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# Neutron beam reproducibility for the accelerator-based boron neutron capture therapy system employing the solid-state lithium target


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## ABSTRACT

Purpose: Accelerator-based boron neutron capture therapy (BNCT) system employing a solid-state lithium target has been implemented into clinical practices. However, due to the degradation of the Li target over its lifetime, periodic replacement is necessary. This study aims to evaluate the reproducibility of neutron distribution for the accelerator-based BNCT system across different Li targets. Methods: The system (CICS-1) was installed at the National Cancer Center Hospital, Tokyo, Japan, and used in this study. Depth and lateral thermal neutron distributions within PMMA phantoms were measured with four Li targets from different lot numbers in the accelerator-based BNCT system. These distributions were compared with the representative distributions for each Li target using the statistical analysis (Shapiro-Wilk, Bartlett, and One-Way analysis of variance tests). A p-value of less than 0.05 was considered statistically significant. Thermal neutrons were evaluated by saturated radioactivity of gold wire encapsulated with and without the cadmium capsule in each measurement position. Results: Discrepancy (mean ± standard deviation) between the measured and representative depth thermal neutron distributions in the four Li targets followed a normal distribution (p = 0.10, 0.20, 0.72, and 0.30) and showed equal variance (p = 0.79), and was (-0.407 ± 0.770), (-0.33 ± 0.91), (0.883 ± 0.721), and (-0.146 ± 0.752)%, respectively. The discrepancy for the lateral distributions also followed a normal distribution (p = 0.39, 0.24, 0.98, and 0.51) and showed equal variance (p = 0.87), and was (-0.068 ± 0.994), (-0.456 ± 0.879), (0.582 ± 0.878), and (-0.058 ± 0.875)%, respectively. These discrepancies were within the measurement uncertainty of the thermal neutron flux (2.6%). Furthermore, these discrepancies had no statistical differences among the four Li targets (p = 1.00 (depth), 1.00 (lateral)). Conclusion: This study demonstrates the neutron beam reproducibility in the accelerator-based BNCT employing the solid-state Li target. These findings are important for ensuring the stable dose delivery and contributing to robust quality assurance protocols in clinical practice.



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## INTRODUCTION

- Accelerator-based boron neutron capture therapy (BNCT) employing a solid-state lithium target has been implemented into clinical practices (Fig. 1).
- Safety and effectiveness of the system have been validated through several clinical trials (Fig. 2, [1-2]).

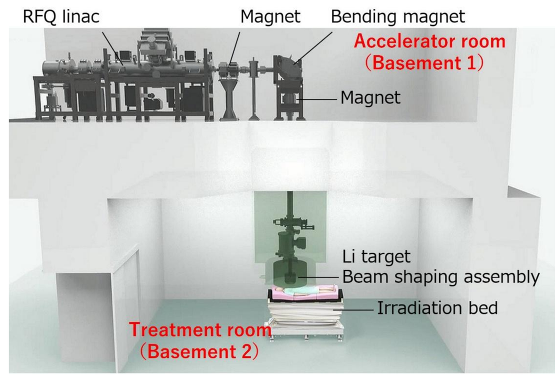


Fig.1: Schema of the accelerator-based BNCT system.


Fig.2: Clinical photo of a patient with (a) angiosarcoma (right temporodorsal scalp mass) and (b) acral melanoma.

- Due to the degradation of Li target over its lifetime, the reduction of neutron output was observed (Fig. 3, [3]).
- Periodical target replacement is necessary for the system.

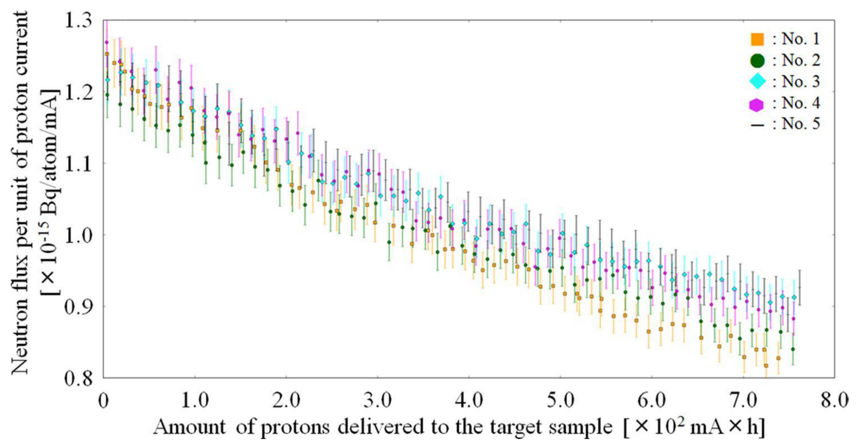


Fig.3: Neutron output reduction over the lifetime of Li target.

