

Cyclotrons for Isotope Production

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Abstract

Cyclotrons continue to be efficient accelerators for **radioisotope production**. In recent years, developments in the accelerator technology have greatly increased the practical beam current in these machines while also improving the overall system reliability. These developments combined with the development of new isotopes for medicine and industry, and a retiring of older machines indicates a strong future for commercial cyclotrons. In this paper we will survey recent developments in the areas of cyclotron technology, and isotope production, as they relate to the new generation of commercial cyclotrons. We will also discuss the possibility of systems capable of extracted energies up to **100 MeV** and extracted beam currents of up to **2.0 mA**.

I. Introduction

For many decades accelerators have been used to produce proton rich isotopes, as a complement to the neutron rich isotopes produced in reactors. Initially this production was done in a parasitic mode, on accelerators originally constructed for nuclear physics research. However over the past couple of decades there has been a large number of commercial facilities designed solely for the production of isotopes. In particular the production of isotopes with long enough half-lives that regional distribution is practical, and yet sufficiently short that "just-in-time" production is required, has developed into a specific market. In this market cyclotrons in the energy range of 20 to 40 MeV have become the accelerator of choice, primarily because of their power efficiency and compactness. While the production of **PET isotopes** represents a significant new market, the requirements of these very short lived isotopes (eg. ^{18}F), leads to different approaches, not considered in this paper.

The first generation of commercial cyclotrons were primarily proton machines that were very similar to the original research machines. In order to simplify operation and reduce costs these machines were often run with the isotope production target inside the cyclotron magnet (ie. no extracted beam). In the 1970's it was recognized that the old trick of accelerating H^- , and extracting by stripping, offered the advantages of separating the target and accelerator without the difficulties of positive ion extraction. The CP42 built by TCC [1] was the first commercially available cyclotron to exploit these advantages. While these machines demonstrated themselves to be able work horses, over the following decade, many short comings in the design were identified. Recognizing the possibilities presented, Ion Beam Applications (IBA) in Belgium, followed by Ebro

Technologies in Vancouver, developed the Cyclone 30 [2] and the TR30 [3] cyclotrons respectively. These machines are sometimes referred to as the third generation commercial cyclotrons. Since the initial introduction of these machines, they have dominated the market, and are now available in several different configurations to meet specific market niches.

II. Market Requirements

In North American and Asia the cyclotron produced isotope business has grown about 20% per year for the past decade, predominantly reflecting the increased use of ^{201}Tl in the US and ^{125}I products in Japan. While the Japanese market is expected to continue to grow (10%/yr) for the next few years, many people have predicted that the ^{201}Tl usage in North America will decline although no evidence of this has yet emerged. While other products continue to be developed, none have truly blossomed. Therefore the market stability is hard to predict, and this generates uncertainty when making decisions about future facilities.

The production of short lived isotopes, as is the case for most commercial cyclotron production, imposes certain important characteristics to the business. In particular;

- Irradiation, processing and shipping are on a "just-in-time" basis.
- Round the clock operation
- Weekly scheduling with much flexibility to handle customer requirements and recover from system failures.
- Costs are dominantly fixed, ie. little scaling with the level of production (for a given facility).
- Radiation dose accumulated by maintenance and repair personnel represents a serious cost component.

To respond to these requirements, the cyclotron system needs to be reliable, flexible, and designed to minimize personnel dose. As the market for isotopes matured, producers learned that the increased cost of production enhancing features in these areas could be quickly recovered. The principle production enhancing developments in third generation cyclotrons are:

- A magnet design that guarantees strong vertical focussing for reduced losses during acceleration.
- H^- acceleration to allow extraction by stripping, which is basically lossless and allows easy energy variability.
- Targets located in separate caves, since these represent the most radioactive components of the system.
- Good vacuum (low 10^{-7}) inside the acceleration tank to reduce beam losses from gas stripping of the H^- .
- External ion source, which improves the vacuum, the ease of operation and the reliability.

