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RESEARCH ON AN ACCELERATOR-BASED BNCT FACILITY*

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Abstract

Eight people are being diagnosed with cancer per minute in China, and cancer has been the leading cause of death with about one fourth of all deaths in China. As an effective method and way without surgeries for cancer therapy, Bo-ron Neutron Cancer Therapy (BNCT) has drawn greater attention. Accelerator based neutron source is a compact and safer neutron source, and technologies of accelerating a high current beam has matured. We proposed an accel-erator based BNCT (AB-BNCT) facility, which can accel-erate a 10mA proton beam up to 7MeV and produce over 10^{13} n/cm^2/sec thermal neutrons by bombarding on a shielded Beryllium target. The dynamics of accelerators and produced neutron calculations will be reported in this paper.

INTRODUCTION

In China, cancer patient increased 4.3 million, and there were over 2.8 million deaths from cancer in 2015 [1]. It is urgency to develop a safer, cost-down, more effective treatment technique. The Boron neutron capture therapy (BNCT) is an innovative cancer treatment method, which is an ideal therapy for cancer would be one whereby all tumor cells were selectively destroyed without damaging normal tissue. By the end of the 2017, 76 particle treat-ment facilities were proposed and launched, but only two AB-BNCT facilities were proposed in mainland (Fig. 1). In this research, we proposed a linear accelerator-based BNCT (AB-BNCT) facility, which include a CW 7 MeV injector (2.5MeV-RFQ+7MeV-DTL) and a solid Beryl-lium target, aiming to provide a safer and cost-down treat-ment for cancer therapy. This proposal is a BNCT with driven accelerators working in middle energy region. Ac-cording to preliminary design and calculation, more than 10^{13} neutron will be produced when the 10mA 7MeV pro-ton beam bombarded the Beryllium (Be) target, that will satisfy the requirement (10^9 n/cm^2/sec neutrons) of BNCT. In this research, we need to finish the dynamic design of the proton beam, the RF design and the multi-physics analysis of the cavities and the neutron target.

BOMBARDMENT CALCULATION

For BNCT designs, the first step is to calculate pro-duced neutron that require 10^9 n/cm^2/sec neutrons for de-livering to patients. Based on the calculation of produced neutron, the designs of target and the accelerator will be started. In our study, beam bombardment was calculated for initial designs. Because thermal load of Lithium (^{7}Li) is lower than Be, the ^{7}Li is easy to change to liquid state when the ^{7}Li was bombarded, and the mixed isotope ^{6}Li is also easy to be transmuted ^{7}Be with 53 days' radioactive half-life [2]. Thus, we chose Be as our neutron target ma-terial.

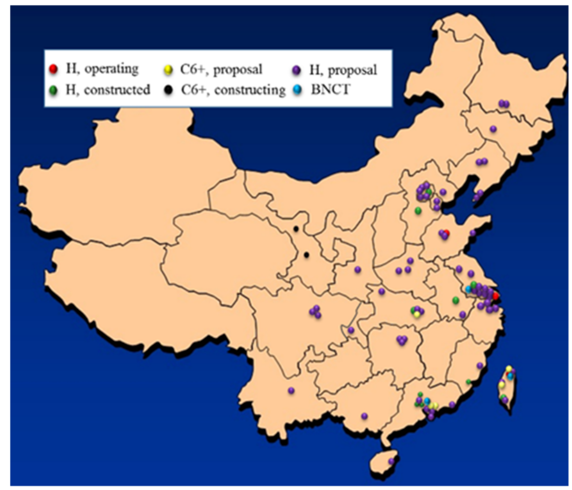

Figure 1: Particle treatment facilities in China.

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As an initial calculation, the beam spot on target was Φ20, and the beam was Gaussian distribution. As shown in Fig. 2 and Fig. 3, the proton stops 0.41mm and 6.78×10^{-4} neutron was produced when a 7 MeV proton particle bombarded on the Be target by using FLUKA code. That means 4.24×10^{13} neutrons will be produced when the beam current and energy are 10 mA and 7 MeV. According to our calculation, the maximum energy of neutron was about 5 MeV and over 10^9 n/cm^2/sec neutrons will be delivered to patients, and the 7 MeV proton parti-cle could be stopped at 0.4mm.

