Development of Real Time Boron Dosimetry for Boron Absorption Dose in Boron Neutron Capture Therapy Using Optical Fiber

Hyun Do Huh, Chang Yeol Lee, Woo Chul Kim, Hun Jeong Kim, Jeong shim Lee

Department of Radiation Oncology, College of Medicine, Inha University, Incheon, Korea

Introduction

1. BNCT Of The History

Boron Neuron capture radiotherapy was first proposed by Chadwick in 1932 shortly after neutron discovery. In 1934, Goldhaber presented the elaboration of a naturally occurring ^{10}B abnormally large thermal neutron capture cross section by Goldhaber. ^{10}B immediately becomes ^{11}B after capturing the thermal neutrons and immediately collapses. During the decay process, alpha particles, lithium ions, and gamma rays are typically emitted. These particles have a binding region of 12-13 µm (similar to cell size) in the tissue. The combined average energy is about 2.33 MeV. Gordon Locher first proposed the principle of boron neutron capture therapy(BNCT) in 1936. He hypothesized that if boron could be selectively concentrated in the tumor, the volume of neutron irradiation would result in relatively high radiation doses to adjacent normal tissues.

Based on the experience of carrying out reactor-based boron neutron capture treatment in Europe and Japan, the research focused on miniaturizing neutron irradiation devices that can be installed in medical institutions around the world(tab.1).

Table 1. Current statute accelerator-based BNCT facilities in the world.

No	Machine(status)	Target & reaction	Proton Beam Energy(MeV)	Proton beam current(mA)	Location
1	Vacuum insulated Tandem(Ready)	solide $^{7}Li(p,n)$	2	2	Budker institute(Russia)
2	Cascade generator KG-2.5(Ready)	solide $^{7}Li(p,n)$	2.3	3	iPPE-Obninsk(Russia)
3	Dyanutron	solide $^{7}Li(p,n)$	2.8	1	Birmingham UNiv.(UK)
4	RFQ-DTL(Ready)	Liquid $^{7}Li(p,n)$	4	1	Soreq(Israel)
5	RFQ single ended Tandem	Be(p,n)	4-5	30	Legnaro INF(Italy)
6	Electrostatic Quadrupole(TESQ)	solide $^{7}Li(p,n)$	2.5	30	CNEA Buenos Aires(Argentina)
7	Cyclotron(clinical trial)	Be(p,n)	30	1	KURRI(japan)
8	RFQ-DTL(Ready)	Be(p,n)	8	10	Univ. Tsukuba(japan)
9	RFQ(Ready)	solide $^{7}Li(p,n)$	2.5	20	NC center.CICS(japan)
10	Cyclotron	Be(p,n)	30	1	Fukushima South Tohoku Hospital(japan)
11	Neutron target system	Liqued $^{7}Li(p,n)$	2.5		Osaka Univ.(japan)
12	Dynamitron	solide $^{7}Li(p,n)$			Nagoy Univ.(japan)
13	RFQ-DTL	Be(p,n)	10	10	Incheon, Korea

2. BNCT absorbed dose measurement method

Thermal neutral beams used in BNCT radiotherapy generate four absorbed dose components in the irradiated tissue.

- photon dose $D\gamma$
- High Speed Neutron Dose Dn
- nitrogen dose D_N
- Boron dose D_B

Photon doses are delivered by electrons generated by interactions with photons in the tissue. he photon beam dose is caused by the photon beam component of the incident beam and the photon beam generated by neutron capture by hydrogen ^{1}H (n, γ) ^{2}H in the tissue. The fast neutron doses are mainly delivered by the fast neutrons and the bounce protons by the ^{1}H (n, n) p reaction of the hot neutrons with hydrogen. Nitrogen doses are delivered by protons produced by the ^{14}N (n, p) ^{14}C reaction by neutron capture of nitrogen. The boron dose is caused by the boron neutron capture action ^{10}B (n, α) ^{7}Li and is transmitted by alpha particles and bounced lithium ions(tab.2).

