Optimization of the ion source for the compact superconducting AMIT cyclotron for radioisotope production

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AMIT Tecnologías de Imagen Molecular Avanzadas

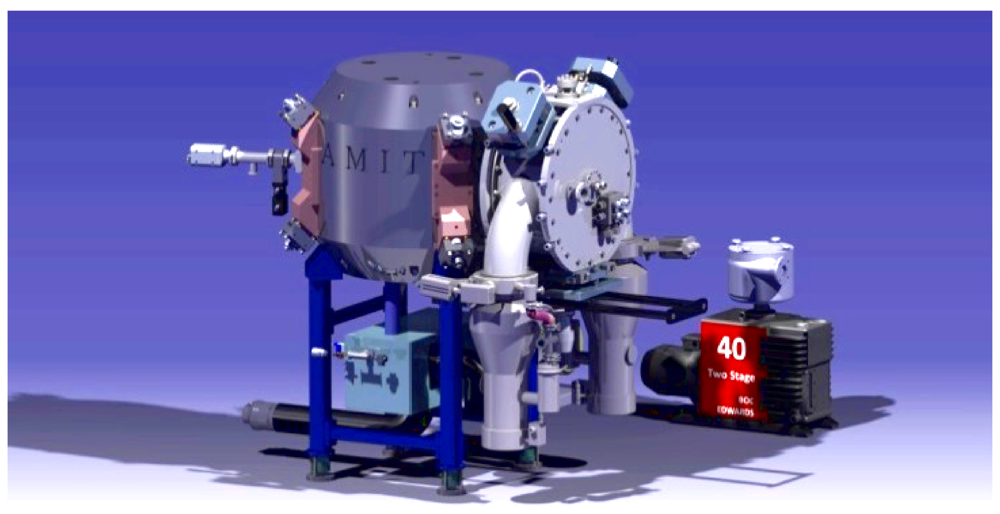
Abstract

The aim of the AMIT project is to deliver a classical weak focusing cyclotron for the radioisotope production due the growing demand of PET radioisotopes as diagnostic tools in hospitals. The radioisotopes are produce as from the collision of the accelerated ions with the target. The AMIT cyclotron accelerate negative ions, that are injected from a internal ion source. A test bench have been required for the optimization of the ions production in the ion source designed, to comprise the different aspects that determine the proper ion production, the different losses in the system and the correct operation of the ion source.

Cyclotron

General	
Cyclotron type	Classical
Energy	$>$ 8.5 MeV
Current	10 μA
RF system	
Configuration	One 180° Dee
Acceleration voltage	$>$ 50 KV per Dee
Ion source	
Type	Internal
Ions	H^-

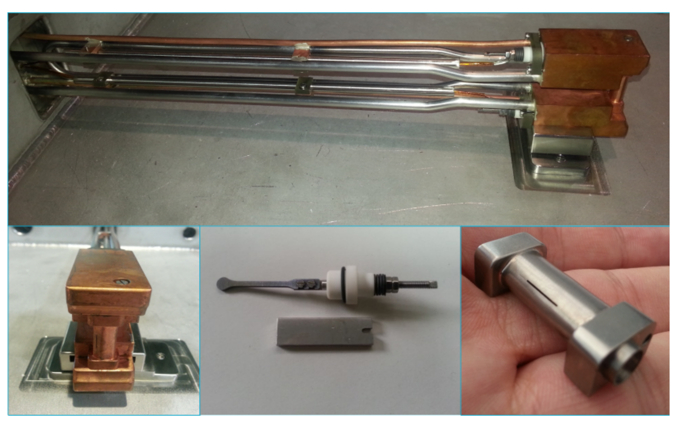
Magnet	
Type	Low T_c superconductor
Configuration	Warm iron
Superconductor material	NbTi
Central field	4 T
Extraction	
Extraction System	Stripping foil at 110 mm
Position	External
Target	Nitrogen gas $\rightarrow {}^{11}$C ^{18}O enriched water $\rightarrow {}^{18}$F



The high magnetic field required for the compact design of the AMIT cyclotron makes the classical cyclotron choice to be considerably less complicated than the corresponding isochronous solution. A combination of high magnetic field and a high-alternating electric field accelerates the charged particles from the central axis, where they are injected, in an outward spiralling path. The magnetic field decreases along the radius of the orbit providing radial and axial stability of the beam (weak focusing). The oscillation frequency of the gap voltage remains constant while the ion orbital frequency decreases due to the relativistic mass increase with the energy and to the radial decrease of the magnetic field.

