

Performances actuelles de la tomographie neutronique : quels atouts pour quels cas spécifiques?

*NeXT-Grenoble, le nouvel instrument de
tomographie
Neutrons et Rayons X à Grenoble*

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Over 50 years of achievement



50
years of scientific
excellence

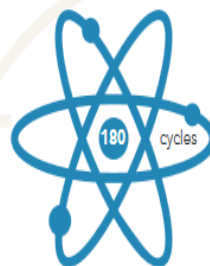
Founded on

1967
19 JAN

Scientists from over
1000
laboratories worldwide
visit the facility each year



21,000
scientific publications



120,000

visitors



40,000

experiments



486 staff members



biology



chemistry



engineering



medicine



nuclear physics

Research is conducted in almost
every field of science

Partner
and Member
countries



1967 - 1970

1967 - 19 January: signing
of the Intergovernmental
Convention

1971 - 1980

1971 - 31 August: Reactor
goes critical

1981 - 1990

1986 - Horizontal cold source & second guide hall built

1991 - 2000

2000 - The Millennium Programme is launched

2001 - 2010

2012 - Post-Fukushima
reinforcement work starts

2011 - 2017

2014 - The Endurance
programme is launched

1969 - Work starts on the reactor

1972 - The founders confirm a user service philosophy for the ILL

1995 - Reactor restarts with new reactor vessel

2013 - The Intergovernmental
Convention is extended to 2023

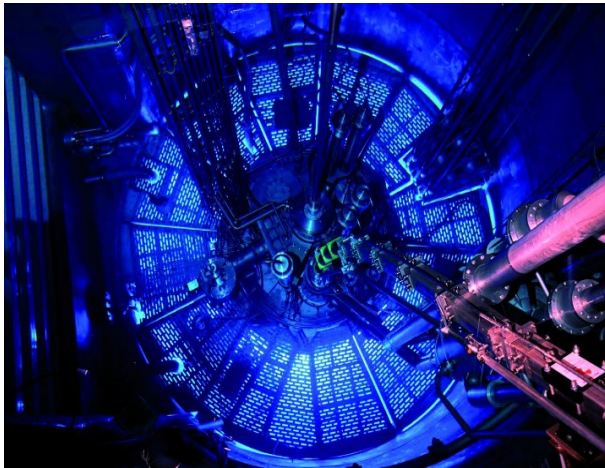
2017 - 50th anniversary
of the ILL

Timeline

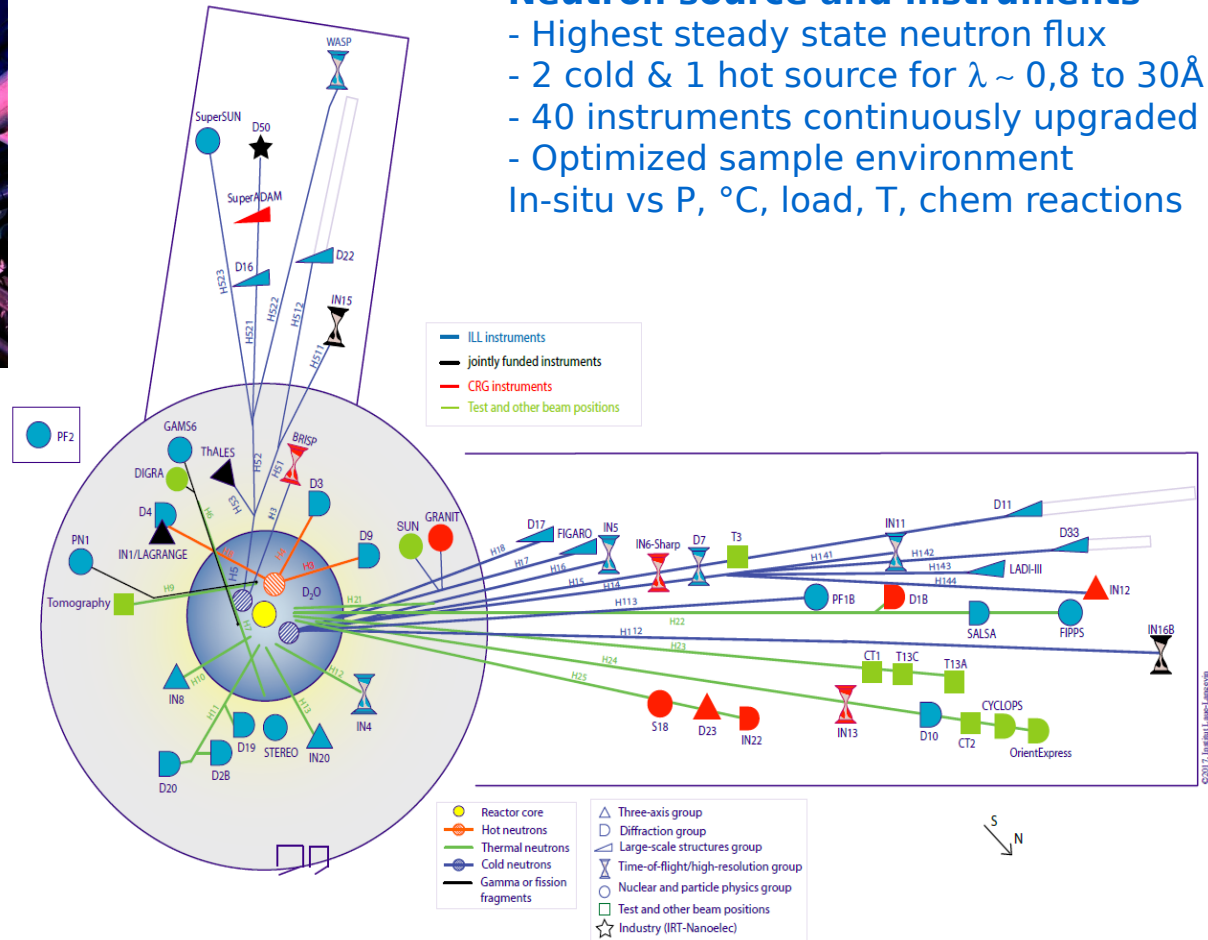
50 YEARS OF SERVICE TO SCIENCE AND SOCIETY

1967 - 2017

What makes the ILL a world leader?



