Activity estimation during accelerator-based BNCT treatment

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Introduction

Boron neutron capture therapy (BNCT) is one of the particle therapy that can selectively kill only cancer cells by irradiating epithermal neutron to cancer cells which uptake ^{10}B compound. Since BNCT requires neutron irradiation for a long time, activation of all constituent elements contained in the patient's body might be a problem. Concerns regarding radiation may include exposure of the patient, exposure of medical personnel, public exposure, etc. In this report, we investigated the effective radiation dose associated with patient activation predicted by accelerator-based BNCT neutron source using a particle transport Monte Carlo code.

Objective

In this presentation, we will report on the effective radiation dose associated with patient activation predicted by accelerator-based BNCT neutron source using a particle transport Monte Carlo code.

Materials and Methods

Neutron source

- The neutron energy spectrum of Cyclotron based epithermal neutron source (C-BENS) at Kyoto University was assumed for the accelerator-based BNCT neutron source (Fig. 1).

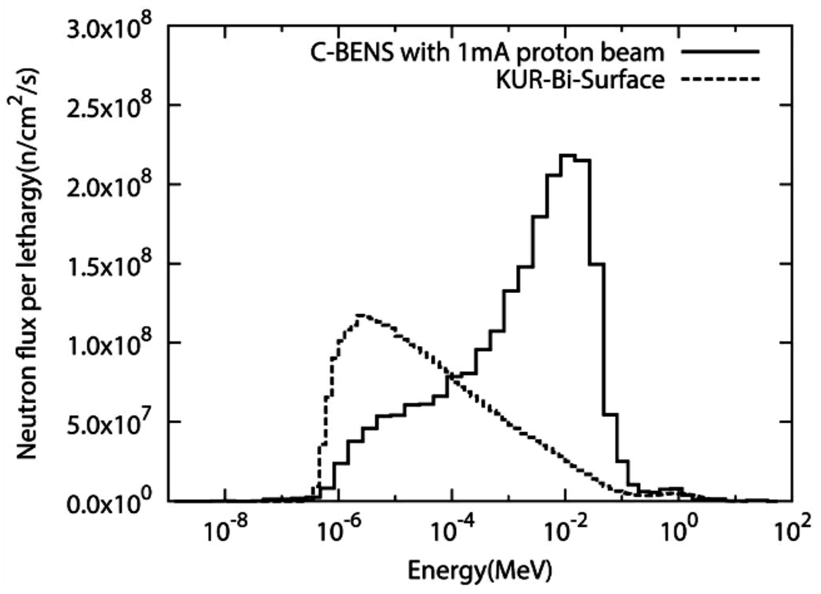


Fig. 1 The neutron energy spectrum of C-BENS.

Body elements

- The tissue composition and density in the body were obtained from ICRU No.44 (Table 1)[1].
- Since activation by dental prosthetic materials might be occurred in the treatment of the head and neck region, the elements contained in dental materials and the maximum expected usage were listed in Table 2.
- For estimation of blood activation due to ^{23}Na and ^{37}Cl, the density of blood and the amount of irradiated blood were assumed to be 1 g/cm^3 and 100 cm^3, respectively.
- For estimation of bone activation due to ^{48}Ca, the irradiated volume with bone was assumed to be 10 cm^3.

Table. 1 Tissue composition and density in the body.

Symbol	H	C	N	O	Na	Mg	P	S	Cl	K	Ca	Fe	I	Density [g/cm^3]
Soft tissue	10.5	12.5	2.6	73.5	0.2		0.2	0.18	0.22	0.21	0.01	0.01	0.01	1.05
Adipose	11.4	59.8	0.7	27.8	0.1			0.1	0.1					0.95
Lung	10.3	10.5	3.1	74.9	0.2		0.2	0.3	0.3	0.2				0.26
Muscle	10.2	14.3	3.4	71.0	0.1		0.2	0.3	0.1	0.4				1.05
Skin	10	20.4	4.2	64.5	0.2		0.1	0.2	0.3	0.1				1.09
Cartilage	9.6	9.9	2.2	74.4	0.5		2.2	0.9	0.3					1.10
Bone	3.4	15.5	4.2	43.5	0.1	0.2	10.3	0.3			22.5			1.92
Red bone marrow	10.5	41.4	3.4	43.9			0.1	0.2	0.2	0.2		0.1		1.03
Yellow bone marrow	11.5	64.4	0.7	23.1	0.1			0.1	0.1					0.98

