THE CYCLOTRON RADIOISOTOPES PRODUCTION FACILITY OF THE ARGENTINEAN ATOMIC ENERGY COMMISSION (CNEA)

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Abstract

A Cyclotron facility for radioisotopes production has been in operation in the Atomic Center Ezeiza since 1994. An H^- 42 MeV Cyclotron, two target vaults, three hot-cells and a radiochemistry laboratory are dedicated for routinely production of ^{201}Tl and FDG. A ^{123}Xe target station is being currently constructed in a third target vault under an IAEA support project. The Cyclotron is a CP42 H^- model, which was refurbished in Karlsruhe, Germany. This CP42 has a few added improvements, which make it one of the best of its class. The improvements included a source vacuum lock and a precise position control. The original variable energy extractor was also changed. The new one extracts the beam through another port than the original, which was selected for better beam quality for 25 MeV to 42 MeV. Recent improvements to the central region increased the internal beam available for acceleration, reaching a maximum of more than 400 µA. An external current in excess of 200 µA is also routinely achievable. Very high vacuum and very efficient and reliable RF system must be maintained to increase this limit. In addition, beam current limitations due to axial space charge effects in terms of vertical aperture and axial betatron frequencies will be discussed. The target systems are being improved for higher beam current. A new modern PC control software coupled to the original electronic control system will be described here. This program simplifies and fastens the operator tasks, providing also more information for diagnostics.

1 FACILITY DESCRIPTION

About 15 years ago, after a persistent effort by Prof. and Dr. Palcos, The Atomic Center Ezeiza (CAE) obtained the approval for the construction of the first short-lived radioisotope production facility in Argentina. Dr. Palcos, the project leader at that time, favored a variable energy and high current proton cyclotron as the driver for the facility. It happened that a refurbished CP42 H^- cyclotron was available from Kraftanlagen Heidelberg, Germany. Thus, over other possibility, the Argentinean Atomic Energy Commission (CNEA) signed a contract for the purchase of such machine, three beam lines and a solid target station. It's worth to mention that, the more advanced high current isotope cyclotrons, like Cyclone 30 and TR30, were not yet emerged from the market. By financial reasons, the facility construction was delayed until 1991 and commissioned in 1994.

A main vault allocates the CP42 cyclotron, a switching magnet and three beam lines [1]. Since 1997, the solid target vault has been routinely used for ^{201}Tl production. About 900 mg of enriched ^{203}Tl are electroplated over a 12mm x 75mm area of the silver target plate. For the routinely used beam currents (~150 µA), we get a yield in the order of 25 mCi/µA.hr (EOB+40hr), using our own radiochemical module. Solid targets are pneumatically transferred to the hot cell area. In another vault, $^{18}F^-$ is produced by bombardment 1.2 ml of $H_2{}^{18}O$ (80%) at 12 bar with 30 µA protons at 22 MeV. The silver target body is rhodium plated to minimize F^- losses. The yield is in the order of 215 mCi/µA.hr (EOB). FDG is produced in an own designed synthesis module. The third target vault is being prepared for ^{123}I production, using a ^{123}Xe gas target designed and constructed under IAEA support.

2 CYCLOTRON IMPROVEMENTS

Forschunszentrum Karlsruhe made some improvements to the CP42. They included a source vacuum lock and a precise position control. The original variable energy extractor was also changed. The new one extracts the beam through another port than the original (P14), which was selected for better beam quality for 25 MeV to 42 MeV. In addition, the main magnet power supply was replaced.

2.1 Ion Source and Central Region

Considering the beam losses during acceleration, the internal beam current capability should be at least 50% bigger than the desired external one. To improve the first, we installed a new anode for the PIG ion source, which has an optimized slit area and shape for maximum H^- production with a minimum vacuum pressure increment [2]. In addition, H^- production and survival inside the chimney was optimized by adjustment of the plasma expansion gap between the arc column and the exit slit. Furthermore, the original graphite puller was replaced by a Molybdenum one. The older puller had a poor resistance to beam striking. It liberated trapped molecules, worsening the vacuum conditions and producing electrical discharges. RF sparking in this region is greatly reduced.

A four-dimensional positioning system [3] permits the optimization of initial orbits, H^- production (adjusting the plasma expansion gap by rotation) and the transit time from source to puller (adjusting the source-puller

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distance). The source to puller gap adjustment also reduces the space charge effect due to large electron current extracted simultaneously with the H^- ions. The vertical drive coupled with the well-aligned puller (with magnet midplane) minimizes the initial vertical oscillation.

