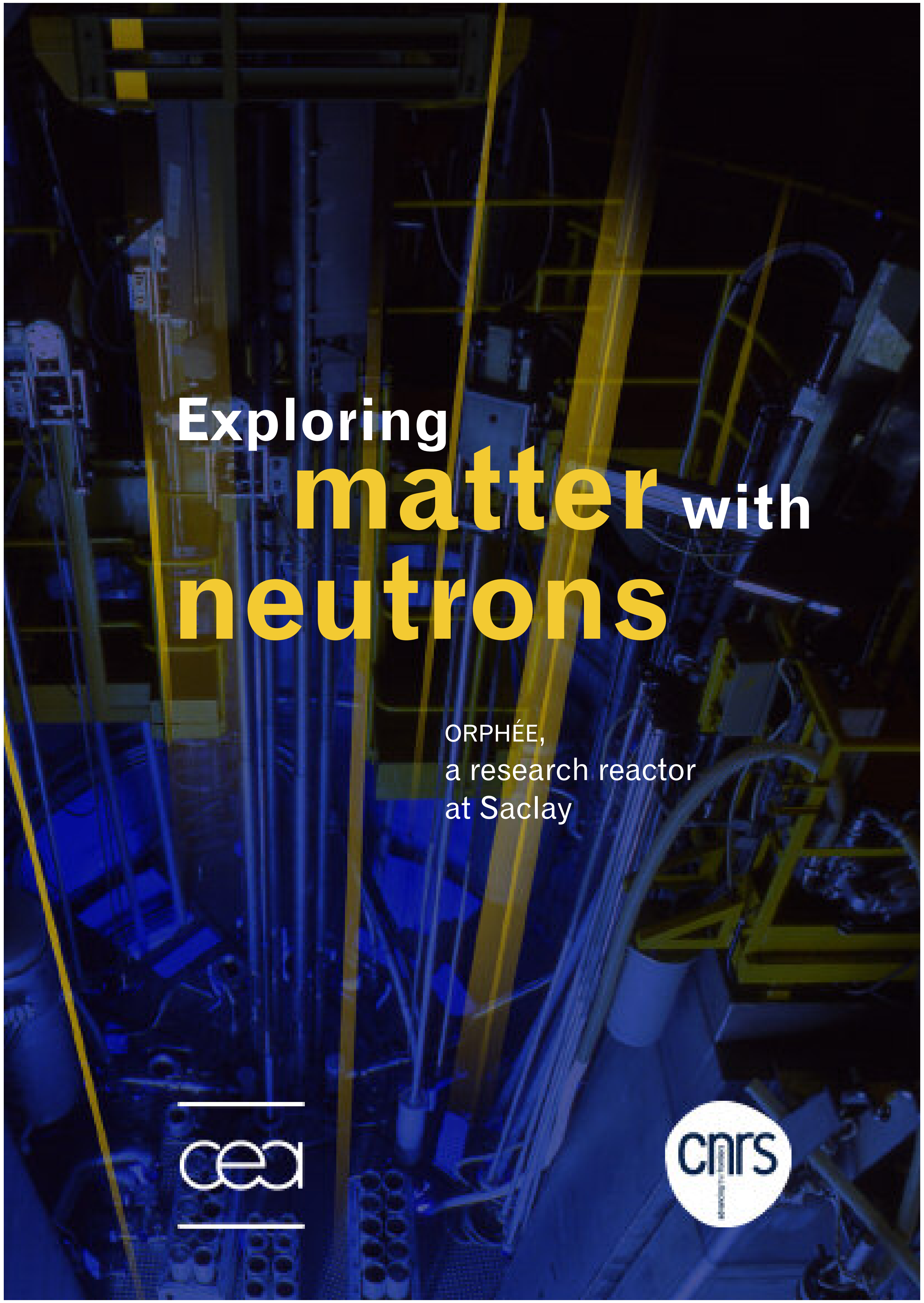


Exploring matter with neutrons

ORPHÉE,
a research reactor
at Saclay

ORPHÉE

A RESEARCH REACTOR AT SACLAY

ORPHÉE:

- Neutrons for science and industry
- Neutron radiography
- Silicon doping
- Radio isotope production for medicine
- Trace measurement by neutron activation
- Determination of textures and mechanical stress

ORPHÉE/LLB:

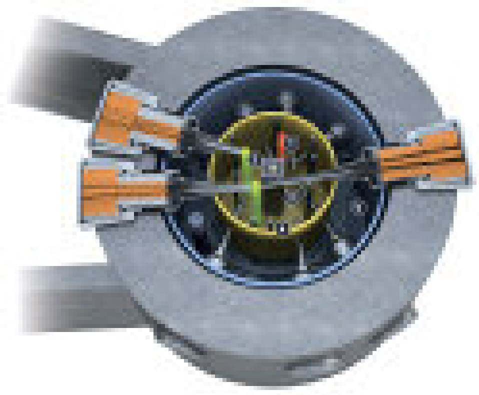
- An integrated facility for the investigation of matter using neutrons

THE LLB BUILDS INSTRUMENTS AROUND ORPHÉE, AND PROVIDES ACCESS TO THE FRENCH AND INTERNATIONAL SCIENTIFIC COMMUNITIES. LLB DEVELOPS ITS OWN RESEARCH PROGRAMS ON:

- Phase transition and dynamics in solid state physics
- Magnetism
- Physical chemistry; study of soft matter
- Biology

ORPHÉE is a research reactor whose first purpose is to provide neutron beams for fundamental research on condensed matter. It is a complementary tool to the neighbouring SOLEIL synchrotron. The reactor went critical for the first time on the 19th December 1980. Every year it receives around 500 scientific visitors from France and from around the world.
ORPHÉE is a "pool" type reactor. It has thermal power of 14 MWth and generates a thermal neutron flux of $3x10^{14}$ per cm^2 per second.

The reactor has 9 horizontal channels (feeding 20 neutron beams) and 9 vertical channels (4 pneumatic channels for analysis by activation, 5 pits use for the industrial irradiation in the pool).
The core of the reactor is very compact and cooled by light water located in the centre of a heavy water tank. The latter has both the role of reflector and thermalisor and is an accumulation volume of thermal neutrons with energy around 25 meV.
The core and the heavy water tank are immerged in a pool filled with demineralised light water. This ensures protection from radiation and facilitates handling above the pool.
The reactor is also equipped with three local moderators: two cold sources and one hot source. These equipments provide neutrons of lower and higher energy through 8 thermal neutron beams, 8 cold neutron beams and 4 hot neutron beams.



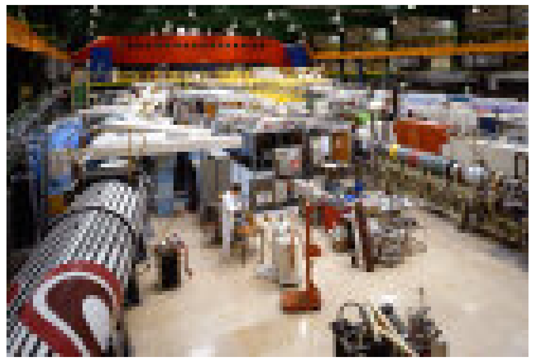
26 experimental areas are located around the reactor, either in the reactor building or along the neutron guides located in the guides hall.

Neutrons produced by ORPHÉE	Energy	Speed	Wavelength (Å)	Equilibrium temperature
Neutrons resulting from core fissions	2 MeV	20 000 km/s	$2x10^{-04}$	Out of thermal equilibrium
Thermal neutrons	0.025 eV	2 200 m/s	1.8	300 K
Cold neutrons (cold sources)	0.002 eV	600 m/s	6.8	20 K
Hot neutrons (Hot source)	0.120 eV	4 800 m/s	0.8	1 400 K