Table. 2 Elements contained in dental materials and assumed maximum usage

Elements	Abundance or content	Usage [g] (Worst case)
Na	Ex: 145mM In: 12mM	
Cl	Ex: 116mM In: 4mM	
Ca	25% (Bone)	
P	12% (Bone)	
V	3.5-4.5%*	
Ti	100%*	
Au	≧ 65%*	42.2
Ag	≧ 60%*	16.2
Pt	≦ 12%*	2.3

Elements	Abundance or content	Usage [g] (Worst case)
Pd	≧ 20%*	6.3
Cr	≧ 25%*	
Co	~ 70%*	
Ni	≧ 70%*	
In	≦ 25%*	4.7
Mo	≧ 4%*	
Cd	≦ 0.02%*	
Be	≦ 0.02%*	
Cu	≦ 7%*	6.9
Al	5.5-6.75%*	2.2
Fe	≦ 0.3%*	

Elements	Abundance or content	Usage [g] (Worst case)
Zr	ZrO_2*	11.7
Y		0.4
Ba	Contrast media*	
Sr	Contrast media*	
La	Contrast media*	
Zn	ZnO*	3.7
I	CHI_3*	

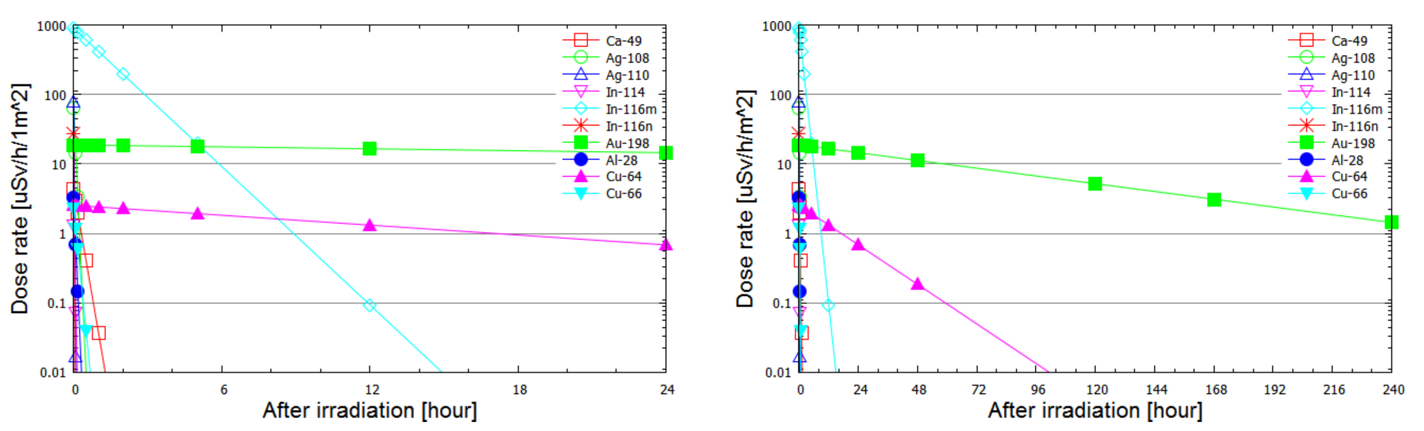
Ex: Extracellular, In: Intracellular
* Dental material

Activity estimation

- For the activity estimation, particle transport Monte Carlo calculation code PHITS ver.2.89[2] and DCHAIN-SP (ver. 2014)[3] were used.
- Assuming a cylindrical phantom of 18 cmϕ×20 cm filled with each element as a density of 1 g/cm^3, and a neutron irradiation of 1 cm ϕ parallel beam of C-BENS along the central axis of the phantom was assumed.
- DCHAIN-SP was used to calculate the effective dose rate change assuming irradiation of epithermal neutrons for 1.0 hour at 1.0×10^9 [n/cm^2/s] (composition of epithermal neutrons: 93.7%, 0.5 eV to 10 keV).
- The change in the effective dose rate at a position 1 m away from the patient when each constituent element and the maximum amount of dental material assumed were activated by irradiation was calculated. Patient shielding is not considered in this study.