Table 2. The dose components in tissue in an epithermal neutron beam and their source reactions. Example methods for determining the dose components and their reported uncertainties are listed. The relevance of each dose component for the treatment can be appreciated through their contribution to the total biologically weighted dose in normal brain (healthy tissue) and target (tumour).

Dose component	Dose due to (particle)	Dose deposited locally* (yes/no)	Particle due to (reaction)	Reaction due to (particle)	Example method of measurement	Measured quantity	Required calculated result for method
D_γ	Photon	No	$^{1}H(n,g)^{2}H^{\dagger}$	n_{th}	Mg(Ar) IC	D_γ	
D_n	Proton	Yes	$^{1}H(n,n')p$	n_{fast}	Mg(Ar) IC	$D_\gamma+D_n+D_N$	Neutron spectrum, n_{th}
D_N	Proton	Yes	$^{14}N(n,p)^{14}C$	n_{th}	Foils	Reaction rate	n_{th}_calc
D_B	α, Li-ion	Yes	$^{10}B(n,a)^{7}Li^{\ddagger}$	n_{th}	Foils	Reaction rate	n_{th}_calc

1. A measurements of absorbed dose by a ion chamber.

The dual ion ionization method is used to determine the fast neutron and nitrogen absorbed doses combined with photon rays. A-150 Tissue Equivalent (TE) Ion ionizers (TE (TE)), filled with plastic and tissue equivalent gases, are used to determine neutron doses.

2. A measurements of absorbed dose by a microdosimetry.

Microdose measurement using a tissue equivalent proportional counter can be applied to measure photon and neutron doses. The boron dose can be measured using a TEPC containing ^{10}B in the walls of the detector and in the gas. Unlike the ion ionization method, the counter operates in pulse mode. The difference in amplitude between events related to photon dose and neutron dose enables the separation of these dose components.

3. A dose evaluation method by gel dosimetry

Polymer and Fricker gels have been introduced as excellent tools for the dosimetry of BNCT.

A various methods for measuring the dose of boron neutron capture radiotherapy (BNCT) have been proposed. However, no standard measurement method has yet been proposed for BNCT.

Therefore, this study attempted to suggest a method to measure the dose of boron neutron capture radiotherapy in real time using a optical fiber system.

Materials and Methods

In this study, the system was constructed using commercially available applications. A scintillator material (BCF-12) was used to generate the primary optical signal when boron neutron capture. A signal amplifier(PMT, signal rise time:0.57ns. Hamamatsu, japan) was used. An analog signal conversion digitizer(Model : DT5743, CANE, italy) was used. The software(CANE, italy) used mc^2 (Fig.1).

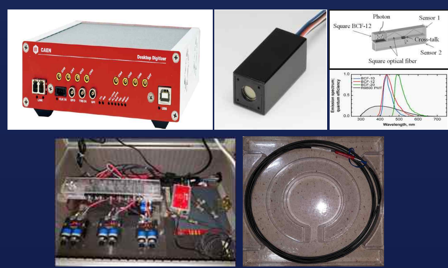

Fig.1. This diagram shows the system configuration using optical fiber for the treatment of boron neutron capture.

In this study, this system was used to evaluate the usefulness of the system using light beams prior to boron neutron dose measurement in the BNCT system.

Results

The usefulness of the optical fiber real-time boron absorbed dose measurement system constructed in this study was evaluated using the light beam. The result is as shown in the figure(Fig.2).

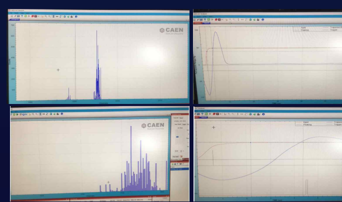

Fig. 2. The schematic diagram is a preliminary tests using a normal light beam prior to measuring boron neutron absorbed dose.

Summary

As a result of this study, it is strongly expected that the absorbed dose of boron neutrons can be measured in real time. However, further experiments with neutron beams and boron should be further studied

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