Nieuwe onderzoeksmogelijkheden met de Delftse reactor

Jeroen Plomp, Delft

REACTOR INSTITUTE DELFT

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OYSTER

Available probes

- 2 MW pool-type research reactor
- Unique radiation available for research:
  - Neutrons
  - Positrons
  - Radio isotopes (α,β,γ)

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DIT IS EEN OVERGANG
DEZE DIA NIET VERWIJDEREN A.U.B.

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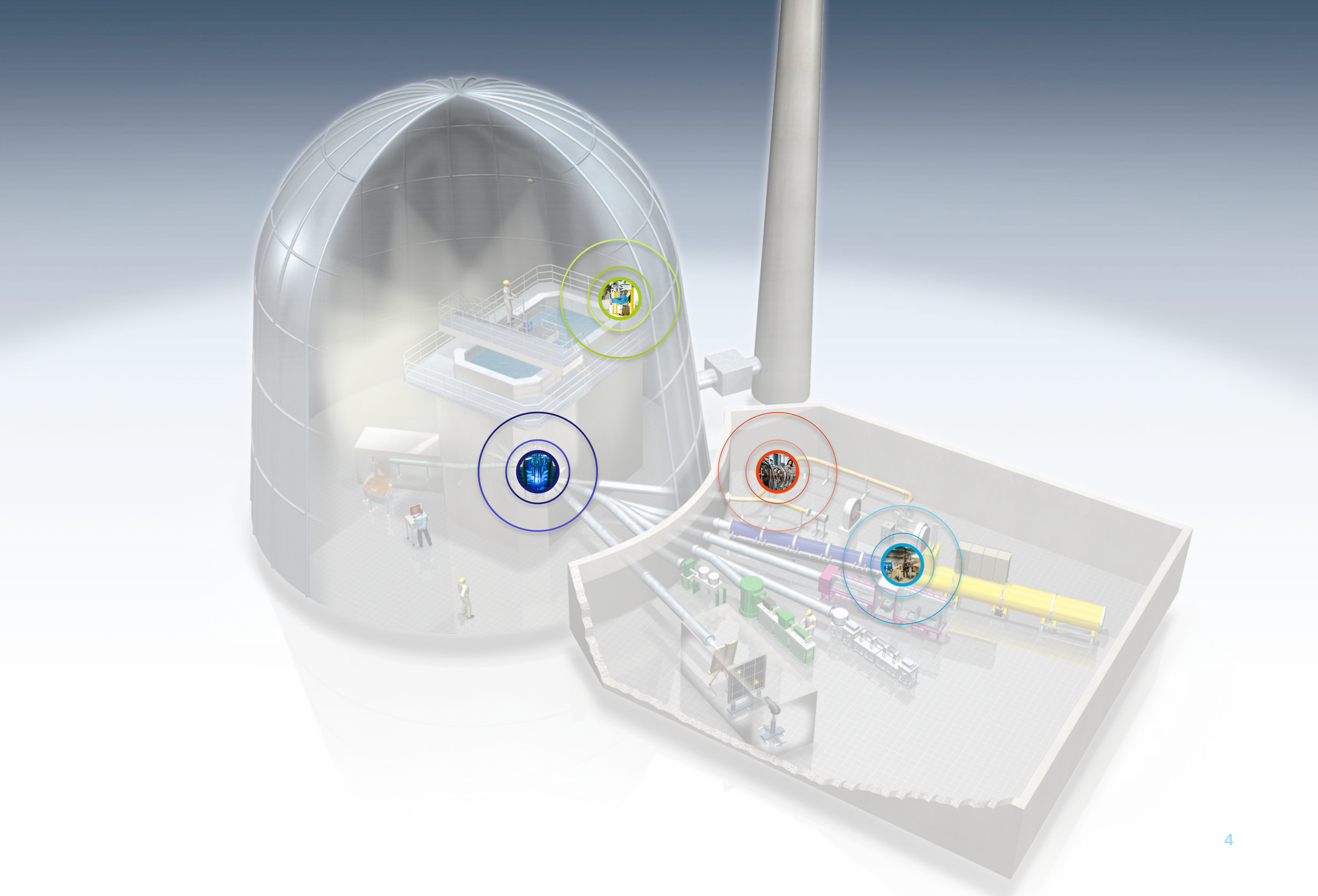