- ✓ **Neutron source and instruments**
 - Highest steady state neutron flux
 - 2 cold & 1 hot source for $\lambda \sim 0,8$ to 30\AA
 - 40 instruments continuously upgraded
 - Optimized sample environment
In-situ vs P, °C, load, T, chem reactions



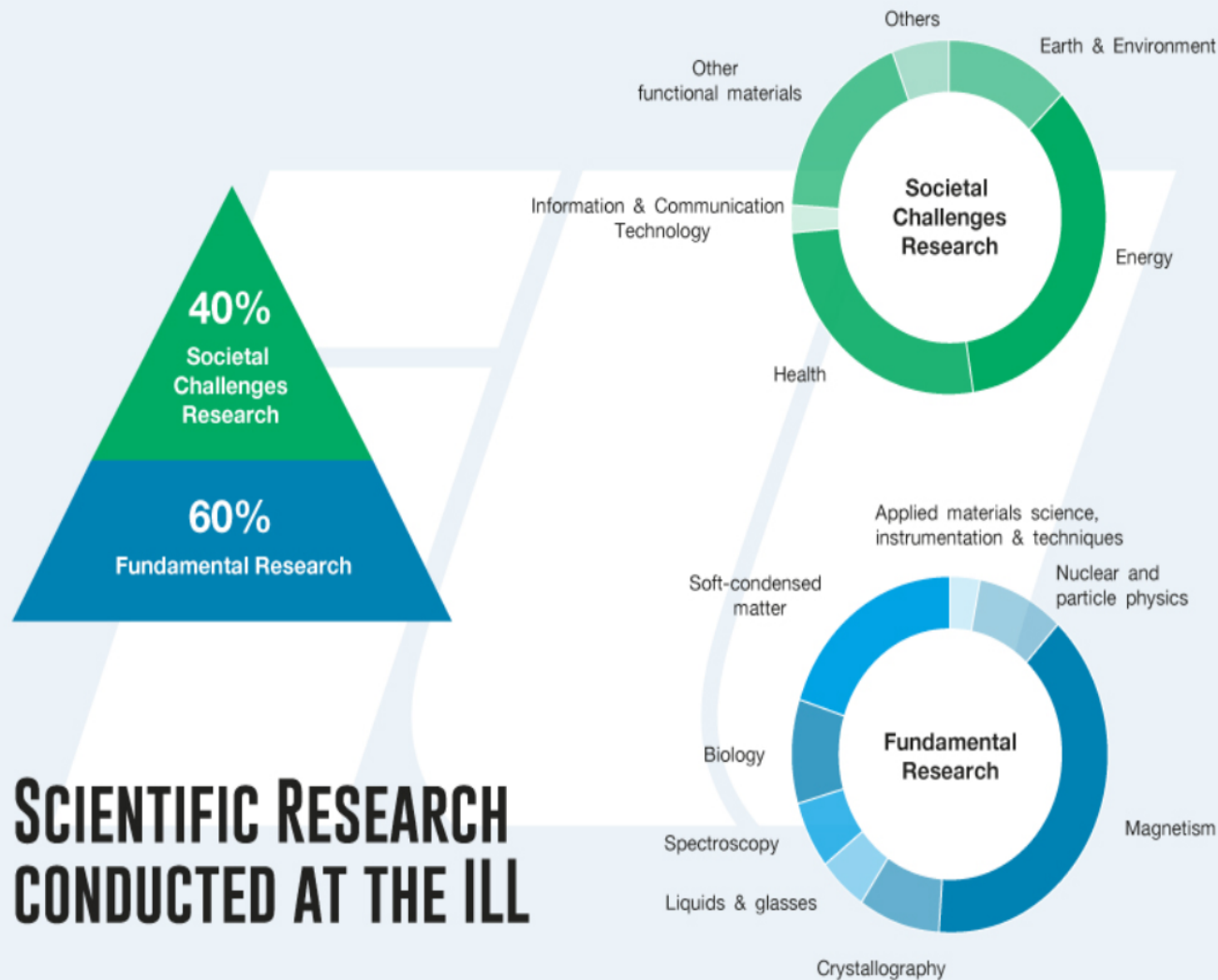
- ✓ **International staff of experts in their own fields and in neutron science**



39
PHDs

100
SCIENTISTS

45
TECHNICIANS
& ENGINEERS



NEXT-Grenoble for Neutron and X ray Tomography in Grenoble

NeXT-Grenoble is a new Neutron and X-ray Tomography facility in Grenoble, born in 2016 from a collaboration between the Institut Laue-Langevin and the Université Grenoble Alpes (specifically Laboratoire 3SR), and takes advantage of its world-leading cold neutron flux.

A major upgrade of the instrument is foreseen in the forthcoming two years to further improve its performances as well as to add new options (e.g., monochromation, polarised neutrons, grating interferometry).

