Compact accelerators for Radioisotope production:

The AMIT Project

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on behalf of the AMIT Collaboration

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OUTLOOK

The AMIT Project: Structure
The AMIT Cyclotron: Requirements
The AMIT Cyclotron: Concept

Magnet design
Cryogenics
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The AMIT project: Advanced Molecular Imaging Technologies

SEPT 2010 - DEC 2013 Partners: 10 companies, 14 research labs + Other Collaborations.

Work supported by the Spanish Ministry of Science and Innovation

- Target: Development of the core technology for molecular imaging in Medicine and Biomedicine with special focus in the human brain and in particular in mental diseases

WP1. Development of a compact cyclotron for $^{11}$C y $^{18}$F single doses production

- CIEMAT is the scientific leader of this cyclotron project
- At the present stage: 3 Scientific programs are funding the project

2014 - 2017 The OPTIMHAC program (Plan Nacional): Beam optimization

2016 - 2019 The CIENTO program (Plan Nacional): Cryogenics and operational optimization

2017 - 2021 The ARIES program (H2020): Integration as a research infraestructure

2014 - 2017 CIEMAT Own Funds
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The AMIT Cyclotron: Requirements

- **MOTIVATION:** To develop a Compact cyclotron able to produce short half-life isotopes for sintering PET radiotracers, including:
  - Capability of producing radiopharmaceuticals on demand:
  - Extending the production of radioisotopes to hospitals and institutes which are not prepared for hosting conventional facilities
  - Disposing a back-up system for producing selected radiotracers at prices that can compete in specific cases with those of standard production centers.

- **CYCLOTRON REQUIREMENTS:**
  - $^{11}$C & $^{18}$F on-site isotope production
  - Single dose production
  - Minimum size & weight
  - Minimum radiation levels
  - Affordable price (construction & operation)

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Dose</th>
<th>Target</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{18}$F</td>
<td>40 mCi</td>
<td>Water enriched in $^{18}$O</td>
<td>$^{18}$O$+^{1}$H$^+$ → $n + ^{18}$F</td>
</tr>
<tr>
<td>$^{11}$C</td>
<td>100 mCi</td>
<td>Nitrogen gas</td>
<td>$^{14}$N$+^{1}$H$^+$ → $^{4}$He$^{++} + ^{11}$C</td>
</tr>
</tbody>
</table>

$\Rightarrow$ Beam requirements: $E > 8.5$ MeV  $I > 10\mu$A
The AMIT Cyclotron: Solution

**Compact** + \( E \approx B^2 R^2 \text{(MeV)} \) ➔ **High B** ➔ **Superconducting Magnet** ➔ **NbTi based** ➔ **Classical Cyclotron**

- (Compared to a resistive magnet, given the same space for acceleration chamber)
- Smallest cyclotron possible for a given \( E \). For a NbTi magnet:
  - 50% less diameter and height
  - About 1/10 cyclotron weight
  - \( x2.5 \) less shielding weight
- Low Power Consumption
- Cryogenics needed
- More maintenance

- Well known technology
- Affordable price
  (for manufacturing and operation)
- Higher improvements up to 4 T
- Such saturation level at 4T gives poor flutter for a conventional isochronous cyclotron
- Classical cyclotron is easier and cheaper while weak focusing is still suitable for this beam
- This solution is valid for such level of energy (8.5 MeV) provided the accelerating voltage is high enough (60 keV)

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![Graph showing weight vs. magnetic field strength](image)
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The AMIT Cyclotron: Concept

**Magnet**
- Low Tc superconductor (NbTi)
- Warm Iron
- 4 T Central Field
- Decreasing field (focusing)
- Low thermal losses

**RF System**
- One 180° Dee
- 60 kV minimum

**Source**
- Internal
- Hydrogen > H⁻

**Extraction**
- Stripping foil
- Targets:
  - Nitrogen gas (¹¹C)
  - ¹⁸ O enriched water (¹⁸F)

**Cryogenics**
- Closed-loop LHe circuit
- Single commercial cryocooler

**Control system, Diagnostics,...**
- Robust and Simple operation

**Beam Dynamics**
- E>8.5 MeV
- I>10µA
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The AMIT Cyclotron: Magnet design

- Electromagnetic design was performed 2D for optimization, 3D for final design

- Working point of cable, Quench analysis developed from previous know-how of Ciemat team

- Thermo-structural design was performed at different levels:
  - from wire to coil approach for stability
  - Magnet behaviour for optimization on shielding and supports
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The AMIT Cyclotron: Cryogenics

- **Thermal design:**
  - LHe flow inside casing, intimate contact to coils
  - Gas He for shield cooling
  - G10 rods for support
  - HTS current leads

- **LHe liquefaction and pumping:**
  - System outside the radiation shielding (Cryogenic Supply System – CSS)
  - Just one cryocooler (1.5 W@4K)
  - Vaporized He used for thermal shield and current leads
The AMIT Cyclotron: Cryogenics

Cyclotron including all the components and the cryogenic supply system
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The AMIT Cyclotron: Manufacturing

- **Magnet**

- **RF**
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The AMIT Cyclotron: Tests done

- Validation of cooling concept for coils:
  - **Same concept for LHe flow inside casing**
  - **Experimental values as expected from calculations**

- Training of AMIT coils in bath-cooling
  - **First quench at critical current, no training**
The AMIT Cyclotron: Tests done

- RF conditioning at ALBA facilities (Barcelona)
  - Nominal power achieved
The AMIT Cyclotron: Tests done

- New Ion Source Testing Facility at CIEMAT for design and fine tuning
  - > 150 µA obtained
- Resistive Magnet available for beam characterization
The AMIT Cyclotron: Tests done

- **CSS (Cryogenic Supply System) at CERN**
  - Stand-alone System characterization
  - **He circuit** as close as possible to real system, including coils and shield mock-ups
  - CSS delivers **1.5W@4.2K** by means of just one commercial cryocooler located some meters away from the cyclotron
  - Some improvements will be included for faster cooling down
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The AMIT Cyclotron: On-going Tests

- New Magnetic Field Measurement Bench at CIEMAT
  - Collaboration of ALBA
  - First phase: low current measurement (resistive mode) Ready
  - Second phase: Nominal current measurement (superconductive mode)
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The AMIT Cyclotron: Next Steps

- At this moment, all components are getting close to final stage
  - Fine tuning still in progress
  - Big effort is being done for perfect behavior of each component prior integration

-Then, integration phase will start:
  - Bunker is ready at CIEMAT

-After commissioning, cyclotron will be functional at final place in CIEMAT

-Here are some rough highlights expected for magnet operation:

  >10µA @ 8.5 MeV
  - Superconducting technology
  - Cyclotron weight ≈ 2.5 t
  - No need for cryogens during operation

- About Manufacturing components:
  - NbTi wire
  - One single cryocooler
  - One turbomolecular pump