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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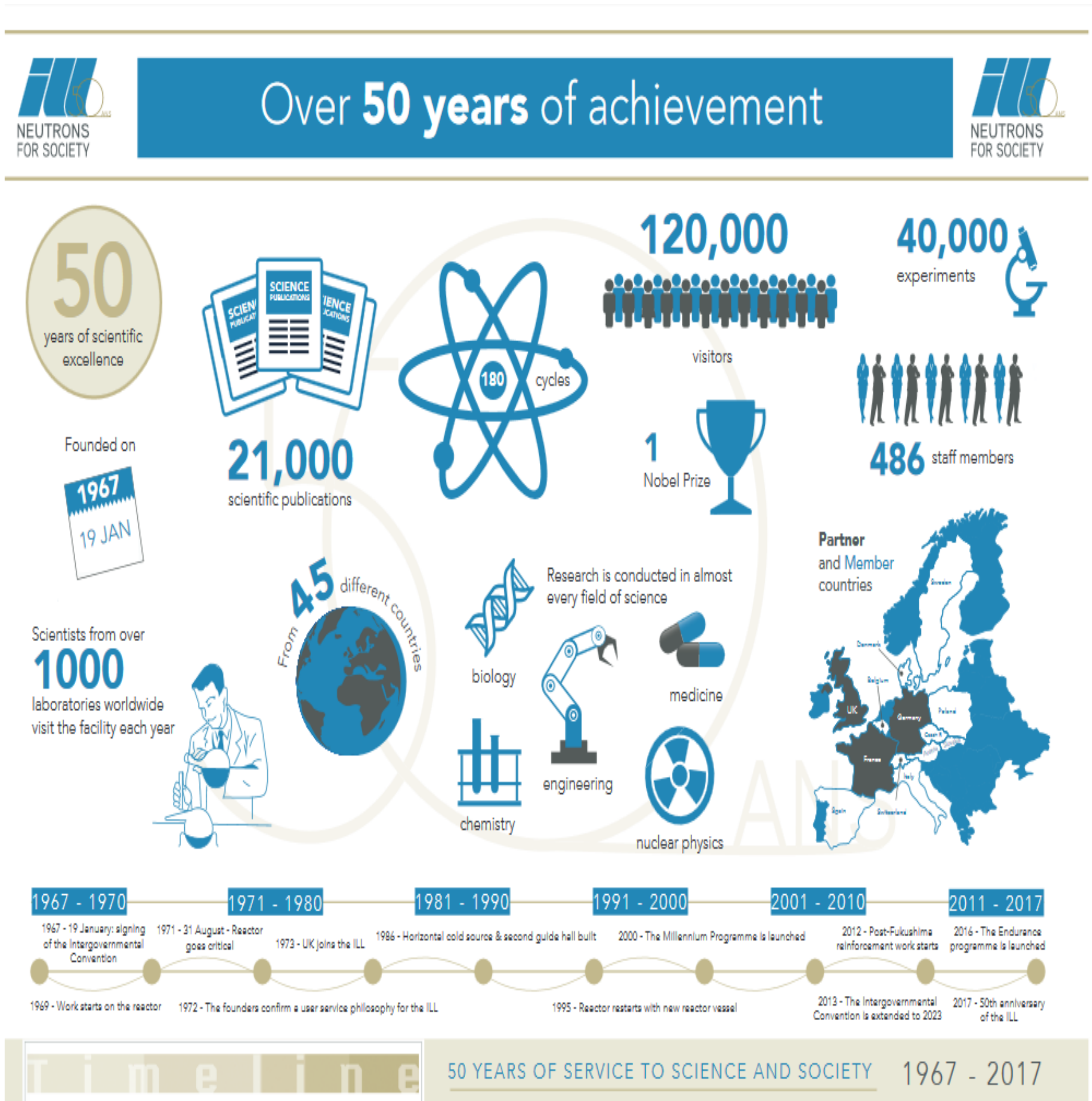

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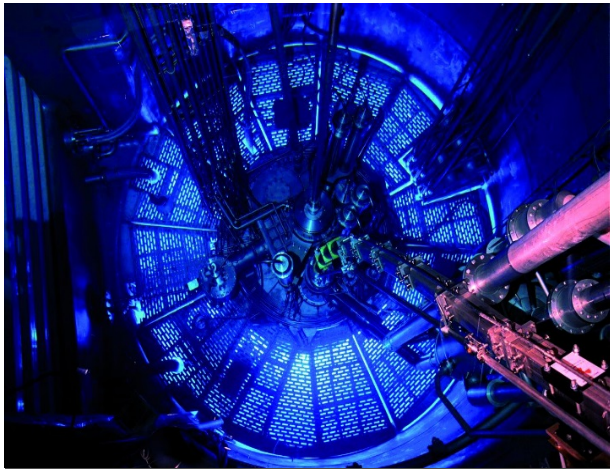
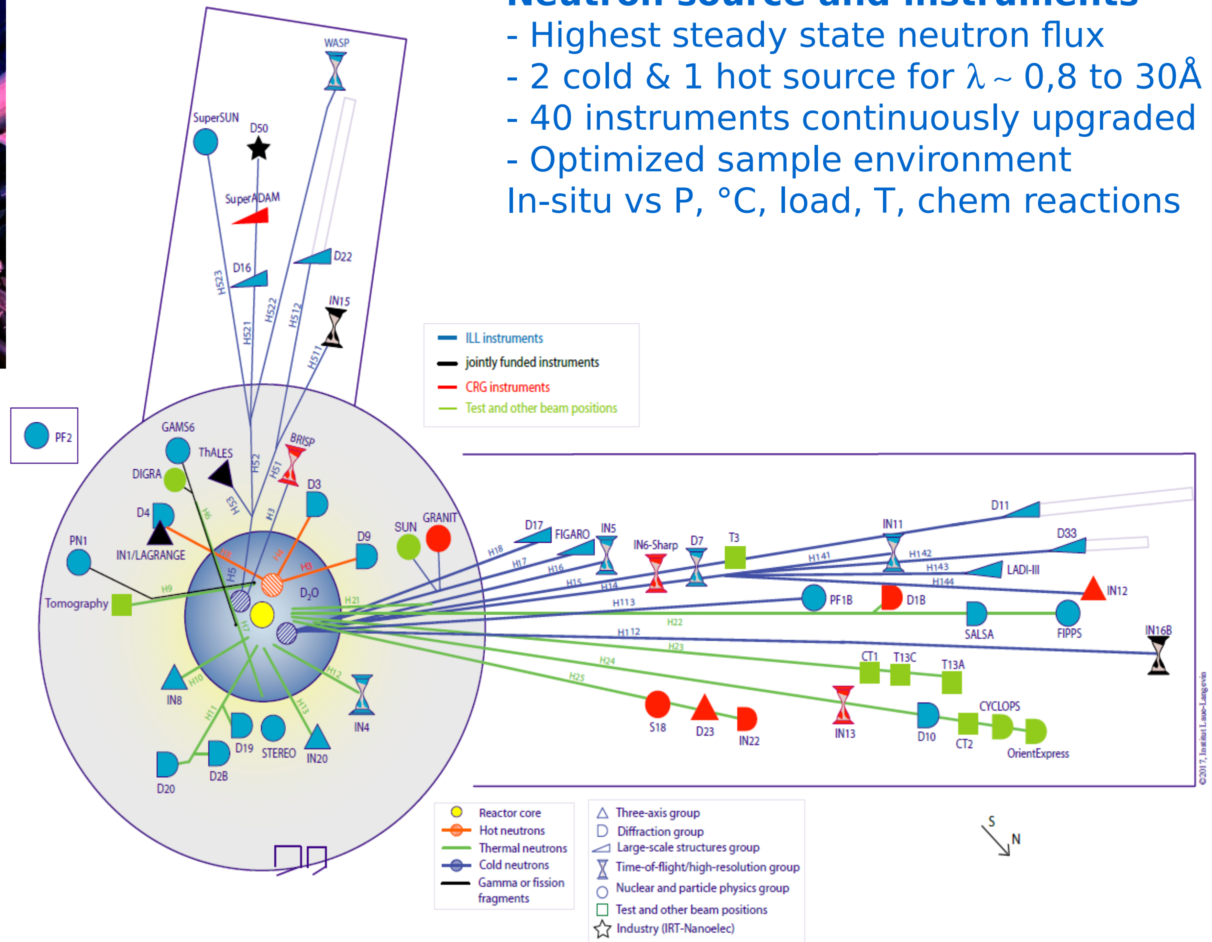
What makes the ILL a world leader?