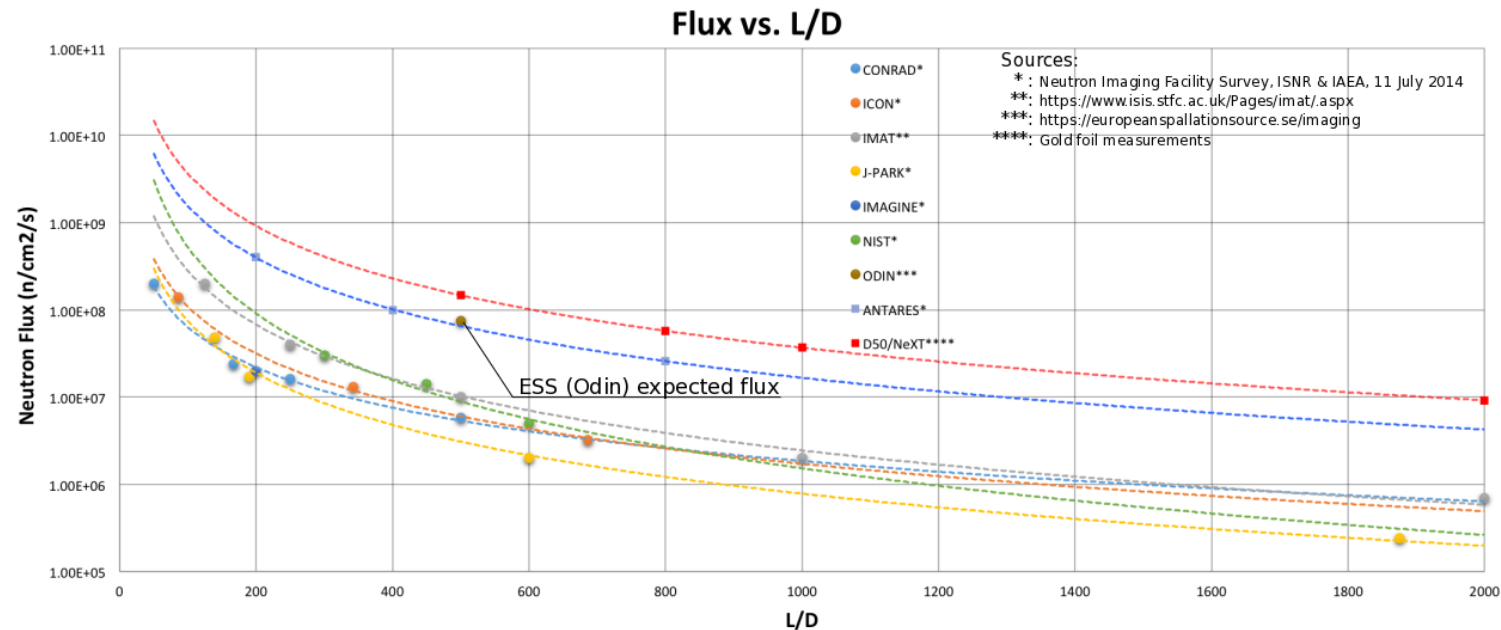
Motivations

Why neutrons?

- light element sensitivity (*notably, hydrogen and lithium*)
- isotope sensitivity (*e.g. water H2O and deuterium D2O*)
- heavy element insensitivity (*notably metals, i.e. thick sample environments*)
- low radiation damage

Why neutrons at ILL ?

- taking advantage of the highest available neutron flux

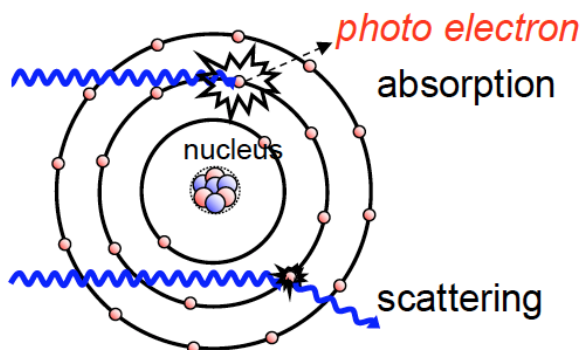


Motivations

Why neutrons and x-rays?

- high complementarity of interaction with matter

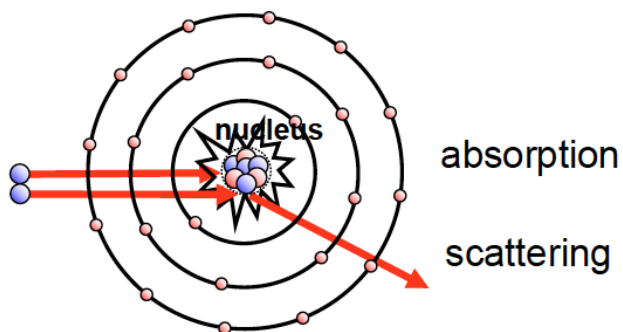
X-rays



Attenuation coefficients with X-ray [cm²]

1a	2a	3b	4b	5b	6b	7b	8	1b	2b	3a	4a	5a	6a	7a	0
H 0.02															He 0.02
Li 0.06	Be 0.22									B 0.28	C 0.27	N 0.11	O 0.16	F 0.14	Ne 0.17
Na 0.13	Mg 0.24									Al 0.38	Si 0.33	P 0.25	S 0.30	Cl 0.23	Ar 0.20
K 0.14	Ca 0.26	Sc 0.48	Ti 0.73	V 1.04	Cr 1.29	Mn 1.32	Fe 1.57	Co 1.78	Ni 1.96	Cu 1.97	Zn 1.64	Ga 1.42	Ge 1.33	As 1.50	Se 1.23
Rb 0.47	Sr 0.86	Y 1.61	Zr 2.47	Nb 3.43	Mo 4.29	Tc 5.06	Ru 5.71	Rh 6.08	Pd 6.13	Ag 5.67	Cd 4.84	In 4.31	Sn 3.98	Sb 4.28	Te 4.06
Cs 1.42	Ba 2.73	La 5.04	Hf 19.70	Ta 25.47	W 30.49	Re 34.47	Os 37.92	Ir 39.01	Pt 38.61	Au 35.94	Hg 25.88	Tl 23.23	Pb 22.81	Bi 20.28	Po 20.22
Fr 11.80	Ra 24.47	Ac 24.47	Rf 24.47	Ha 24.47										At 9.77	Rn 9.77
Lanthanides		Ce 5.79	Pr 6.23	Nd 6.46	Pm 7.33	Sm 7.68	Eu 5.66	Gd 8.69	Tb 9.46	Dy 10.17	Ho 10.91	Er 11.70	Tm 12.49	Yb 9.32	Lu 14.07
Actinides		Th 28.95	Pa 39.65	U 49.08	Np 39.65	Pu 49.08	Am 49.08	Cm 49.08	Bk 49.08	Vf 49.08	Es 49.08	Fm 49.08	Md 49.08	No 49.08	Lr x-ray

neutrons



Attenuation coefficients with neutrons [cm²]