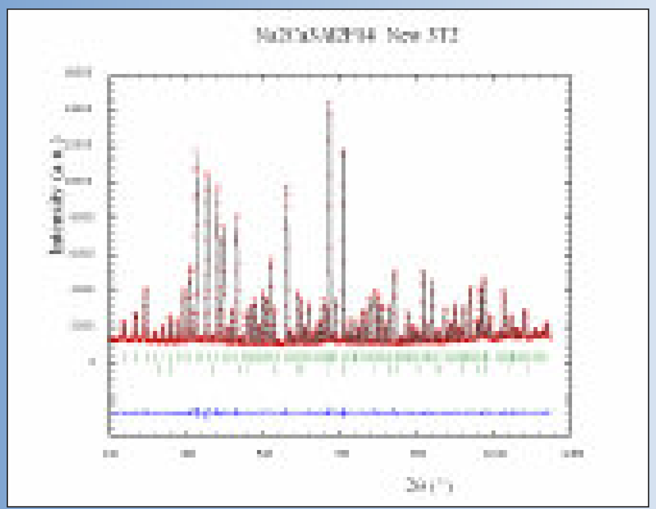
REACTOR SAFETY

The design of the reactor is based on the defense in depth principle in order to ensure permanent control of the three main safety functions: reactivity control, residual heat evacuation and containment of radioactive material.
The design includes the following elements:
- Permanent reactor monitoring by a safety system using 3 completely independent channels. 2 of the 3 channels will trigger an emergency shutdown of the reactor (fast control rod drop by gravity).
- Once the reactor has been stopped, the residual power can be evacuated by natural convection between the core and the reactor pool.
- The core and the main circuits are located in the reactor building made of reinforced concrete. The lower section of the building is surrounded by an outer tank which purpose is to collect leaks which may occur to each pipes that exit the building.

Three impervious, resistant and stand-alone barriers are placed between dangerous products and the environment. These barriers are: the reactor fuel cladding, the reactor main coolant circuit and the reactor pool, and the reactor building.
During normal operation, the reactor building is maintained at lower pressure than outside. The reactor building has also been designed to sustain any accident which could occur to the reactor.
The supervision of the impact of the installation onto the environment is included in the Saclay Centre environmental monitoring program.



LABORATOIRE LÉON BRILLOUIN



Determining a crystalline structure using powder diffraction.

NEUTRON SCATTERING

The neutron scattering techniques which are in use at the ORPHÉE reactor were discovered at the end of the1930s. Ever since then these techniques have been developed. They were originally used to study condensed matter and magnetic structures. Now they have been considerably diversified.

Neutrons are a powerful tool for investigating matter.
• They are interacting directly with the nucleus of the atom. As they do not carry an electrical charge, they have a great power of penetration. They can see light atoms such as hydrogen and the use of isotopic substitution allows to perform “differential” measurements.
• Their mass means that 2 requirements can be satisfied at once as:
- They have a wave-length which is comparable to inter-atomic distances.
- They have kinetic energy which is more or less the same as that of atomic energy of movement in solids and liquids.
- They have a magnetic moment which is used to determine magnetic structures.

A neutron scattering experiment reveals the atom organisation and dynamics of a condensed matter sample. Several types of measurements can be done: elastic neutron scattering, inelastic neutron scattering, polarised neutron scattering and small angle neutron scattering.

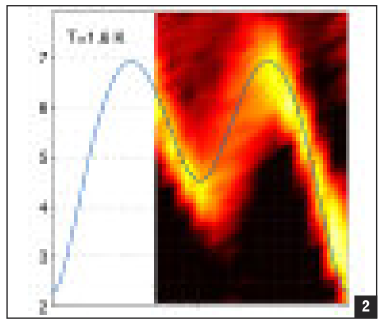
Thermal neutron scattering has multiple applications: Structural studies on liquids and solids; studies of the dynamics of atoms and phonon analysis, molecular movement and phase transitions determinations, magnetism and superconductivity research, texture and stress determination, study of the local structure of disordered systems, biological (conformation and dynamics of large molecules) and physico-chemistry research (polymer research, microemulsions, gels and liquid crystals).

