Optimization of Beam Shaping Assembly and Thermal Neutron Flux Measurement for BNCT

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Highlights

- The pilot design of the beam shaping assembly (BSA) is optimized.
- By adding the reflector and increased density of the moderator, the BSA configuration D successfully satisfied the IAEA criteria
- The TLD-600 and TLD-700 were proposed to measure a thermal neutron flux, which is used to evaluate ^{10}B and ^{14}N doses for boron neutron capture therapy (BNCT).
- The thermal neutron flux was accurately measured by TLDs having a 5% difference from the one by the gold wire.

Material and Method

BSA optimization

- For the optimization, the pilot design was modified except the proton beam parameters (8 MeV and 10 mA), the beryllium target shape (2-cm thick), and the size of the beam exit port (12-cm in diameter).
- Accordingly, the thickness and material combination of BSA components, such as moderator, collimator, reflector, etc., were changed to satisfy IAEA criteria [1].

TLD reading

- The TLD-600 and TLD-700 (Harshaw, USA) chips were prepared for this study. Its diameter was 4.5 mm and the thickness was 0.6 mm. The TLDs used in this study are lithium fluoride based materials (LiF:Mg,Ti). TLD-600 was enriched by ^{6}Li (95.6%) whereas TLD-700 was enriched by ^{7}Li(99.99%) [2].
- The TLDs were annealed with an electric furnace at 400℃ for 1 hour followed by 100℃ for 2 hours to eliminate the residual signals before the irradiation. The readout of TLDs was done by using Harshaw TLD reader (Model 3500). The TLDs were linearly heated from 50 ℃ to 300 ℃ at 10 ℃/sec. The acquisition time was 33.3 seconds. The TL signal was converted in the unit of electric charges by integrating the glow curves from channels 72 to 200.
- The thermal neutron induced TL signal was separated by using the combination of TLD-600, TLD-700 and cadmium sheets with their different interaction probabilities of neutrons and gamma rays.

TLD calibration factor

- The TLDs were calibrated using a ^{252}Cf neutron source within a 30 cm-diameter D_2O sphere to produce the thermal neutron flux calibration factor.
- The calibration factor was obtained by dividing the neutron-induced TLD readings by the thermal neutron fluence.
- The neutron self-shielding correction was calculated to compensate for the perturbed neutron fluence in TLDs.

TLD validation

- To evaluate whether the calculated TLD calibration factor is valid, a research/educational reactor, known as a thermal neutron source, was used.
- The thermal neutron flux measured through the applying calibration factors of TLDs was compared with the thermal neutron flux using the conventional gold wire activation method.

Results and Discussion

BSA optimization

BSA configuration	ϕ_{epi} [cm^{-2} s^{-1}]	ϕ_{th} / ϕ_{epi}	Hydrogen dose / ϕ_{epi} [Gy-cm^2]	Photon dose / ϕ_{epi} [Gy-cm^2]	Directionality
IAEA recommendation	> 1×10^9	< 0.05	< 2×10^{-13}	< 2×10^{-13}	> 0.7
Pilot design (8 mA)	1.40×10^9	0.015	6.80×10^{-13}	0.69×10^{-13}	0.780
A (8 mA)	2.14×10^9	0.011	8.64×10^{-13}	0.39×10^{-13}	0.715
B (8 mA)	2.97×10^9	0.012	8.55×10^{-13}	0.40×10^{-13}	0.714
C (8 mA)	1.92×10^9	0.045	1.78×10^{-13}	0.91×10^{-13}	0.714
D (8 mA)	1.78×10^9	0.031	1.84×10^{-13}	0.87×10^{-13}	0.715

Table 1. The beam characteristics of various BSA designs.

TLD validation

Irradiation	#1 (2W, 0.5 h)	#2 (2W, 0.5 h)	#3 (4W, 0.5h)	#4 (4W, 0.5h)
Thermal neutron induced signal (nC)	6720.67	6396.22	13873.72	13573.92
Calibration factor [cm^{-2} nC^{-1}]	**3.8×10^4**			
Thermal neutron flux [$cm^{-2}s^{-1}W^{-1}$]	2.29×10^5	2.18×10^5	2.36×10^5	2.31×10^5
	Gold wire: 2.17×10^5			
Relative difference [Flux TLD / Gold]	**1.05**	**1.004**	**1.08**	**1.06**

Table 2. The results of validation of TLDs at the reactor.

- The beam characteristics of configuration D fully satisfied all of the IAEA criteria.
- The thermal neuron flux at the reactor was 2.28×10^5 $cm^{-2}W^{-1}s^{-1}$ by the TLD method and 2.17×10^5 $cm^{-2}W^{-1}s^{-1}$ by the gold activation method. And the difference in the thermal neutron fluxes was 5%.

Conclusion

- In this study, the BSA was optimized, and the alternative thermal neutron flux measurement was established.
- The TLD was successfully validated against an unknown mixed neutron/gamma field from the reactor, showing about 5% difference in measured thermal neutron fluences when compared to the conventional gold activation method.
- Therefore, the two major dose components of BNCT, 10B and 14N doses can be accurately evaluated by the neutron-induced TLD dose.

References

[1] Current Status of Neutron Capture Therapy. 2001, Vienna: INTERNATIONAL ATOMIC ENERGY AGENCY
[2] Model 3500 Manual TLD Reader With WinREMS, Operator's Manual, Thermo Scientific. 2010.