1a	2a	3b	4b	5b	6b	7b	8	1b	2b	3a	4a	5a	6a	7a	0
H 3.44															He 0.02
Li 3.30	Be 0.79									B 101.60	C 0.56	N 0.43	O 0.17	F 0.20	Ne 0.10
Na 0.09	Mg 0.15									Al 0.10	Si 0.11	P 0.12	S 0.06	Cl 1.33	Ar 0.03
K 0.06	Ca 0.08	Sc 2.00	Ti 0.60	V 0.72	Cr 0.54	Mn 1.21	Fe 1.19	Co 3.92	Ni 2.05	Cu 1.07	Zn 0.35	Ga 0.49	Ge 0.47	As 0.67	Se 0.73
Rb 0.08	Sr 0.14	Y 0.27	Zr 0.29	Nb 0.40	Mo 0.52	Tc 1.76	Ru 0.58	Rh 10.88	Pd 0.78	Ag 4.04	Cd 115.11	In 7.58	Sn 0.21	Sb 0.30	Te 0.25
Cs 0.29	Ba 0.07	La 0.52	Hf 4.99	Ta 1.49	W 1.47	Re 6.85	Os 2.24	Ir 30.46	Pt 1.46	Au 6.23	Hg 16.21	Tl 0.47	Pb 0.38	Bi 0.27	Po 0.27
Fr 0.34	Ra 0.34	Ac 0.34	Rf 0.34	Ha 0.34											
Lanthanides		Ce 0.14	Pr 0.41	Nd 1.87	Pm 5.72	Sm 171.47	Eu 94.58	Gd 1479.04	Tb 0.93	Dy 32.42	Ho 2.25	Er 5.48	Tm 3.53	Yb 1.40	Lu 2.75
Actinides		Th 0.59	Pa 8.46	U 0.82	Np 9.80	Pu 50.20	Am 2.86	Cm 2.86	Bk 2.86	Cf 2.86	Es 2.86	Fm 2.86	Md 2.86	No 2.86	Lr neut.

Motivations

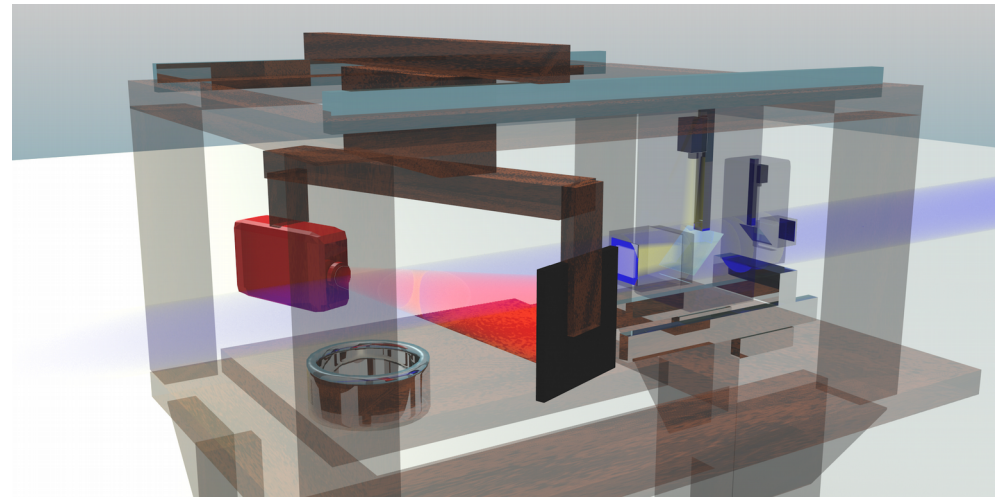
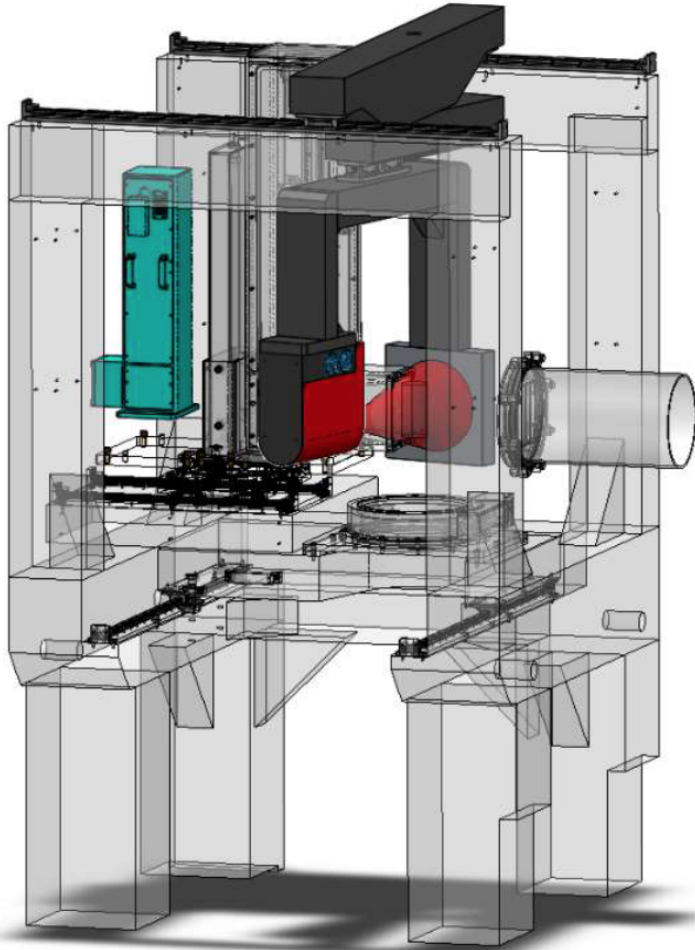
NeXT takes full advantage of this great complementarity by allowing simultaneous x-ray and neutron acquisitions during in situ/operando experiments



