HIGH CURRENT OPERATION OF THE ACSI TR30 CYCLOTRON

V. Sabaiduc, J. Burbee, D. Du, K. Erdman, W. Gyles, R.R. Johnson, B. Kovac, A. Manigoda, S. Medianu, I. Popa, L. Popa, A. Terentyev, E. vanLier, R. Watt, B. Wilson, J. Wong, A. Zyuzin, Advanced Cyclotron Systems Inc., Richmond, BC, Canada
T. Kuo, Concord, CA 94521, U.S.A., W.H. Uzat, Cyclotron West Inc., South Surrey, BC, Canada

Abstract

Advanced Cyclotron Systems Inc. (ACSI) manufactures high current commercial cyclotrons of various energies. The cyclotron design first originated in TRIUMF and has been further developed at ACSI. This note presents the progress that has been made in increasing the intensity of the beam current extracted from the TR30 cyclotron. At the present time, ACSI has successfully commissioned 30MeV, 1200µA of proton beam through complex acceptance and uptime testing and extracted 30MeV, 1600µA of stable proton beam current on a commercial 30MeV cyclotron. The performance and steps taken to achieve them are given in this paper.

INTRODUCTION

The TR cyclotrons were originally designed at TRIUMF, Canada's national subatomic physics laboratory located on University of British Columbia campus in Vancouver, Canada. Two magnet platforms have been designed for maximum extraction energy of 30MeV and 19MeV. TR30 and TR19 cyclotrons are powerful and reliable commercial cyclotrons using a modern design. ACSI manufactures TR cyclotrons and develops new cyclotron models and associated systems. The ACSI systems include dual particle cyclotrons, beam lines, target systems and radiochemistry modules.

TR30 CYCLOTRON PROJECTS

The design, manufacture and commissioning of the first TR30 cyclotron was a joint effort of TRIUMF and EBCO Technologies Inc., with the continuing support of Nordion the first beneficiary of a TR30 cyclotron. The cyclotron has been initially commissioned at 500µA of extracted proton beam in 1990 [1] and upgraded by TRIUMF to 1mA in 1996, [2] [3]. Since then, ACSI has commissioned five more TR30 cyclotrons at MDS/ Nordion, COVIDIEN/ Mallinckrodt, GE Healthcare/Amersham and TR30/15 proton/deuteron cyclotron at the Institute of Nuclear Energy Research (INER) in Taiwan. All TR30's have been commissioned to 1mA of proton current with the most recent installation also commissioned at 1.2mA. The INER TR30/15 cyclotron has been upgraded to 1mA capability as well [4].

CYCLOTRON UPGRADES

The general concept promoted for the TR30 cyclotrons and implemented in manufacturing is that installed cyclotron subsystems must be upgradeable to 2mA of proton beam current (from which 1.6mA has been already achieved). Likewise, maximum reliability is required at the same time. Consequently, most of the cyclotron subsystems as well as the beam lines and solid target stations have been significantly upgraded.

Ion source and injection line (ISIS)

Extensive development work has been done on the ion source and injection system by T. Kuo et. al. [2] [3]. Many of these improvements have been implemented by ACSI on the TR30's, including the four half ring filaments, the cusp confinement and virtual filter arrangement and the extraction electrodes. These improvements have significantly increased the ion source beam intensity and brightness. With the ion source operating at an arc of 20A &100Volts, 10mA of beam can be extracted at 28kV, with a normalized 4rms emittance of 0.43π-mm-mr. This gives an emittance-normalized brightness of 5 mA/mm^2-mr^2.

Ongoing fine tuning of the ion source and injection line at ACSI has steadily increased the performance of the recent TR30's from 1.0mA up to 1.4mA. The performance has been increased further on the latest TR30 by the addition of an Einzel lens. This cyclotron routinely operates at 1.2mA with an ion source arc of only 12 to 13A (at 100V). At higher arc current of 35A, the cyclotron delivers 1.6mA

The excess capacity from ISIS improves the cyclotron operation and reliability making the operation much easier at routine production levels of 1.2mA.

RF System and Extraction Probes

The RF system has been upgraded with a more powerful amplifier (100kW) suitable for 2mA beam operation with regulated plate power supply, a larger 6 1/8" transmission line and improved design of the coupler with the addition of cooling water. The RF control system maintains the dee voltage at 50kV with a stability of 10^{-4} at full beam loading.

The extraction probes have five foil carrousels for extended operation between servicing, an improved driving mechanism and cooling water. A carrousel will last from 5 to 7 days when operating in double beam extraction mode at 600µA beam current on each side.

Beam Line

The beam line design allows for the beam on target to be tuned to a focused spot or uniformly distributed on a larger window (90% of the beam on 11mm x 35mm vertical window) suitable for radioisotope production. The 1.6mA run had a distribution of 80% on target faces, 18.4% on target collimators and 1.6% beam line losses. Typical beam line losses at 1200uA beam current operation are below 1.5%. Radiographs tests of the targets confirmed the uniform distribution of the beam on the target face.

