The SONATE project. A new neutron scattering platform for materials science research.

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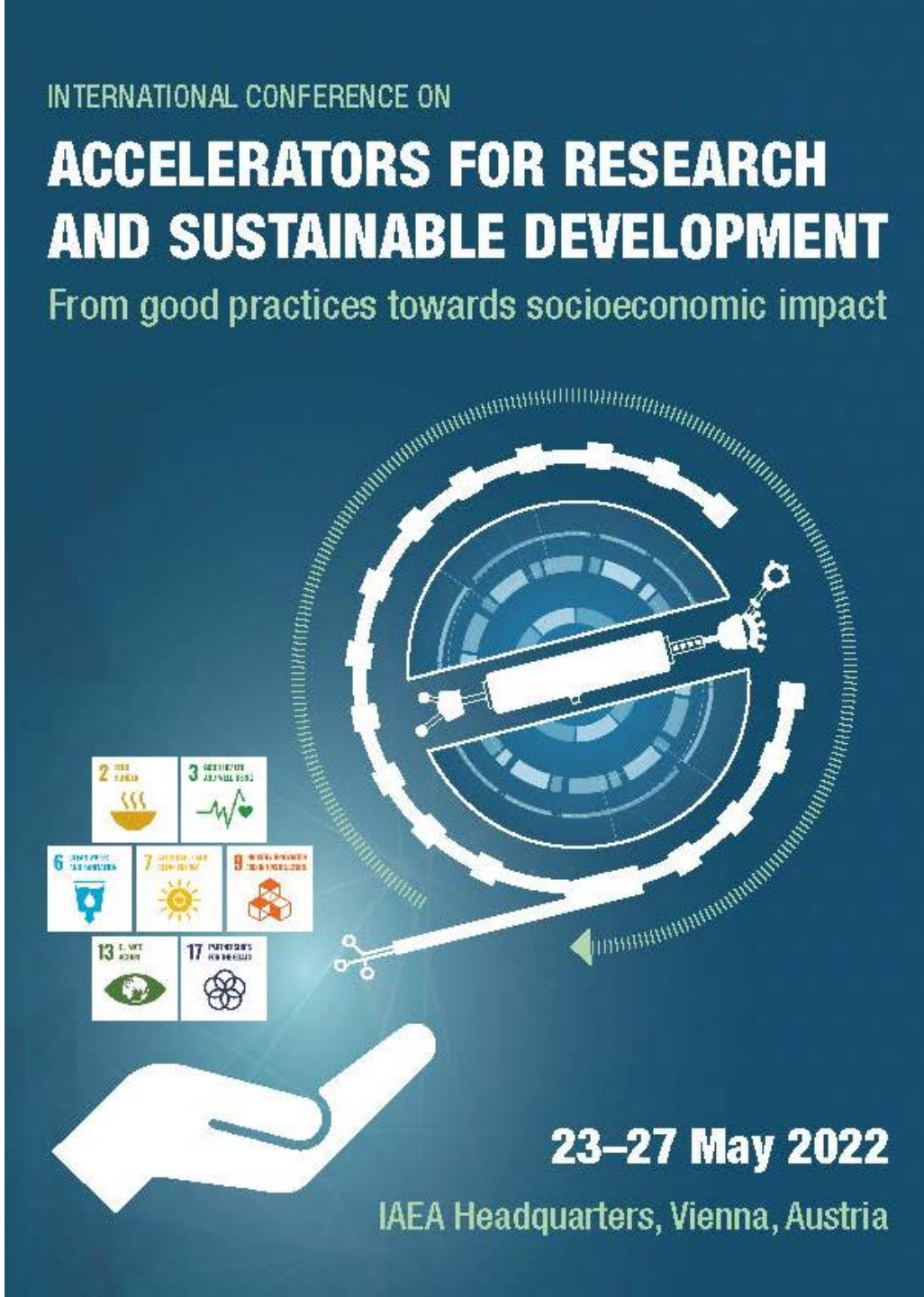
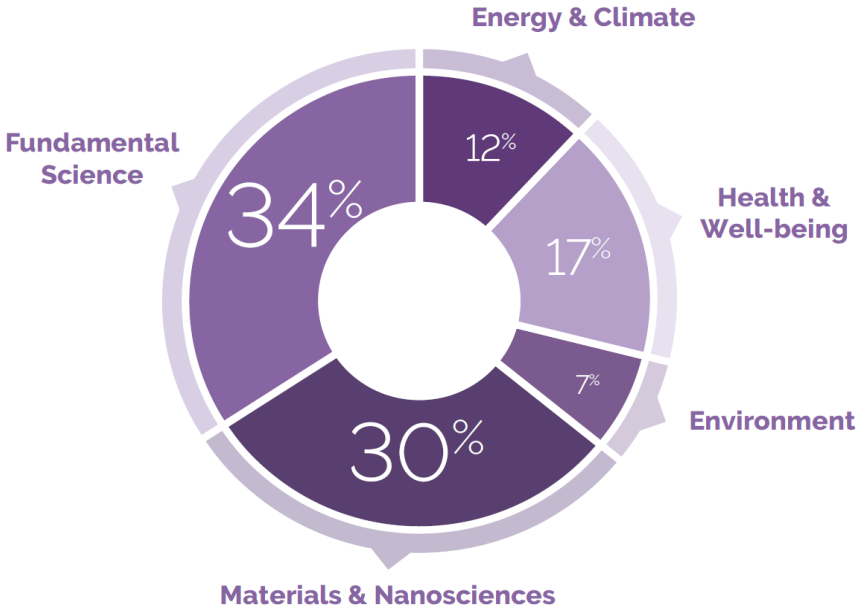


