SPECT system for boron neutron capture therapy (BNCT-SPECT) for real-time measurement of therapeutic effect

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Project Outline

Boron Neutron Capture Therapy(BNCT) is a promising and quite new cancer therapy. However, the therapeutic effect cannot be known easily during the treatment (neutron irradiation). The basic technique for that is to measure promptly emitted 478 keV gamma-rays from boron neutron capture (BNC) reaction with a SPECT system. However, it is known to be very difficult. This is due to the fact that BNCT is a treatment, not a diagnosis such as MRI and CT. More practically, **①Primary radiation for BNCT is neutron, however, the SPECT measures secondary radiation of extremely weak 478 keV gamma-rays.** In addition, **② The SPECT system cannot move 360 deg. like X-ray CT due to various constraints, e.g., a patient should contact the neutron exit wall.** As the result, it is known that the technical difficulty is critically serious, and it is thus very hard to obtain accurate images. Now, Japan lead BNCT in the world and Japan has first started an accelerator based BNCT in a hospital. Considering this situation, we should put the SPECT system for BNCT (BNCT-SPECT) into practical use in BNCT treatment as soon as possible.

Present status for difficulties ① and ②

①Examination carried out under the support by the following two JSPS KAKENHI. The tables below show the design result which meets requirements of BNCT clinical doctors (spatial resolution of 5 mm and accuracy of 5 %) first in the world.

・Grant-in-Aid for Scientific Research (B), Grant Number 22360405 (2010～2014), I. Murata

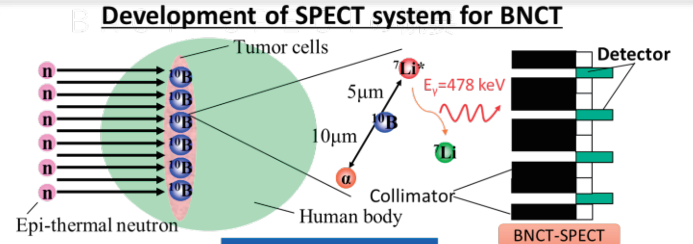
・Grant-in-Aid for Scientific Research (B), Grant Number 15H04242 (2015～2019), I. Murata

②Supported by「Masason Foundation」, reconstruction of image was successfully performed even in case of limited projection angles of 180 deg. with Bayesian estimation. (**H. Inamoto et al., "A New Image Reconstruction Technique with Limited View-angle Projection Data for BNCT-SPECT", 2020 IEEE NSS MIC, Boston, USA, M-08-149 (2020).**)

③For further improvement of the accuracy, we employed coincidence, anti-coincidence and veto detector simultaneously to increase S/N ratio, (**Patent pending, 2022-210091, "SPECT system for real-time measurement of local boron dose for BNCT**")

④**Under the support of METI, Japan**, the prototype SPECT system is being developed now. In parallel, the image reconstruction system was investigated to reproduce images with practically measured data.

Development of SPECT system for BNCT



Principle of BNCT−SPECT

BNCT ^{10}B is accumulated only in tumor cells by administering boron drug, BPA and/or BSH. Then neutrons are irradiated to induce the neutron-^{10}B reaction above to emit α and ^{7}Li particles, which kill the tumor cells selectively, because ranges of the emitted particles are as long as cell size. It means, if ^{10}B is accumulated only in tumor cells, only the tumor cells are killed making adjacent normal cells survive. BNCT is thus a sharper therapy than other radiotherapies, i.e., called the **only tumor-cell selective therapy**.

BNCT-SPECT Emitted ^{7}Li is in its excited state and immediately decays creating a 478 keV gamma-ray promptly. By measuring the gamma-ray with a SPECT system to estimate the three dimensional distribution (image) of the number of above reactions, that is, the therapeutic effect of BNCT.

Table Design examples of SPECT for BNCT in the world.

Author	Institute	Year	Detector element		
			Material	Size	Material
Kobayashi, T.	Kyoto University	2000	CdTe	(not mentioned)	Tungsten
Ishikawa, M.	Hiroshima University	2001	BGO	5 mmΦ x 5 cm	Heavy metal
Minsky, D.M.	San Martin University	2011	$LaBr_3$	1 in x 1 in ϕ	Lead
Hales, B.	Tokyo Institute of Technology	2017	CZT	1 x 1 x 1 cm	Lead
I. Kanno	Kyoto University	2019	TlBr	0.5x0.5x1cm	Tungsten
Murata, I.*1	Osaka University	2019	GAGG	3.5 x 3.5 x 30 mm	Tungsten

*1 From the present result, *2 From detector pitch

Table 6 Design result and performance.

Design item		Design result
Scintillator	Material	GAGG(Ce)
	Dimensions	3.5 x 3.5 x 30 mm^3
Collimator	Material	Tungsten
	Hole pitch	4.0 mm
	Hole diameter	3.5 mm
	Length	26 cm
Design goal item		**Performance (Goal)**
Statistical accuracy		4.4 % (5 %)
Spatial resolution		5.1 mm (5 mm)

←Design and performance of BNCT-SPECT, cited from the paper: I. Murata et al., "Design of SPECT for BNCT to measure local boron dose with GAGG scintillator", Applied Radiation and Isotopes, **181**, 110056 (2022).

↑Cited from design criteria of BNCT compiled by IAEA (2021).

We aim to spread BNCT by employing an accelerator based neutron source instead of nuclear reactor. Japan is leading in BNCT and five projects are underway in Japan, including our group. Accelerator based BNCT system is small and cheap compared to conventional nuclear reactor based BNCT, and thus one machine in one prefecture is aimed. It means, 50 BNCT-SPECT machines are required inside Japan and ten to hundred times are required commercially in the world. We completed the basic performance characterization of the machine and now making the prototype machine to verify the real performance. Then we are aiming at producing the real machine with a partner company.