**Aim: Evaluation of the reproducibility of neutron distribution for the system across different Li targets**

## METHODS AND MATERIALS

- System: CICS-1 in National Cancer Center Hospital, Tokyo, Japan (provided by Cancer Intelligence Care Systems, Inc., Tokyo, Japan)
- Measurement: Depth and lateral neutron (20 mm depth) distribution within a PMMA phantom (Fig. 4)
- Measurement: Radioactivity of a gold wire after neutron exposure was measured by a high-purity germanium detector. (Fig. 5)
- Neutron evaluation: Saturated radioactivity calculated from the radioactivity of gold and Eq. (1) to eliminate the effects of the fluctuations of the delivered protons, the individual difference in each gold wire, and the radioactive decay in each measurement.

$$\mathit{Saturated\ radioactivity} = \frac{\mathit{Radioactivity\ of\ gold}}{N_{gold} \times \sum_{i=1}^{n} A_i \times (1 - e^{-\lambda \times T}) \times (e^{-\lambda \times (n-i) \times T})} \ [\mathrm{Bq}/atom/\mathrm{mA}] \quad (1)$$

A: proton current, $N_{gold}$: number of atoms in the gold, T: one of the neutron irradiation time, which have been divided into n

Fig.4: Photo of experiment

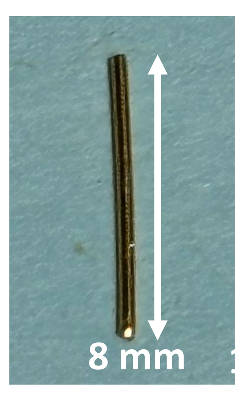


Fig.5: Photo of a gold wire

- Evaluation: Neutron beam reproducibility among four Li targets from different lot numbers through comparison between the measurement results and representative beam data
- Statistical analysis: statistically significant difference ($p < 0.05$) Shapiro-wilk test, Bartlett's test, One-way ANOVA