Solid Target Stations

The solid target stations have been significantly improved to increase the current capability and reliability. They are fully automated and built using radiation resistant materials. The target collimators and entrance mask have been replaced with new design providing trouble free operation at 600µA per target station.

In routine operation at 600µA, typical target station measurements are:

- 500µA beam current on target face, uniformly distributed on a 90mm x 35 mm surface area.
- A total of 70µA to 90µA on four target collimators and 20µA to 30µA on target station entrance mask. The individual collimators sustained currents above 50µA repeatedly.
- All tests have been performed on blank copper targets for a typical 12 hour run between target changes. Target changes take an average of 15 to 20 minutes.

The beam performances at 1600µA of extracted proton current equally split down two beam lines are:

- 675µA beam current on target face, uniformly distributed on a 90mm x 35 mm surface area.
- 120µA to 150µA beam current on target station collimators and entrance mask.
- The test has been performed on blank copper targets for over four hours. There were no significant limitations that precluded continuing. For safety and radiation exposure reasons we elected to limit the beam current and testing time.

BEAM STABILITY PERFORMANCE

The stability of the beam current throughout the machine has been demonstrated in long term operations tests. From the ion source to target stations we have significant data that documents the beam characteristics at various points of the machine, beam losses in the cyclotron and beam lines, and stability of the extraction mechanism. The stability is defined as the ration of the maximum peak to peak beam current fluctuation reported to the average value over a 15 minutes period of time. The beam current drift is defined as the ratio of the change in the average value of the beam current for periods of time longer than 15 minutes:

- Ion source current is measured on a beam stop in the injection line at 28kV injection energy. The stability for a total current of 10mA is in the 1x 10^{-4} range. There is no drift recorded on the ion source output more than the normal wear of the filament.
- Main magnet current stability is $1x10^{-5}$ given by a digital controlled (18 bits) power supply.
- Dee voltage stability of $1x10^{-4}$.
- Cooling water stability of ±0.25°C.
- Total extracted beam long term stability is typical 0.5% at full current of 1200µA as illustrated in Fig. 1. The data is logged over a 30 minutes period of time at a rate of one sample per second.

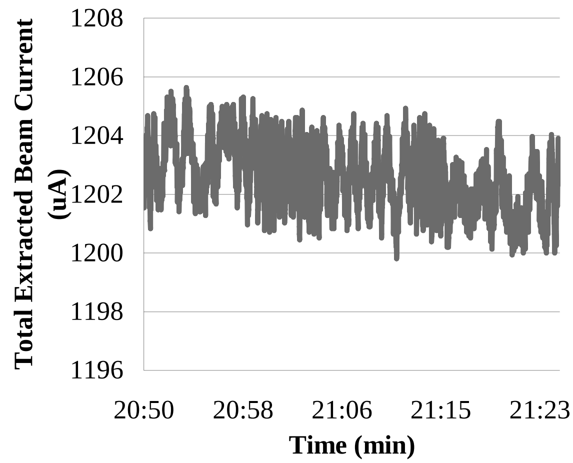

Figure 1: Total extracted beam current

- The beam split ratio stability is measured at 1% of the extracted current or less (0.5% extracted beam stability on each side). The drift is due to the carbon foil wear. This drift is usually compensated by operator intervention when necessary.
- Target current stability of 1.1 to 1.3% at full specified current of 500µA on target face as illustrated in Fig.2. An automated computer routine keeps the target current stable with the beam drift in the horizontal plane by controlling the combination magnet with an error signal from the left-right target current balance.

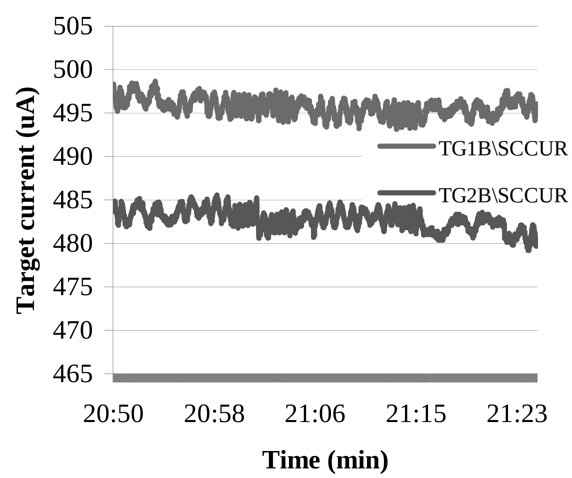

Figure 2: Target currents

UPTIME PERFORMANCE TESTING

A second very important parameter of a radioisotope production system is the uptime performance of the system. This is an absolute measure of the stability and reliability of the entire cyclotron system. The uptime performance of the TR30 cyclotron systems was thoroughly tested at a total extracted beam current of 1mA and 1.2mA. A total of three tests have been performed over the two TR30 cyclotrons (TR30/1 and TR30/2), each test for a consecutive period of 13 weeks. During the testing time the machines have been continuously operated at maximum beam current as specified. The uptime has been defined as the ratio between the time the beam current was at an average value of 1mA or 1.2mA and the time scheduled, 24 hours per day, seven days a week, excluding the target transfer time and scheduled maintenance time.

