Philippe Barberet

AIFIRA

Applications Interdisciplinaires des Faisceaux d’Ions en Région Aquitaine
Outline

1. Description of the facility
   1. Technical description
   2. Organisation & staff
   3. Running costs & funding

2. Scientific activity
   1. Ion beam analysis
   2. Micro-irradiation
   3. Detector characterization

3. Evolution of the facility
The AIFIRA facility

AIFIRA: Applications Interdisciplinaires des Faisceaux d’Ions en Région Aquitaine

- Material analysis and irradiation using light ion beams (H\(^+\), \(^2\)H\(^+\), He\(^+\))
- Single stage electrostatic accelerator (3.5 MV Singletron™, HVEE)
- 5 beamlines
- CENBG research facility opened to the scientific community & companies
Beamlines

• Macrobeam
  - Ion beam analysis at mm scale
  - RBS; NRA; PIXE; PIGE

• External beam
  - Ion beam analysis for cultural heritage
  - PIXE; PIGE

• Nuclear microprobe
  - Ion beam analysis at the µm scale
  - RBS; NRA; PIXE; PIGE; ERDA IBIC; STIM; SED

• Micro-irradiation
  - Targeted irradiation of living cells with the µm precision

• Physis beamline
  - Production of secondary fields (n or γ) for nuclear physics and detector characterization
Organization & staff

CENBG head:
• F. Piquemal (Director)
• L. Serani (Technical director)

AIFIRA team: 3 people (1.5 FTE)
• Philippe Barberet, MCF UB, scientific coordinator (0.2 FTE)
• Stéphanie Sorieul, IR CNRS, operation coordinator (0.8 FTE)
• Philippe Alfaurt, IE CNRS, technical coordinator (0.5 FTE)

AIFIRA committee: beamtime reviewing and technological survey
• AIFIRA team
• Laurent Daudin, IE CNRS
• Guillaume Devès, IR CNRS
• Ludovic Mathieu, CR CNRS
• Stéphane Roudeau, IR CNRS
• Hervé Guégan, ARCANE
Operation & access

AIFIRA is a *research platform* (≈ 200 days of beamtime / year)

- Research projects of the CENBG teams
- Opened to external academic users
- Support to external teams using the facility

Services are provided by the **ARCANE** technology transfer unit (ADERA)

- Systematic measurements using well established techniques
- Contracts with industries
- Complete services
- 20 % of AIFIRA beamtime
- ~ 80 contracts / year
## AIFIRA users

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<th>CNRS - IN2P3</th>
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Running costs & funding

• **Running costs = 90 k€ / year**
  - 60 k€: running costs and maintenance of the accelerator and the beamlines
  - 20 k€: electricity and fluids
  - 10 k€: cover accidental breakdown of big equipment + regulatory controls

• **Recurrent funding**
  - 15 k€ IN2P3
  - ≈ 20 k€ University of Bordeaux (fluids)
  - 15 k€ ARCANE
  - Users fees: currently ≈ 10 k€ / year average

• **Equipement on projects, e.g. in the last years:**
  - iRiBio group CENBG (MITI, Physicancer INSERM …) : ≈ 60 k€ (last 5 years)
  - Région Nouvelle Aquitaine: “Plateforme Mutualisée” : ≈ 230 k€ (last 5 years)
Ion beam analysis (IBA)

Applications:
- Thin layers / materials
- Geology / geochemistry
- Archaeometry and cultural heritage
- Life science

Techniques: PIXE/PIGE, RBS, NRA, STIM, ERDA

« Classical » IBA:
Quantification of light elements by RBS / NRA (e.g. Li)
Hydrogen mapping using ERDA

External beam: Non destructive measurements of the chemical composition of large and/or fragile samples

Collaboration CRP2A : Sourcing of obsidians from mediteranean basin

Xray det. Xray det.

AIFIRA external beam

Beam extraction window
μ-IBA: Tissue & section analysis

Analysis at the μm scale & elemental mapping

• Mainly used for life science application
• Main feature: quantitative measurement, μg/g sensitivity, imaging

Development of bioactive materials used as bone substitutes (LPC Clermont)
  # Materials behaviour at the interface with living tissues
  # Release of trace elements in tissues


Patents
J. Lao, J. Lacroix, X. Dieudonné, E. Jallot. ‘Implant with controlled porosity made of a hybrid material.’
J. Lao, J. Lacroix, X. Dieudonné, E. Jallot. ‘Implant with controlled porosity comprising a matrix covered by a bioactive glass or by a hybrid material.’
J. Lao, X. Dieudonné, E. Jallot. ‘Implant with variable porosity made of a hybrid material.’
J. Lao, C. Bossard, H. Granel, Y. Wittrant., E. Jallot, ‘Implant with controlled porosity made of a hybrid material doped with osteoinductor nutriments.’
**μ-IBA: Tissue & section analysis**

**Analysis at the μm scale & elemental mapping**

Quantify the presence of hydrothermally transported inorganic elements in analogous sediments

physical and chemical conditions for prebiotic reactions?

