The C400: the ARCHADE multi-ions cyclotron

Jacques BALOSSO
CFB at Caen and UGA at Grenoble
Outline

- History of the C400 project
- The ARCHADE project in Caen
- The CYCLHAD SAS in Caen
- The use of C400 in CYCLHAD
- The production of C400 by Normandy Hadrontherapy SAS
- Medical interest and constrains
History of the C400 project

• After **ASCLEPIOS** (2005-2007) challenger of ETOILE ...
• **ARCHADE** was a pure scientific resource project (2008) with a unique industrial partner (**IBA**)
• But... **economically unsustainable**
• Introduction of the principle of a limited proton treatment production (2012) by a Proteus®One equipment
• **ARCHADE** progresses as a scientific project with mixed clinical/scientific activities
• A specific Co. and building are devoted: **CYCLHAD SAS**
• The heart of the project is the development and the scientific use, mostly by **external users**, of the multi-ions superconducting cyclotron **C400**
The ARCHADE project in Caen

Normandy Region

Research Institutions
CHU Caen

ARCHADE
(Assoc loi 1901)
2008

Medical institution
CRLCC F. Baclesse
The ARCHADE project in Caen

Normandy Region

Research Institutions
- CHU Caen
- UNICAEN
- ENSICAEN
- GANIL
- CYCERON
- CNRS
- CEA
- Etc.

Archade (Assoc loi 1901)
2008; 2010

Cyclhad (SAS)
2010; 2017

Stockholders

Medical institution
CRLCC F. Baclesse

Saphyn (SEM)
2009

Iba

Stockholders
The ARCHADE project in Caen

Normandy Region

Research Institutions
- CHU Caen
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- Etc.

ARCHADE (Assoc loi 1901) 2008; 2010

CYCLHAD (SAS) 2010; 2017; 2022

Normandy Hadrontherapy (SAS) 2018; C400

Medical institution
- CRLCC F. Baclesse

SAPHYN (SEM) 2009

Stockholders
6

Medical institution
CRLCC F. Baclesse
The ARCHADE project in Caen

Normandy Region

ARCHADE (Assoc loi 1901) 2008; 2010

SAPHYN (SEM) 2009

Research Institutions
CHU Caen
UNICAEN
ENSICAEN
GANIL
CYCERON
CNRS
CEA
Etc.

Scientific project

External users

Proton therapy

Stocke holders

Medical institution
CRLCC F. Baclesse

CYCLHAD (SAS) 2010; 2017; 2022

Normandy Hadrontherapy (SAS) 2018; C400
The ARCHADE project in Caen

ARCHADE partners are all located in the « North end » of Caen

- CYCLHAD
- GANIL
- Guesthouse for external users
- CIMAP-LARIA
- CYCERON-ISTCT-CERVOxy
- Medical School
- ENSICAEN-LPCCaen GREYC
- Scientific Univ.
- Univ. Hospital
- ABTE-TOXEmac
- Centre Fr Baclesse
GANIL as > 30 years of experience on welcoming experiments
The ARCHADE project in Caen
Organization with a Proposal advisory committee

Practical organization
The ARCHADE project in Caen: position in France...

... coming soon: RADIOTRANSNET
An exact correspondence of ARCHADE scientific program and FrHA project

- **WP1**: Clinical research in hadrontherapy
- **WP2**: Basic physicochemical data for hadrontherapy
- **WP3**: Radiobiology data for hadrontherapy
- **WP4**: Operational developments for improving the quality of treatments
The CYCLHAD SAS in Caen building completed in 2017
The CYCLHAD SAS in Caen
the treatment and experimental rooms

1 Hadrontherapy center:
   - Proton therapy treatments
     Proteus One (S2C2)
     Protons at 250 MeV
   - Research in carbon-therapy
     - Physics
     - Biology
     - Clinical testing

2 Supraconducting Cyclotron C400
   $^{12}C$ at 400 MeV/u
   Protons at 250 MeV
   All light nuclei with A/Z=2
At the 2\textsuperscript{nd} floor, 28 rooms devoted to science (researcher offices, laboratories, animal house, and logistic spaces) totalizing about 500 m\textsuperscript{2}
The CYCLHAD SAS in Caen
the installation of the Proteus® One in September 2017
The CYCLHAD SAS in Caen the pillars to receive the C400 for its assembly starting in 2020
The CYCLHAD sAS in Caen
the beam lines hall seen from the physics exp. room
The production of C400 by NHa SAS

