THE CURRENT STATUS AND FUTURE PROSPECTS OF TR 30/15 H^-/D^- CYCLOTRON FACILITY AT INER IN TAIWAN

T.S. Duh, W.J. Lin, L.H. Shen, G. Ting, Y.K. Fu, Institute of Nuclear Energy Research, Longtan, Taoyuan 32546, Taiwan, R.O.C. and T. Kuo, Concord, CA 94521, USA

Abstract

The TR30/15 H^-/D^- Cyclotron installed at the Institute of Nuclear Energy Research (INER) was mainly used for the production of radioisotopes for medical applications, as well as material research. INER has developed the production facilities and techniques of radionuclides and radiopharmaceuticals for SPECT and PET applications. A radiopharmaceutical manufacturing plant with GMP/cGMP system is now operating routinely to supply domestic approved radiopharmaceuticals to the hospitals in Taiwan area. For the future expansion in medical applications, we are making effort to upgrade our cyclotron reliability and injection capacity. The injection beam current at 1 MeV has been improved to 1 mA. Future addition of a new RF amplifier to achieve 1 mA at 30 MeV is being planned.

INTRODUCTION

The INER TR30/15 H^-/D^- Cyclotron has been in operation for more than 10 years. This cyclotron is a negative ion and dual particle cyclotron, which can accelerate H^-/D^- with variable energy of 15–30/8–15 MeV and with a maximum extracted beam of 500/150 μA. The cyclotron is now operating routinely to supply domestic approved radiopharmaceuticals, such as TL-201-TlCl, Ga-67-citrate and F-18-FDG injection solution, to the hospitals in Taiwan area. We are making effort to upgrade our cyclotron reliability and injection capacity for the anticipated future growth in medical applications. The first goal to achieve an injection beam currents at 1 MeV up to 1 mA has been reached. The plan to acquire a new RF amplifier to accelerate this beam to 30 MeV and two high power target stations is being proposed.

TR30/15 CYCLOTRON AT INER

The TR30/15 cyclotron at INER was designed by TRIUMF [1,2] and built by EBCO Technologies Inc. in Canada in 1990 - 1993. This cyclotron is a negative ion and dual particle cyclotron, which can accelerate proton/deuteron with variable energy of 15–30/8–15 MeV and with a maximum extracted beam of 500/150 μA. Figure 1 illustrates the overall layout of cyclotron facility. Four external beam lines with nine exit ports are connected to the cyclotron and with the capability that two opposite direction beams can be extracted simultaneously. There are four target rooms around the cyclotron, each with a concrete wall of 2 meter thick to shield the radiation. Of the nine beam ports, six of them are used for isotope production, and the rest are for research purpose.

Basically our cyclotron parameters, except those for deuteron mode, are the same as those of Triumf/Nordion TR30 cyclotron. The TR30 cyclotron is a proton machine, while TR30/15 is a dual particle cyclotron, and both cyclotrons have the same design by TRIUMF. An external dc H^-/D^- multicusp source is used to generate a beam of 25 keV for axial injection into the centre of the cyclotron using an electrostatic spiral inflectors. Originally, the maximum output of the ion source was 5 mA for H^- ion with normalized emittance of 0.34 π mm-mrad. After improving the ion source this year, it is increased to at least 8 mA. The peak D^- dc beam was 1.8 mA and it is now 4 mA.

The cyclotron is a four-sector radial ridge design with two 45° dees in opposite valleys. The dees operate in phase with a voltage of 50 kV and 27 kV for H^- and D^- respectively. The operating frequencies are 73.129 and 36.578 MHz. There are four gap crossings per orbit providing 200 keV per turn acceleration. The RF frequency is the fourth harmonic of the orbital frequency. The RF power is delivered to the dees through a capacitive coupling via a 50 Ω transmission line. The RF amplifier system is located outside the cyclotron room. The beam extraction is accomplished by passing the H^-/D^- beam through a thin graphite foil to strip off the electrons. Then the H^+/D^+ beam deflects into the exit channel, where a dipole magnet (combination magnet) can guide the beam further into either of the external beam lines.