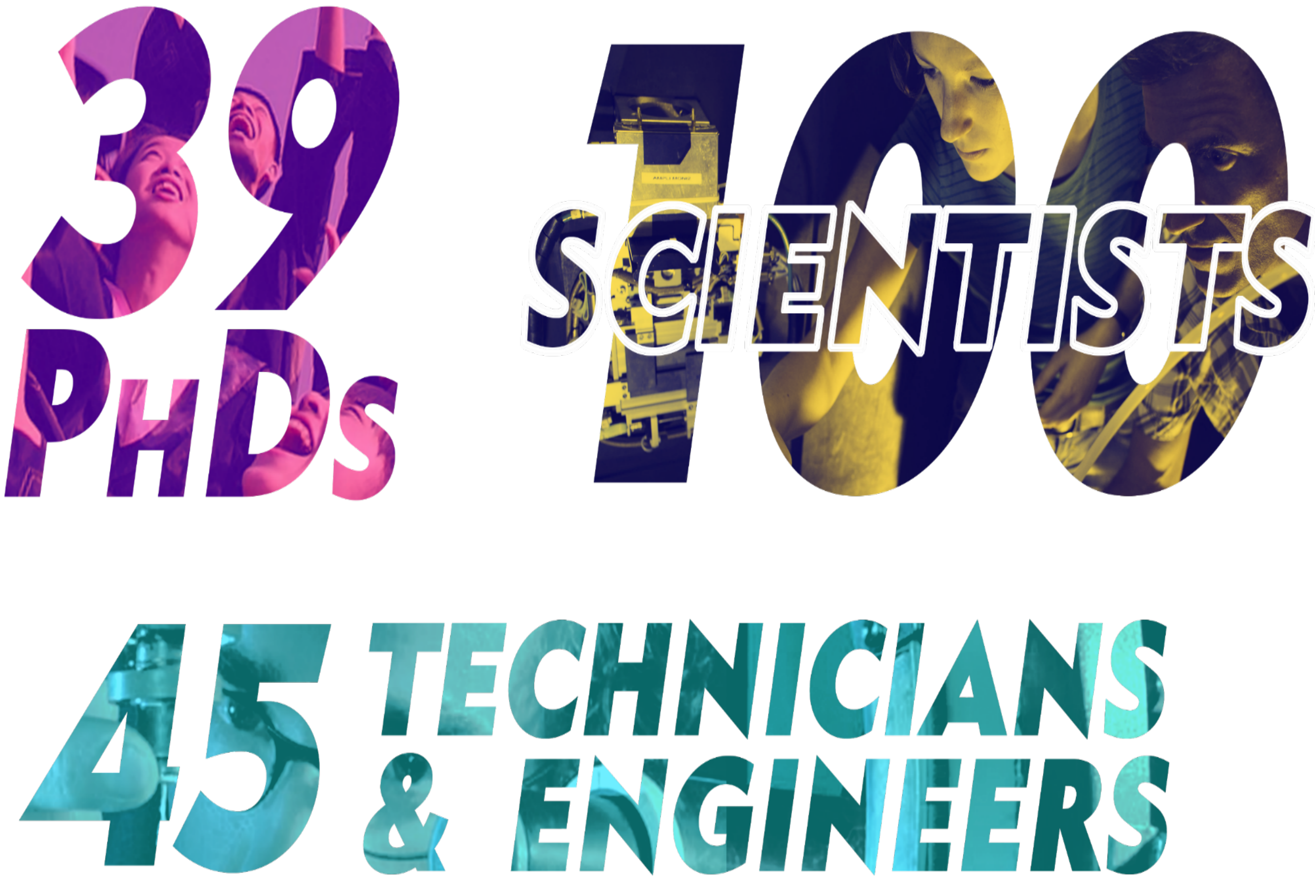
✓ **Neutron source and instruments**

- Highest steady state neutron flux
- 2 cold & 1 hot source for λ ~ 0,8 to 30Å
- 40 instruments continuously upgraded
- Optimized sample environment

In-situ vs P, °C, load, T, chem reactions

Institut Laue-Langevin (ILL)