	1989	1992	1995
Europe	8 H ⁺ 2 H ⁻	8 H ⁺ 4 H ⁻	8 H ⁺ 5 H ⁻
North America	13 H ⁺ 1 H ⁻	13 H ⁺ 4 H ⁻	13 H ⁺ 5 H ⁻
Asia-Pacific (exc. China)	5H ⁺	5 H ⁺ 4 H ⁻	4 H ⁺ 5 H ⁻
Total H ⁺	26	26	25
Total H ⁻	3	8	15
Total No. Cyc.	29	34	40

Table I

Installed and operating commercial cyclotrons used for isotope production

- Modular systems, with a lot of hardware (eg power supplies) located outside the vault.
- Use of low activation materials, and a reduced dependence on materials that are subject to radiation damage.
- Use of more power efficient designs.
- Improved beam quality and stability to reduce hot spots on the target.
- More sophisticated control system using PLCs and commercial graphics based user interface.

Table I shows the number of commercial cyclotrons installed for commercial isotope production. As can be seen, since the introduction of these machines in 1988 all new commercial isotope production machines have been in this class of third generation of cyclotrons. (Note: A couple of proton cyclotrons with internal targets have been sold during this period, for a highly specialized isotope production use.)

The fact that at TRIUMF we have a CP42 (2nd gen.) and a TR30 (3rd gen.) operating along side one another provides a unique opportunity to directly compare the two. Both machines are run by the same staff, and have similar schedules, however as shown in figure 1 there is a significant difference in the total charge delivered by the two machines. With continued improvements on the third generation machines their outputs have substantially increased during the last five years. Table II shows some representative make rates available over the years (note: the values given are for typical production and not best available). At the present time Nordion International in Vancouver is upgrading its TR30, so that it will be capable of delivering in excess of 1 mA of beam on target. This represents a considerable increase in the production capability, at very

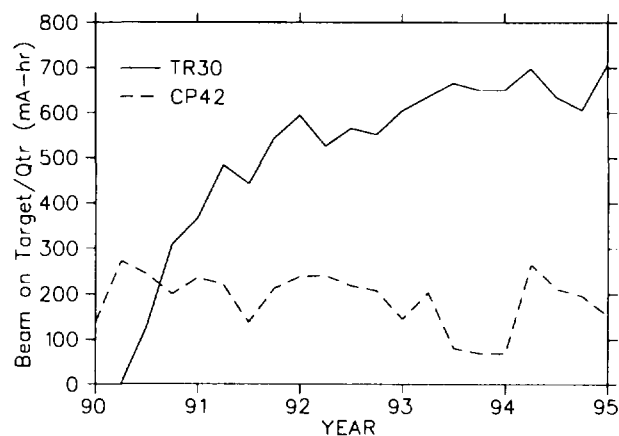


Figure 1. Total charge delivered on target each quarter by the TR30 and CP42 cyclotrons located at TRIUMF, and owned by Nordion Int.

Year	Cyc.	Current (μ A)	Energy (MeV)	Make-Rate (mCi/beam-hr) [EOB+56hrs]
1989	CS30	350	26.5	190
	CP42	180	29	160
1992	CYC30	360	29	320
	TR30	360	29	320
1994	TR30	440	29	400
1995	TR30	900	29	800

Table II

Make Rates of ²⁰¹Tl for representative Commercial Cyclotrons

little additional costs. It is also quite remarkable considering that this TR30 was originally designed to operate at 350 μ A.

A comparison of accumulated **personnel dose** between the two cyclotrons also shows a dramatic difference. As seen in figure 2 there is nearly an order of magnitude improvement over the previous generation, particularly when compared on a dose per charge delivered basis. This improvement represents both a significant cost saving and an improved work environment for the staff. It is also believed that proposed new dose rules will increase the pressure to retire the existing first generation machines, and replace the capacity using third generation machines.