Neutron scattering

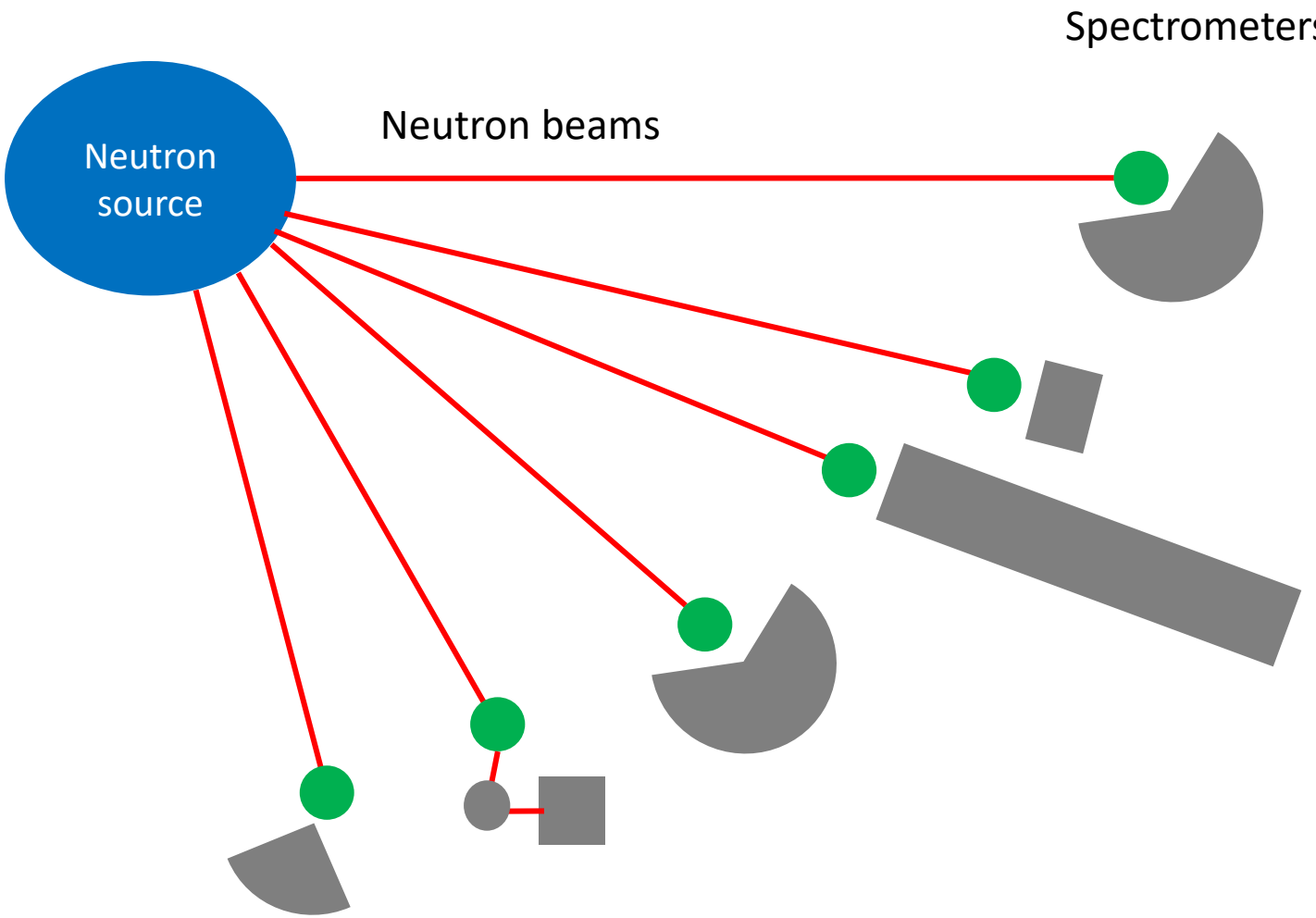
- The different research fields
  - Chemistry and Materials Science
  - Magnetism and Magnetic Materials
  - Metallurgy - Engineering
  - Soft matter / Polymers / Liquids
  - Biophysics



ILL Associates, Strategy for Neutrons, 2013

- Motivations for using thermal and cold neutrons
  - Length scales from A° to µm (diffraction – SANS - radiography)
  - Time scales from the ps to the µs (spectroscopy) / Energy scales from 1eV to 1neV
  - Light atoms (typ. Hydrogen) / Isotopic labelling (H/D)
  - Magnetism
  - Penetration
  - Precision

Neutron scattering
A large panel of techniques for condensed matter studies



Diffraction

Small angle scattering

Reflectivity

Imaging

Spectroscopy
(3 axes, time of flight, spin-echo)