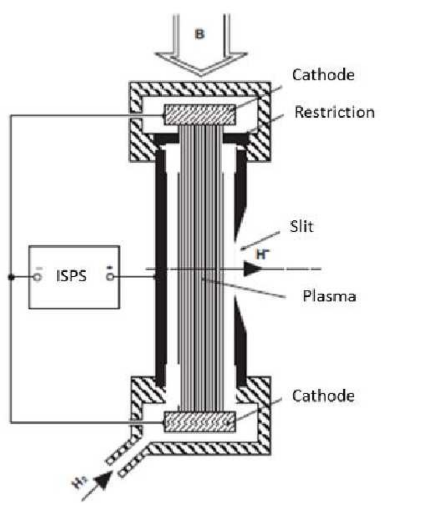
Ion source

The ion source of the cyclotron is of the Penning Ionization Gauge type (PIG) with cold cathodes. This internal ion source is used for the production of negative hydrogen ions. The ion source consists of two main components: the ion source tube or anode and two cathodes made of tantalum. The anode is grounded while the two cathodes are biased at a high negative potential with a power source. The voltage difference between the cathodes and the anode create a plasma discharge in the hydrogen gas, creating positive (H^+) and negative ions (H^-). These particles are confined by a magnetic field along the length of the ion source tube. The anode has a slit opening along the side of the ion source where the H^- ions are extracted. The beam parameters have a strong dependence on the geometrical parameters, such as the distance between the slit opening and the edge of the plasma column, and the shape of the plasma column.