EXPERIMENTAL EQUIPMENT

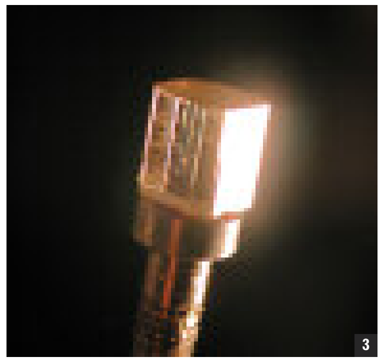
In 2007 the LLB has over 20 spectrometers that are using the neutrons produce by the ORPHÉE reactor. They are grouped into large families:

Measurement required	Technique used	Spectrometers available
Study of the atomic structure of a powder sample	Powder diffraction spectrometers (2 axis)	3T2, G4.1, G6.1
Study of texture and stress	Powder (2 axis) and single crystal (4 circles) spectrometers	6T1, G5.2
Study of atom organisation in liquids and amorphous matter	Powder spectrometers (2 axis)	7C2
Study of atomic structure of a single crystal sample	Single crystal diffraction spectrometers (4 circles)	5C1, 5C2, 6T2
Study of large molecule conformation	Small angle Scattering spectrometer	Paxy, Paxe, Pace, Papyrus, TPA
Study of atom dynamics on a single crystal sample	Inelastic scattering spectrometer (3 axis)	1T, 2T, 4F1, 4F2, G4.3
Study of molecule dynamics	Quasi elastic scattering spectrometers (time of flight, spin echo)	Mibémol, Muses
Study of magnetism	All types of spectrometers	

1



2



3

1. Installing a sample on a spin echo spectrometer for measuring slow molecule movement.

2. Calculation (blue line) and measurement of atomic vibration in $KCuCl_3$.

3. A single crystal about to be measured on a 4-circles.

ORPHÉE IN INDUSTRY

Our eyes, X-rays and neutrons give a different vision of the same object.

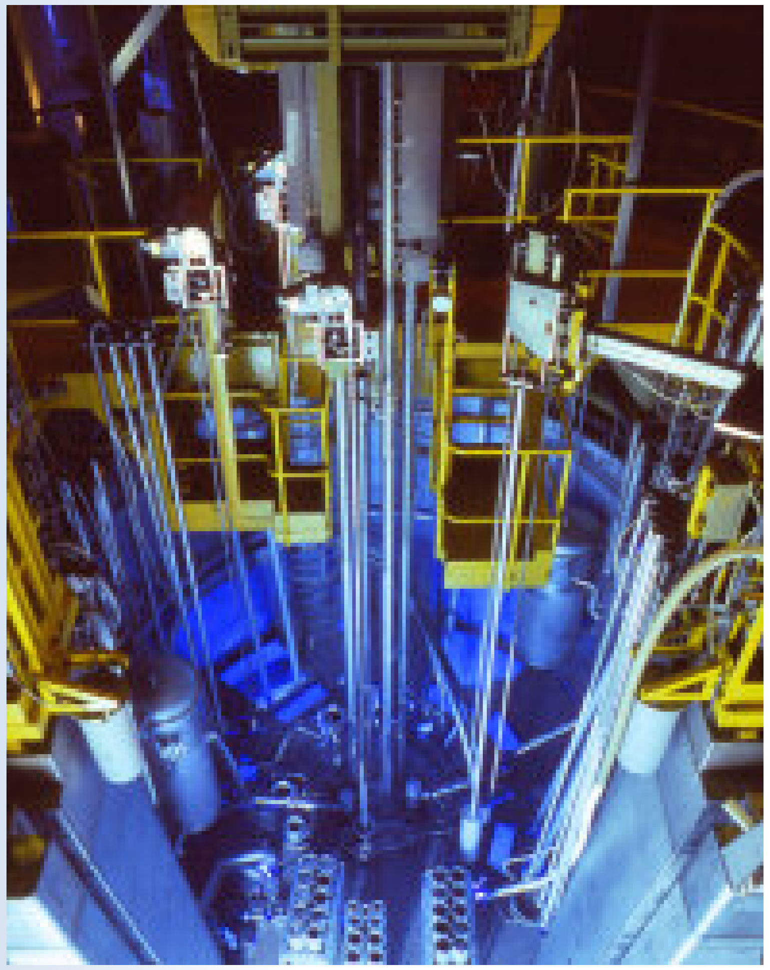
NEUTRON RADIOGRAPHY

Neutron radiography is a non-destructive test method. Like the X-ray, it is a transparent test method. Neutron radiography makes use of the fact that certain light elements scatter neutrons very well and that certain heavy elements absorb them very little. We can thus visualise light atoms within a metal container.
Neutron radiography at ORPHÉE is used as a final acceptance test on pyrotechnic components (powders and explosives containing hydrogenated molecules) used by the aeronautical or space industries, in particular for the European Ariane launchers.