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



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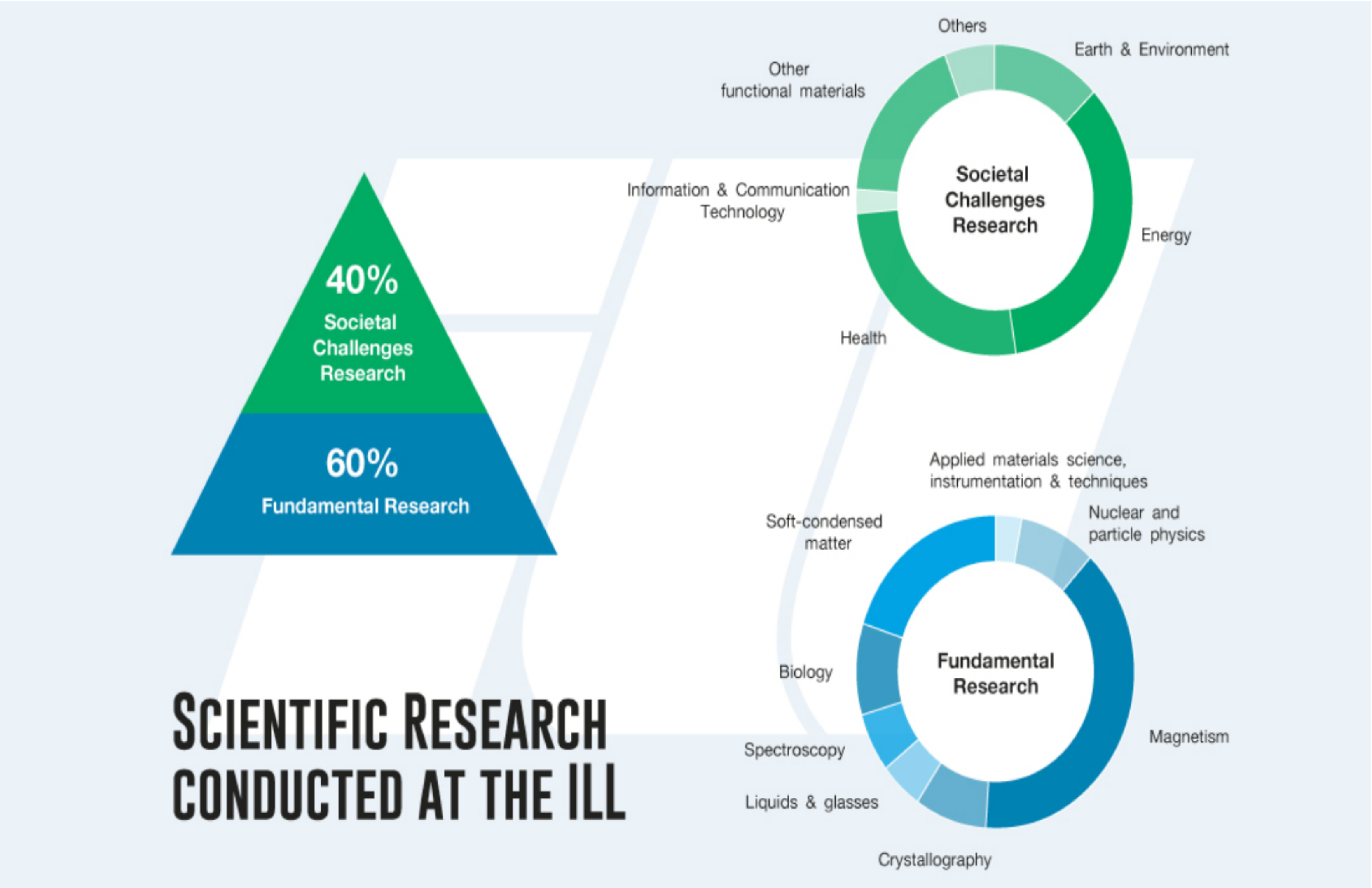


NEXT-Grenoble for Neutron and X ray Tomography in Grenoble

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).

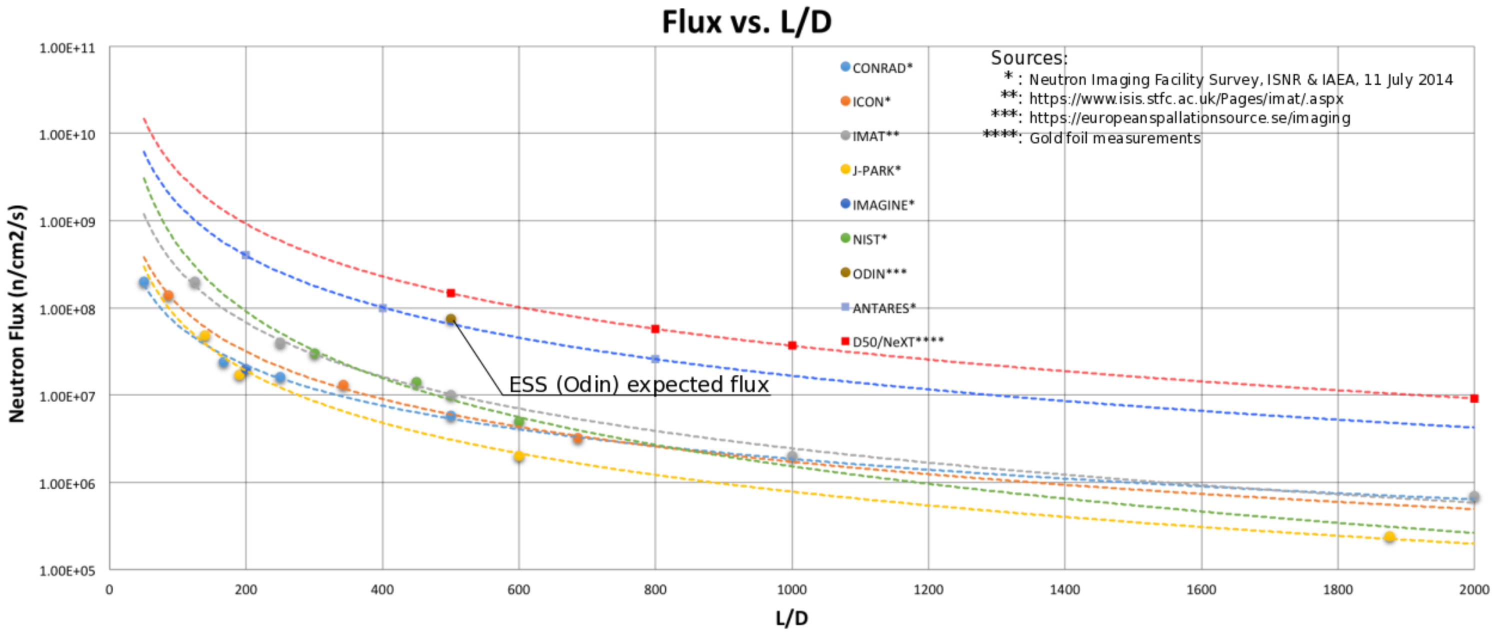
Motivations

Why neutrons?