A few technical details

Mechanical set-up

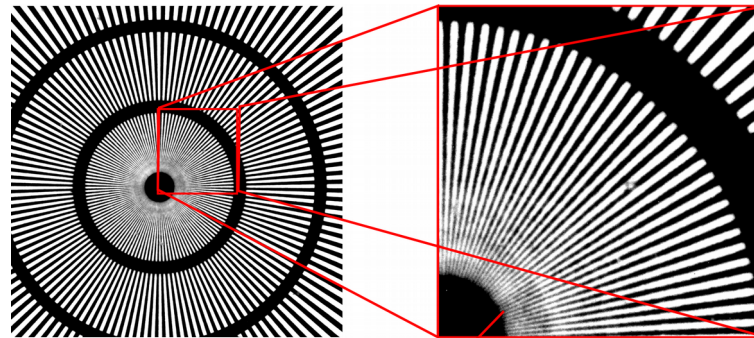
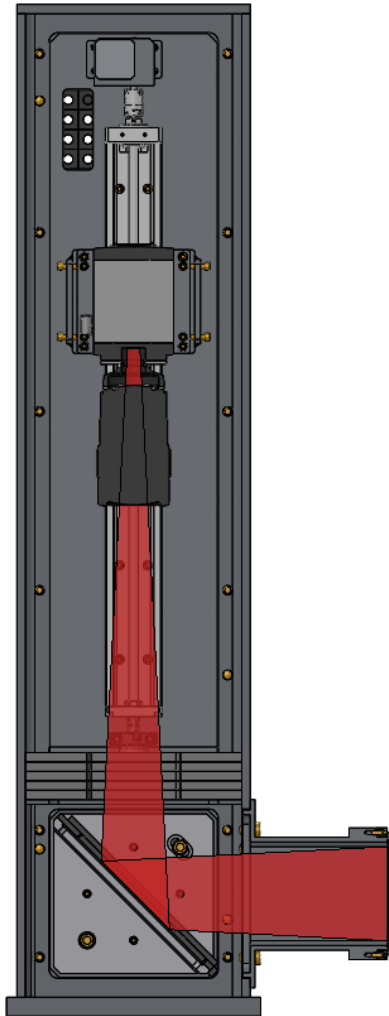
- Large granite exoskeleton
- Can accommodate large objects up to several hundreds of kilograms
- Large hollow rotary stage



A few technical details

Neutron imaging

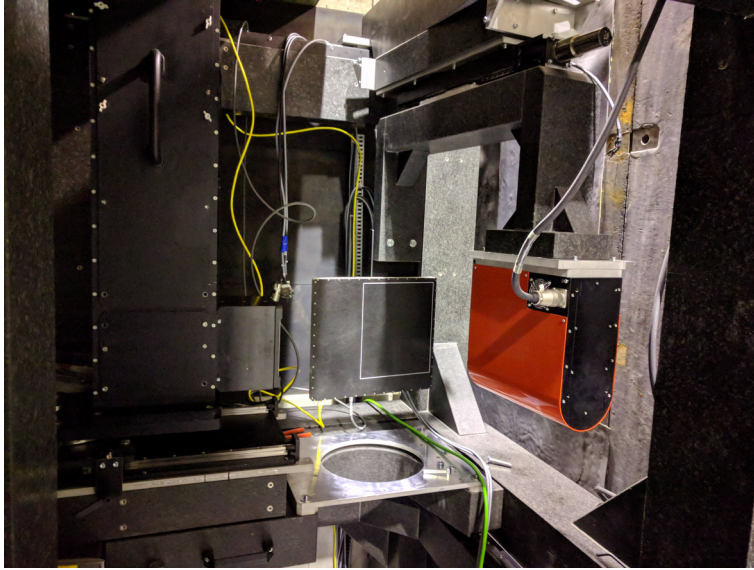
- Different optics and scintillator (LiF and Gadox)
- Maximum field of view: 160x160 mm (in different working environment it is possible to go up to 200x200 mm)
- Resolution: from 160 microns at 160x160 down to 4 microns (and 2 or less in the next future)
- Maximum speed of the camera: 100 Hz (sCMOS).
- Pixels (currently): 2048x2048



4 um true resolution

10 sec exposure time (average 5)

A few technical details



Xray imaging

- Microfocus x-ray 75 W, 150 kV
- FOV: 25x30 cm max
- Resolution: down to 5 microns (spot size)
- Pixels : $\sim 2200 \times 1800$

Control software

- User friendly environment for control and image reconstruction

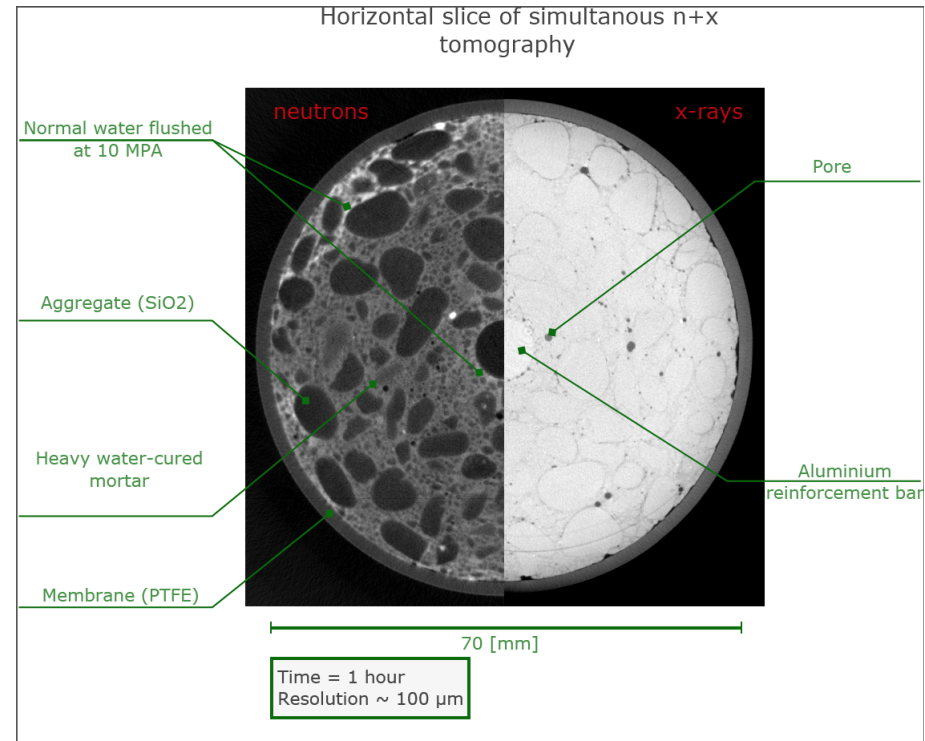
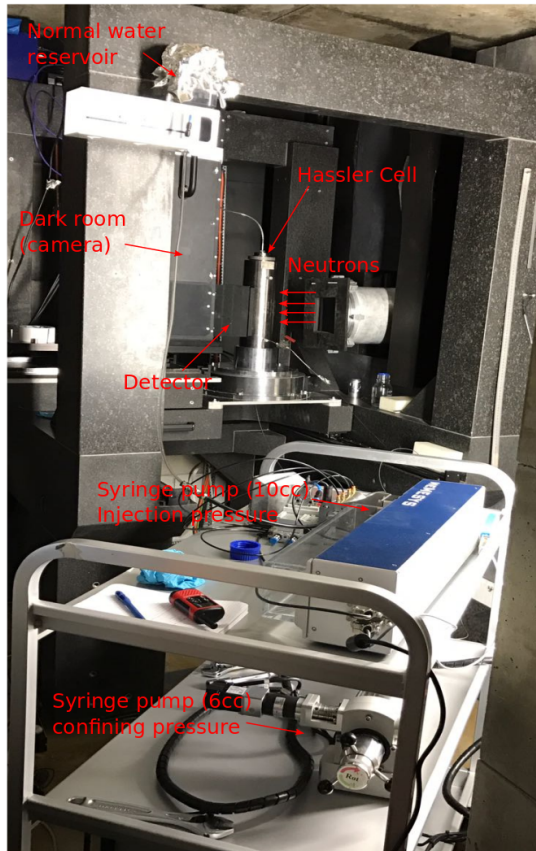
collaboration with RX-Solutions



