text{Li}$ or ${}^{10}\text{B}$. In addition, we are also considering to develop the conversion factor that combines experimental measurements with Monte Carlo simulations. Flux-to-dose conversion factors will enable the quantitative evaluation of boron doses in future experiments.

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[1] International Atomic Energy Agency, Advances in Boron Neutron Capture Therapy, IAEA, Vienna (2023) 1–416.

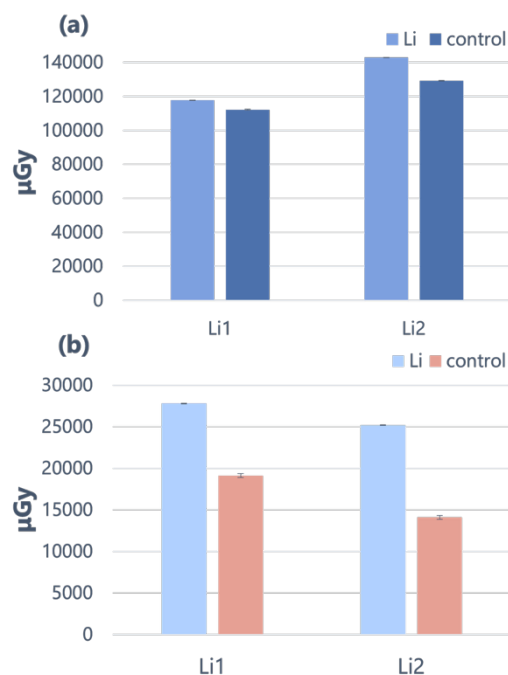


Fig.1. Dose results for glass dosimeters containing ${}^6\text{Li}_2\text{CO}_3$ powder and the control group, irradiated by (a) thermal neutrons and (b) epithermal neutrons.