- light element sensitivity *(notably, hydrogen and lithium)*
- isotope sensitivity *(e.g. water H20 and deuterium D20)*
- 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

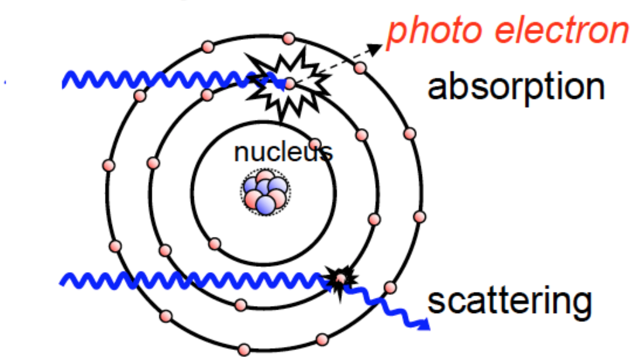


Motivations

Why neutrons and x-rays?

- high complementarity of interaction with matter

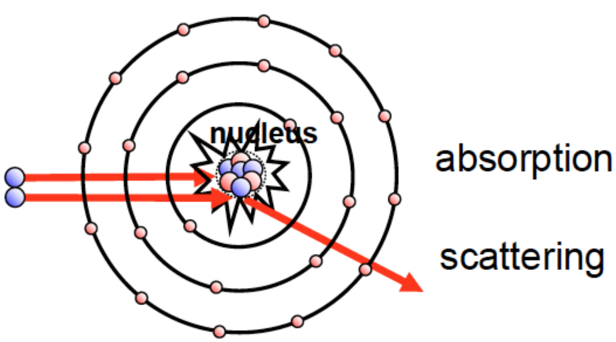
X-rays



Attenuation coefficients with X-ray [cm?^{1}]

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	Br 0.90	Kr 0.73
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	I 3.45	Xe 2.53
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	At	Rn 9.77
Fr	Ra 11.80	Ac 24.47	Rf	Ha													
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	Pu	Am	Cm	Bk	Vf	Es	Fm	Md	No	Lr x-ray			

neutrons



Attenuation coefficients with neutrons [cm?^{1}]

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	Br 0.24	Kr 0.61
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	I 0.23	Xe 0.43
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	At	Rn
Fr	Ra 0.34	Ac	Rf	Ha													
*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	Bk	Cf	Es	Fm	Md	No	Lr neut.			

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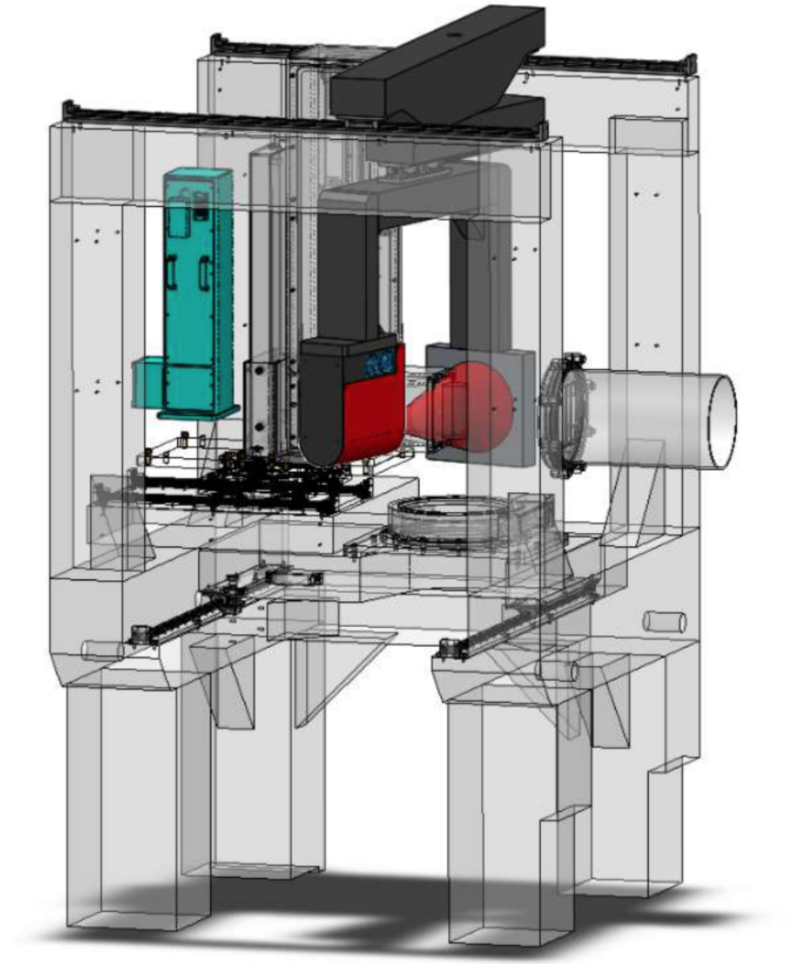
Motivations

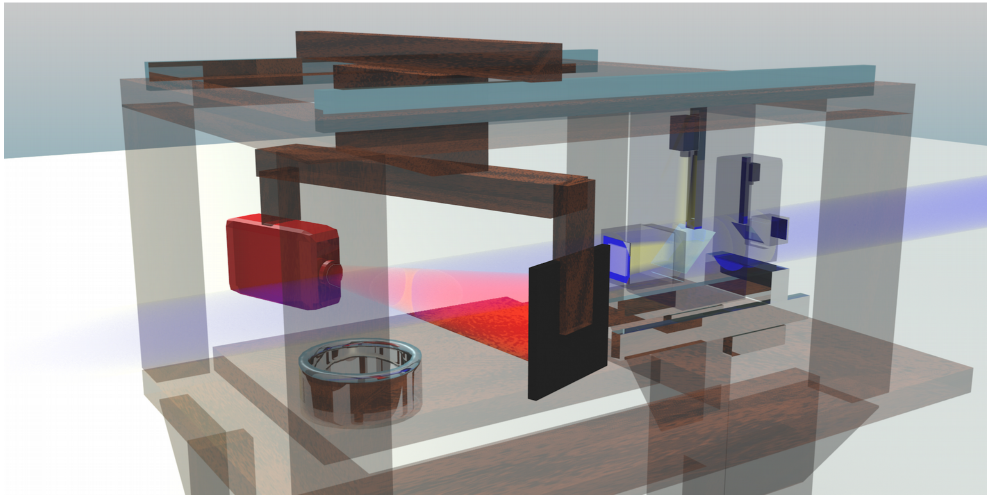
NeXT takes full advantage of this great complementarity by allowing simultaneous x-ray and neutron acquisitions during in situ/operando experiments