A few technical details

In-house software for Neutrons and Xray registration (collaboration between 3SR - Ando and Roubin & LMT-Cachan - Roux)

<https://ttk.gricad-pages.univ-grenoble-alpes.fr/spam/intro.html>

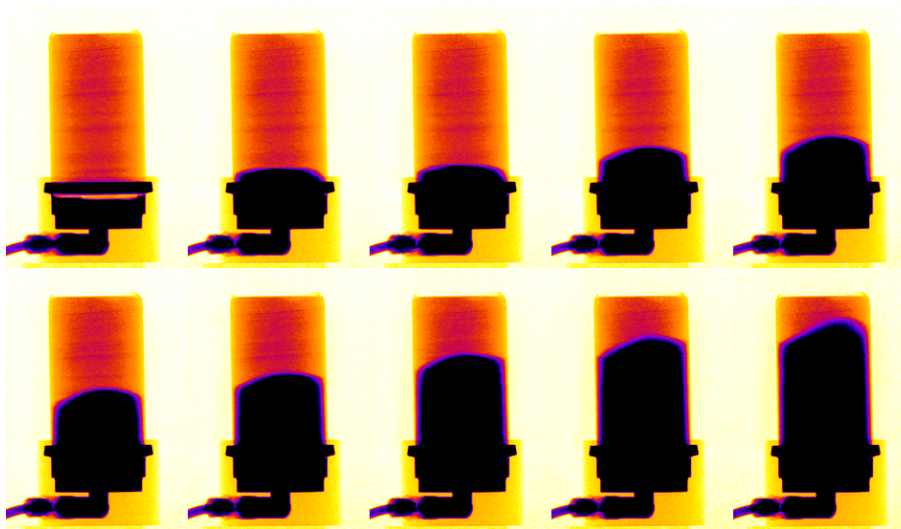
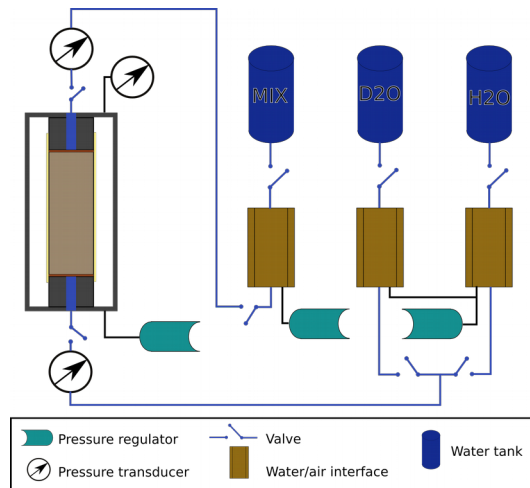


Example of fluid flow along bars in reinforced concrete

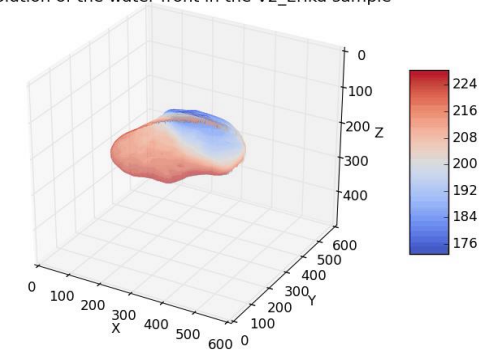
See also Yehya et al., Nuclear Instruments and Methods, (2018)

A few examples

Fluid flow in porous materials (isotope sensitivity)



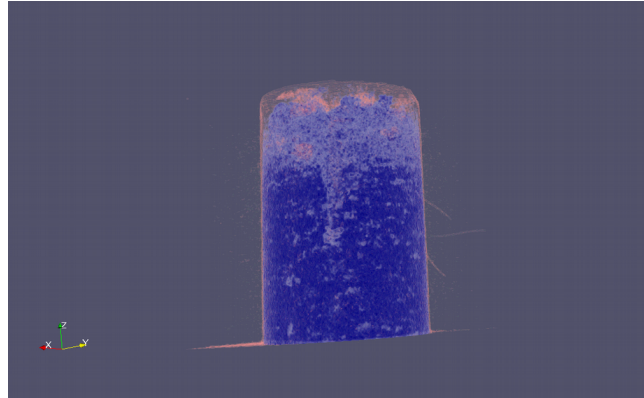
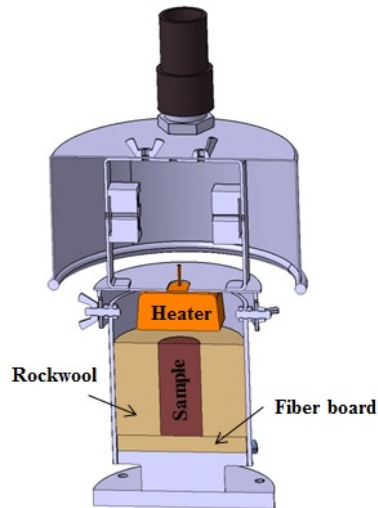
Evolution of the water front in the V2_Erika sample