…

Examples at LLB – Orphée / Energy

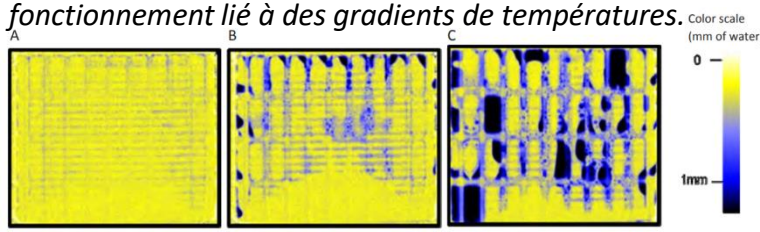
- Improvement of the operation of fuel cells (BIC – DRT)
  - In-situ visualisation of the fuel cell operation
    Correction of the simulations

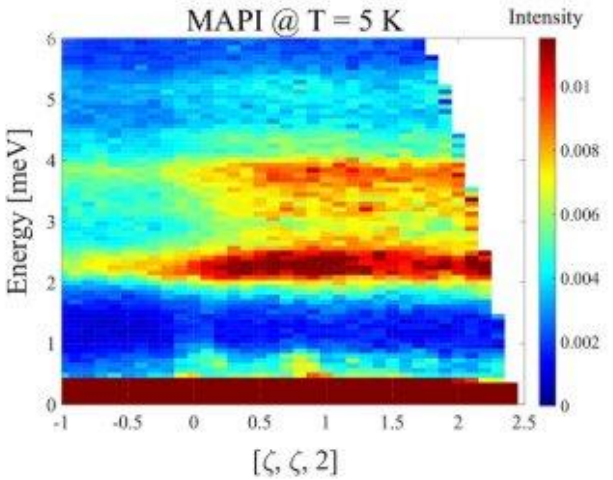
- Blockades in heavy crude oil pipelines
  - SANS helps understanding the blockades origins

- Diffusion dynamics in electrolytes for batteries
  - QENS and spin-echo spectroscopies allow studying diffusion dynamics at several spatial length scales.

- Improvement of the efficiency of photovoltaic cells and thermo-electric materials
  - Reflectivity on thin films
  - Spectroscopy of lattice excitations

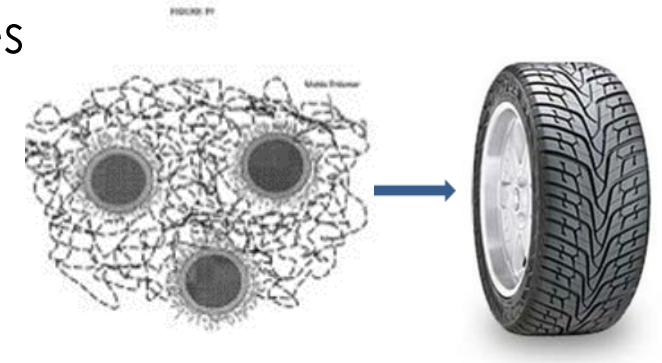
Suivi du noyage d'une cellule PAC en cas d'écart de fonctionnement lié à des gradients de températures.



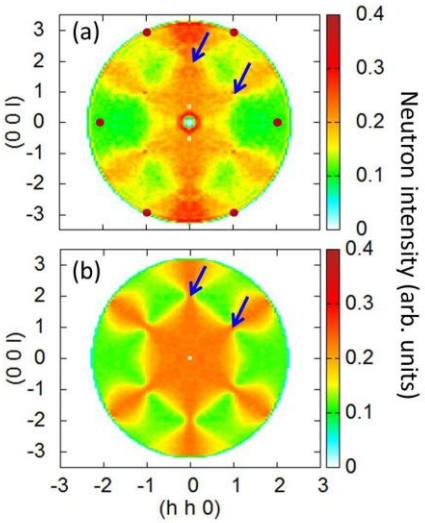


Examples at LLB – Orphée / Materials

- Reinforcement of composite polymer materials by nanoparticles inclusions
  - SANS allow understanding the organisation of nanoparticles



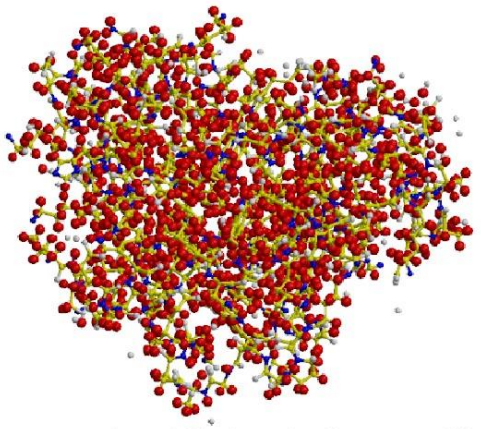
- Reinforcement of metallic alloys by nanoparticles
  - Inclusion of nitrates for high performances alloys
  - ODS nuclear alloys for new generation nuclear power plant