A few technical details

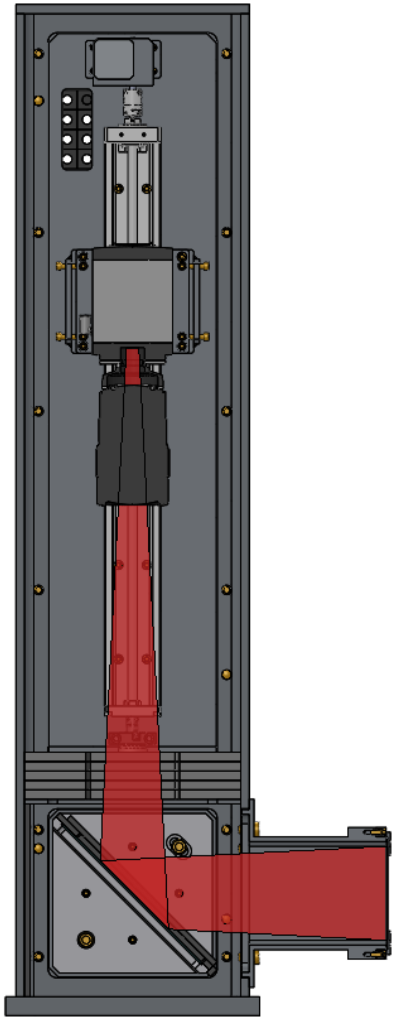


Mechanical set-up

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



A few technical details



Neutron imaging

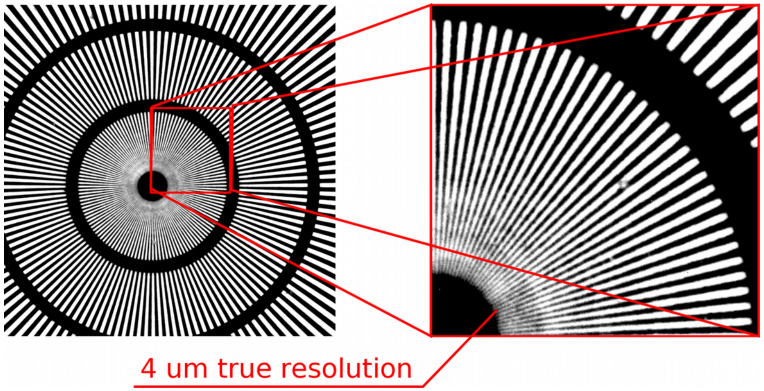
- Different optics and scintillator (LiF and Gadox)

- 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)

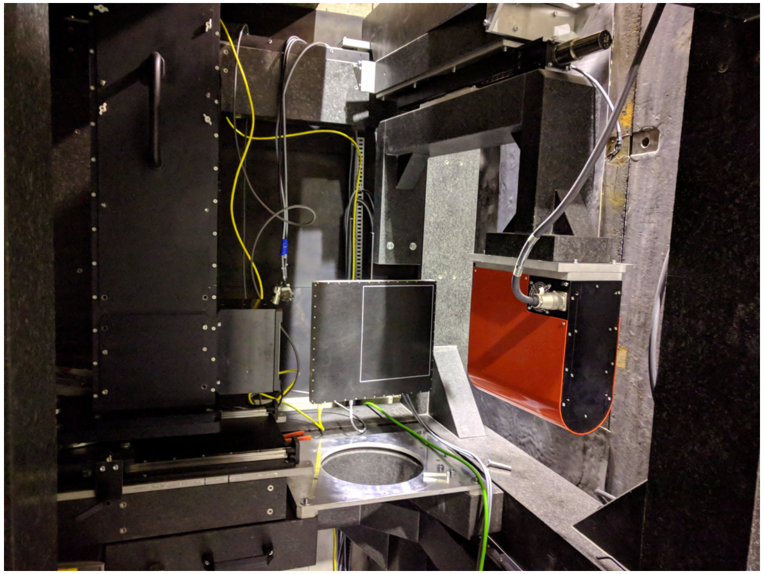
- Maximum speed of the camera: 100 Hz (sCMOS).