For the deuteron acceleration [3], the orbits are designed to be as same as those of the protons. To do so, the RF voltage on the Dees and the injection energy of the deuterons are reduced by a factor of two. The RF system is tuned to the 4th harmonic of the rotation frequency of the deuterons by extending the tuning stems on the resonators. Trim coils are added in the valleys of the magnet for matching isochronisms.

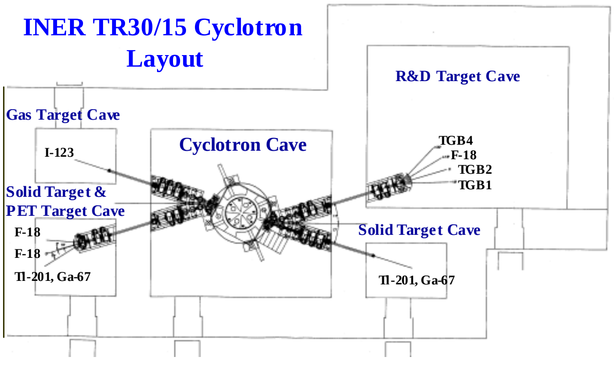

Figure 1: Layout of the INER TR30/15 Cyclotron.

APPLICATIONS AND RADIO PHARMACEUTICALS PRODUCTION

The INER TR30/15 H^-/D^- Cyclotron has been mainly used for the production of radioisotopes for medical applications. As show in Fig. 1 two solid target systems developed by Nordion are used for TL-201 and Ga-67 irradiations. In addition, there exist one gas target station for I-123 and three liquid target stations for F-18. INER has developed the production facilities and techniques of radionuclides and radiopharmaceuticals for SPECT and PET applications. A radiopharmaceutical manufacturing plant with GMP/cGMP system is now operating routinely to supply domestic approved radiopharmaceuticals, such as TL-201-TlCl, Ga-67-citrate and F-18-FDG injection solution, to the hospitals in Taiwan area. The cyclotron also produces I-123. The I-123 is to make I-123 MIBG for neuroblastoma imaging and I-123 IBZM for dopamine D_2 receptor imaging. The In-111 produced at INER is to prepare In-111-DTPA-Octreotide, a promising diagnostics tool for localizing primary tumors.

The external proton beam is occasionally used for semiconductor irradiation to study the change of crystal structure and the change of electrical property.

CYCLOTRON UPGRADE

Beginning from early this year, INER's directing management is planning on expanding the distribution of radio-pharmaceutical products throughout the Taiwan and nearby area. The projected isotope yield requirement and funding situation demand that not only the cyclotron beam current capability be doubled but the cyclotron reliability be substantially improved, being close to that from a two-cyclotron facility. An upgrade project is thus launched and expected to be completed in the year 2006.

Source-Injection Upgrade

In order to determine whether a 1 mA capability can be obtained from the source-injection system of the exist cyclotron, a proof-of-principle effort on the said system has been initiated following the work reported by Kuo et. al. [4]. The plan for this upgrade effort is shown in Fig. 2 where the broad-faced indicate new devices.

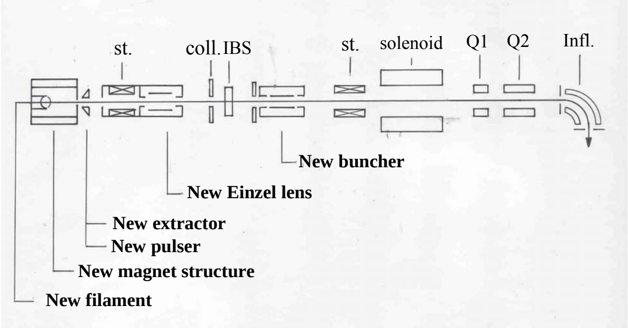

Figure 2: System schematics for source-injection upgrade.