TR30/1 1.0mA Uptime Test

The TR30/1 cyclotron has been tested in 2006 for the total extracted beam of 1.0mA during a consecutive period of 13 weeks. The average uptime was 90% as illustrated in Fig. 3. The most significant part of downtime was caused by problems we encountered with the extraction system and target stations. Those problems have been corrected and design changes implemented on the later cyclotrons.

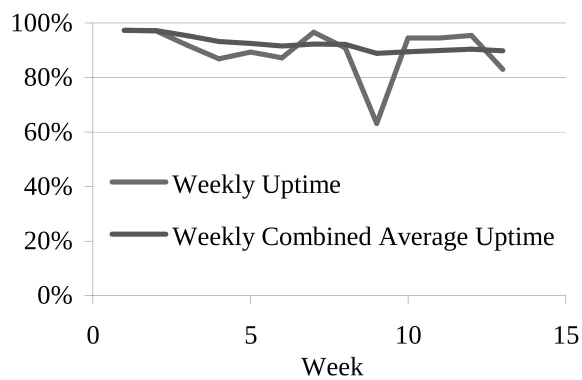

Figure 3: TR30/1 1.0mA Uptime Test

TR30/2 1.0mA and 1.2mA Uptime Tests

The TR30/2 cyclotron was commissioned in 2007 and it went through two consecutive 13 week tests the first at 1.0mA and second test at 1.2mA still to be completed. The average uptime of the first 1.0mA test was 89.3% as illustrated in Fig.4.

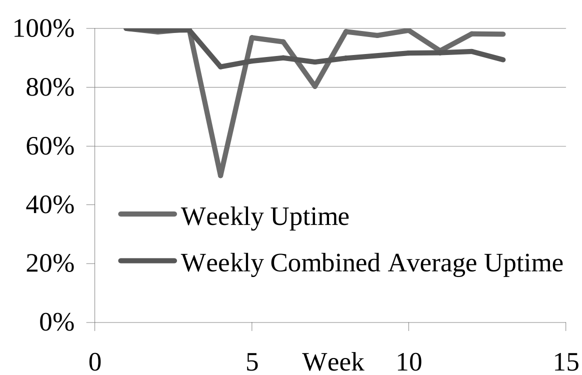

Figure 4: TR30/2 1.0mA Uptime Test

The design changes implemented where successful and the cyclotron operated free of problems on extractors and target stations. During the test we encountered problems with the inflector causing the down time. An in depth analysis was done and a new solution has been successfully implemented by T. Kuo. The significant increase in uptime is visible in the latest 1.2mA test that was practically free of problems. The test is scheduled to complete first week of October and is presently running close to maximum uptime. The average up to date uptime for the 1.2mA test is 98.3% as illustrated in Fig. 5.

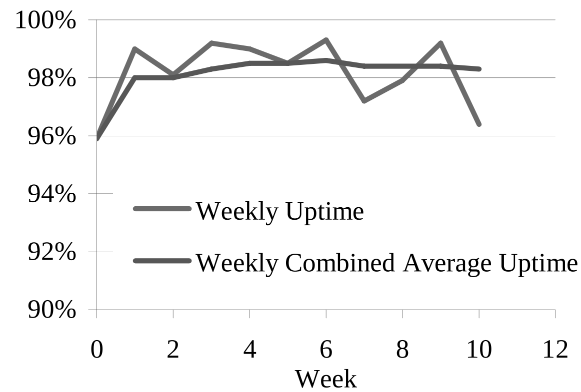

Figure 5: TR30/2 1.2mA Uptime Test

CONCLUSION

The TR30 cyclotron systems have been significantly upgraded to increase the system output to over 1.6mA and ensure reliable 24/7 operation at 1.2mA. Accordingly, the radioisotopes production increased; for example, over 400Ci Pb-201 per day may be produced for Tl-201 generation.

REFERENCES

[1] B.F. Milton et. al., “Commissioning and First Operation of a 500μA, 30 MeV, H^- Cyclotron”, Proc. IEEE PAC 1991, p65.

[2] T. Kuo et. al., “On the development of 2mA RF H^- Beam for Compact Cyclotrons”, Proceedings of 14th ICC, Cape Town, S. A. 1995.

[3] T. Kuo et. al., “Development of a 15mA DC H^- Multicusp Source for Cyclotron”, Proceedings of 14th ICC, Cape Town, S. A. 1995.

[4] T.S. Duh et al., “The Current Status and Future Prospects of the TR30/15 H^-/D^- Cyclotron Facility at INER Taiwan”, Proceedings of 17th ICC, Tokyo 2004.

[5] R.R. Johnson et. al., “Advances in intense beams, beam delivery, targetry and radiochemistry at Advanced Cyclotron Systems”, NIM B **261** (2007), 803.