## RESULTS

- Depth neutron profile reproducibility

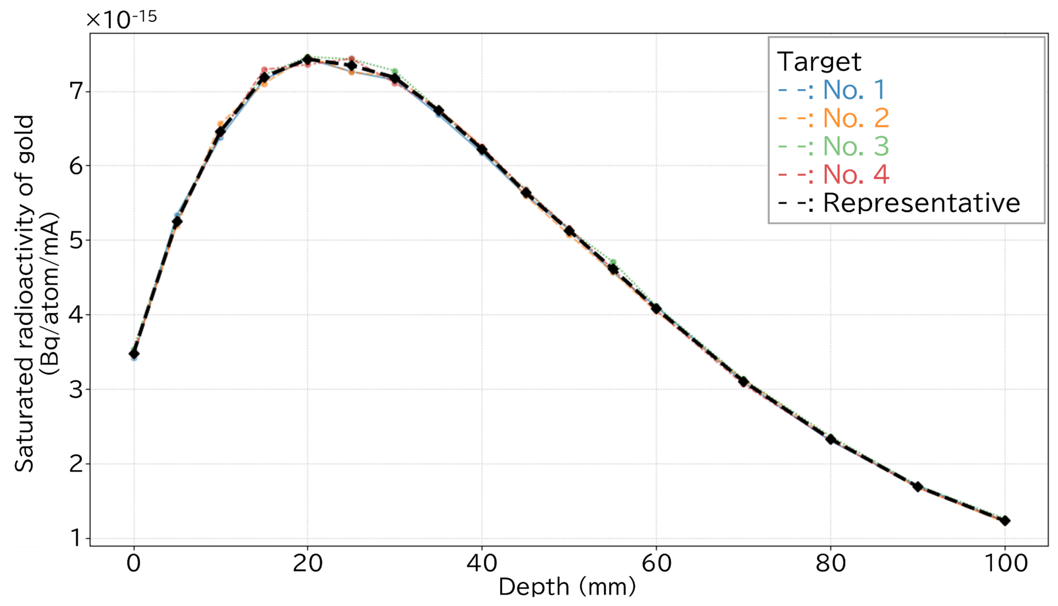


Fig.6: Depth profile on the central beam axis in four Li target

- Lateral neutron profile reproducibility

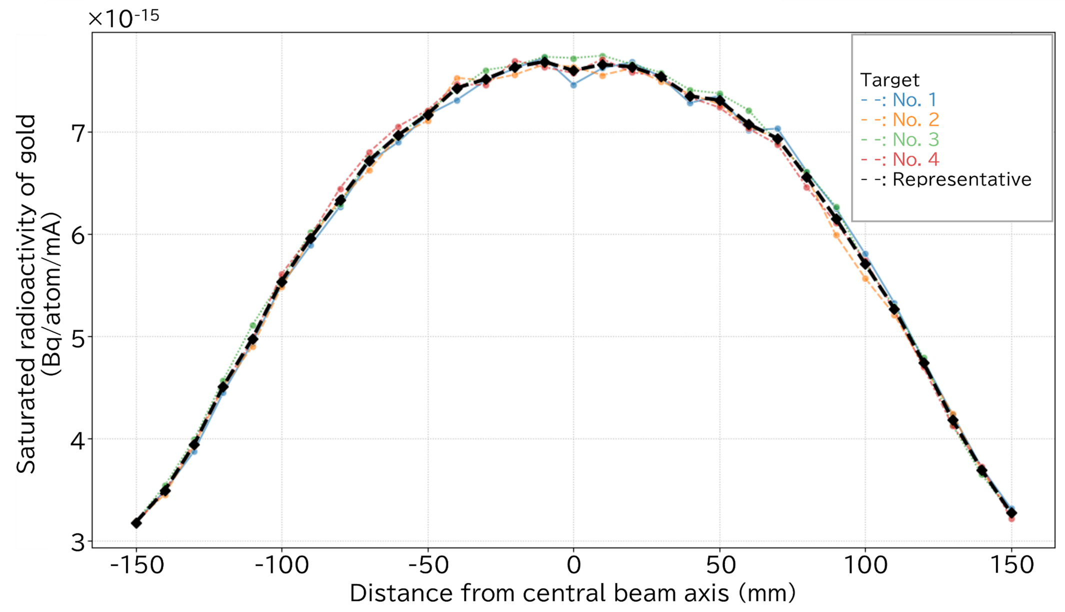


Fig.8: Lateral profile at 20 mm depth in four Li target

Table 1: Discrepancies between the measured depth profile and the representative beam profile in each Li target

| Li Target No. | Discrepancy (Mean ± SD) |
|---|---|
| 1 | (-0.407 ± 0.770)% |
| 2 | (-0.330 ± 0.910)% |
| 3 | (0.883 ± 0.721)% |
| 4 | (-0.146 ± 0.752)% |

Table 2: Discrepancies between the measured lateral profile and the representative beam profile in each Li target

| Li Target No. | Discrepancy (Mean ± SD) |
|---|---|
| 1 | (-0.068 ± 0.994)% |
| 2 | (-0.456 ± 0.879)% |
| 3 | (0.582 ± 0.878)% |
| 4 | (-0.058 ± 0.875)% |

