1. Who are we?
2. SACM competences
3. Projects for neutron production
1. Who are we?

- CEA
- IRFU
- SACM
- SACM missions
CEA is the French Alternative Energies and Atomic Energy Commission

- 16000 employees, 3900 M€
- 10 centers in France

We are located in Saclay, 20 km South-West from Paris, in the new Paris-Saclay campus
IRFU:
- ~ 800 FTE
- 3 physics divisions, 3 technological divisions

Building a (compact) neutron source requires a large number of competences
SACM is organized in 5 laboratories:

- **LEAS**
  - JM. Rifflet, A. Payn
  - **Superconducting Magnets**

- **LEDA**
  - J. Schwindling, R. Gobin
  - **Particle Accelerators**

- **LCSE**
  - C. Mayri, R. Vallcorba
  - **Cryogenics & Test Facilities**

- **LISAH**
  - C. Marchand, G. Devanz
  - **Accelerating & Radiofrequency Systems**

- **LIDC2**
  - C. Madec, J.P. Charrier
  - **Superconducting cavities & Cryomodules**

Direction: P. Védrine
Deputies: P. Brédy, O. Napoly

CSTS: Président A. Chancé
Irfu/SACM is developing and realizing particle accelerators, cryogenic systems and superconducting magnets for the scientific programs of Irfu and more widely of CEA.

Irfu/SACM is also involved in large scale projects in Europe and Japan.
These projects are managed within the Irfu project organisation.

They rely on the skills and activities of SACM, SIS, SEDI and SPhN.

Iru/SACM develops R&D activities to support theses programs.

In December 2014, 81 engineers and 44 technicians, CEA staff, belong to the Irfu/SACM division.
### Superconducting magnets

- **High field magnets**
  - 2012: ISEULT
  - 2013: LNCMI Hybrid
  - 2014: 43 T Gradiens Coils
  - 2015: LNCMI 30+ T T

- **GSI – Fair Magnets**
  - 2014: R3B Glad
  - 2015: Super FRS dipoles

- **Cryogenic test facilities**
  - 2012: JT60 SA
  - 2013: End of CTF construction
  - 2020: ITER - Activities

- **LHC**
  - 2020: Eucard 2 FP7 & CEF

### Cryogenic test facilities

- **Coil test facilities**
  - 2012: JT60 SA
  - 2013: End of CTF construction
  - 2020: ITER - Activities

### Sources et Injectors

- **Injectors for ion beams**
  - 2013: FAIR p-Linac

- **Deuton sources & injectors**
  - 2013: SPIRAL2
  - 2014: IFMIF-EVEDA
  - 2015: SARAF

- **High intensity injectors**
  - 2013: IPHI

### Superconducting LINACS

- **Protons-Deutons SC Linacs**
  - 2019: Validation of SRF-Linac concept
  - 2020: IFMIF-Eveda

- **Cryomodules for electrons**
  - 2019: E-XFEL
2. SACM competences

- High Intensity Light Ion Sources
- Beam Transport Lines
- Beam Diagnostics
- Radio-Frequency Quadrupoles
- Superconducting RF Cavities and Cryomodules
- Superconducting Magnets
- Beam Dynamics
HIGH INTENSITY LIGHT ION SOURCES

We are specialists of high intensity (5 – 100 mA) light ion (H\(^+\), D\(^+\)) sources for accelerators
• Current, emittance, species proportions, stability, reliability
• Pulsed or continuous modes

- Since 1996
- 95 kV, 100 mA
- Fraction H\(^+\) > 80 %
- Source of the IPHI project
- Licence Pantechnik

SILHI reliability tests during 7 days, 114 mA : 99,8 %
8 trips > 3s

IFMIF

FAIR

Pulsed mode: duty cycle 20%
Vert: courant sortie source (25 mA/V)
Magenta: courant en fin de ligne (20 mA/V)
Orange: cadencement

SILHI

SPIRAL2

- 40 kV, 10 mA
- Permanent magnets
- Cost, size

• Pulsed proton beam (30 ms - 300 ms @ 4Hz).
• 95 keV, 100 mA
Since beginning 2013, contract with the Pantechnik company (Bayeux, France) for building and selling a commercial version of the SILHI source (50 mA, 50 keV)

Pantechnik is a world-wide known company for medical sources (Carbon ion sources for CNAO and MedAustron for example)

SILHI2 sources sold in China and India

SILHI2 installed on the BETSI test bench by M. Xavier Donzel (Pantechnik)

A SILHI2 source at Pantechnik
Purpose of the LEBT:
• House beam diagnostics
• Focus the beam at the entrance of the acceleration stage
• « Chop » the pulses
• Challenge = keep the beam emittance small (in particular space charge effects at high intensity)
BEAM DIAGNOSTICS

Needed to characterize the beam: current, proportions, position, profile, emittance

- High intensity = high power → non interceptive beam diagnostics

![Diagram of beam diagnostics](image)

Cooled emittance-meter with thermal screen

2D tomographic profile

Proportions measured by Doppler shift method
Radio-Frequency Quadrupoles (RFQ)

High intensity = high space charge $\rightarrow$ beam tends to blow up
$\rightarrow$ Need for continuous focusing

An RFQ has a quadrupolar structure required for the focusing. It also bunches the beam and accelerates it up to a few MeV.