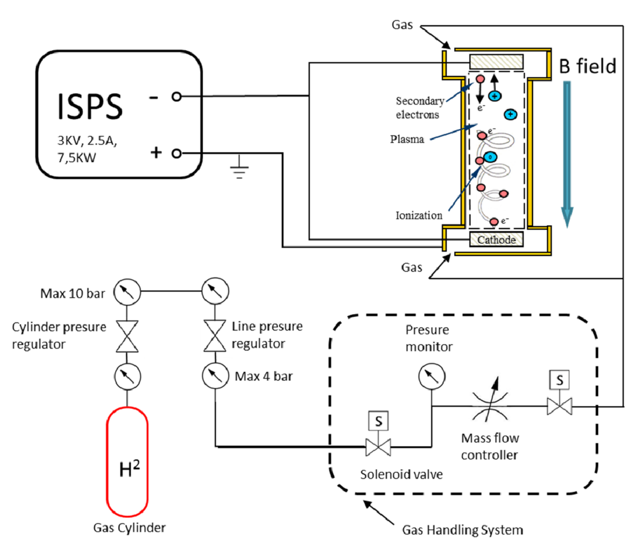


Ion source

Ion source power supply



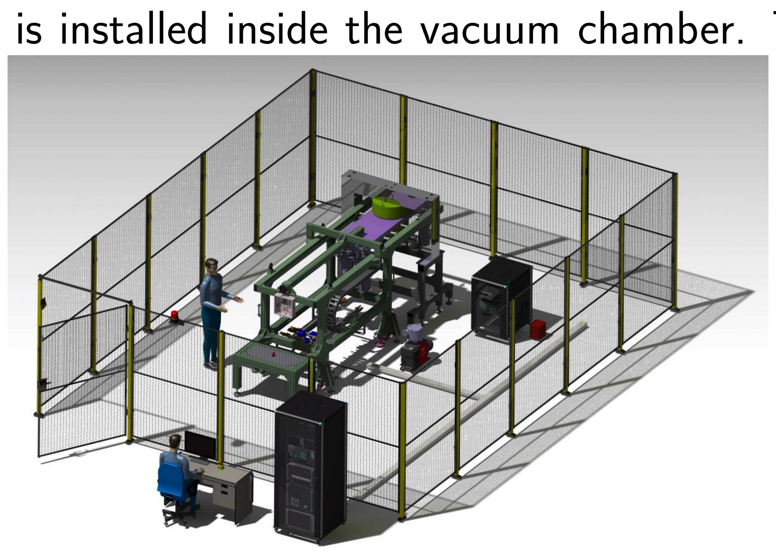
Ion source scheme



System diagram

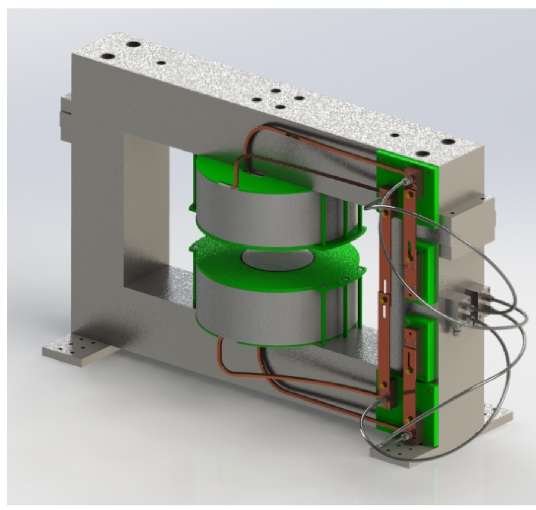
IS Test bench

The test bench required for the optimization of H^- formation in this kind of ion source needs to be carefully designed due the related disadvantages as the high voltage loading spark and low vacuum level. In this test, the ion source is grounded whereas the puller, at positive DC high voltage, extracts the negative particles. An electrical shield box is installed inside the vacuum chamber. This box shields the applied electric field like a Faraday cage and therefore the trajectories of negative ions are only affected by the magnetic field which separates them for different q/m ratios. A beam probe, located according to H^- trajectory, measures the ion current. Electrons hardly enter in the measurement area with such a strong magnetic field (orbit radius is much smaller).



IST facility components

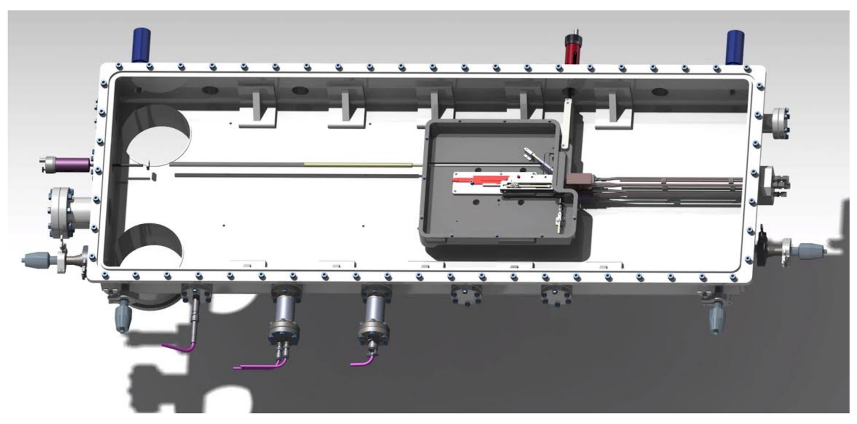
IST system



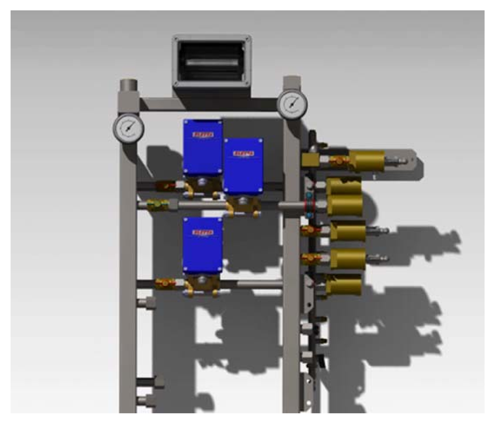
Dipole magnet

The main components needed for the experimental setup are:

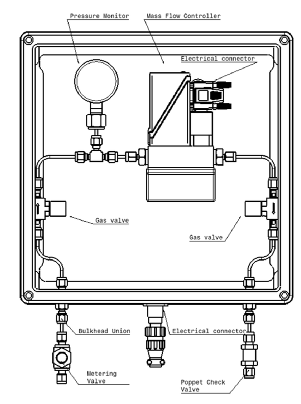
- **Dipole magnet**
  The PIG ion source test stand will be mounted in a dipole electromagnet which has been constructed by ANTEC.
- **Vacuum chamber**
  It is extremely versatile due its accessibility, geometry and the numerous ports. The support have a modern design and a robust structure, optimum dimensions and very low weight.
- **Gas handling system**
  Sophisticated system for the distribution and control of gas in the ion source.
- **Faraday cage**
  An electrical shield box for the free movement of the ions in the magnet field, where are introduced the beam probes for the detection.
- **Water cooling system**
  Cooling for the dipole magnet, the ion source, and the vacuum system.
- **High voltage and mechanical cage protection**
  The HV test area is separated from the other working areas by a mesh fence of 2m high and has a system of protection against electrical hazards.



