CONSTRUCTION OF AN ACCELERATOR-BASED BNCT FACILITY AT THE IBARAKI NEUTRON MEDICAL RESEARCH CENTER

M. Yoshioka#, T. Kurihara, S. Kurokawa, H. Kobayashi, H. Matsumoto, N. Matsumoto, KEK, Tsukuba 305-0801, Japan
H. Kumada, A. Matsumura, H. Sakurai, S. Tanaka, Tsukuba University, Tsukuba 305-0005, Japan
T. Sugano, T. Hashirano, Mitsubishi Heavy Industries, LTD., Mihara 729-0393, Japan
T. Nakamura, JAEA, Tokai 319-1195, Japan
F. Hiraga, Hokkaido University, Sapporo 060-8628, Japan
T. Ohba, N. Nagura, NAT, Nippon Advanced Technology CO., LTD., Tokai 319-1112, Japan
T. Nakamoto, T. Zagar, Cosylab, Tsukuba 305-0044, Japan
T. Ouchi, ATOX CO., LTD., Tokai 319-1112, Japan

Abstract

An accelerator-based BNCT (Boron Neutron Capture Therapy) facility is being constructed at the Ibaraki Neutron Medical Research Center. It consists of a proton linac of 80kW beam power with 8 MeV energy, a beryllium target, and a moderator system to provide an epi-thermal neutron flux sufficient for patient treatment. The technology choices for this present system were driven by the need to house the facility in a hospital where low residual activity is essential.

OUTLINE OF THE PROJECT

An accelerator-based BNCT facility, (hereafter, i-BNCT [1]) is being constructed at the Ibaraki Neutron Medical Research Center (INMRC) with broad a collaboration coming from universities and organizations: KEK, Tsukuba University, Hokkaido University, JAEA; and commercial enterprises: Mitsubishi Heavy Industries, NAT, ATOX and COSYLAB. It consists of a high-power proton linac of 80 kW beam power with 8 MeV energy (3MeV RFQ + 5MeV DTL), a beryllium target, and a moderator system to provide a high enough epi-thermal neutron flux for patient treatment. The main parameters of the i-BNCT are summarized in Table 1 and the layout and a block diagram are shown in Figures 1 and 2, respectively. The basis for the technology choices will be described in the next section. Presently the construction of the accelerator system has been completed and RF conditioning of the RFQ and DTL is in progress. The first phase beam commissioning will be carried out this fall with a small beam current (a few μA) by using a target without a beryllium layer and the second phase full beam commissioning is scheduled for next year with a beryllium target and moderator system to provide the epi-thermal neutron flux.

Since the INMRC is a retrofit into an existing building, the layout of the irradiation room, accelerator and klystron modulator is not optimum as can be seen in Figure 1. In particular, the design of the beam transport line optics is made complex because of the 1.8 m floor level difference between the accelerator and irradiation room.

#masakazu.yoshioka@kek.jp

Table 1: Main Parameters of the 80 kW Linac

Beam energy	8 MeV (50kV ion source, 3MeV RFQ and 5MeV DTL)
Peak current	50 mA
Repetition rate	200 Hz
Pulse Width	1 msec
RF Frequency	324 MHz (also used by the J-PARC front-end linac)

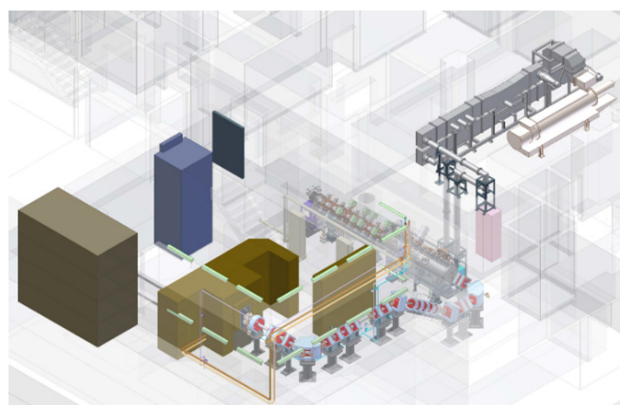

Figure 1: Layout of the i-BNCT, (left) Irradiation room, (middle) accelerator and (right) Klystron, modulator and LLRF, and magnet power supplies

TECHNOLOGY CHOICES

In order to reduce R&D requirements, the RF design of the RFQ and DTL builds on the same design as the J-PARC front-end Linac. However, in order to obtain an 80 kW beam power the duty factor of the i-BNCT is very high (20%) as compared with J-PARC (2.5%).

The technology choice of an 8 MeV Linac for the present system was driven by the need to site the facility in a hospital where low residual activity is essential. Neutron energy spectra are shown in Figure 3 for various production angles from 0 to 110 degree.