The developmental source models behind the Triumf design [5] using 10 rows of 13 kG NdBFe magnet bars and 10 rows of 10 kG SmCo bars. The plasma chamber is 10cm in diameter and 10cm in length. A special virtual filter and two half-ring filaments are used. The extraction electrode has been modified in such a way that the stripping loss in the extraction channel is reduced and focusing strength increased. The beam out of this source-extraction system shows exceptionally good quality and is very stable. Typical e^-/H^- ratio can be as low as 4 ± 2. Filament lifetime will be about 1000 hours after a four-filament configuration is installed. The beam current obtained as a function of arc power is shown in Fig. 3a. As can be seen the source-extraction system has been improved to obtain 8 mA H^- at 25 A arc power at 100V and 10 mA when the 40 A arc power supply arrives. The peak D^- beam current reaches 4 mA. Due to an aperture restriction in the ground-end acceleration column which is not yet modified, the goal of 12 mA H^- / 5 mA D^- has not been achieved. Effort is being made to remove such restriction.

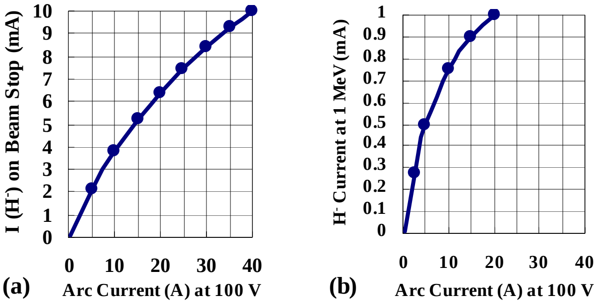

Figure 3: IBS dc current and 1 MeV pop-up current as a function of source arc power.

The transmission-acceptance efficiency of the SQQ injection line and the central region has been around 9% peak and 8% routine in the past with the use of 25 keV beam energy and 50 kV dee. The optimal beam energy and dee voltage are found to be 27.5 keV and 56 kV respectively. This setting will give 12% efficiency.

In order to further improve this efficiency a buncher has been added and tested. The two-gap buncher excited by the fundamental frequency of 73.129 MHz uses a $3/2\beta\lambda$ gap length and a 20mm aperture. The buncher is designed to be maintenance free and transparent to beam transmission. The bunching gain factor as a function of unbunched beam is shown in Fig. 4a. The falling trend is due to the space-charge effect in the injection beam. At very low beam current, the gain factor can be up to 3 while at routine 500 μA operation it is about 2. It is anticipated that at 1 mA operation the gain factor will be about 1.5. The 1 MeV pop-up probe was designed to take 600 μA only, so the 1 MeV beam current beyond this value will be measured after it is replaced by a new high power pop-up. A study on gain factor dependence on arc voltage from 60 V to 100V was performed and no strong relationship was found.

The addition of a 20mm ϕ buncher collimator before the entrance of the SQQ section will lower the beam transmission, for example, only 6% at low beam intensity and 7.5% at medium intensity can be maintained. To recapture the lost efficiency an Einzel lens has been installed immediately behind the ground-end acceleration column. During the proof-of-principle test, the 6% at low beam current was able to return to 9% at routine accelerating setting and from 8% to 12% at optimal setting. There seems to be little loss of DC beam transmission if we couple the Einzel lens and the buncher together. Our original SQQ [6] transmission line now becomes EBSQQ. The transmission efficiency supported by this new system is shown in Fig. 4b. However, the proof-of-principle lens sits behind a small beam tube inside the ground-end acceleration column. The location does not fit the optics requirement. A new column and Einzel lens combination will be redesigned and built in 2005.

As can be seen from Fig. 4b, transmission efficiency up to 36% can be achieved at low beam intensity, 22% at 500 μA and 17% at 1 mA operation. The RF beam capability at 1 MeV as a function of source arc power is illustrated in Fig. 3b.