SACM has the following competences:

- Beam dynamics simulations
- RF design
- Thermomechanical studies
- Cooling
- Mechanical design
- Ancillary equipment
- Realization with industries
- Assembly
- Tuning
- Conditioning
RADIO-FREQUENCY QUADRUPOLES (RFQ)

- Design and/or fabrication and/or tuning of the RFQs for LINAC4 and SPIRAL2
- In the coming years, RFQ for ESS: design and realization of the RFQ, tuning, RF conditioning
- IPHI is a local R&D project to accelerate a 100 mA cw beam to 3 MeV.
THE IPHI PROJECT @ SACLAY
HIGH INTENSITY PROTON INJECTOR

- CEA / CERN / CNRS collaboration to build a 3 MeV, 100 mA, continuous mode proton accelerator
- RF conditionning of the RFQ has started
- We expect to test with beam (pulsed, cw) in 1st semester 2016
- IPHI will then be available at Saclay for R&D (beam diagnostics, neutron source …)
SUPERCONDUCTING RF TECHNOLOGY

- Based on bulk Niobium, SRF technology is used for most of the linear accelerators since 2000: EU-CARE (SRF, HIPPI), XFEL, ESS, IFMIF, SPIRAL2, SARAF…
- Simulation, design & realization of all the critical components: cavities, couplers, tuners.
- All types of cavities: multi-cells, HWR, QWR – Low β, High β.
- R&D programs for high gradient cavities: mechanical and chemical processing, multilayer…
EXAMPLE OF CRYOMODULE DESIGNS FOR SPIRAL2, ESS, IFMIF AND SARAF
Assemblage d’un coupleur

Assemblage d’un train

Aire de positionnement

Alignement

Enfourneur

Envoi
SUPERCONDUCTING MAGNETS

- Design, fabrication, integration, test of SC magnets (NbTi) for various projects
- R&D on other superconductors (Nb3Sn, MgB2, YBACUO)

Particle Physics: ATLAS Toroïd

Nuclear Physics: R3B-GLAD magnet

Fusion reactors: Test station for the JT60SA coils

MRI magnets: Iseult, $B = 11.75$ T
Understanding of physics processes, help for design and operation

Sources and extraction systems

Electromagnetic computation
Realistic field maps

Plasma simulations
- Modeling of ion sources
- Space charge effects
- Laser – plasma acceleration

Beam transport (non linear effects)

High energy colliders design
• SACM is developing codes since 90’s. TRACEWIN is commercially distributed.
• 160 users, 47 laboratories, 3 companies, 18 countries

Source to target simulation of the IFMIF accelerator
SACM PLATFORMS

(25 000 M²)
INDUSTRIAL RELATIONSHIPS

- Subcontracting the realization or integration of accelerator parts
- But also common R&D, co-financing of PhD students…
MEDICAL APPLICATIONS

- SACM is involved in some medical applications: superconducting magnet for MRI, improvement of a cyclotron for radio-isotope production, design of a superconducting gantry for proton-therapy
- In relation with industry (PMB, IBA, Thales) and/or with life science division at CEA (DSV)

- Design of a 90° SC magnet for gantries
- Lotus cyclotron for radio-isotopes production
- Iseult MRI magnet $B = 11.75 \, T$
3. Projects for neutron production
THE ESS PROJECT @ LUND, SWEDEN
EUROPEAN SPALLATION SOURCE

- 2 GeV protons, 60 mA, 2.86 ms / 14 Hz pulses, W target
- Neutrons as a probe for matter studies
- First neutrons in 2019
• SARAF is an Israeli project of an accelerator based neutron source to replace a nuclear reactor → 40 MeV, 5 mA, CW deuteron beam
• Will be used for nuclear physics, neutron science but also for medical applications: BNCT and radio-isotope production
• Are / will produce neutrons with Be or liquid Lithium target (LiLit)
• Commissioning in 2022
• IFMIF LIPAc is a 9 MeV prototype for the future IFMIF 40 MeV accelerators (material studies for fusion reactors)
• 125 mA deuterons, cw → ~ 1 MW of beam power
• Source and LEBT are installed in Japan and is being commissioned.
IPHI AS A NEUTRON SOURCE

- With the current beam dump (Nickel), $10^9$ n/s are produced @ 100 mA CW, 3 MeV
- If replaced with a Be target, $10^{13}$ n/s, $\langle E_n \rangle = 600$ keV
WHICH MACHINE FOR BNCT?

- **ESS**: 5 MW, 70 n/p, 2 × 10^{11} n/J
- **IPHI**: 300 kW, 2 × 10^{-5} n/p, 5 × 10^{7} n/J
- **SARAF**: 200 kW
- **IFMIF-LIPAC**: 1.1 MW
- **KURRI**: 30 kW
- **Legnaro**: 150 kW
- **iBNCT**: 80 kW
- **KUANS**: 0.2 kW
- **RANS**: 7 kW
- **LENS**: 6 kW

**Typical thermal neutron flux at research reactors**

**Some ABNCT projects**

**Some Compact Accelerator Based (thermal) Neutron Sources**
CONCLUSIONS

• Irfu, and in particular SACM, is working on various **national and international accelerator projects**
  
  In particular on several accelerator based neutron sources

• This is done in **collaboration** with other French or European labs, and in collaboration with industry

• SACM has large competences on **high intensity proton / deuteron beams**: production, transport, acceleration, characterization, simulation
  
  In addition, competences at Irfu on thermomechanical studies, neutron simulation, neutron detection

• We are willing to participate to an ABNCT project in France or in Europe
What is needed for BNCT is not this…
CONCLUSION (2)

...but rather something like this...
(with more intensity)
NEUTRON PRODUCTION

- Large gain in n/p, n/W, n/€ with increasing energy but…

![Graph showing neutron flux at the target level with energy in MEV on the x-axis and flux in n/s per mA or n/s per 100 kW on the y-axis. The graph indicates a significant increase in flux with energy, marked by factors of 3, 4, and 40.]