2.2 Magnet

Axial focusing is provided by three spiral sectors. The weak focusing in the magnet center was improved by increasing the field bump using a large central plug [4]. Three centering harmonic coils, located in the valleys at about 15 cm, provide fast traversal for the ν_r=3/3 radial resonance. While a set of outer harmonic coils provide more than the function of increasing/decreasing beam separation at the outer $\nu_r \sim 1$ region. They act like trim coils by moving beam orbits into better fit of isochronism.

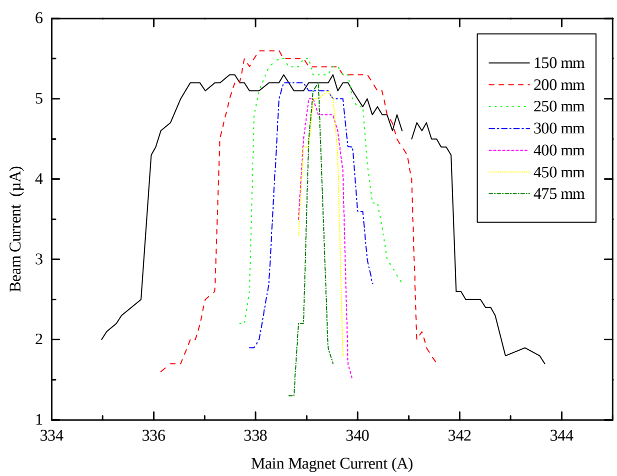

Figure 1: Resonance plots

Neither a magnetic map for our cyclotron nor a phase probe was available. Therefore, we got some information about phase excursion appealing to the resonance curves method [5, 6]. A series of plots for various radii is shown in Figure 1. The flattop at 150 mm indicates a good positioning of the central region and good initial axial focusing. The slope at the right corner is an evidence of axial losses with increment of magnetic field (phase is more advanced). The fall-off slopes on both sides represent the beam phase width. A width of about 60 degree at r = 150 mm was estimated from this plot**.** The well-centered phase plots at various radii indicate that the phase excursion from 150 mm to 475 mm is small.

2.3 RF System

The DC anode input to the oscillator [7] is from a 68 kW HV power supply, which provides dee voltage control and regulation plus a fast optocoupled crowbar protection. The load's power consumption without beam is about 53 kW DC. The remaining 15 kW can accelerate only 200µA up to 30 MeV, indicating a low DC to RF efficiency. Therefore to achieve higher currents with the existing DC power supply, we'll need to reduce the power losses and beam loading, compensating by cavity detuning [8]. Since we lack a spectrum analyzer, this task is deferred.

2.4 Control System

We developed a new control program under Visual BASIC environment, which runs on a PC under Windows NT. The PC communicates to the TCC control system though the TCC bus using an ad-hoc constructed interface. In this way, we replaced the old DEC PDP-11/03 microcomputer. The TCC system configuration tables, where the cyclotron equipment description is stored, were imported into the new program. Each register from this table is assigned to different kind of objects. New features to the control system were added: operator customized environment, alarm panel, customizable plots, log register, test panel for control modules, etc. Furthermore, an electronic logbook maintains databases for operations, calibrations, services, production and spare parts. For a future replacement of the TCC crates by PLC's, a modified communication subroutine is foreseen. Automated tuning routines for the different subsystems are also planned.

3 BEAM CURRENT CAPABILITY AND LIMITS

3.1 Beam Current capability

The internal beam capability is quite reproducible. With an arc current of 1 A and a gas flow of 6 sccm, more than 400 µA were measured at 150 mm radius (~3.3 MeV). Figure 2 shows the probe current as a function of arc current for different gas flows. Extra amounts of gas above 6 sccm do not show significant improvements. Aside from the stripping effects, this behavior may indicate that the space charge effect on the slit exit is limiting the beam extraction from the ion source.