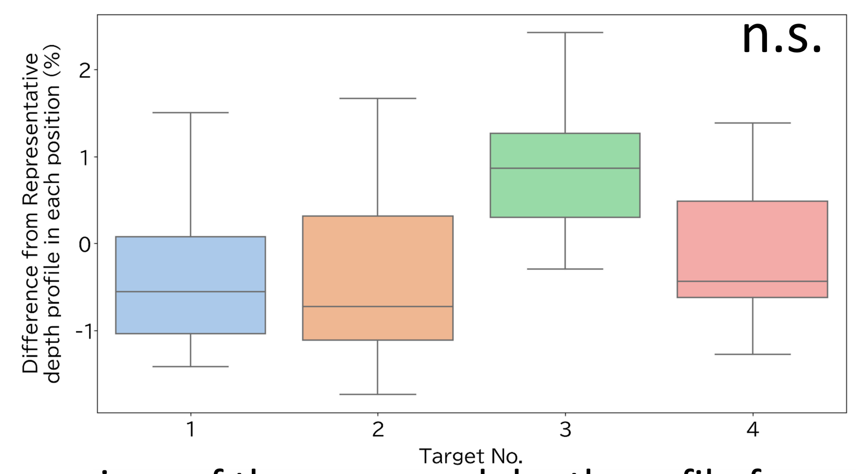


Fig.7: Comparison of the measured depth profile for each Li target with the corresponding representative beam profile

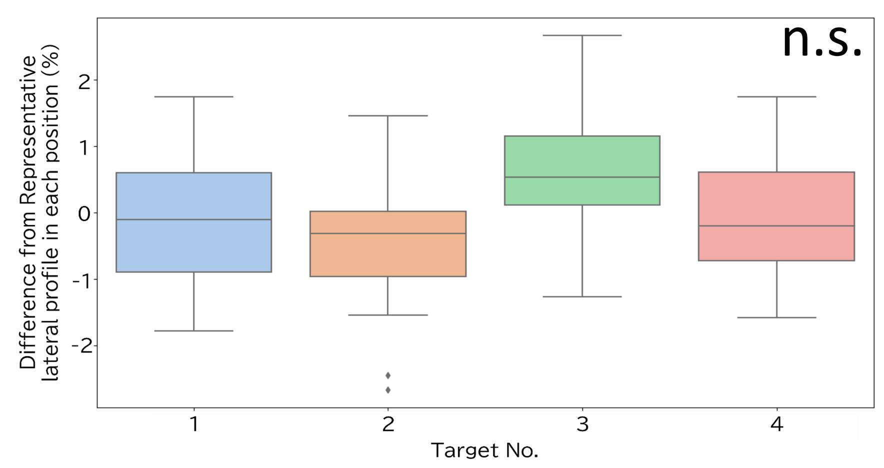


Fig.9: Comparison of the measured lateral profile for each Li target with the corresponding representative beam profile

- **These discrepancies were within the measurement uncertainty of 2.6%.**
- **Furthermore, these discrepancies had no statistical differences among the four Li targets**

**☞ Neutron Beam Reproducibility among the Li targets was validated.**

## DISCUSSION

To deliver the required dose to a patient, it is important for the accelerator-based BNCT system employing the Li target that should be replaced due to neutron output reductions over lifetime of each Li target.
This study has an impact because it explains and validates reproducibility for each Li target for neutron source in the accelerator-based BNCT system.
Because a previous study reported that the total neutron flux could be evaluated by the saturated radioactivity of gold, this study evaluated them in each measurement position.

- From the comparisons, the neutron beam reproducibility was validated among Li targets from different lot numbers in the system.
  - Neutron profile agreed the representative beam profiles within the measurement uncertainty of 2.6%.
  - No statistical difference between the measured and representative profiles was observed among the Li targets.

## CONCLUSIONS

- This study demonstrates the neutron beam reproducibility in the accelerator-based BNCT employing the solid-state Li target.
- These findings are important for ensuring the stable dose delivery and contributing to robust quality assurance protocols in clinical practice.

## REFERENCES


1. Igaki H, Murakami N, Nakamura S, et al. Scalp angiosarcoma treated with linear accelerator-based boron neutron capture therapy: A report of two patients. Clin Transl Radiat Oncol. 2022;33:128-133.
2. Igaki H, Nakamura S, Yamazaki N, et al. Acral cutaneous malignant melanoma treated with linear accelerator-based boron neutron capture therapy system: a case report of first patient. Front Oncol. 2023;13:1272507.
3. Nakamura S, Igaki H, Ito M, et al. Neutron flux evaluation model provided in the accelerator-based boron neutron capture therapy system employing a solid-state lithium target. Sci Rep. 2021;11(1):8090.
4. Nakamura S, Takemori M, Nakaichi T, et al. A method for delivering the required neutron fluence in an accelerator-based boron neutron capture therapy system employing a lithium target. Sci Rep. 2024;14(1):11253.