- The C400 has been designed by Russian teams of Doubna between 2006-2009 for IBA under the direction of Yves Jongen
- The PI is presently owned by the ARCHADE organization
- It will be an isochrone super conducting cyclotron able to accelerate **Protons, He, Li, B, C, N, O, Ne**
### The main parameters of the C400 cyclotron for carbon ions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (fixe)</td>
<td>400 MeV/u</td>
</tr>
<tr>
<td>Courant extracted beam</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>30 enA</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.03 enA</td>
</tr>
<tr>
<td>Emittance of extracted beam</td>
<td></td>
</tr>
<tr>
<td>maximum (1 (\sigma))</td>
<td>6 (\pi) mm.mrad</td>
</tr>
<tr>
<td>(horizontal)</td>
<td></td>
</tr>
<tr>
<td>(vertical)</td>
<td>8 (\pi) mm.mrad</td>
</tr>
<tr>
<td>External diameter of the magnet</td>
<td>628 cm</td>
</tr>
<tr>
<td>Total height of the magnet</td>
<td>340 cm</td>
</tr>
<tr>
<td>Total weight</td>
<td>694 tonnes</td>
</tr>
</tbody>
</table>

The production of C400 by NHa SAS
### The main parameters of the C400 cyclotron **helium ions**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (fixe)</td>
<td>400 MeV/u</td>
</tr>
<tr>
<td>Courant extracted beam</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>300 enA</td>
</tr>
<tr>
<td>Minimum</td>
<td>0,3 enA</td>
</tr>
<tr>
<td>Emittance of extracted beam</td>
<td></td>
</tr>
<tr>
<td>Maximum (1 σ) (horizontal)</td>
<td>6 π mm.mrad</td>
</tr>
<tr>
<td>(vertical)</td>
<td>8 π mm.mrad</td>
</tr>
</tbody>
</table>

### The main parameters of the C400 cyclotron for **protons**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (fixe)</td>
<td>260 MeV/u</td>
</tr>
<tr>
<td>Courant extracted beam</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>500 enA</td>
</tr>
<tr>
<td>Minimum</td>
<td>0,5 enA</td>
</tr>
<tr>
<td>Emittance of extracted beam</td>
<td></td>
</tr>
<tr>
<td>Maximum (1 σ) (horizontal)</td>
<td>8 π mm.mrad</td>
</tr>
<tr>
<td>(vertical)</td>
<td>9 π mm.mrad</td>
</tr>
</tbody>
</table>
The production of C400 by NHa SAS

Fig. 1.3.3. C400 magnet design
The production of C400 by NHa SAS

Table 1.3.1. Main parameters of C400 magnetic system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer diameter (m)</td>
<td>6.636</td>
</tr>
<tr>
<td>Height (m)</td>
<td>3.4</td>
</tr>
<tr>
<td>Total iron weight (t)</td>
<td>694</td>
</tr>
<tr>
<td>Pole radius (m)</td>
<td>1.87</td>
</tr>
<tr>
<td>Valley depth (cm)</td>
<td>60</td>
</tr>
<tr>
<td>Sectors gap (cm)</td>
<td>12/0.6</td>
</tr>
<tr>
<td>Sector angular width (max) (deg)</td>
<td>45</td>
</tr>
<tr>
<td>Sector spiral angle (max) (deg)</td>
<td>74</td>
</tr>
<tr>
<td>Bending limit</td>
<td>K=1600</td>
</tr>
<tr>
<td>Hill field (T)</td>
<td>4.5</td>
</tr>
<tr>
<td>Valley field (T)</td>
<td>2.45</td>
</tr>
<tr>
<td>$A^{*}$turn (1 coil)</td>
<td>1 291 777</td>
</tr>
<tr>
<td>Current density (A/mm$^2$)</td>
<td>28</td>
</tr>
</tbody>
</table>
Fig. 5.1.1. General view of main elements of axial injection channel
Fig. 6.4.1. Layout of the cyclotron C400 with two extraction systems (C400-360 map)
Figure 7.1: Example of energy selection system used in proton therapy system.
The production of C400 by NHa SAS