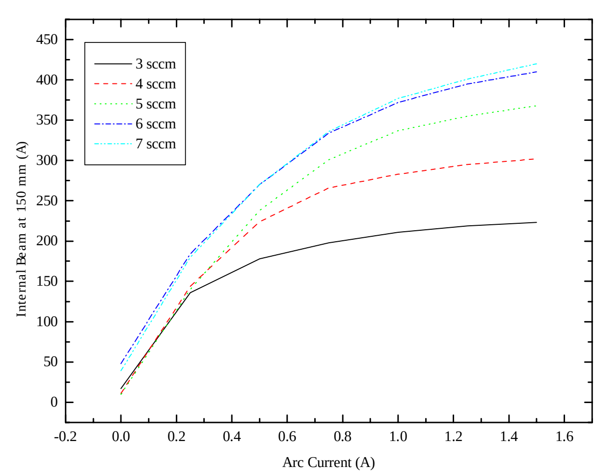

Figure 2: Internal beam capability at r=150 cm.

Although the internal beam current was highly increased, the capability to accelerate a big portion of this is limited. Since, the gas pressure loads the tank pressure, a good balance should be maintained between the source feed and stripping losses. A high energy gain per turn is also required to reduce the stripping losses, which are in the order of 35% for 200 µA extracted at 30 MeV with a base pressure of 500 nTorr.

3.2 Current limitations due to space charge

Space charge effects have been investigated using simplified models [9,10,11] and particle simulation methods [12]. They were summarized by different authors in the Santa Fe Workshop on Critical Beam Intensity Issues, LANL (1995) and more recently by Stammbach [13]. As the CP42 has H^- multi-turn extraction and it is mainly used for radioisotope production, we don't need to worry about the longitudinal space charge, which increases the energy spread and destroys the turn separation. On the other hand, the axial space charge produces tune shift putting a serious limit on our achievable beam current.

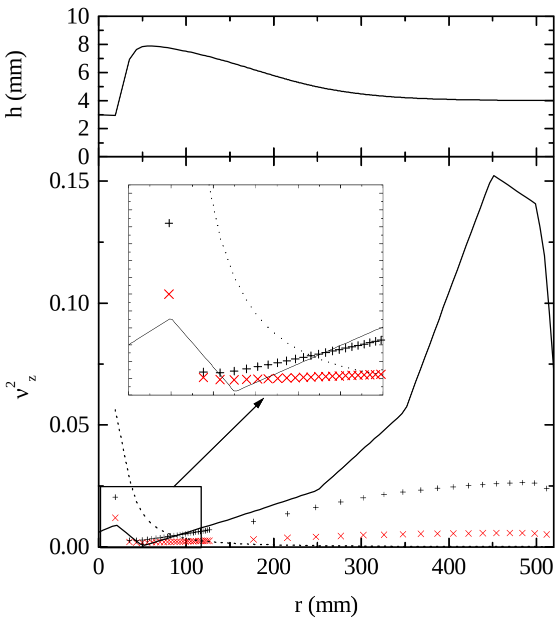

Figure 3: Above, axial envelope adopted for the vertical clearance. Below, tune shift computed for 500µA: Gaussian widths of 100% (x) and 20% (+) of the clearance. Axial betatron frequency for a CP42 prototype (solid) and Electric focusing (dots) [14].

We used the Reiser model [10] to compute the total electric field on the outer edge of an angular sector due to finite bunches distributed in separated orbits. The beam envelope function for the axial height was defined to fit the puller, dee's and extractor clearance. The angular periodicity structure due to axial focusing was disregarded. The charge density distribution was a three-dimensional Gaussian function. The beam width to height ratio was fixed to the initial values along the different orbits. All the calculations were made for constant energy gain per turn of 90 keV. Figure 3 shows the calculated tune shift for a beam current of 500 µA and a phase width of 60°. We used two Gaussian widths: 100% and 20% of the free space available for each direction. The computed tune shift increases with the radius in an inverse proportion to the beam height modulation. The predicted tune shift after the first turn, using the 20% Gaussian width density distribution, was $\Delta\nu_z^2=1.07\times10^{-3}$, about the double of the predicted for the Joho's ellipsoid model, indeed, half the maximum current.

As we lack the magnet field map for our cyclotron, we computed the axial betatron frequency for a CP42 prototype magnet. For this magnet, 500µA seems to be reasonably achievable current.

4 SUMMARY AND CONCLUSIONS

We have obtained a very stable external beam in excess of 200 µA for 30 MeV with the usual operational parameters. Vacuum and RF power transference should be improved for a further increase. A good knowledge of the cyclotron physics was necessary to overcome the lack of expensive measurement devices.

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