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μ-IBA: single cells

Analysis at the single cell scale
- Exposure to exogenous compounds, metals and nanoparticles (NPs)
- Up to now mainly toxicology studies

10 publications in the last 5 years
μ-IBA: starting projects

Internalization for treatment

Metals, NPs or radio-isotopes designed to be internalized in cells

Ongoing work (iRiBio group @ CENBG):
- Standardizing the protocols
- Increasing the analysis throughput
- User-friendly data analysis


- Automation ➔ 50-100 cells/day
- Correlative imaging
- Data processing …?
Targeted $\mu$-irradiation

- 3 MeV protons / helium ions
- beam size ~ 1.5 µm (FWHM)
- Beam extracted in air to irradiate living cells
- Dose control down to a single particle
- Electrostatic beam scanning
- Online fluorescence time-lapse imaging

Latest developments:
Thin diamond detectors

Muggiolu et al., Scientific Reports 7, 41764 (2017)

Bourret et al., NIMB 325 (2014)
Single cell targeting & protein kinetics

- Cell nucleus of a cell line with GFP-tagged protein involved in DNA damage repair
- Micro-irradiation with counted number of ions focused in a spot
- Fluorescence Spot: Protein Accumulation at the damage site

Time-lapse acquisition after irradiation
- Real time measurement of fluorescence intensity
- $T = \text{recrulement time (s)}$
- $A = \text{Max intensity value}$

Marie Curie RTN : SPRITE (2013-2016)
Thesis of Giovanna Muggiolu, University of Bordeaux 2017
Muggiolu et al., Scientific Reports 7, 41764 (2017)
Single cell targeting & mitochondria

**TMRE** accumulates in polarized mitochondria

**Matrix-roGFP** test for mitochondrial matrix integrity

55 MeV Carbons (SNAKE, Munich) and 3 MeV protons (AIFIRA, Bordeaux)

Radiation-induced change in mitochondrial membrane potential

Walsh et al., Scientific Reports 7,46684 (2017)
Towards multicellular models

Challenge: targeting a single cell in an organism

Scheme of the irradiation setup

In progress & perspectives:
PRIME80: RADIANCE
"Etude des conséquences biologiques radio-induites sur le métabolismeARN chez Caenorhabditis elegans"

Torfeh et al., Scientific Reports 9:10568(2019)
Biophysics – Study of DNA fragmentation

• INSIDE Project:
  IN SItu DEtection of DNA fragmentation induced by proton collision (MITI)


Hyp:
If impact parameter < R_{rea}+R_g
probability p of DNA fragmentation

Towards DNA fragmentation vs impact parameter

Tracking of phage T4 DNA at concentrations of 30 pg/µL
Mean inter-DNA distance ~ 20 µm

Observable providing hte DNA topology or the fragmentation dynamics?
Characterization of detectors
µ-IBIC : Ion Beam Induced Charge

Micro-scale characterization of a CMOS-based neutron detector

Context: Development of a neutron dosimeter in-phantom measurements in radiation therapy  AlphaRad Sensor

Aim:
• Precise calibration of the signal amplitude
• Charge collection in the different parts of the sensor?
Characterization of detectors (2)

DIADEM Project:
Diamond membrane based microdosimetric system for radiation quality assurance in hadron therapy

Aim:
- Charge collection efficiency vs biasing
- Mapping edge effects & bounding
- Radiation damage

Characterization of detectors (3)

Use of mono-energetic ion beams to calibrate detectors:
- Nuclear physics
- Ion acceleration using high power lasers

Characterization of a gaseous proton-recoil detector for neutron flux measurements

ACEN group @ CENBG


Calibration of Thomson parabola for experiments @ high power lasers

ENL group @ CENBG

Publications & users (2015-2020)

40 interdisciplinary publications

Journals:

≃ 20 laboratories:
- IRAMAT-CRP2A UMR5060
- CEA-DSM/LLAN
- ICMCB UPR9048
- IMS UMR5218
- IPNL UMR5822
- IRSN-LMDN
- ISTerre UMR5275
- ISTO UMR7327
- LPC UMR6533
- PACEA UMR5199
- CBM UPR4301
- CELIA UMR5106
- LCP UMR8000
- CEA-DSM/SRMA/LA25M
- Institut Fresnel UMR7249
- OASU-LAB
- INCIA UMR5287
- CEA-DST/LIST
Practical work for students

Projects for master students (nuclear physics specialization):
- Measurements of cross sections for nuclear and atomic reactions
- 2 days of beamtime / year

Projects for students in master of engineering: instrumentation
- Instrumentation & automation
- Design of detection systems for IBA normalization
- Up to now 1 day of beamtime / year

Internships for Bachelor and master students
Evolutions

Renewing the «Physics beamline» (funding Région Aquitaine 2016-2019 - 80 k€)
  • Commissioning => end 2020

Renewing the External beamline (funding Région Aquitaine 2019-2022 – 66 k€)
  • Switching to SDD detectors

Upgrading microbeam line (DIADEM project – 30 k€)
MERCI POUR VOTRE ATTENTION