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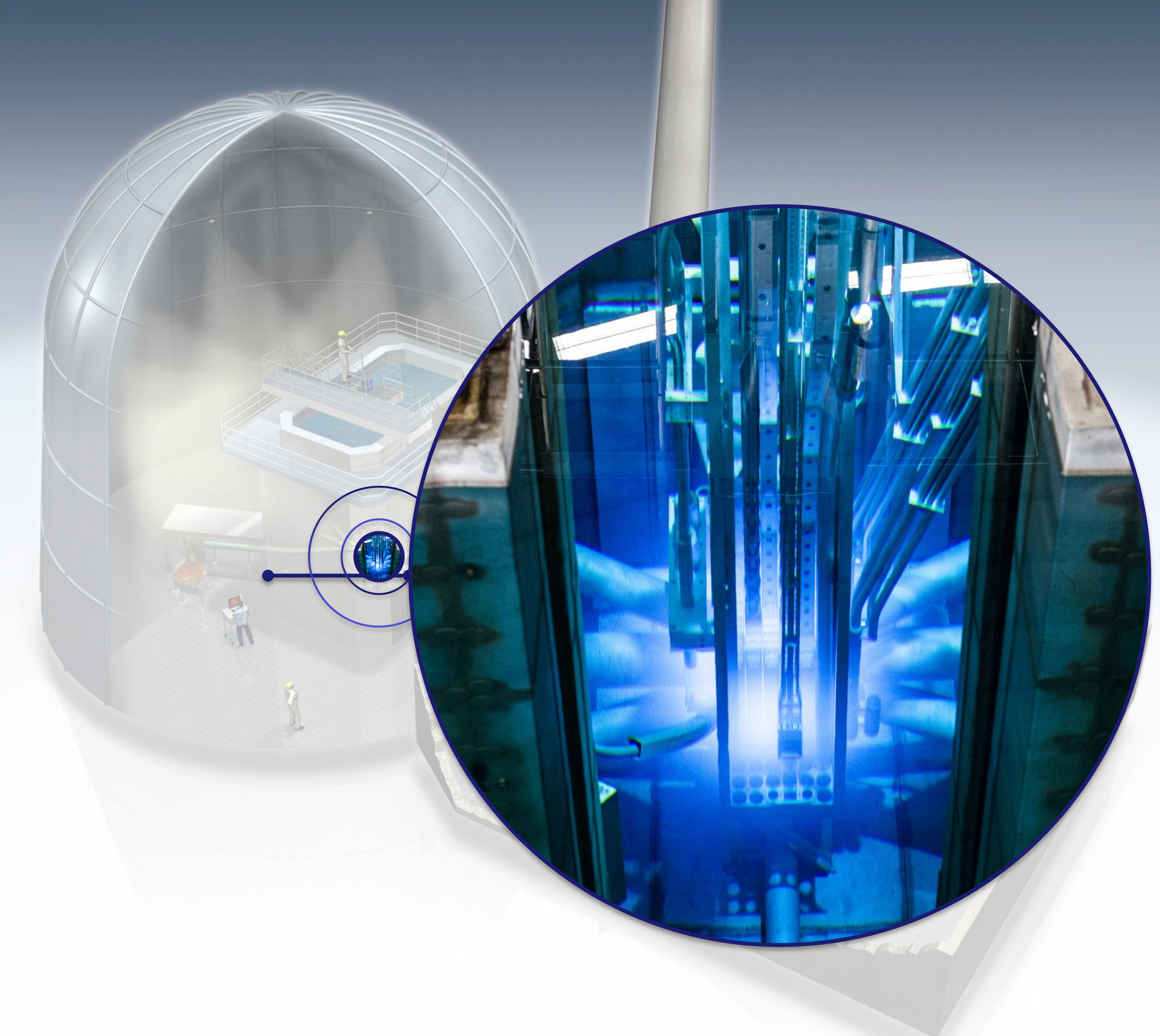