- Study of new magnetic materials
  - Diffraction / Spectroscopy / Reflectivity

Examples at LLB – Orphée / Health

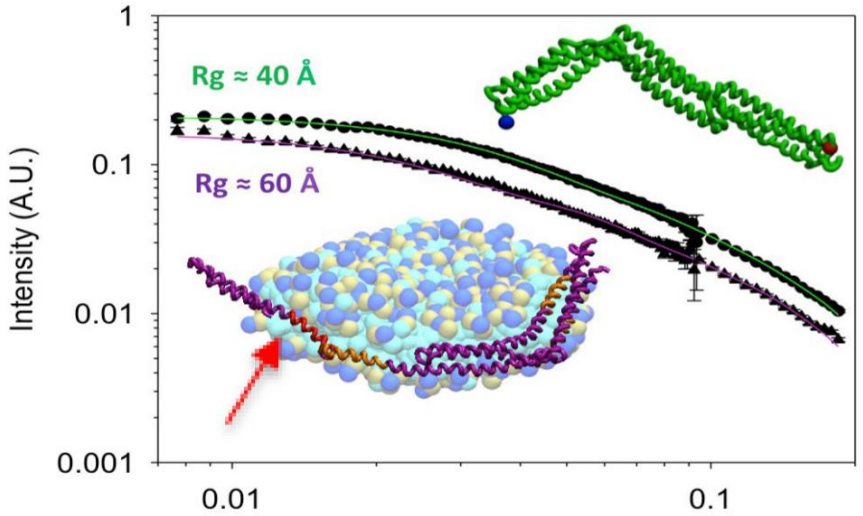
- Protein hydration
  - Neutron diffraction allow localizing water molecules around biological proteins to better understand their operation mechanism



Tertiary structure of myoglobin determined by neutron diffraction

● nitrogen, ● carbon, ○ oxygen, ● hydrogen

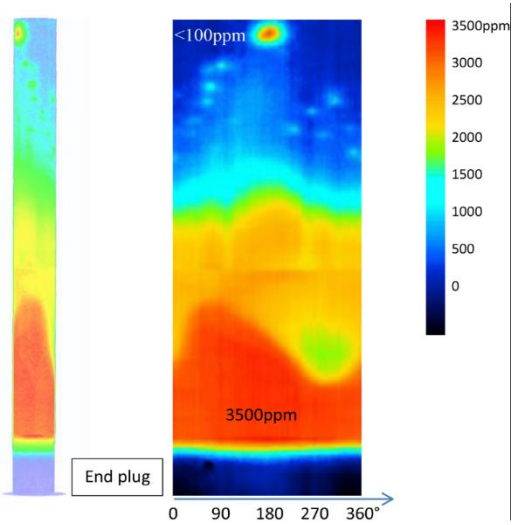
- Interaction of proteins with cell membranes
  - SANS / Reflectivity
  - Application to the understanding of myopathie ou Alzheimer disease



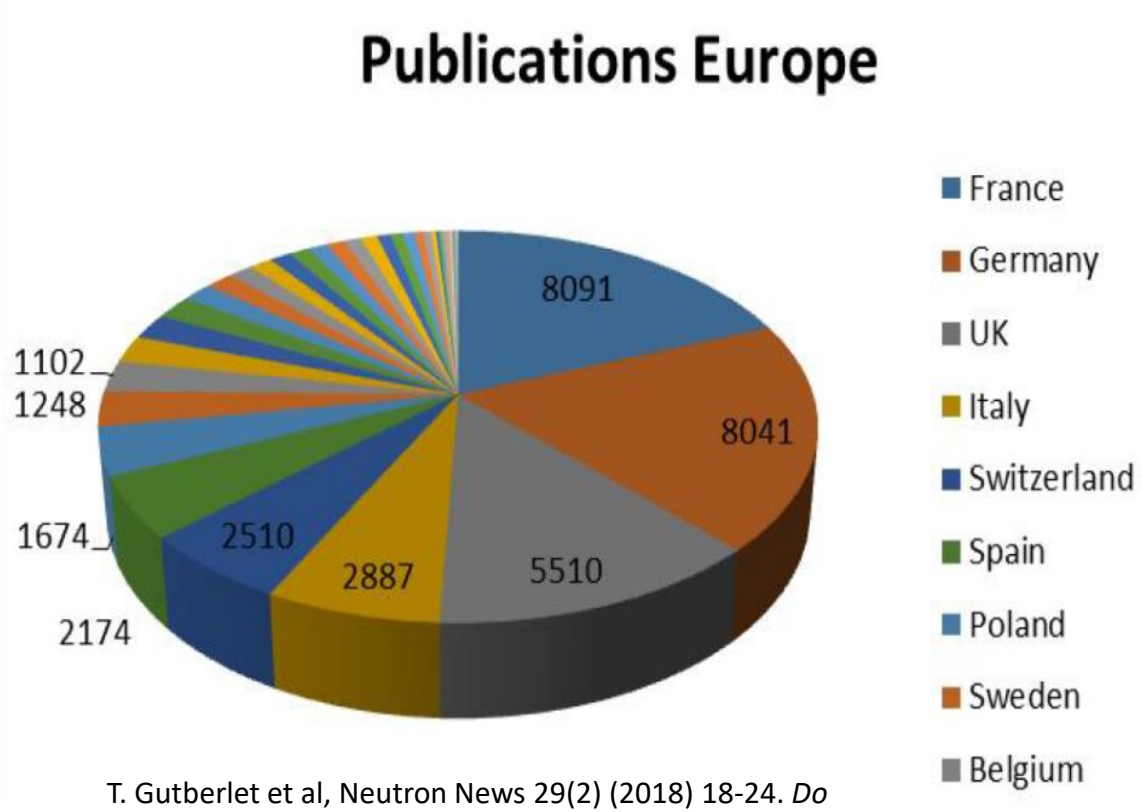
Examples at LLB – Orphée / Nuclear

- Nuclear steel aging under irradiation
  - Following the formation of Cu aggregates and the fragilization of reactor vessels
  - Allow prolonging the lifetime of nuclear power plants beyond 40 years to 50 or 60 years