- Pixels (currently): 2048x2048



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 : ~ 2200x1800

Control software

- User friendly environment for control and image reconstruction

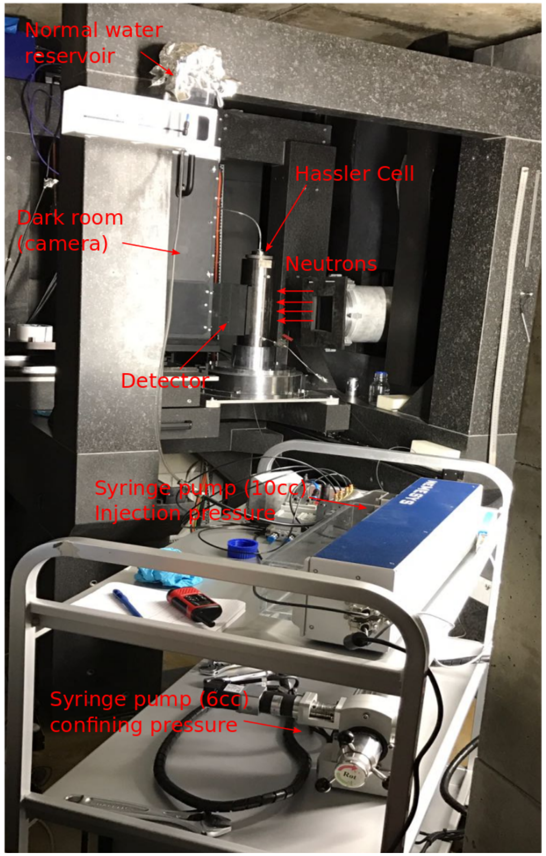
collaboration with RX-Solutions

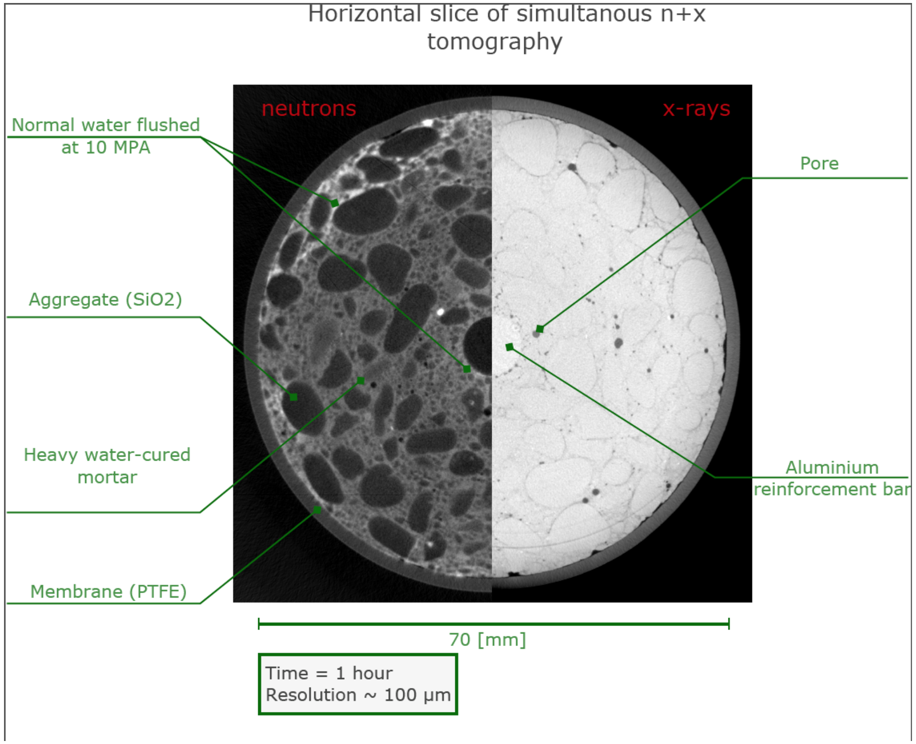
A few technical details

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)

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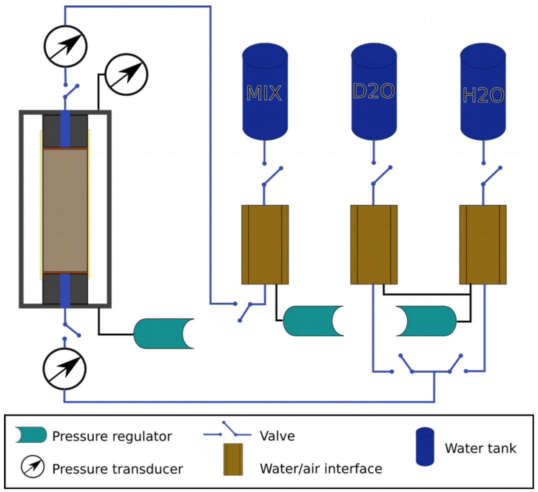
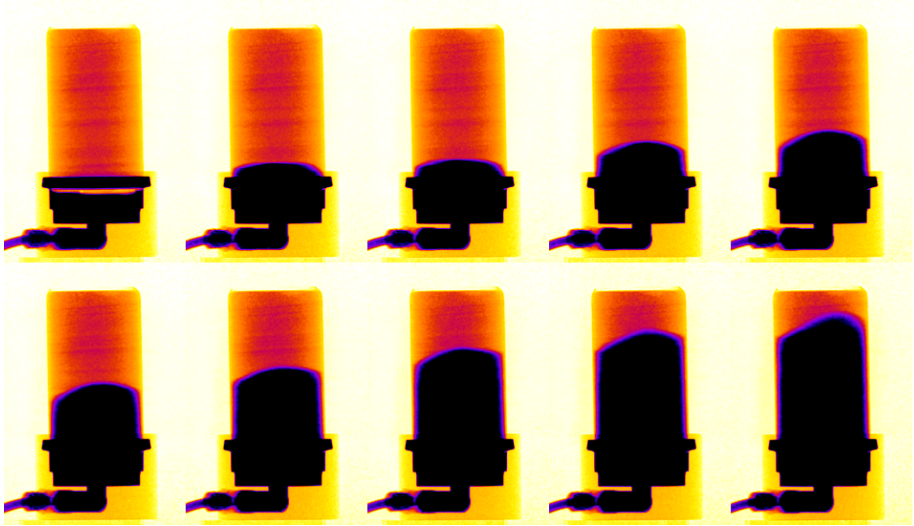
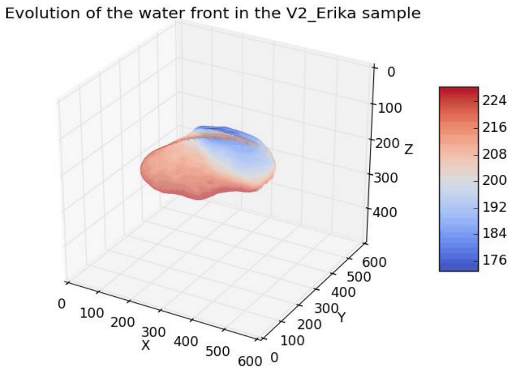
A few examples

Fluid flow in porous materials (isotope sensivity)





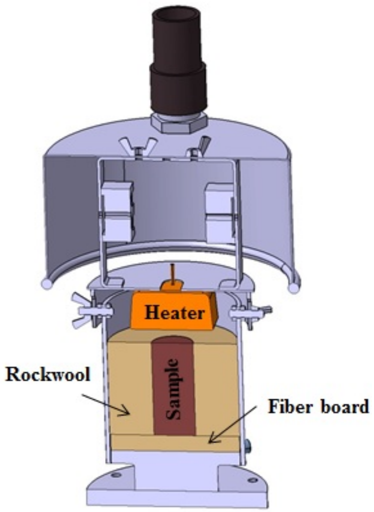


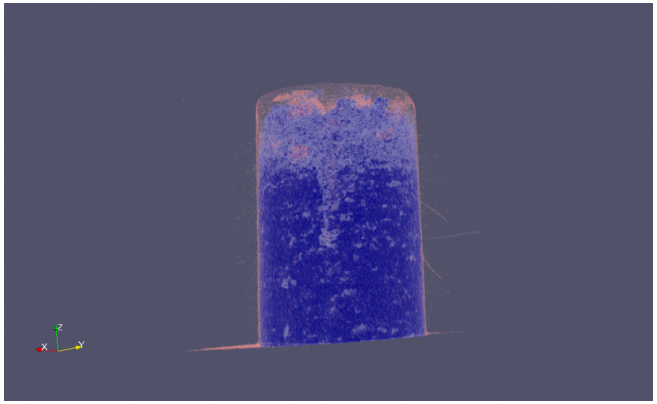
3D water front

Vosges sandstone (collaboration 3SR, Univ. Of Lund and Heriot Watt)

