Design of Beam Shaping Assembly (BSA) for Accelerator Driven Boron Neutron Capture Therapy (AD- BNCT)

D. Saikia[1],* M. Baro[1], M. M. Devi[2], S S Ghugre[3], A. Barthakur[1], J.J. Das[1], A. Nath[1], M Patgiri[1], D. Sarma[1], G. C. Wary[1], K. Boruah[4], B. Jyrwa[5], N. Nimai Singh[6], P. C. Rout[7], Rajarshi Raut[7], S. Santra[7], V. M. Datar[8], S. Sharma[9], P Kalita[4], S Goswami[9]

[1]*Department of Physics, Cotton University, Guwahati, Assam*
[2]*Department of Physics, Tezpur University, Guwahati, Assam*
[3]*UGC-DAE CSR, Kolkata Centre, WB*
[4]*Department of Physics, Gauhati University, Guwahati, Assam*
[5]*Department of Physics, North Eastern Hill University, Shillong, Meghalaya*
[6]*Department of Physics, Manipur University, Imphal, Manipur*
[7]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai*
[8]*Raja Ramanna Fellow, IMSc, Chennai*
[9]*Dr. B. Borooah Cancer Institute, Guwahati, Assam*
[*]*Email: dimsaikia.22@gmail.com*

Introduction: CUPAC-NE collaboration (Cotton University Particle accelerator Centre and North East Collaboration) has proposed to construct a discovery class accelerator facility with a 5 MV Van de Graff accelerator with an ECRIS at terminal. The accelerator is capable of delivering 1 mA proton beam and other heavy ion beams including inert gases like Ne, Ar, Xe, Kr etc [1]. If funded, the accelerator will not only be the first in the NE region but also will be the first of its kind in the nation. With an aim to optimally use the enormous capabilities of the accelerator, the collaboration has started looking for world class research ideas which will provide scientific justification for the mega investment needed for the project. Realizing that 5 kW proton beam power available from the facility (1 mA at 5 MeV) can be used to construct a world class neutron source, neutron science became one of the natural choice for the collaboration and identified AD-BNCT as a strong area of focus.

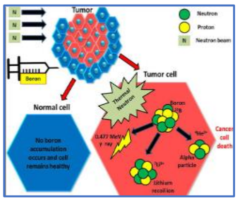

Fig.1a Destruction of Cancer cell in BNCT

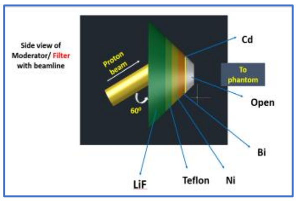

Fig.1b: The 3D CAD model of BSA developed at Cotton University.

AD-BNCT (refer to Fig. 1a) is a two-stage cancer treatment process: First, a ^{10}B-containing drug is infused into the patient's bloodstream and the Borons preferentially accumulate in cancer cells. When a cancer cell containing boron is irradiated with ENB (epithermal neutron beam), B fissions into an α & Li particles. Both of these have ~MeV energy with a range of about the size of a cell. Thus the entire energy gets deposited in the cancer cell and destroys it while sparing neighbouring healthy cell unlike other current methods of cancer treatment. Historically, BNCT was performed using neutron beam from reactors. However due to inherently complex nature of reactors, its high cost of construction & operation and associated regulatory issues, its access was highly limited. To add to it, various safety incidents involving reactors in 1990s resulted in nearly complete shutdown of such facilities. So, during the last 3 decades, scientists started focusing on producing high flux neutron beam using an accelerator. To achieve flux similar to a reactor required high current proton accelerator with commensurate development of target capable of withstanding high power and highly efficient neutron optics which will result in delivering entire neutron flux to the patient. These efforts resulted in development of AD-BNCT. After prolonged clinical trials, the first Boron drug was approved by FDA (USA, 2020) and the device license for AD-BNCT was issued by FDA, Japan in 2019. However, the technology is strictly prohibited for export to India and our collaboration has started R&D for indigenous development of the technology. In this paper, we will report status of our efforts towards developing one key element of AD-BNCT technology, the high efficiency neutron optics, called BSA. Apart from ensuring efficient delivery of neutrons produced in the target to the patient, BSA also has several other critical functions. The IAEA has strictly defined the characteristics of the neutron beam that can be used for BNCT to treat patients (see Table (1)). We can clearly see that the energy spectra of neutrons produced from a thick Li or Be target using (p,n) reactions does not have any of these characteristics. This defines the expected functioning of the BSA and hence criticality of the design parameters.

Methodology: BSA is composed of the following parts: a) Target, b) Moderator/ Filter, c) Reflector and d) shielding. According to the IAEA TECDOC-1223, neutrons from 0.5 eV to 10 keV are desired for the deep position cancer. Little bit higher mass number nucleus than hydrogen are preferable. In such materials, fluorine is the best candidate since it also has low threshold energy, about 100 keV, of inelastic scattering, another process of slowing-down, which can effectively reduce the neutron energy. Purpose of reflector is to reflect the fast neutron produced and eventually focussing them towards the exit window. To obtain high intensity of the epithermal neutrons, the reflector should not have high slowing down efficiency. Therefore, high mass number materials are preferable.

Table (1) IAEA recommended values

BNCT beam parameters	IAEA recommended value
$f_{epithermal}$ (n cm^{-2} s^{-1})	~ 10^9
$f_{epithermal}/f_{fast}$	>20
$f_{epithermal}/f_{thermal}$	>100
$D_{fast}/f_{epithermal}$ (Gy cm^2)	< $2x10^{-13}$
$D_{\gamma}/f_{epithermal}$ (Gy cm^2)	< 2 x 10^{-13}

In the BSA set-up, neutrons will be produced after Proton beam strikes the target. Then fast neutrons will be moderated by LiF and Teflon filters. The fast neutrons mainly interact with reflector via elastic scattering. Then, Ni thermalises the fast neutrons to epithermal neutrons. Bi filers the gamma that is produced. After Bi, 0.5mm Cd is used to convert epithermal neutron to thermal neutron. There is shielding of lead surrounding the moderator and reflector. The shielding reduces the background radiation and also shields the produced daughter products from the surrounding.

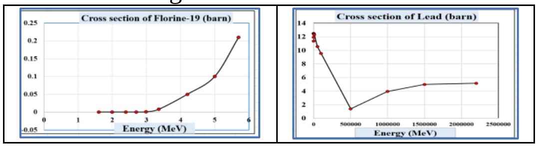

Fig. (2) Cross sections (in barn) of Florine and Lead for different energies of neutron

Discussion and Summary: We have carried out investigation of material properties to determine its availability in India and/or prevalant export restrictons, machining requirements, chemical toxicity etc. before choosing these materails. ENDF calculations were done to ascertain the baseline suitability of the chosen materials to deliver desired results. A sample result of our effort is shown in Fig.2. In the next stage, we propose to perform extensive investigation using GEANT4 and/or MCNP simulations and finalize our BSA design. We may mention here that we also considered another very recent BSA geometry [Naonori Hu and Hiroki Tanaka]. However, we opted for the geometry reported in this paper. The reason being, in our judgement, geometry (Fig. 1b), will match the beam hall configuration of our accelerator proposal better [1].

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References:

[1] Wary, G.C. et. al., 'Proposed accelerator facility for fundamental and applied sciences by CUPAC – North East', Proceedings of the DAE Symp. on Nucl. Phys. 65 (2021), pp. 5-6.

[2] CRS/2021-22/02/526; Development of high flux Neutron Beam Shaping Assembly (BSA) for BNCT applications; M. Baro, Sandeep S Ghugre et. al.