Exploring Research Reactors for Boron Neutron Capture Therapy as an Alternative Treatment for *Cholangiocarcinoma*

Yuwadee Malad[1], Dea Aulia Kartini[1], Atirat Pitaktrakul[1], Natsuko Kondo[2], Yoshinori Sakurai[2], Chutima Talabnin[3], and Chinorat Kobdaj[1]

[1] *School of Physics, Institute of Science, Suranaree University of Technology: Nakhon Ratchasima, 30000, Thailand, y.malad.research@gmail.com (Y.M.), dea.kartini@sut.ac.th (D.K.), M6400156@g.sut.ac.th (A.P.), kobdaj@g.sut.ac.th (C.K.)*
[2] *Institute for Integrated Radiation and Nuclear Science, Kyoto University (KURNS): Osaka 590-0494, Japan, kondo.natsuko.3x@kyoto-u.ac.jp (N.K.),sakurai.yoshinori.8n@kyoto-u.ac.jp (Y.S.)*
[3] *School of Chemistry, Institute of Science, Suranaree University of Technology: Nakhon Ratchasima, 30000, Thailand,* chutima.sub@sut.ac.th (C.T.)

EXTENDED ABSTRACT

Recently, Boron Neutron Capture Therapy (BNCT) has received increased attention as an alternative treatment for aggressive and recurrent cancers. This work explores and compares five different research reactors—Kyoto University Reactor (KUR), Tsing Hua Open-pool Reactor (THOR), the Institute of Heavy Ion Nuclear Industry (IHNI), the Thai Research Reactor-1/Modification 1 (TRR-1/M1) from the Thailand Institute of Nuclear Technology (TINT), and the Suranaree University of Technology Research Reactor (SUT-RR). The comparison focuses on beam shaping assembly (BSA) designs, moderator and shielding materials, and the readiness for BNCT implementation in Asia.

SUT-RR is designed with a 45 kW power output and a BSA optimized for BNCT, which is expected to play a major role in future studies and clinical translation in Thailand. Table 1 summarizes the BSA material compositions used across these Asian BNCT facilities. The table highlights design diversity, particularly regarding use of fission converters and shielding elements for optimizing beam quality. SUT-RR aims to provide a BNCT-optimized beamline with a fission converter, whereas TINT is currently assessing the feasibility of establishing a localized BNCT platform based on its TRR-1/M1 reactor.

Currently, only in vitro experiments on KKU-055 cholangiocarcinoma (CCA) cells have been conducted to demonstrate biological efficacy. Cells were treated with boron compounds and irradiated using neutron fluxes of 2.6×10^8 n·cm^{-2}·s^{-1} for 30 minutes at TINT and 1.89×10^9 n·cm^{-2}·s^{-1} for 5 minutes at KUR. The resulting neutron fluences were 4.68×10^{11} n·cm^{-2} and 5.67×10^{11} n·cm^{-2}, respectively. Post-irradiation analyses included cell viability testing (MTT assay), clonogenic survival, and γH2AX immunofluorescence staining to assess DNA damage.

The results indicated significant DNA damage, as evidenced by increased γH2AX foci, and neutron fluence-dependent cell death. At TINT, ^{10}B uptake for 24 hours led to stronger DNA damage signals and lower viability (80%) compared to shorter uptake times. At KUR, cells exposed to higher ^{10}B concentrations (10–20 ppm) and high neutron flux exhibited intense γH2AX expression and reduced survival fractions. The Relative Biological Effectiveness (RBE) derived from KUR data was 4.34, suggesting a substantial therapeutic benefit over conventional X-ray irradiation.

These findings support the potential of BNCT as an effective treatment for CCA, particularly when neutron beam intensity and boron uptake conditions are optimized. This work underscores the readiness of multiple Asian reactors for BNCT and introduces Thailand's forthcoming capability at SUT-RR. Integrating these platforms enhances regional preparedness for implementing risk-informed, reactor-based therapies. The development of SUT-RR is expected to provide a controlled environment for optimizing BNCT beam design and biological safety thresholds, further supporting its translational potential within Southeast Asia.

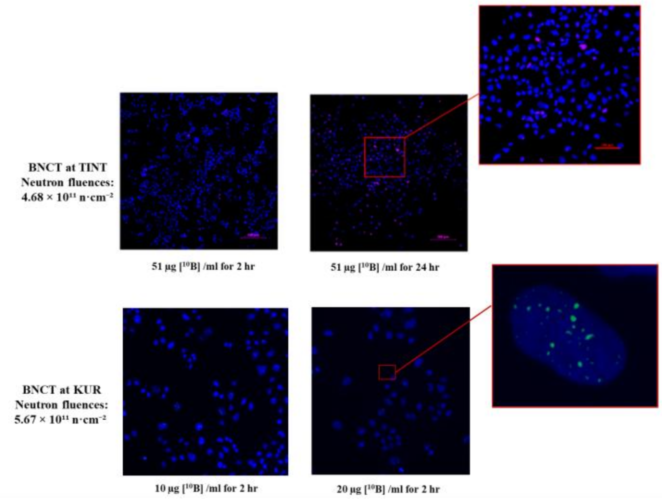

FIGURE 1. γH2AX immunofluorescence images of KKU-055 cells following BNCT at TINT and KUR. DNA damage, shown by green γH2AX foci, increases with longer boron uptake time and higher ^{10}B concentration, indicating fluence- and dose-dependent effects.

TABLE I. BSA materials used in BNCT beams in Asia

Reactor	BSA Materials	Fission Converter	References
KUR	$Al/D_2O/Bi/Pb$/Polyethylene/B-Polyethylene/Cd	No	1]
THOR	Al/Fluental/Pb/Bi/Li-Polyethylene/Heavy concrete	No	[2]
IHNI	Epithermal mode: $Al/Al_2O_3/Pb/Bi/C$, Thermal mode: Bi/Pb/C/PE(Pb)	No	[3]
SUT-RR	$AlF_3+Al+LiF/Pb/H_2O$/Pb-B-Poly/Cd/Li-Poly/Al/Bi/SS/Heavy concrete	Yes	*Unpublished manual*
TINT	Unspecified	Yes	*Not reported*

Representative γH2AX immunofluorescence images show DNA double-strand breaks in KKU-055 cells following BNCT irradiation. Cells treated with ^{10}B and irradiated for 5 minutes at KUR (Japan) and 30 minutes at TINT (Thailand) display increased γH2AX foci (green), indicating neutron fluence- and uptake-time dependent DNA damage. These results support the potential of BNCT for CCA treatment and demonstrate reactor capabilities in Asia. The forthcoming SUT-RR reactor is expected to extend BNCT accessibility within Thailand.

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