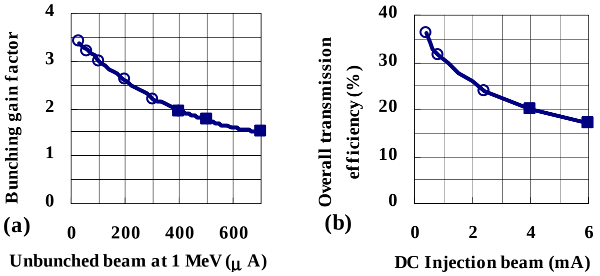

Figure 4: Bunching gain factor as a function of unbunched beam and overall transmission as a function of injection beam.

RF and Target System upgrade

At present, our RF amplifier is a dual frequency, 40 kW for 500 μA H^- operation. In order to accelerate the extra 500 μA to 30 MeV energy, it is necessary to add a single frequency high power amplifier up to 70 kW following the example set by Triumf/Nordion TR30 cyclotron. It is planned to keep the 40 kW amplifier as a stand-alone spare for reliability consideration. Attention must be given to the special H^-/D^- frequency switching shortening rings on the dee stems. It is not sure whether these rings can take the extra high RF current. In addition, the transmission line may need to be changed from 10 cm to 15 cm. For the last two reasons it might be a good option to limit the peak H^- current to 800 μA while keeping these two RF components undisturbed until these restriction are removed. It is hoped that the new RF amplifier system could be ready by the summer of 2006.

Two new target stations with targets capable of taking 500 μA will be purchased and be installed by the end of 2006. A new cooling system will be added to support these high power target stations and the new RF power amplifier. The optics and beam handling capability of the external beam lines will be reviewed and methods of improving the emittance of the external beams at high current will be explored.

Reliability Upgrade

As the reliability of the cyclotron becomes the highest priority of the future program, any upgrade effort will look into its contribution to the reliability first, functional capability second. For example, the source-injection improvement makes the cyclotron much easier to attain the beam current requirement thus results in a higher probability of more reliable operation. Under the guideline of this program, efforts will be made to prepare sufficient spare parts, to perform preventive maintenance, to promote longer lifetime of critical components, etc. The policy of modular and duplicate replacement should be adopted such as setting up a stand-alone spare RF amplifier system and a complete spare target station.

Nonetheless there is no assurance for 100% reliability and no substitute for high skill technical staff. It is suggested that reliability official be assigned in the operation group to manage the reliability issues. The culture of achieving highest reliability merit should prevail throughout the whole cyclotron facility.

Summary

The TR30/15 at INER has been serving the radio-isotope and radio-pharmaceutical research community well in the past. It is now providing the products for clinical use, e.g., 75% of the local demand on Tl-201 injection solution. The cyclotron is making F-18/FDG five days a week. The foreseeable future growth in demand leads us to start an upgrade program. Our institute decided to carry out this task by ourselves with certain help from abroad. The first phase of the improvement project has been making progress very successfully. The goal of achieving 1 mA at 1 MeV is attained several months ahead of schedule. This paper reports some of the work done and those lying ahead.

REFERENCES

[1] R. Baartman, K.L. Erdman, W.J. Kleeven, R.E. Laxdal, B.F. Milton, A. J. Otter, J.B. Pearson, R.L. Poirier, P.W. Schmor, H.R. Schneider and Q. Walker, Proc. IEEE PAC(1989) p.1623.

[2] B.F. Milton, G. Dutto, P.W. Schmor, H.R. Schneider, R. Dawson, K.L. Erdman, W. Gyles, J. Sample, and Q. Walker, Proc. IEEE PAC(1991) p.65.

[3] Karl Edman, R. Dawson, B.F. Milton, and N. Stevenson, Proc. IEEE PAC(1993) p.1733.

[4] T. Kuo et. al., “On the Development of 2 mA RF H- Beam for Compact Cyclotrons”, Proceedings of 14th Int. Cyc. Conf., Cape Town, S. A. 1995.

[5] T. Kuo et. al., “Development of a 15 mA DC H- Multicusp Source for Cyclotron”, Proceedings of 14th Int. Cyc. Conf., p.420, Cape Town, S. A. 1995.

[6] R. Baartman, “Matching of Ion Source to Cyclotron Inflector”, Proc. 1st EPAC, p 947, Rome, 1988.