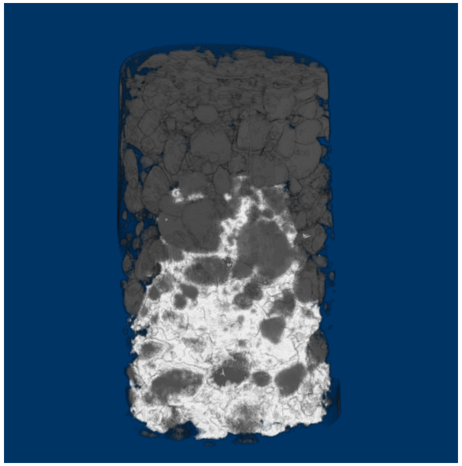
A few examples

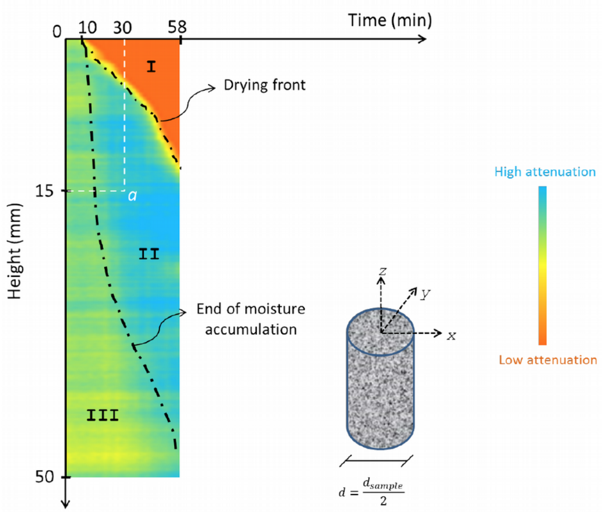
Analysis of moisture migration in concrete at high temperature





here 1min scan
(now 20 sec!)



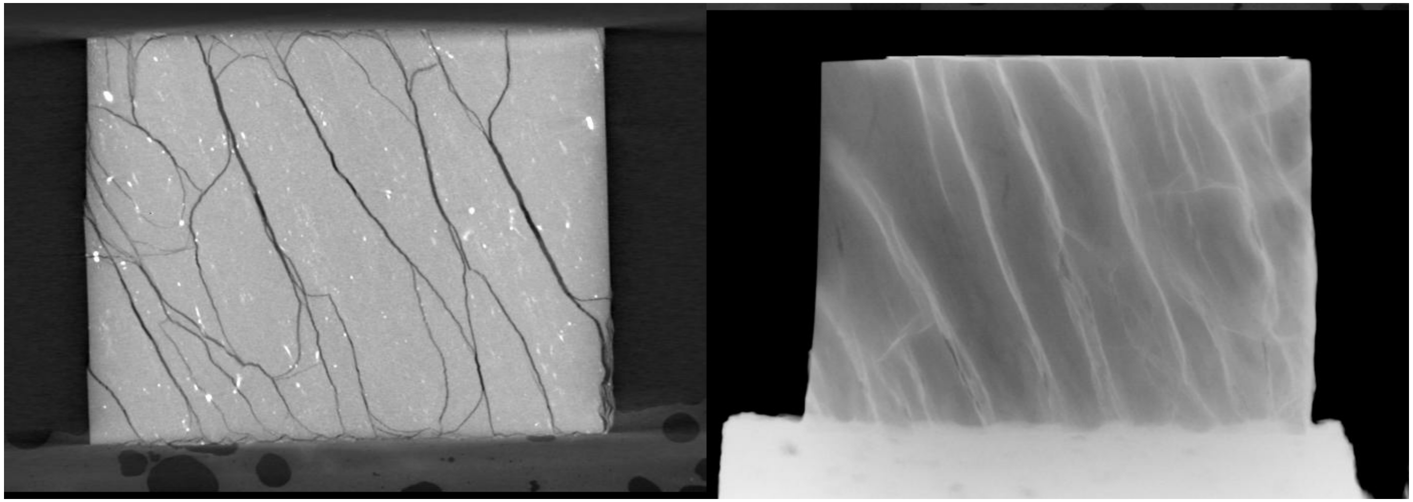


Dauti et al., Cement and Concrete research, (2018)

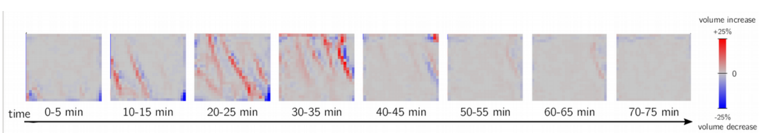
A few examples

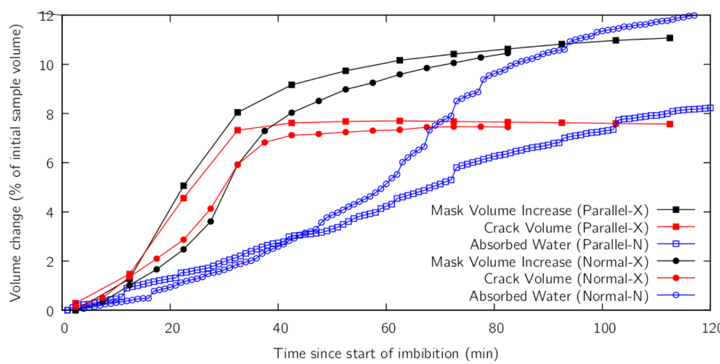
HM behaviour of shale for radioactive waste disposal

(NB : first test not under in situ conditions)



40 mm





DIC analysis

Stravopoulou et al., Acta Geotechnica, (2018)