- Improvement of the fuel claddings in case of a Fukushima type accident (loss of cooling)
  - Neutron radiography allows understanding hydruration and fragilization processes of the cladding



Landscape of neutron scattering in Europe and France



T. Gutberlet et al, Neutron News 29(2) (2018) 18-24. *Do neutrons publish? A neutron publication survey, 2005–2015*

Europe Neutrons: 2250 pub/year

Synchrotrons: 4680 pub/year

Europe is the main user of neutron scattering techniques

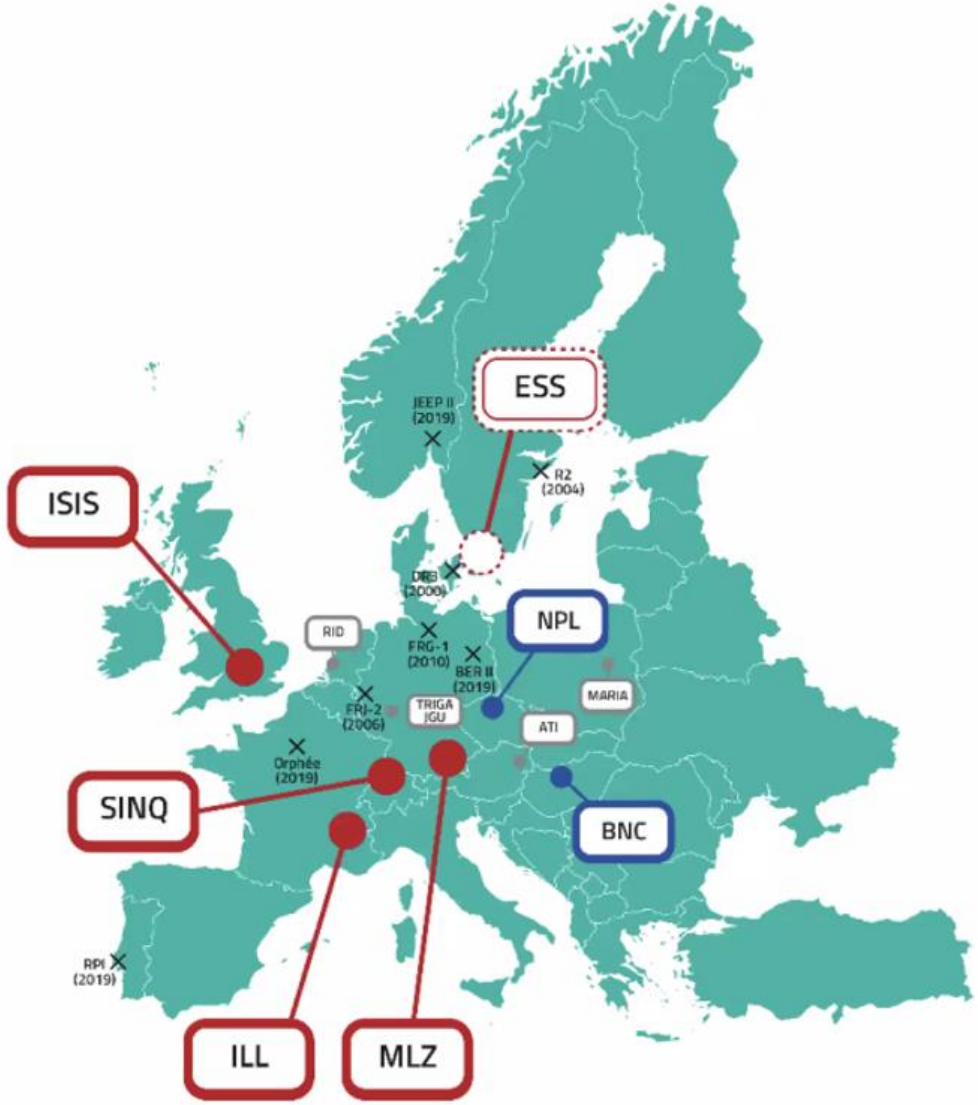
A community of 6000 – 8000 users

~50% of the world scientific production

Evolution in Europe
Of Neutron scattering facilities

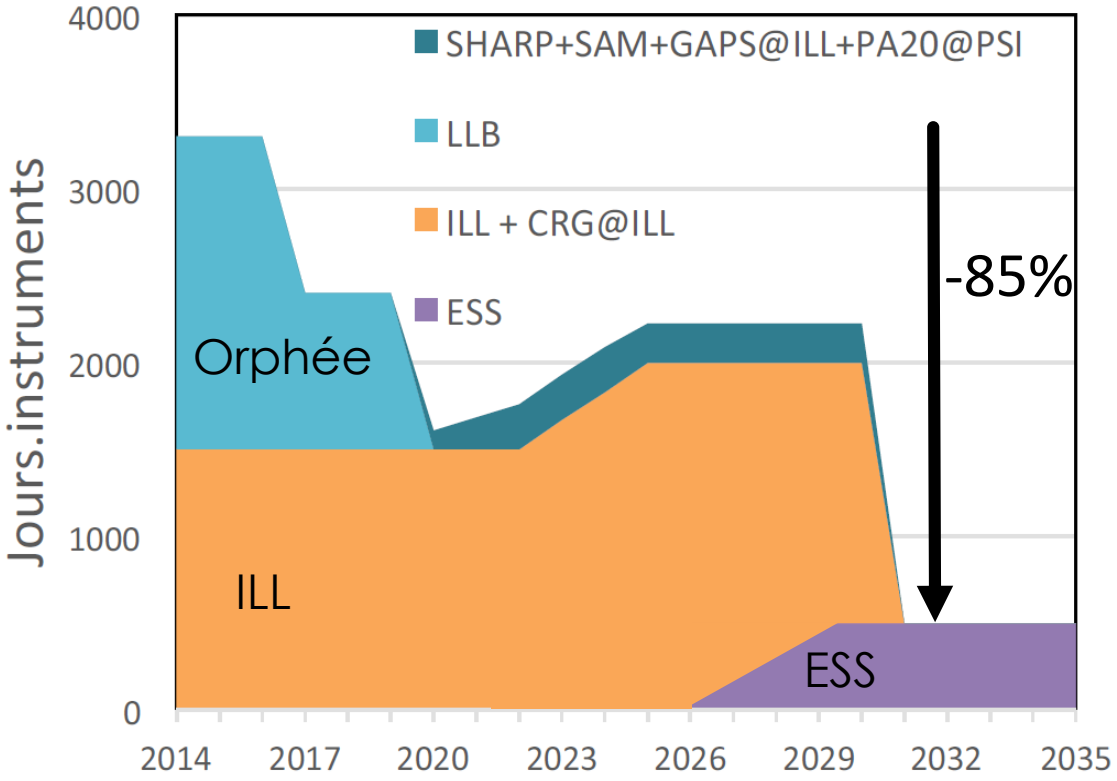