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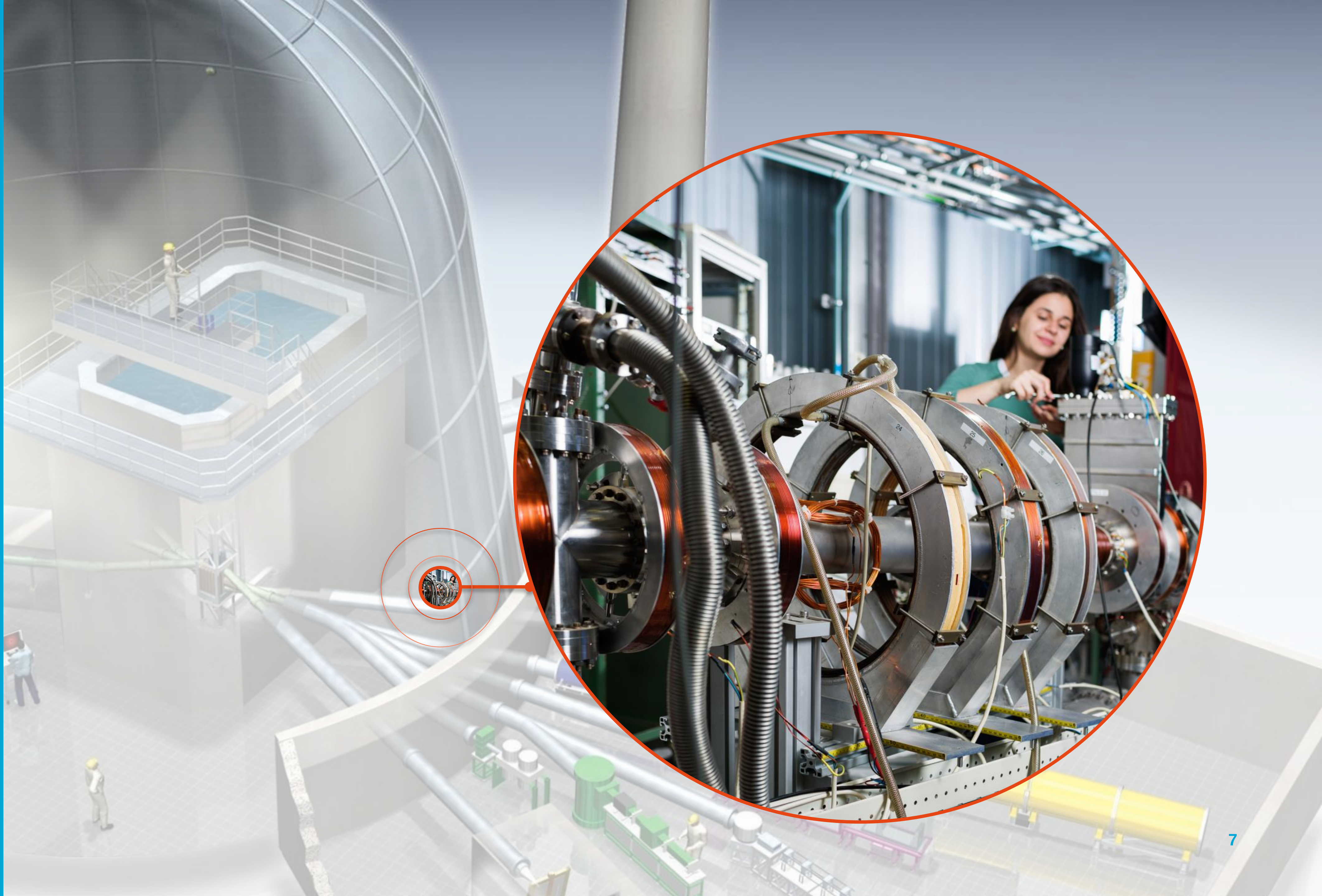

