CONSTRUCTION AND OPERATION OF CYCLOTRONS FOR MEDICAL ISOTOPES

Nigel Stevenson, TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C., Canada V6T 2A3

Abstract

Modern high intensity commercial cyclotron systems are continuously being improved to achieve higher beam power, reliability and ease of operation. Other factors playing a part in the ongoing development of commercial cyclotrons include the need for lower radiation dose to personnel, flexibility of operation (multiple beams, variable energy), and the desire to minimize the routine maintenance requirements. In the case of the TRIUMF TR30 we examine the evolution of the cyclotron and targetry systems that have occurred over the past six years. Our efforts have now brought the system to the stage of having the highest available external beam current of any commercial cyclotron in operation. A contrast is made with the older CP42 cyclotron system installed 15 years ago. In this case, while developments have resulted in a significantly better operating environment, the inherent limitations of the older "base technology" inhibit the progress towards the goals of higher beam currents, greater flexibility and lower maintenance requirements. In both cases, the potential for further improvements is discussed and compared with an ideal commercial cyclotron isotope production facility.

1 ISOTOPE PRODUCTION CYCLOTRONS

Cyclotrons have been used to produce medical radioisotopes for several decades. At first, cyclotrons designed for nuclear physics research were parasitically employed to produce small quantities of isotopes. As the use and demand increased some of these machines were dedicated to isotope production and specialized targetry were developed for this purpose. "First Generation" commercial compact cyclotrons were cyclotrons specifically designed and built for isotope production. These were characterized as positive ion; internal ion source; poor tank vacuum; internal targetry; and due to less that optimal shielding were prone to severe problems associated with radiation fields and radiation damage of components. Remarkably, some of these older machines are still in existence after 30 years or more and are still used for routine isotope production. The Cyclotron Corporation CS30 is an example of this generation of technology.

In the late 1970s "Second Generation" machines came onto the scene. These systems are characterized as negative ion; internal ion source; moderate tank vacuum; external targetry; single beam; and are less prone to suffer radiation damage since beam stripping by residual gasses is reduced and the targetry is external to the cyclotron (although often in the same room). The Cyclotron Corporation CP42 is an example of this generation of cyclotron technology. One of these CP42 cyclotrons is located at TRIUMF and has been in operation for the past 15 years producing medical radioisotopes for Nordion Int. Inc. and also for the University of B.C./TRIUMF PET program.

The newest ("Third Generation") cyclotron systems, available during the past few years, employ negative ions; high vacuum systems; external ion sources; multiple beams onto external targetry (located in separate irradiation rooms); are power efficient; and have very few problems associated with radiation damage i.e. they require little repair or maintenance. Ion Beam Applications (Belgium) and EBCO Technologies (Canada) have both produced third generation compact commercial cyclotrons that are presently in use for radioisotope production. The TR30 is one such machine designed by TRIUMF and EBCO. The prototype TR30 system is located at TRIUMF and is operated by TRIUMF staff on behalf of Nordion Int. Inc.

A comparison of the operation of the CP42 and TR30 clearly shows the advantages of the third generation cyclotron systems.

2 THE TRIUMF COMPACT COMMERCIAL CYCLOTRONS

A comparison of the CP42 and the TR30 cyclotrons is summarized in Table 1. The advanced technology employed by the TR30 system allowed routine production to increase from the nominal 350 μA achieved at commissioning in 1990 to almost 500 μA by the end of 1994. In 1994 a decision was made to upgrade the TR30 such that it could double its capacity. By January 1996 this goal was achieved when 1 mA at 30 MeV was successfully achieved.

In parallel with this was a program to improve the second generation CP42. However, inherent problems associated with the older technology were significant deterrents towards progress in the direction of higher beam intensities. Since its installation in the early 1980s, the CP42 had routinely run at the nominal 180 μA but any improvement over this had been difficult to achieve and usually had been short-lived. In 1996, however, there were some significant inroads made into improving this older system thereby allowing routine production up to 250 µA at 30 MeV.