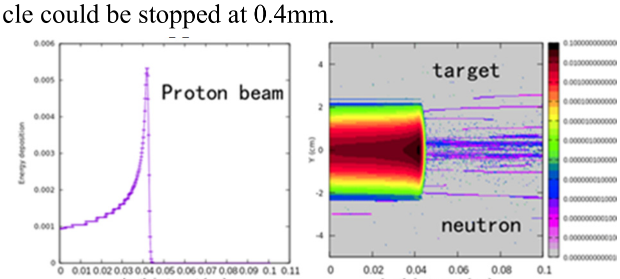

Figure 2: Images of proton ion bombarding on the Be tar-get.

Because only thermal neutrons and epithermal neutrons can be used for BNCT, a fast neutron filter will be de-signed, calculated, and installed behind the Be target in the

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further study. And the whole Be target chamber will be also designed including the moderator, collimator, neutron reflector, neutron shelter and gamma shelter, and finally the calculation of produced neutron at the treatment point will be started.

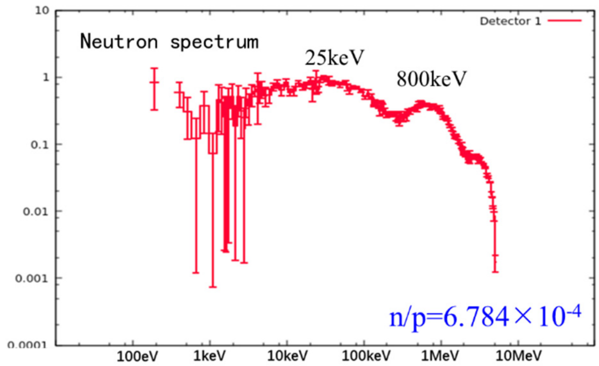

Figure 3: The spectrums of produced neutrons.

BEAM DYNAMICS CALCULATION

Accelerators normally used in BNCT can be simple divided into low, middle and high energy region accelerators. For low energy AB-BNCT, especially the energy is lower than 3 MeV proton machine, the target material normally adopted Li. For middle energy region AB-BNCT (< 3 MeV < 30 MeV), the target normally adopts Be, and heavy metal element like tungsten is adopted to use for few high-energy region AB-BNCT (> 100 MeV). In our study, we adopt a 7 MeV proton injector for generating neutrons by bombarding on Be target. This injector consists of an electron cyclotron resonance (ECR) ion source, a low energy beam transport line (including two solenoids), a 2.5 MeV radio frequency quadrupole (RFQ) type linac, a quadrupole magnet for beam matching, a 7 MeV drift tube type linac (DTL), a triplet magnet for beam adjustment and a dipole magnet for an another Be target (treatment room). The whole image of our designed AB-BNCT is shown in Fig. 4.

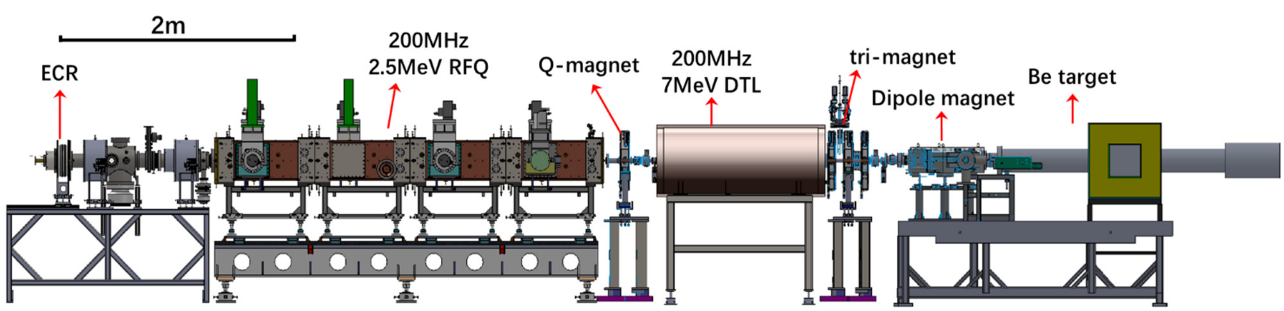

Figure 4: Our designed whole AB-BNCT system which consists of a ECR type ion source and a RFQ and a DTL, and a Q-magnet between two linacs and a tri-magnet system, and the Be target chamber. Also, there is a dipole magnet used for another beam line.