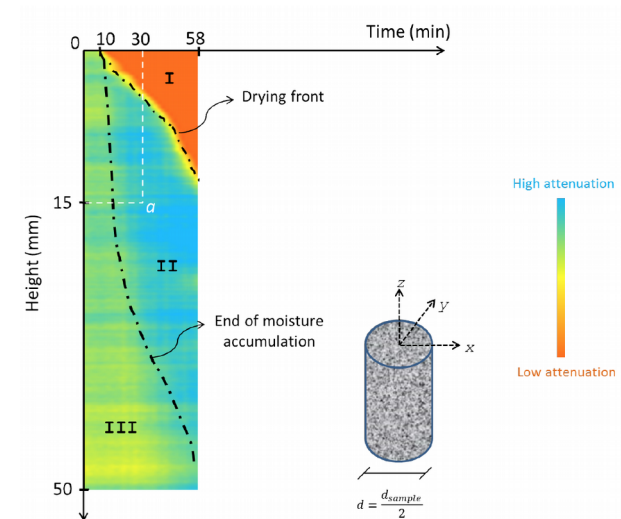
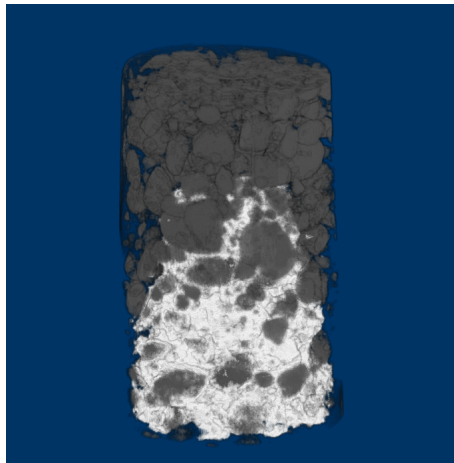
3D water front

A few examples

Analysis of moisture migration in concrete at high temperature



here 1min scan
(now 20 sec!)

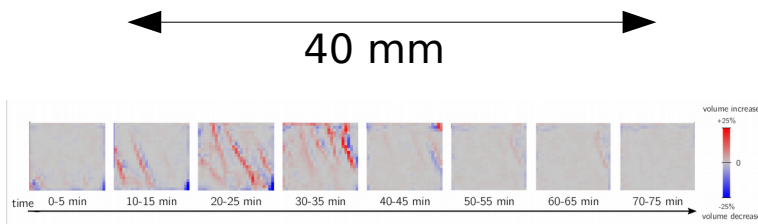
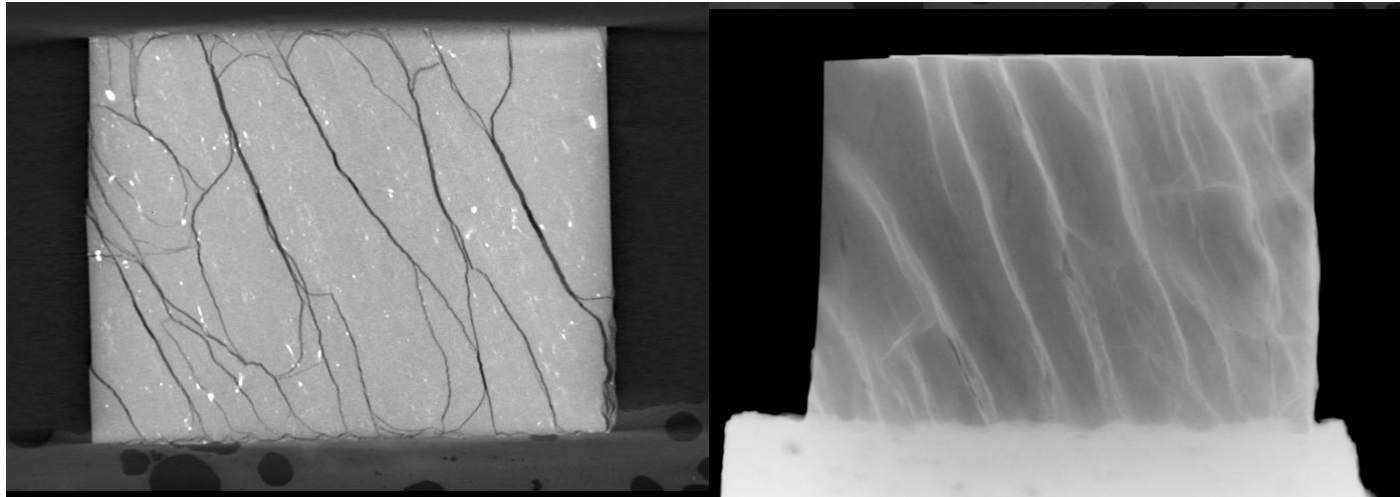


Dauti et al., Cement and Concrete research, (2018)

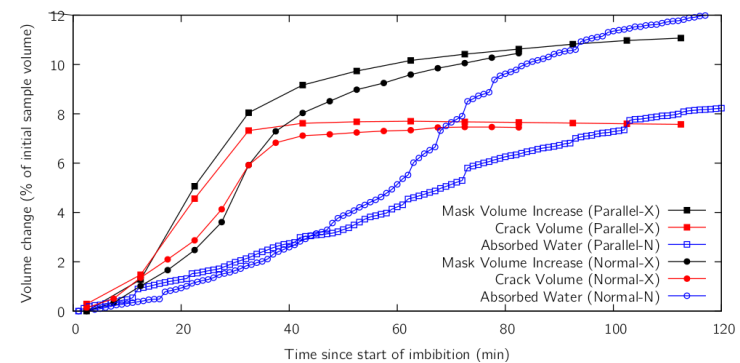
Journée technique Tomographie, PRECEND, Nantes le 14 mai 2019

A few examples

HM behaviour of shale for radioactive waste disposal (NB : first test not under in situ conditions)