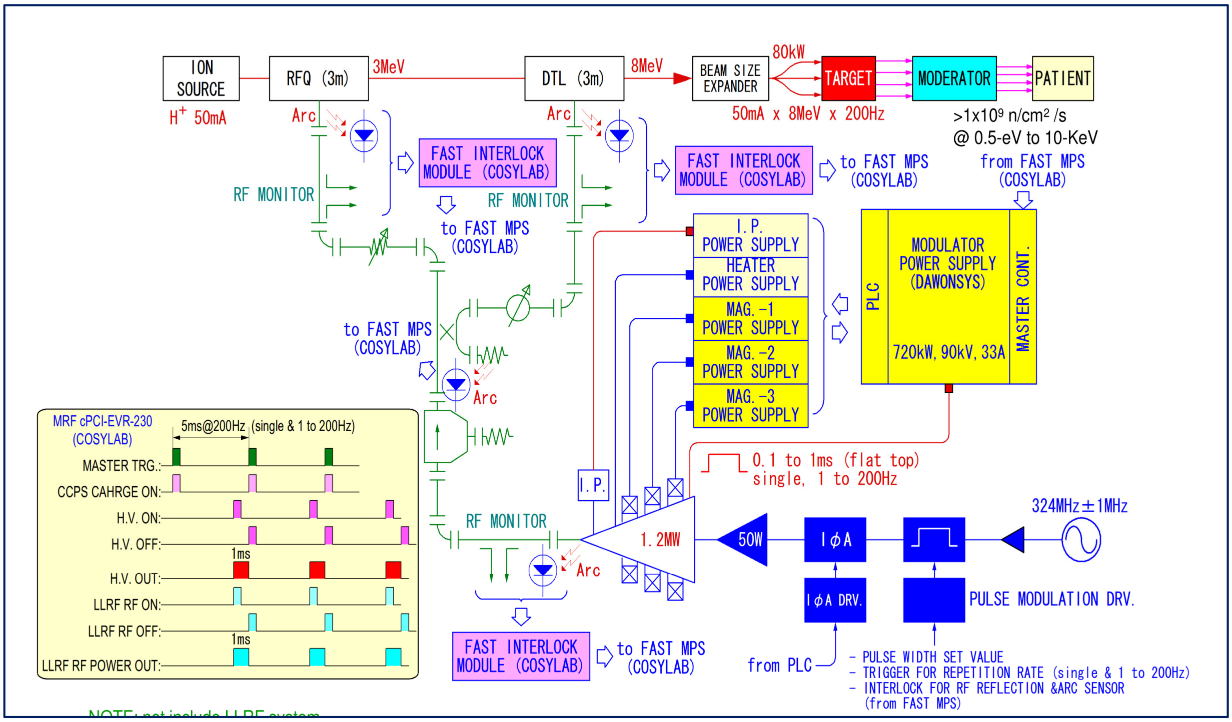

Figure 2: Block diagram of the RF system. The RF power from one klystron is split into two to feed the RFQ and DTL

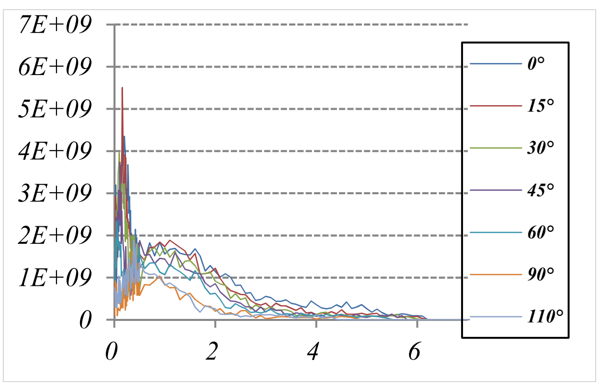

Figure 3: $^{9}Be(p,n)^{9}B$ Neutron energy spectrum ($n/cm^2/mA/sec$) as a function of E_n (MeV) for a 8 MeV primary proton beam on a 3 mm thick beryllium target for various production angles.

The maximum neutron energy produced from an 8 MeV-proton is only 6 MeV which is below the threshold energy for the main nuclear reactions which could produce radioactive products. On the other hand, the maximum neutron energy produced with 30 MeV protons, for example, is 28 MeV, which causes many radioactive products.

The down side of the lower energy choice is increased power requirement that produces a high-density heat load on the target. Accordingly, designing cooling and hydrogen anti-blistering amelioration techniques present sever challenges requiring a successful R&D program.