RADIO ISOTOPE PRODUCTION AND SILICON DOPING

5 vertical pits go down into the heavy water reflector tank.
1 pit is used for the production of artificial radio isotopes for medical or industrial use, or for research.
4 pits are used for doping, by transmutation of silicon single crystal ingots in various diameters (100 to 150 mm). The main application for this activity is the semi-conductor production for the electronic industry (i.e. diodes and IGBTs which are used for electrical motor control in particular for trams, high-speed trains – TGV–, hybrid vehicles…).

Silicon ingot irradiated at ORPHÉE. Their diameter can reach 15cm.



TRACE ANALYSIS BY ACTIVATION

4 pneumatic channels link the ORPHÉE reactor to the Pierre SÜE laboratory. They allow small samples to be sent close to the core and then to be analysed after irradiation.
The activation of certain chemical elements within the samples under neutron irradiation, allows their concentration to be measured by gamma spectrometry. The sensitivity of this technique can reach 10^{-12}g.

Heterogeneous mixture of pumice and scoriae collected around the Stromboli volcano. The traces of different included elements are characteristic of the eruptive activity.

DETERMINATION OF MECHANICAL STRESS, TEXTURE AND PRECIPITATES

Neutron diffraction, by measuring variations in inter-atomic distances, allows the mapping of the stress on industrial components. It provides determination of the preferential crystallographic orientation responsible for the anisotropy of mechanical or electrical properties of metals. The neutron scattering at small angles is sensitive, on a nanometric scale, to the heterogeneous character of materials.

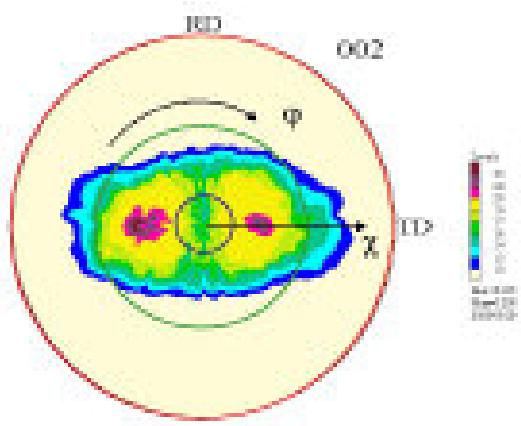


Diagram showing a pole figue measured on a heavily textured zirconium alloy.





CONTACT

ORPHÉE is located within the Saclay Nuclear Research Centre near Orsay. It is accessible by the bus which connects Massy-Palaiseau and Saint Quentin en Yvelyne stations, in the Paris region.
▶ Postal Adress 91191, Gif-sur-Yvette Cedex, France.

THE REACTOR is run by the CEA Direction de l'Énergie Nucléaire (The Nuclear Energy Division) acting for the CEA Direction des Sciences de la Matière (Physical Sciences Division)
▶ Contact: CEA Centre de Saclay, Service d'exploitation du réacteur Orphée, bât. 541
Tel: (33)169085557

INDUSTRIAL APPLICATIONS run by the Nuclear Energy Division of the CEA:
- Neutron radiography
- Silicon doping
- Radio isotope production
▶ Contact: Service d'exploitation du réacteur ORPHÉE (The Orphée operations department)
Tel: (33)169085557
http://www-llb.cea.fr/industrie

FONDAMENTAL RESEARCH at a joint CEA-CNRS laboratory:
– Research on structure and dynamics of solid state using neutron scattering.
▶ Laboratoire Léon Brillouin, UMR12 CEA-CNRS,
Tel: (33)169085241
http://www-llb.cea.fr

Orphée

Laboratoire Léon Brillouin

Production : www.public-histoire.com **Pictures credits :** Orphée ; LLB ; Jacques Boulay / CEA (couv) ; Gonin / CEA ; Jean Biaugeaud **Diagrams :** Fabrice Blanchard (lmdk.com)