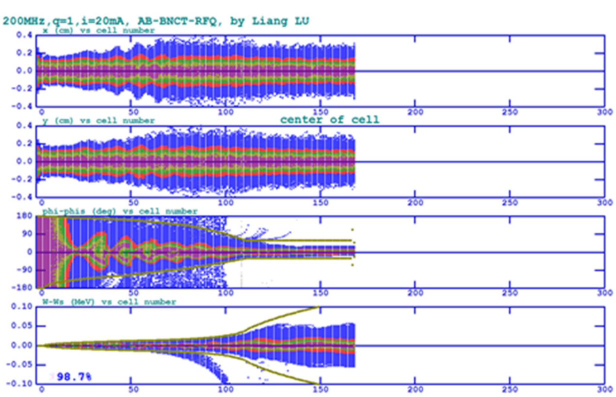

Figure 5: Beam dynamics simulation at 20 mA.

RFQs are wide used for accelerating high current beam in the very low energy region [3]. DTLs are normally used to accelerate ions in meddle or high energy region [3]. The proposed RFQ is calculated by RFQGen which is most popular software for RFQ beam dynamics calculation designed by LANL [3]. For redundant design, the RFQ should uphold high current and high transmission. In our design, the RFQ can accelerate 20 mA protons beam from 50 keV up to 2.55MeV in 3.1m, operating at 200 MHz and with 98.7% transmission. Even at 40 mA, the RFQ transmission is still as high as 95%. Figures 5 and 6 and Table 1 show the calculated results of beam dynamics and main parameters of the RFQ.

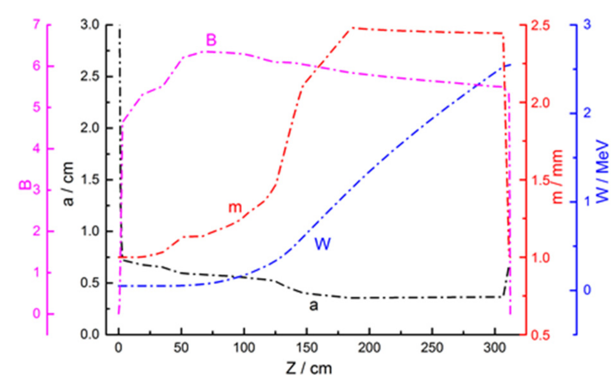

Figure 6: Evolution of main design parameters along RFQ.

The DTL is installed in downstream of RFQ and is required to accelerate 10~20 mA proton ions up to a final energy of 7MeV, operating in long pulse mode. The DTL adopts a power-effective interdigital H (IH) structure and

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an alternative phase focusing (APF) method, and its transmission reaches 99.98%. The DTL consists 17 drift tubes and 18 cells. The orbit calculation is simulated using Pi mode linac orbit calculation (PiMLOC) code which is based on the thin lens principle [4]. The main parameters of the DTL is listed in Table 2. Figure 7 illustrates the calculated results of 10 mA beam orbit dynamics with APF, and Fig. 8 shows the final energy distribution of the DTL. The beam profile at exit of the DTL is shown in Fig. 9.