Results and discussion

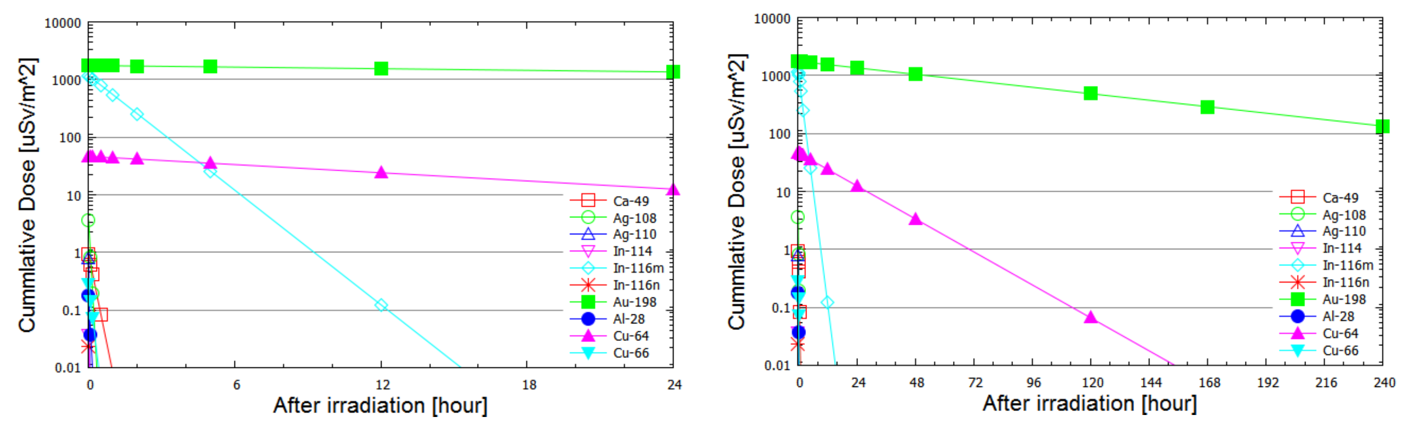
- Figure 2 shows the change in effective dose rate per gram of element at a distance of 1 m due to each element generated by activation. Immediately after the end of irradiation, the effective dose rate by ^{108}Ag is the highest, but it decays quickly and falls to a level that cannot be detected within one day.
- Subsequently, it can be seen that the effective dose rates of ^{198}Au and ^{64}Cu are high. Since ^{198}Au has a half-life of about 2.7 days, and about 7.7% of radioactivity remains even after 10 days from irradiation, there is concern about exposure to the public due to patients going out.
- In this study, the effective dose rate due to activation when irradiated with 1.0×10^9 [n/cm^2/s] of epithermal neutrons for 1 g of element for 1 hour was calculated, but in general BNCT irradiation, the thermal neutron fluence of about 1.6×10^{12} [n/cm^2] was irradiated. Epithermal neutrons were decelerated in the body and changed to thermal neutrons, and the peak value can be estimated as about 2.5×10^9 [n/cm^2/s] for assumed condition. So the total thermal neutron fluence can be estimated as 2.5×10^9 [n/cm^2/s] ×3,600 [sec] = 9.0×10^{12} [n/cm^2].



(a) first 24 hours (b) first 10 days

Fig. 2 Effective dose rate change after irradiation at a distance of 1 m from the patient.

- Therefore, a realistic value can be calculated by multiplying the calculated value performed in this study by a factor of 1.6×10^{12} [n/cm^2] ÷ 9×10^{12} [n/cm^2] = 0.178. Since the gold usage is 42.2 g in the worst case, the effective dose rate at 1 m from the patient is 3.34 μSv/h after 1 day and 2.58 μSv/h after 10 days.
- Figure 3 shows the Relationship between cooling time after irradiation and annual effective dose at a distance of 1 m from the patient. The cumulative effective dose for 1 year after the end of irradiation for one year from the patient is 241 μSv, and it can be reduced to 86.3 μSv after 5-days cooling. Therefore, exposure to the public is considered to be negligibly low.



(a) first 24 hours (b) first 10 days

Fig. 3 Relationship between cooling time after irradiation and annual effective dose at a distance of 1 m from the patient.

Conclusion

As a result of examining the activation of constitutive elements and dental materials by BNCT irradiation using an accelerator neutron source, the exposure to the public by constitutive elements was negligibly small. Among dental materials, gold has a particularly large activation cross section and a long half-life of about 2.7 days, which may exceed the exposure limit for the general public. Furthermore, since the patient himself/herself is exposed to a great deal of radiation, it is essential to take measures such as extracting a tooth in advance when the patient uses gold teeth.

Acknowledgement

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