- Since 2000,
  - 8 sources have been closed
  - 1 source has been opened
  - Only 4 major sources in operation

- Horizon 2030,
  - ESS will replace ILL
  - No extra capacity



Neutron facilities in Europe. Larger facilities indicated in red. Sources that are no longer operating are marked with an X. ESS is under construction. © LENS – Stephanie Chapman

Projection in France



Fédération Française de Diffusion Neutronique 2FDN roadmap (Instruments.Days weighted by the source efficiency)

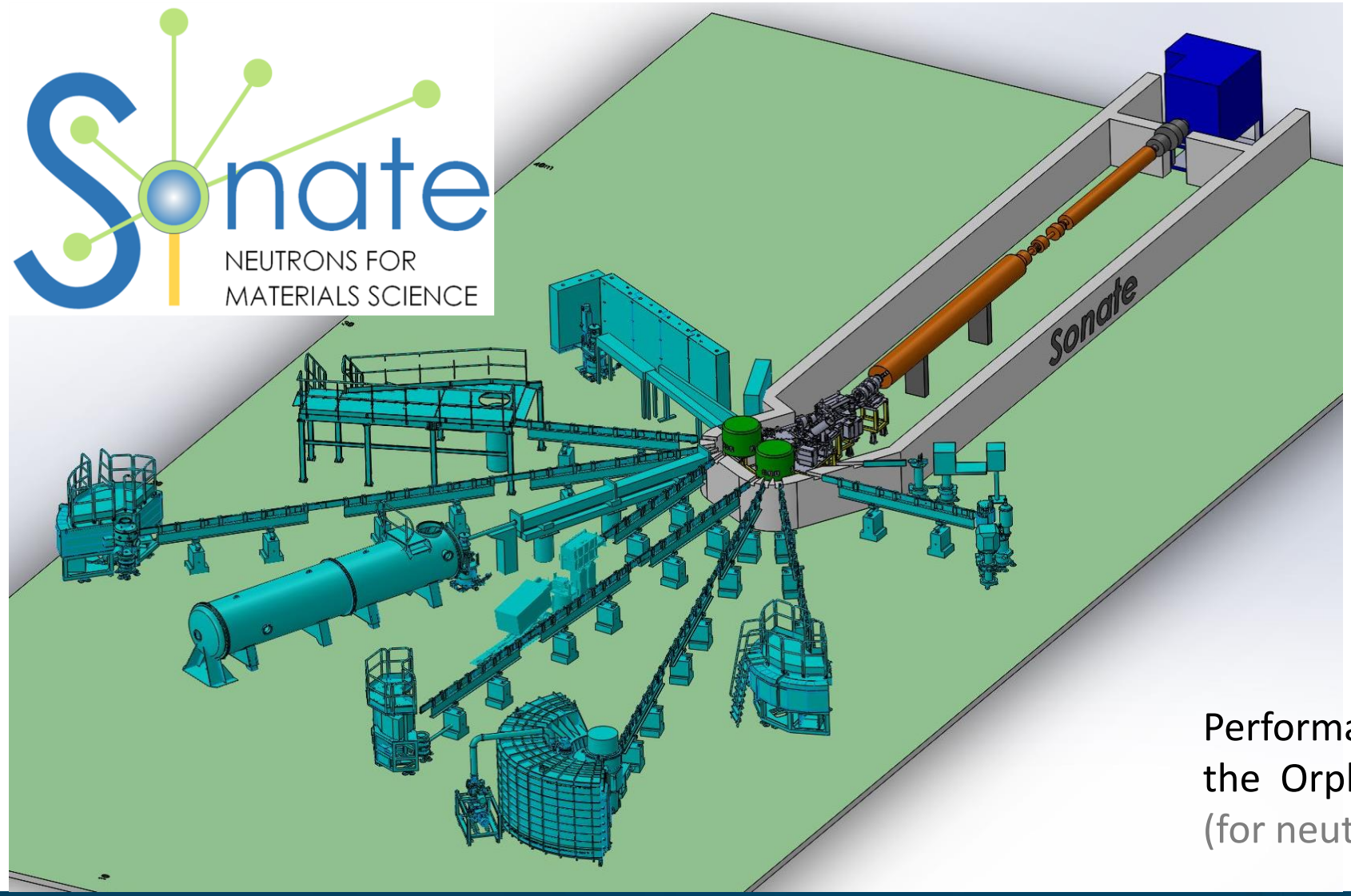
After the ILL stops its operations, access to neutron scattering techniques for French users will be drastically reduced