Apart from beam intensity, the other major factors [1,2] that affect the running of isotope production facilities include repair (downtime) and maintenance requirements, regulations regarding the radiation dose to personnel, flexibility of operation and the level and security of business.

	CP42	**TR30**
Ion Source	PIG	CUSP
(Location)	(Internal)	(External)
Vacuum	3 µtorr	0.3 µtorr
Particle	H- (p)	H- (p)
Beamlines	2	2
Targets	9 + 1	3 + 3
Beam Operation	Single	Dual
Energy	11-42	15-30
Beam Current :		
1990	180 µA	2 x 175 µA
1993	180 µA	2 x 230 µA
1996	250 µA	2 x 500 µA

Table 1: Comparison of the CP42 and TR30 Operation.

3 THE CP42 EXPERIENCE

The CP42 series of cyclotrons were produced by The Cyclotron Corporation in the late 1970s as the successors to the CS series of first generation machines. The TRIUMF machine arrived on-site in 1979 but due to the demise of TCC it was never assembled and commissioned by them. Instead, one of their scientists along with TRIUMF staff had the daunting task of putting the system together and bringing it up to operational standards. By 1983 they had successfully done this and routine isotope production was able to begin. Since that time, step-by-step improvements to the cyclotron and targetry systems have resulted in significant progress in the abilities of this second generation cyclotron. However, progressively higher integrated (annual) beam currents have largely been achieved by reducing downtime rather than by increasing beam currents.

Operating the CP42 with limited staff numbers (6-8 persons) did result in high personnel radiation doses - especially during the first 10 years of operation. During this time integrated beam currents were progressively being raised and ongoing minor improvements to the hardware were continuous. Some of the major changes were :

- New Targetry systems. The TCC supplied system was essentially inoperative and impractical. We designed an improved system [3] which has evolved to the point now where even continuous high intensity operation requires infrequent maintenance (once every 3 months).
- Removal of target systems from the cyclotron vault into dedicated irradiation rooms. This has reduced the radiation damage to components of the cyclotron and beamlines.
- Removal of the water cooling packages from irradiation rooms. Radiation damage to components often resulted in downtime since extensive cooldown was generally required to repair these systems. By having them outside of the radiation areas they rarely fail and can quickly be repaired if this does occur.
- Upgrading components to improve reliability e.g., using rad-hard materials, main magnet coil, dees, etc.

The radiation dose to personnel during this period is shown in Table 2. Peaks in personnel dose usually accompanied dips in production as major repair or upgrade work was undertaken. Despite all of this effort the CP42 has proven to be a stubborn machine to improve significantly due to its inherently limited abilities as a second generation system.

	CP42	**TR30**
1984	80.8	
1987	154.0	
1990	274.3	2.2
1991	202.3	45.0
1992	109.8	42.8
1993	105.2	39.8
1994	84.0	37.7

Table 2: Personnel radiation doses (mSv) for the CP42 and TR30 staff.

4 THE TR30 EXPERIENCE

The TR30 was installed in 1989/90 and began routine production in July 1990. Rapid progress was made in bringing up the beam currents for ongoing radioisotope production over the next few years. In fairness, a large part of this relatively rapid progress was due to already having an experienced cyclotron crew (i.e. the CP42 operators) and also because of the help readily available from the TRIUMF Cyclotron Division.

Commissioning of the TR30 was done at the level of 350 µA. Routine running at this level (dual beam at 175 µA each side) followed almost immediately. Over the next three years the system was pushed to its limit of running 460 µA routinely. At that time a decision was made to upgrade the system to allow 1 mA on-target. The major changes involved [1] were :

- The Ion Source required some modifications and power upgrades to increase the d.c. current from 5 mA up to 10 mA. A small central region model cyclotron, used in the original TR30 feasibility study, was available to test out this upgrade.

- Addition of a buncher to increase the apparent acceptance by about 4%.
- RF power was scaled up by building a new 70 kW amplifier.
- Larger surface area targets and superior targetry systems were developed especially for the TR30.