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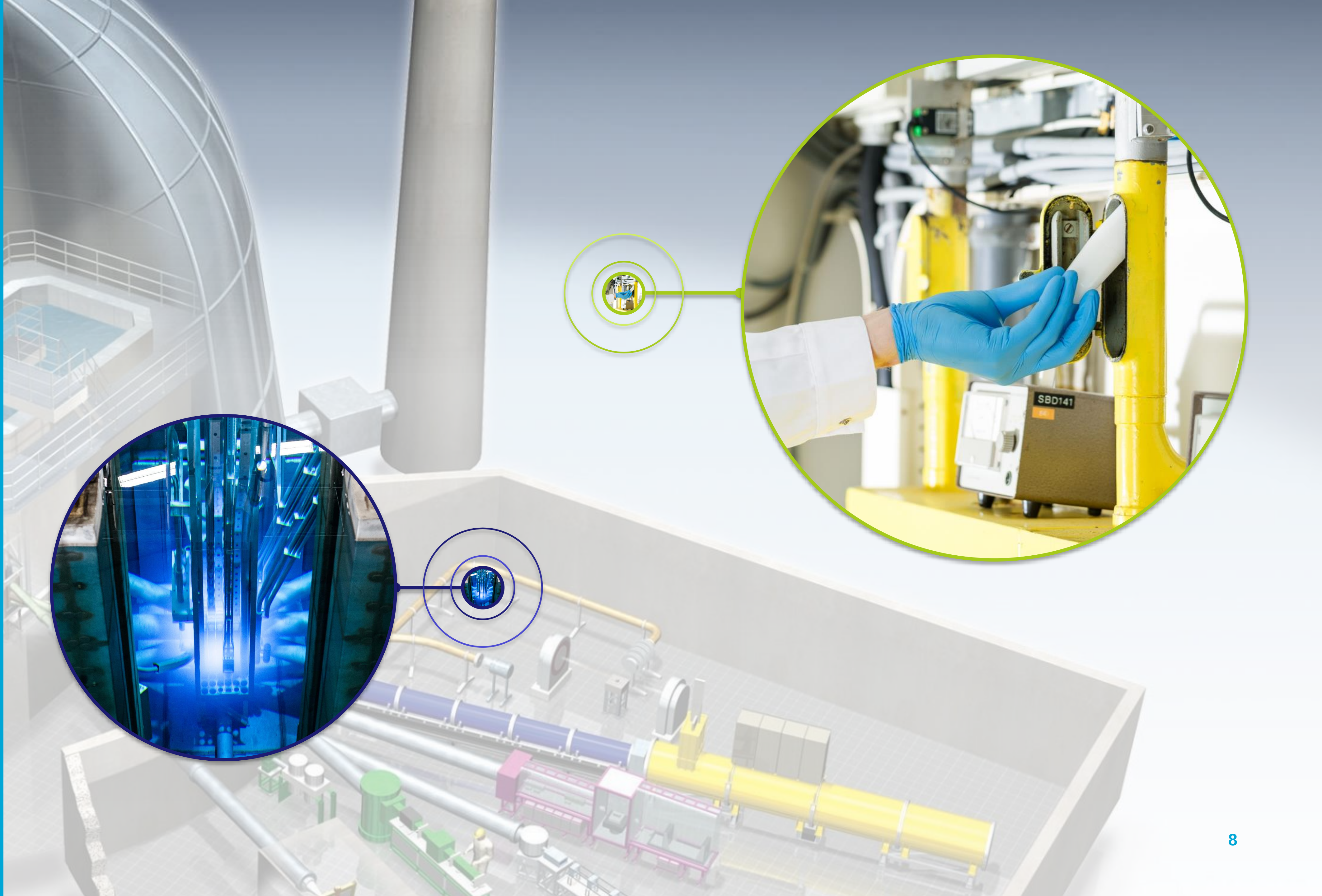