- 2010 the PI of C400 is sold to Normandie
- 2010 legal creation of Normandy Hadrontherapy (Nha)
- 2018 complete capitalization of Nha
- 2019 review of the specifications and design
- 2020 initiation of the construction on site in CYCLHAD
- 2022 starting the commissioning
- 2023 validation and beginning of use / test / upgrade
Medical interest and constrains

• From the C400 we are awaiting:
  – High dose rate for fast irradiation
  – Limited cost of running
  – Real multi-ions capacity in the same fraction...
  – High level of uptime

• The use will be shared:
  – 50% for medical use
  – 50% for experimental use including machine tests and upgrades.
The business model of CYCLHAD could be:

• 50% of the C400 beam time will be devoted to radiation oncology (protons and ions) and sold to the Centre Fr Baclesse (as for the ProteusOne presently)

• Up to 50% will be devoted, “free of charge” to non profit scientific users in the frame of ARCHADE scientific project and external users
  – However the access to CYCLHAD installation will not be “no cost” for ARCHADE: so the ARCHADE costs will have to be compensated.
  – We hope not to have to go beyond “marginal costs” but it will largely depend upon availability of running fundings...
  – Thus ion beam access in CYCLHAD will NOT be no cost!
To conclude... ARCHADE project is three folds

**HEALTH**

Starting July 2018, as a first step of the medical outcome of the ARCHADE project, protontherapy treatments will be available in Normandy at the Centre François Baclesse for cancer treatment. Protontherapy is a major progress in radiation oncology, especially for children and young adults since it is dramatically decreasing the normal tissue irradiation. Adults and children will be treated for the following types of tumors:

- **ADULTS**
  - Meningioma
  - Ependymoma
  - Medulloblastoma
  - Pituitary adenoma
  - Skull base / parasinal sarcomas
  - Nasopharynx and HH Tumor
  - Re-irradiation
  - Orbital tumors
  - and more...

- **CHILDREN**
  - Brain tumors (PNET)
  - Medulloblastoma
  - Cranioopharyngioma
  - Ependymoma
  - Optic pathways glioma
  - Neuro / Retinoblastoma
  - Ewing sarcoma, other sarcoma

A treatment course will last several weeks with daily treatment sessions, thus adapted housing will be available. Treatment sessions will be carried out in a dedicated building called Cyclonad.

**SCIENCE**

Normandy is developing world class research in nuclear physics since decades at GANIL facility. More recently a comprehensive program of scientific research on hadrotherapy (the use of light ions beams for cancer treatment) has been initiated: the ARCHADE project. Several institutions are participating: Caen University, the National Center for Scientific Research (CNRS), the National Atomic Energy Commission (CEA), the François Baclesse Centre for cancer treatment, etc.

Different types and scale of collaborations are possible in the frame of bilateral cooperation agreements:

- Short discovery training of 4 to 6 month in the frame of master degree in sciences
- Complete PhD program of 3 years
- Six months or longer medical training in protontherapy for junior or senior radiation oncologists
- Short stay for scientific teams for intensive experimental periods
- Faculty exchanges

The different research domains are:

- Dosimetry, radiation protection
- Particle fragmentation, radio-chemistry
- Treatment modulation
- Beam control, on line quality assurance
- Tumor and normal tissues radiobiology
- Advanced molecular diagnosis
- Nuclear medicine
- Cancer epidemiology
- Clinical research in oncology

**TECHNOLOGY**

Hadrotherapy is a presently well-defined radiotherapy technology able to cure efficiently very radioresistant tumors.

However, important technological progresses are needed to make it more straightforward, less expensive and feasible to perform. These conditions are critical for its future development. In the frame of the ARCHADE project, Normandy backed by the world leader Co In protontherapy is investing for technology development either for instrumentation development and breakthrough accelerator technology. For developing new accelerator technology, investments are needed and the devoted corporation backed by Normandy Region – Normandy Hadrotherapy (NHa) – is still looking for participation of new investors.

The immediate prospect is the development of a multi-beams superconducting cyclotron, as the entrance form of a new type of hadrotherapy system. Such equipment should be the next generation of accelerator for the future hadrotherapy centers making possible to offer several different types of light ions beams for the best adaptation of the tumor to treat.

Investments are warranted by the Normandy Region in case of failure.

A specific Society of Med Economy (SEM) has been set up to organize and manage these investments, the SAPHYN.

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Thank-you, questions?