These changes were undertaken in 1995 and in January 1996 the final commissioning test (2 x 500 μA) was successfully passed. Since that time, we have been engaged in a program to steadily and progressively increase the routine (full target irradiations) production levels in line with the new capabilities of the TR30. All of this development work and increase in capacity has not had much effect on the remarkably low personnel doses of staff working on this machine.

5 AN IDEAL ISOTOPE PRODUCTION CYCLOTRON SYSTEM

The CP42 and TR30 experiences have taught us much about designing an ideal cyclotron system for isotope production. First of all, it should be noted that trying to combine high intensity isotope production with other applications (e.g. PET, therapy, etc.) leads to operation difficulties that usually result in less than optimal (i.e. maximum output) isotope production running conditions. So an "ideal" system would best be dedicated to high current isotope production.

The design and considerations going into an ideal isotope production facility have been discussed elsewhere [4] and are summarized below :

1. Use negative hydrogen ions only. The added complexity of other species of beam particles will reduce the flexibility of the system at higher currents and only result in higher maintenance requirements. Besides, almost all the desirable isotopes can be produced with protons. High vacuum systems are essential to minimize gas stripping losses.
2. An extension of the above consideration is the use of external targetry to reduce activation of cyclotron components. These targets should be housed in individual target irradiation rooms.
3. Multiple beams that are possible with negative ion systems allow multiple targets to be irradiated simultaneously. Negative ions also allow different energies for each primary beamline.
4. Materials should be chosen to reduce radioactive buildup from stray beams and secondary radiation. For example, the CP42 tank is stainless steel while the TR30 is aluminum. The typical radiation fields emanating from the CP42 is at least an order of magnitude higher than the TR30 despite the much lower beam currents.
5. The walls of each irradiation room should be composed of low-Na cement (preferably have some boron content) to reduce the production of Na-24.
6. Targetry must be built without any components that are easily damaged (O-rings, plastic tubing, electrical insulators, etc.). Whenever possible, all-metal components should be used. Maintenance should be a relatively simple and quick process and be required as infrequently as possible.
7. A comprehensive preventative maintenance program is invaluable[5].

It should be said that the present (and the foreseeable future) requirements of isotope production can easily be handled with the cyclotron systems available today. In the future, higher beam currents may be required for such applications as feeding sub-critical reactors [6]. In this regard, "Fourth Generation" industrial cyclotrons may be produced that can deliver in excess of 10 mA external proton beams [7,8].

REFERENCES

[1] "Future Cyclotron Systems : An Industrial Perspective", *Proc. 14th Int. Conf. on Cyclotrons and their Applications*, Cape Town, (1995), TRIUMF preprint TRI-PP-95-72.

[2] "Cyclotrons for Isotope Production", B.F. Milton and N.R. Stevenson, *Proc. 1995 Particle Accel. Conf.*, Dallas, TRIUMF Preprint TRI-PP-95-39.

[3] "High Current Radioisotope Production with Solid Target Systems", W.Z. Gelbart *et al.*, *Proc. of the 1993 Particle Accelerator Conference*, Vancouver, 3099.

[4] "A Cyclotron Isotope Production Facility Designed to Maximize Production and Minimize Radiation Dose", W.J. Dickie, N.R. Stevenson and F.F. Szlavik, *Nucl. Instrum. Meth.* B79 (1993), 929.

[5] "The Operation of Cyclotrons used for Radiopharmaceutical Production", T. Grey-Morgan and R.E. Hubbard, *Proc. 13th Int. Conf. on Cyclotrons and their Applications*, Vancouver, (1992).

[6] "High Intensity Cyclotrons for Radioisotope Production or the Comeback of the Positive Ions", Y. Jongen et al., *Proc. 14th Int. Conf. on Cyclotrons and their Applications*, Cape Town, (1995).

[7] *Proceedings of the Workshop on Critical Beam Intensity Issues in Cyclotrons*, Dec 3-6, 1995, Santa Fe, NM, USA.

[8] "Isotope Production and the Future Potential of Accelerators", D.M. Lewis, *Proc. 14th Int. Conf. on Cyclotrons and their Applications*, Cape Town, (1995).