Mechanical consequence :
Scientific production will be reduced by a factor 6

Proposal:
High Current Accelerator-based neutron sources - HiCANS

- Historically, neutron scattering techniques have been served by nuclear reactors or spallation sources
- HiCANS are a potential new solution for fulfilling neutron scattering needs
  - Use of low energy protons accelerators (20 – 50 MeV) / Pulsed – I_{peak} 60-100mA (Vs 1-2 GeV for spallation sources)
  - Investment costs are reduced 50-100M€
  - Operation costs are reduced 5-10 M€
  - The solution is scalable and its performances can be tuned to the needs of a specific scientific community
  - High-end HiCANS can be competitive with medium flux nuclear reactors or spallation sources
- The technical concepts need to be experimentally demonstrated

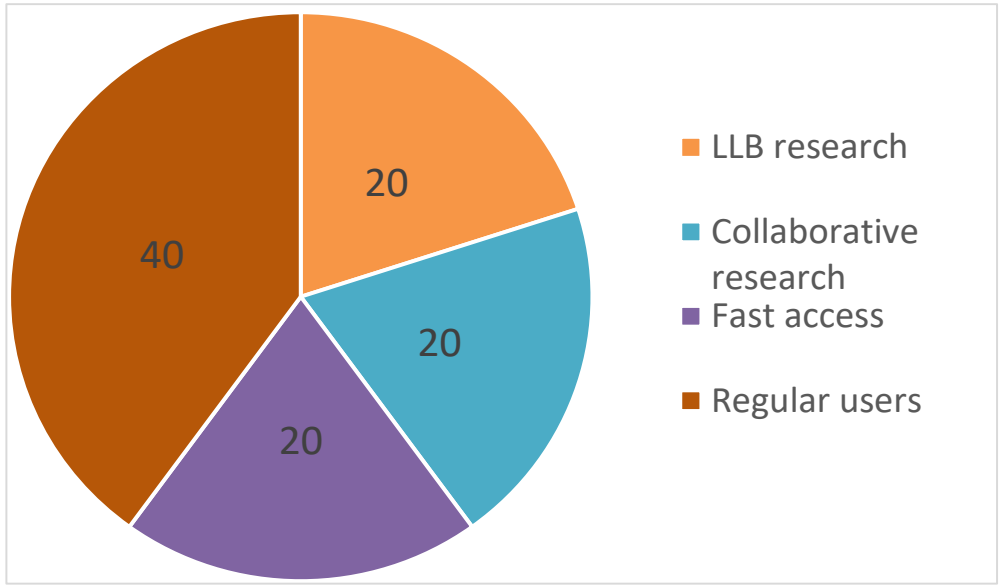
SONATE: 2 targets – 10 instruments



Performances equivalent to the Orphée reactor (14 MW)
(for neutron scattering)

Typical offers

Instrument	Average Run time	Nr. Run / year
SANS1 (soft matter)	2.5 days	64
SANS2 (hard matter)	5 days	32
Reflectometer	5 days	32
Radiography	5 days	32
Powder 1	2.5 days	64
Powder 2	5 days	32
Direct TOF	5 days	32
Inverse TOF	15 days	10
Hot neutrons	10 days	16
Spin-Echo	15 days	10
TOTAL		324



- Potential for 300 experimental runs / year
- Potential for 100-150 publications / year

French assets in such a project

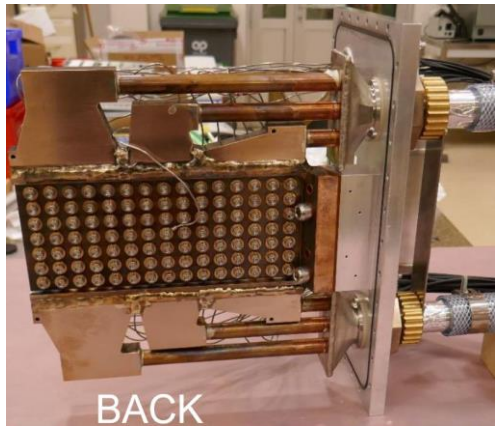
- An extensive scientific and technical expertise in Saclay and Grenoble in the field of neutron scattering
  - 25 instruments around Orphée + SHARP@ILL + SAM@ILL
  - Expertise acquired at the LLB in the construction of ESS instruments
- Large base of French neutron scattering techniques users (~1500)
- Expertise in the construction of high current proton accelerators
  - Projets SARAF, MYRRHA, LINAC4, SPIRAL2
- Possibility to reuse the efforts injected in ESS
  - Accelerator construction
  - Neutron Instrument designs
  - Detector developments
  - Data processing