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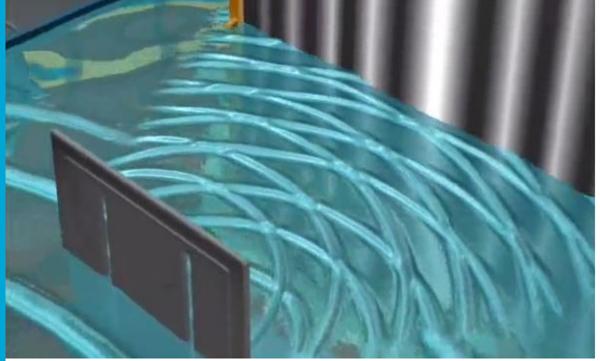


Neutron to see the invisable

- The Nobel Prize in Physics 1994 was awarded "for pioneering contributions to the development of neutron scattering techniques for studies of condensed matter" jointly with one half to Bertram N. Brockhouse "for the development of neutron spectroscopy" and with one half to Clifford G. Shull "for the development of the neutron diffraction technique"
- **How atoms/spins move and where atoms/spins are**

Bertram N. Brockhouse
The Nobel Prize in Physics 1994

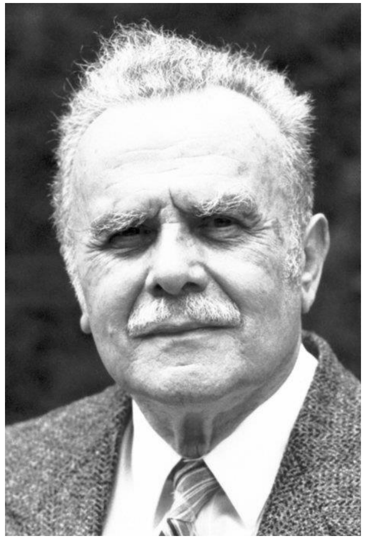
Born: 15 July 1918, Lethbridge, Alberta, Canada

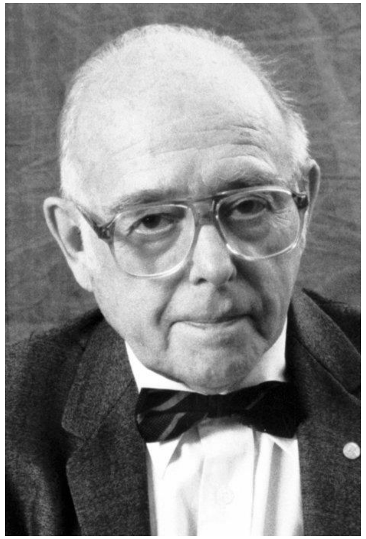
Died: 13 October 2003, Hamilton, Ontario, Canada

Affiliation at the time of the award: McMaster University, Hamilton, Ontario, Canada

Prize motivation: “for the development of neutron spectroscopy”

Prize share: 1/2





Clifford G. Shull
The Nobel Prize in Physics 1994

Born: 23 September 1915, Pittsburgh, PA, USA

Died: 31 March 2001, Medford, MA, USA

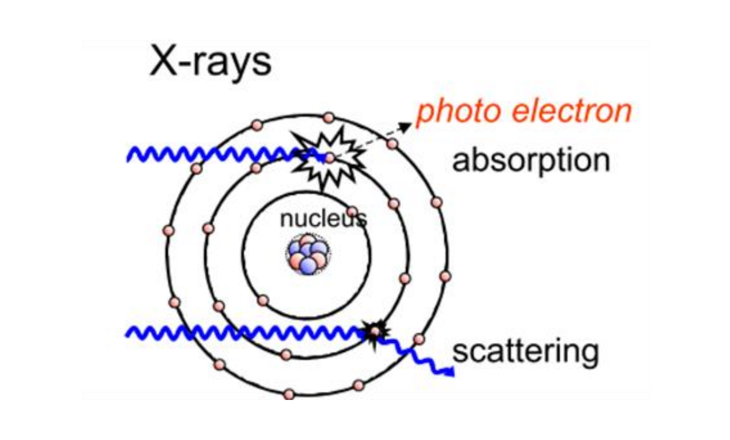
Affiliation at the time of the award: Massachusetts Institute of Technology (MIT), Cambridge, MA, USA