Vacuum chamber with the electric shield box



Water distribution scheme

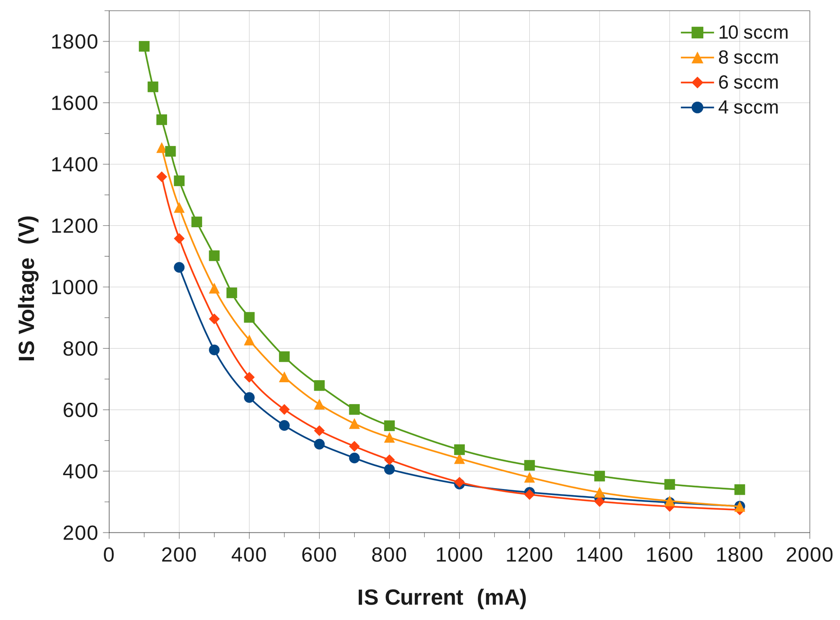


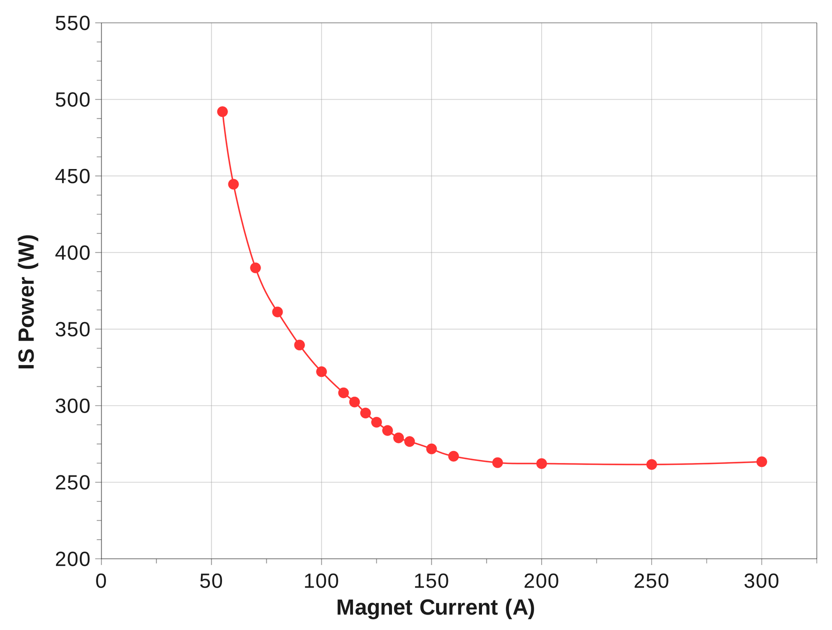
Gas supply system

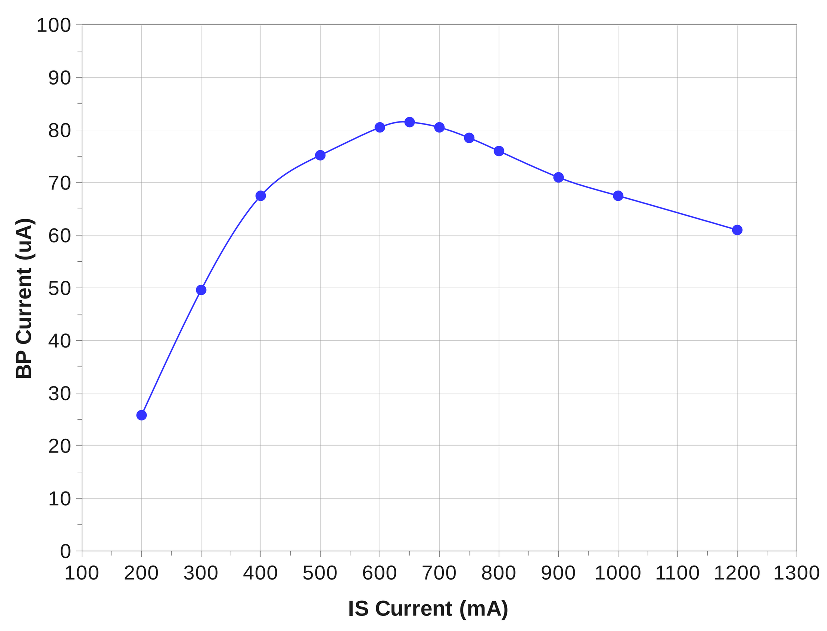
Ion source characterization

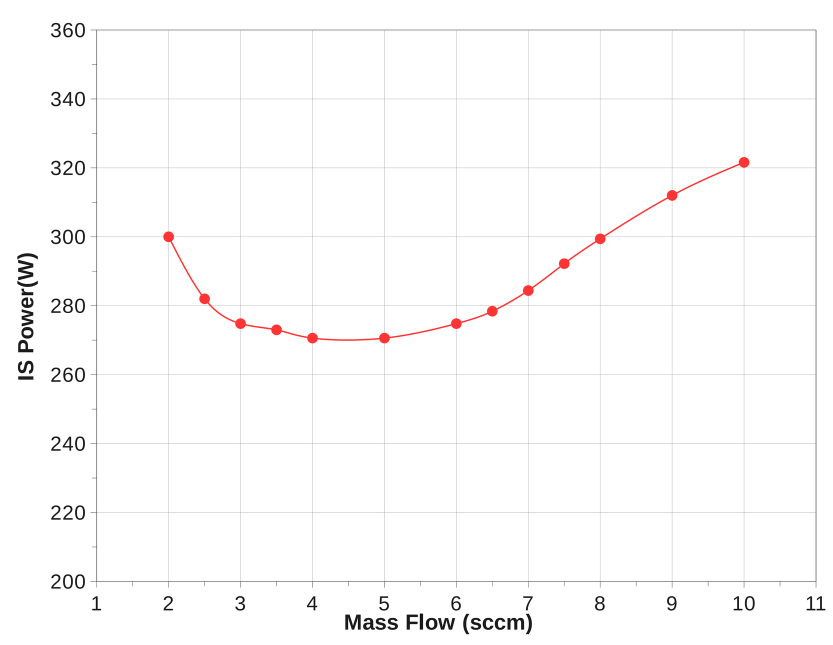
The ion source have been characterized with different measurements:

- **Arc discharge characteristic**
  The electron emission is dominantly thermionic emission due heating of the cathode by back bombardment by the ions in the discharge. In this self-heated mode the voltage-current characteristic has a negative impedance and the ion source is affected mainly by gas flow and arc current. The experimental voltage-current curve is accord with the arc discharge characteristics of a PIG ion source where the impedance is positive for the cold cathode and negative for hot cathode source. The arc voltage decreases rapidly as the arc current increases and gradually saturates at high currents.
- **Magnetic field**
  Applying different currents in the magnet the orbits of the particles are modified in the plasma.
- **Gas flow**
  The specific resistance of a plasma η is often calculated using Spitzer formula:
  $$\eta = \frac{1}{\sigma} = \frac{m_e \nu_e}{e^2 n_e}$$
  The arc power is proportional to the electron collision frequency and inversely proportional to the electron density for constant arc current. Thus, at low flow gas rate, the electron density is dominant so the arc power decreases.
- **Ion current**
  The current in the beam probe have been optimized respect of the arc current, getting a maximum current of $\sim$82 μA.









Acknowledgments

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