In addition, an efficient cooling water system for the high-duty factor RFQ and DTL is crucial. Also, a high-peak current and high-repetition rate ECR ion source needs to be developed.

The latest design of the target and moderator system shows that a flux of 4×10^{9} epi-thermal neutrons / cm^2 / sec can be obtained. This is much higher than the IAEA criteria [2].

HARDWARE DEVELOPMENT

Target System

Figure 4 (upper) shows a photo of a part of the beam transport system including the target. The beam profile is expanded to reduce the power density incident on the target to be lower than 4.5 MW/m^2 by the optics design which uses two octapole- and two quadrupole-magnets and the drift space.

The target is a multilayer structure to solve both cooling and blistering problems. The thickness of the beryllium target is 0.5mm, which is slightly thinner than the Bragg peak depth for an 8 MeV proton. The target heat load is water-cooled with a copper layer heat sink with cooling water channels through which a high speed water flow (10 m/sec) is needed to realize an efficient heat transfer from surface layer to the heat sink at the nuclear boiling region. Even with this cooling mechanism, a simulation shows that the steady state beryllium surface temperature can rise up to 226 degree C.

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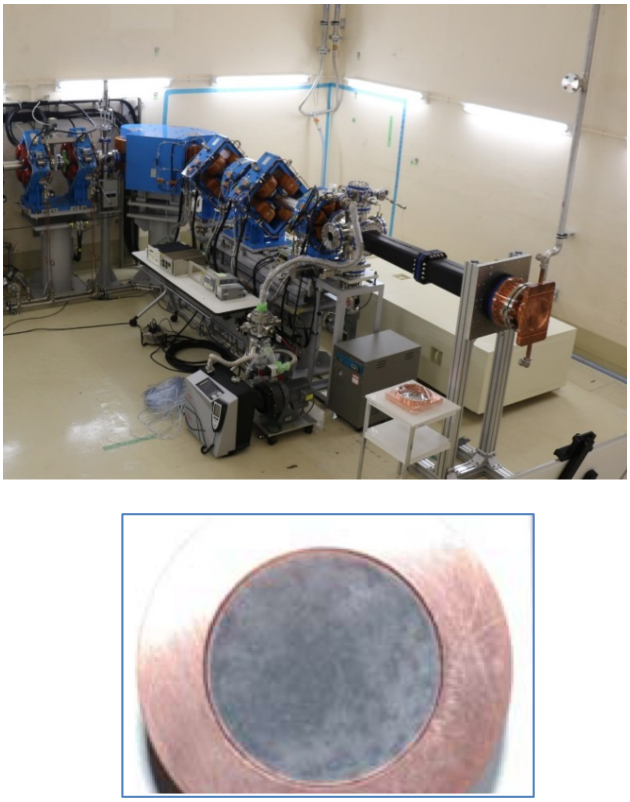

Figure 4: Photo of the beam profile expansion system (upper) and inner surface of the beryllium target (lower).

Cooling Water and High Power RF Systems

The new technical challenges for the high-duty factor Linac call for development of (1) a high efficiency water cooling system with large ΔT (temperature difference between inlet and outlet water) and with a dynamic temperature control system, and (2) a klystron modulator to supply a -90kV high voltage, 1ms pulse width at a repetition rate of 200 Hz to the 1.2 MW klystron manufactured by Toshiba.

Figure 5: Photo of the 1.2 MW, 324 MHz klystron and its modulator power supply.

The klystron modulator consists of a capacitor charging power supply, a main capacitor bank energy store and a high voltage switching unit. The photo is shown in Figure 5. In order to maintain the high voltage output pulse flatness to within +-0.5% accuracy and at the required high repetition rate, a software controlled 48-stage droop compensation circuit was introduced to resupply small amounts of energy with the proper timing to compensate for the droop. This scheme was proposed by DAWONSYS [3] and has been successfully realized in collaboration with the i-BNCT team.

ECR Ion Source and LEBT

The first phase beam commissioning will be carried out by using an ion source without LEBT (Low Energy Beam Transport). For the high current full beam commissioning, it is important to minimize the damage of RFQ vane surface caused by undesirable beam from the ion source. The LEBT system with two focusing solenoids and a chopper will be added to collimate the beam, remove unnecessary ions such as H^{2+} and H^{3+}, and create beam pulses of constant current. The design work of the high current ECR ion source with this LEBT has been completed with which the full beam commissioning will be carried out in next spring.

CONCLUSION

The present technology choices are based on the idea that the facility could be sited in a hospital and that further a low residual activity would be essential. But to be able to meet these desiderata we have to overcome various technical challenges. So far most of development has been completed and the performance of the facility will soon be proven through two stages of beam commissioning.

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