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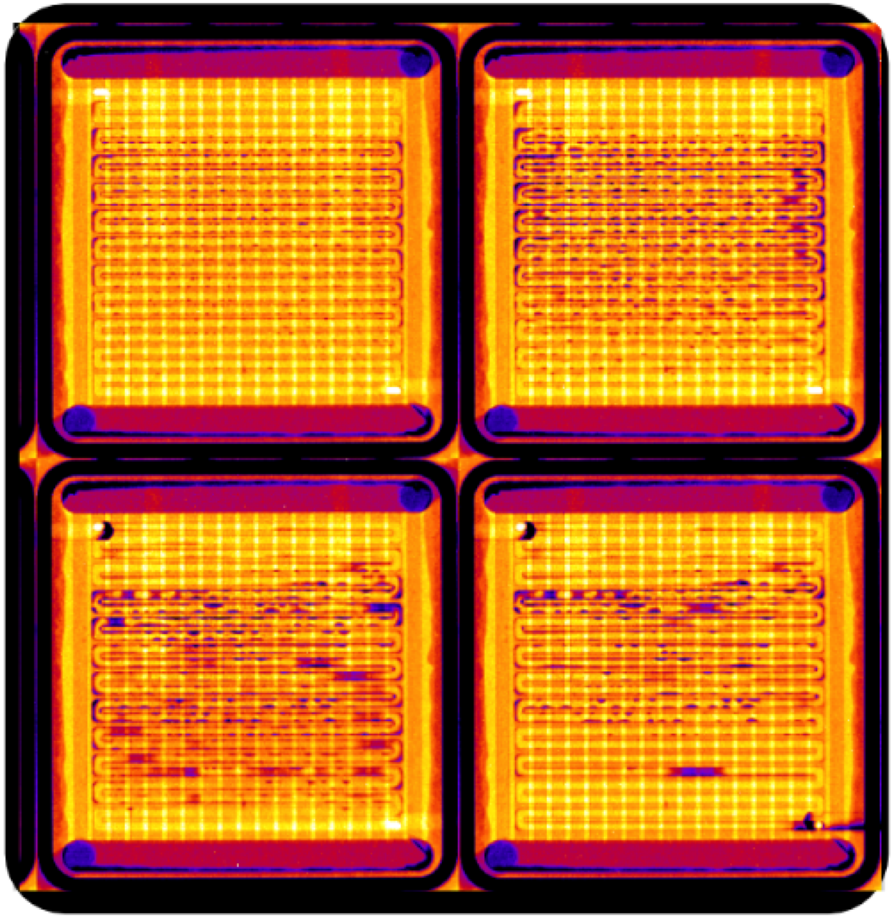
A few examples

In operando fuel cell study

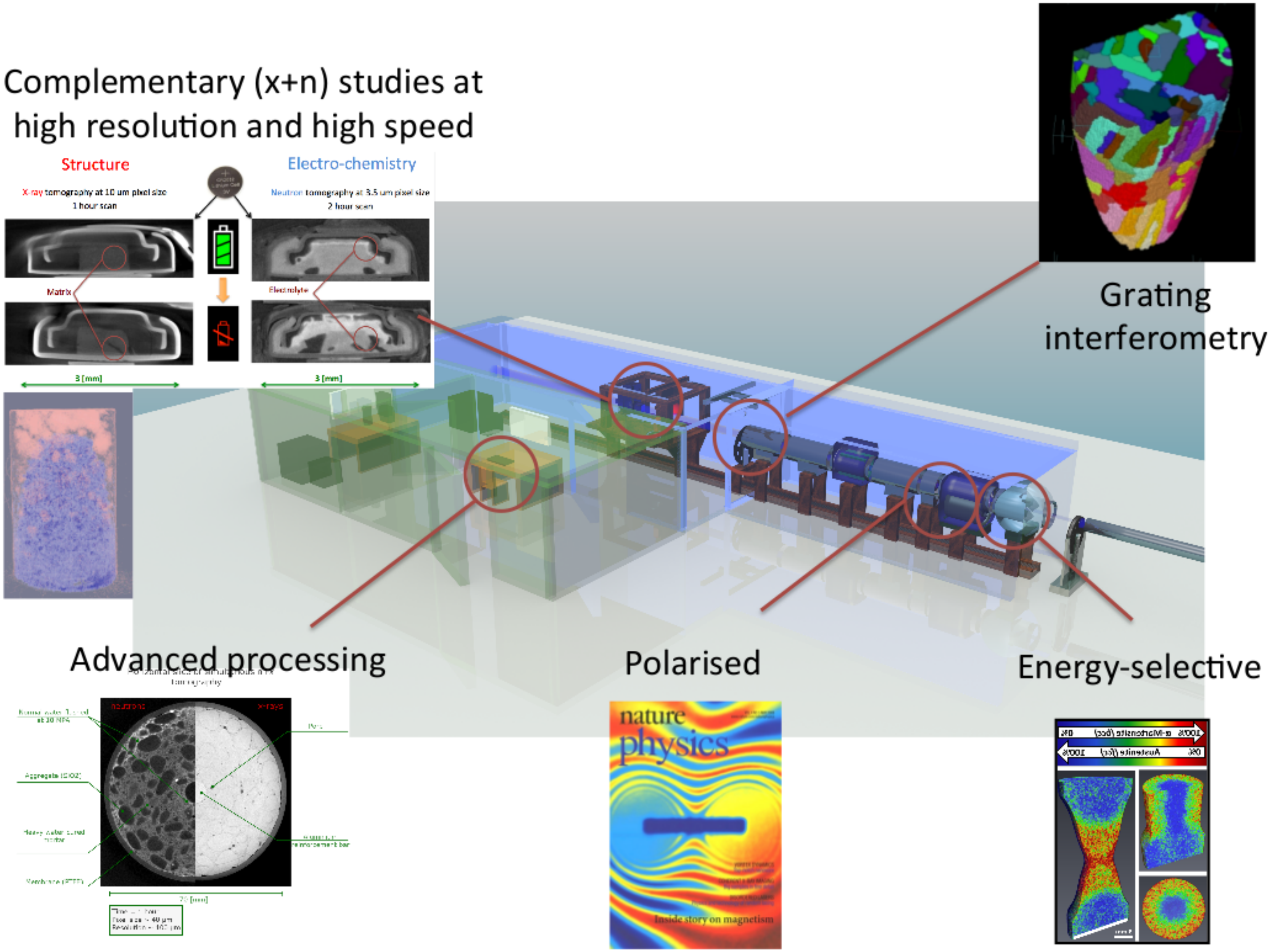


In fuel cells oxygen and hydrogen are injected to generate electricity, having water vapor as the only byproduct. Part of this vapor condenses into liquid water, depending of the testing conditions (temperature, flux).

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)



Collaboration with 3SR, ILL, and HZB

Working together

- **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.

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Contact

Any questions ?

Contact us : industry@ill.fr

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