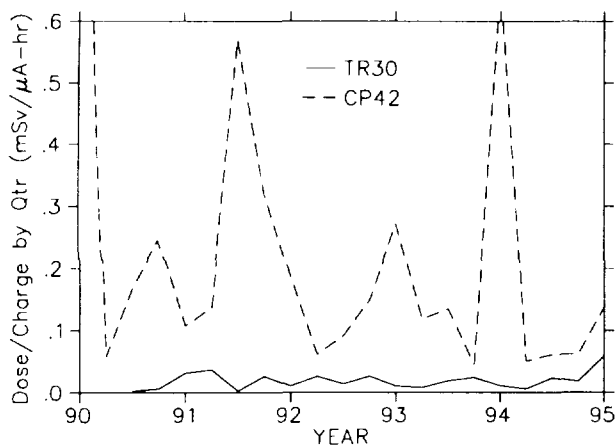


Figure 2. Accumulated personnel radiation dose, by quarter for the TR30 and CP42 cyclotron.

III. Future Developments

The increased beam current available allows more flexibility in scheduling, improved profitability, and reduced strain on systems when not operated at peak capacity. Work at TRIUMF on a model of the TR30 injection system has all ready demonstrated 2 mA of H^- injected and accelerated to 1.1 MeV [4]. This work indicates that the 1 mA machines now being developed, are still a long way from any fundamental limits. Active work on ion source development and low energy injection systems may make this type of capability commercially available in the next few years.

An isotope with increasing potential for clinical PET studies is $^{82}Sr/^{82}Rb$ generator systems. As a generator system, it again lends itself to distribution from a central facility, making it very different from most other PET isotopes, that basically require an on site production facility. Presently this isotope is produced in North America on higher energy accelerators employing spallation from molybdenum, or by bombardment of rubidium metal with 60-80 MeV protons [5]. The ability to produce this generator has been a strong driving force in the design of cyclotron systems under consideration for the U.S. National Biomedical Tracer Facility [6]. Preliminary studies indicate that the design principles used in the current generation of cyclotrons could be extended to the required **80 MeV** (figure 3). The dominant factor limiting the practical energy of a H^- cyclotron, is electromagnetic stripping of the H^- during acceleration. In order to reduce activation of the accelerator systems, caused by the resulting beam spill, these losses should be kept to the few percent level. This requires substantially lower central magnetic field values (B_0) with increasing energy, which in turn leads to a very rapid rise in magnet size. While these considerations do not provide a hard limit on the maximum possible energy, 80 MeV seems to be a practical compromise between the still increasing production cross-section and the accelerator size.

It seems inevitable that commercial cyclotron systems of

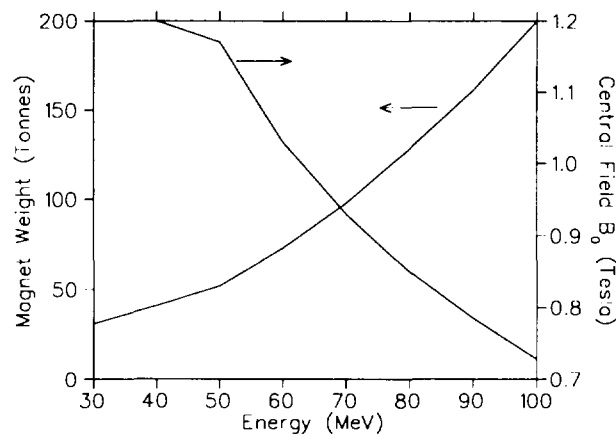


Figure 3. Required Magnet Sizes as a function of Energy for a H^- Cyclotron. The electromagnetic stripping losses have been constrained to be less than 2%.

the future will continue the trend towards higher beam currents, increased flexibility, and a diversity of available beam energies, to produce a broadening range of isotopes. At present it appears that extensions of existing technologies are capable of dealing with the foreseeable needs, however uncertainty in the market place may delay implementation.

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