Table 1: Main List of the RFQ Parameters

RFQ Items	Value
Frequency (MHz)	200
Input energy (keV)	30
Output energy (MeV)	2.55
Voltage (kV)	105
Phase	$-90^0 \rightarrow -22^0$
Kp.	1.58
Cell No.	178
Vane length (m)	3.2

Table 2: Main Parameters of the DTL

DT parameters	Value
Frequency (MHz)	200
Ions	proton
Input energy (MeV)	2.55
Output energy (MeV)	7
Cell Numbers	17
Phase	$-88^0 \rightarrow 30^0$
Kp.	1.6
Drift tube radius (mm)	25
Beam bore (mm)	9
Length (m)	1.6

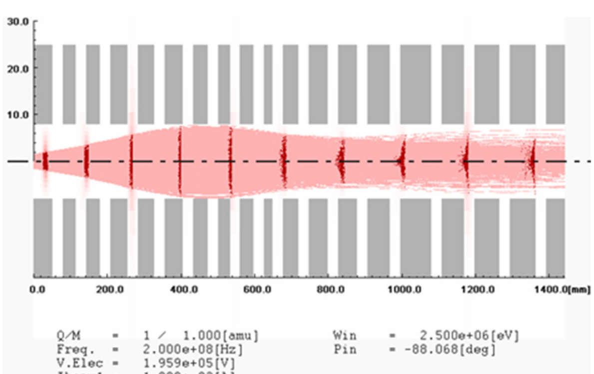

Figure 7: Orbit calculation of 10 mA protons with APF focusing.

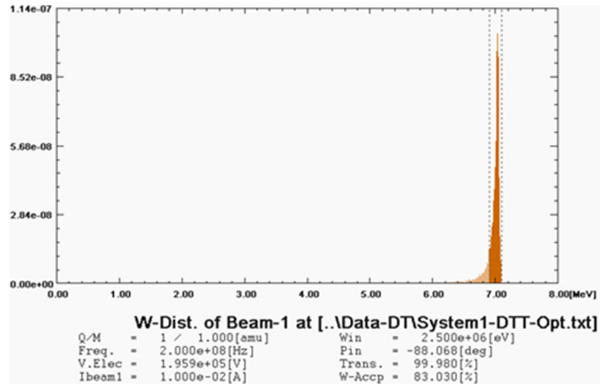

Figure 8: Beam energy distribution of calculated final 7 MeV, 10mA protons with over 99% transmission.

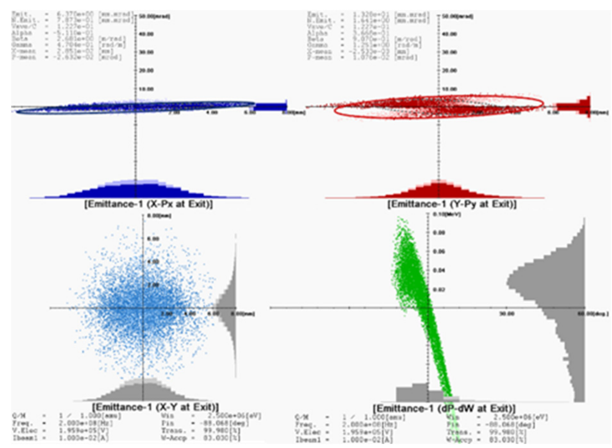

Figure 9: Profile of accelerated ions at the DTL exit.

FUTURE PLAN

Based on calculations of beam bombarding on the Be target, the beam dynamics of proposed AB-BNCT is almost done. In turn, we will start designs and simulations of the RFQ and the DTL cavity, particularly the electromagnetic designs and multiphysics analysis (like thermal calculations, structure deformation and so on) of the cavities. The goals of electromagnetic simulation are improvements of power efficiency and shunt-impedance of the cavities by optimizing electromagnetic structures. And, designs of the Be target including chamber, target cooling, moderator and shielding must be determined and optimized. Also, the convenience and maintenance of the target must be considered in the designs. A better design is to build modular-design for core parts of the target.

CONCLUSION

In this search, a compact linac-based BNCT was proposed. Based on our calculation, by bombarding on a Be target, a 10 mA, 7 MeV proton beam could produce 10^{13} neutrons and over 10^9 n/cm^2/sec neutrons will be delivered to patients that meets BNCT requirements. The linacs we proposed consist of a 2.5 MeV RFQ and a 7 MeV DTL, with high transmission. The electromagnetic designs of the linac cavities, and the designs of the Be target chamber will be started in the next few months.

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