DIC analysis

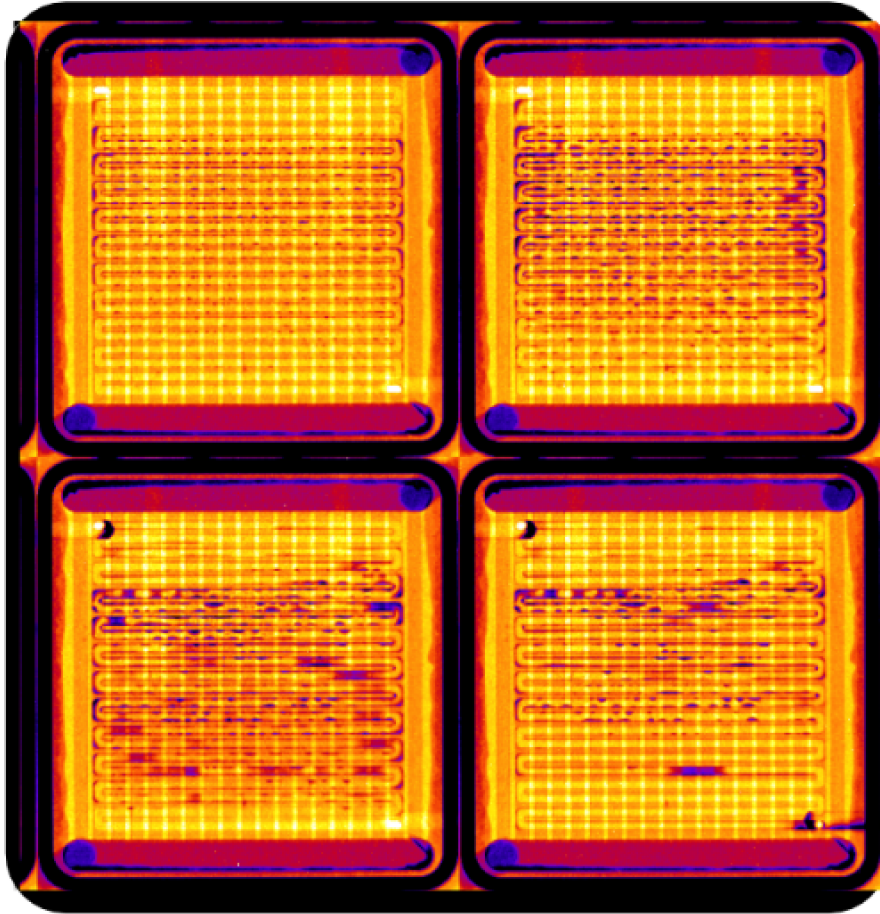


Stravopoulou et al., Acta Geotechnica, (2018)

Journée technique Tomographie, PRECEND, Nantes le 14 mai 2019

A few examples

In operando fuel cell study



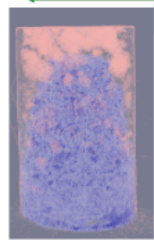
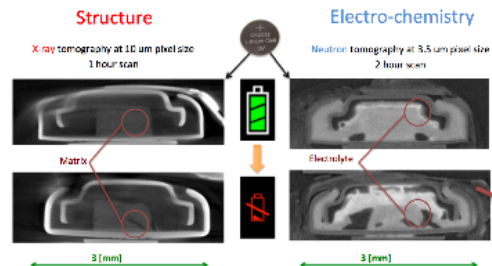
In fuel cells oxygen and hydrogen are injected to generate electricity, having water vapor as the only byproduct. Part of this vapor condenses into liquid water, depending of the testing conditions (temperature, flux).

Neutron imaging allows its quantification and therefore the optimization of the efficiency of the process.

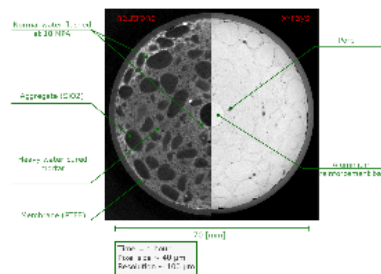
Courtesy of N. Morin (CEA - Grenoble)

The future (spring 2021)

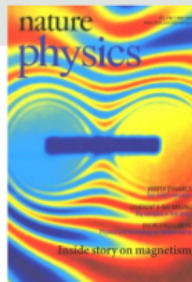
Complementary (x+n) studies at high resolution and high speed



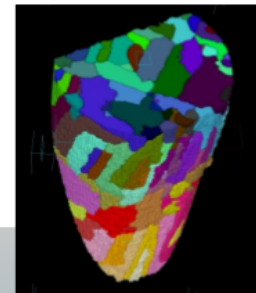
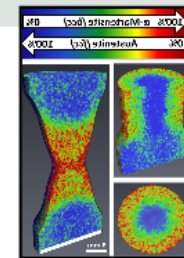
Advanced processing



Polarised



Energy-selective



Grating interferometry



• Peer-reviewed research

- Competitive access to the instruments and result to be published
- Often academic/industrial partnership
- Lead-time: several month

<https://next-grenoble.fr/>

• Proprietary research

- Rapid service access to ILL instruments and expertise
- Confidentiality (NDA)
- Lead-time: from 2 weeks

industry@ill.fr

• Cooperative solutions for industry

Medium or long-term collaboration agreements can include the development of specific instrumentation, the funding of PhD students, post-doctoral researchers or engineers, working on a given subject for several years.

European funded collaborations.

industry@ill.fr

Any questions ?

Contact us : industry@ill.fr

&

Check our website : <https://next-grenoble.fr/>

The screenshot displays the NeXT-Grenoble website interface. At the top, a navigation bar includes the NeXT logo and links for Home, About, and a welcome message. The main content area features a central article titled "New 'Cement and Concrete Research' paper from NeXT!" from ScienceDirect, dated September 2018. To the left, a sidebar contains sections for "What is NeXT-Grenoble?", "Any question? Contact us!", and "Keep in touch!". To the right, there is a "Log In" section with username and password fields, and a "Project advancement" bar showing progress for various experimental areas like "100% Experimental area" and "100% Mid-res N. detector".