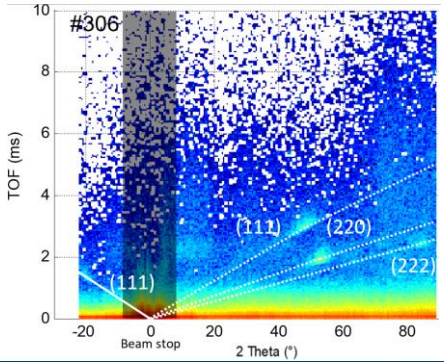
State of the art at Saclay
The « IPHI – Neutron » project

- A 50k Beryllium target has been built and tested (Feb. 2022)
  - 110 hours.run over 2 weeks
  - Target mounting and unmounting has been demonstrated

- A first powder diffraction measurement has been performed

- High resolution radiographs (100µm) have been performed



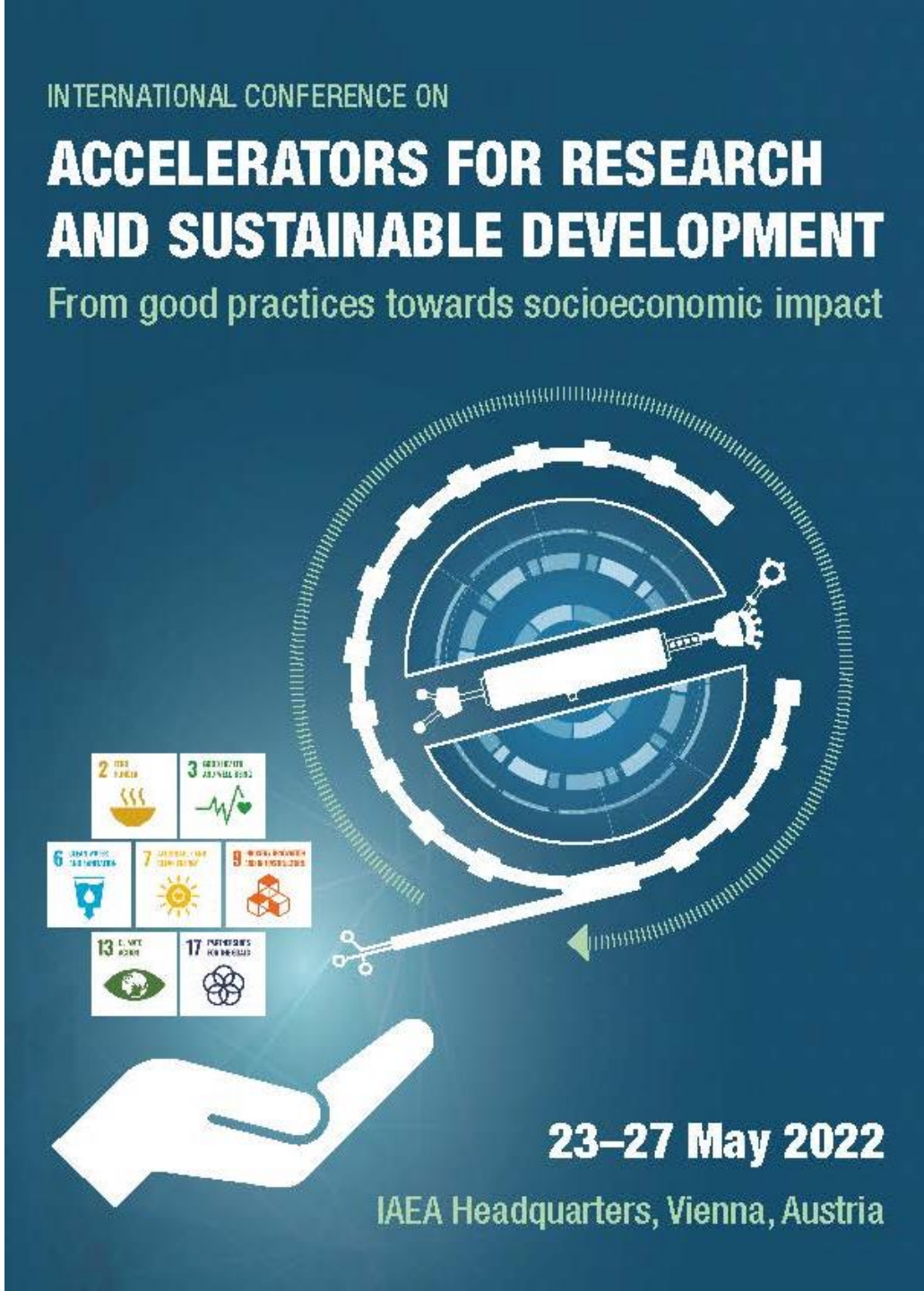


Diffraction on steel
200W – 60 min.

Conclusion

- We are convinced that HiCANS sources can be competitive with medium flux research reactors or spallation sources for neutron scattering techniques
- The technology offers the possibility to build scalable sources in terms of cost and performances
- The « entry » ticket in neutron scattering technique is lower than with a reactor of equivalent performances
- It is a technical solution which may widen the use of neutron analytical techniques by multiplying the number of sources and making access to users easier.

Thank you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