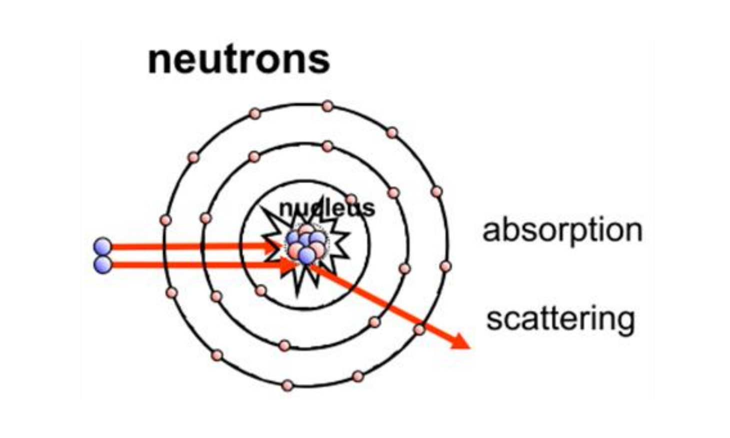
Prize motivation: “for the development of the neutron diffraction technique”

Prize share: 1/2

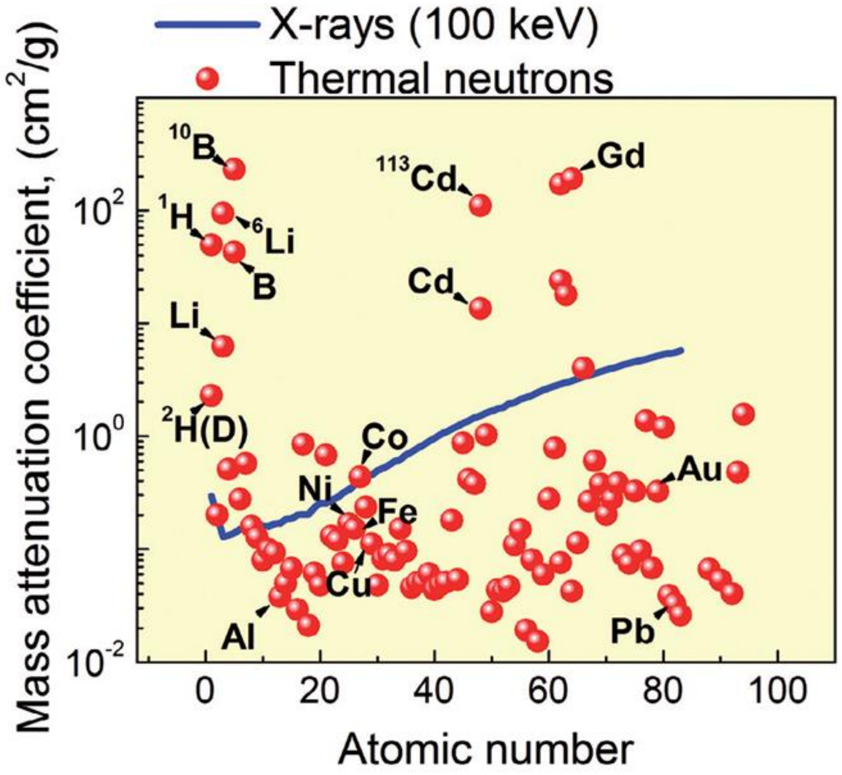
MLA style: The Nobel Prize in Physics 1994. NobelPrize.org. Nobel Prize Outreach AB 2023. Tue. 19 Sep 2023. <https://www.nobelprize.org/prizes/physics/1994/summary/>

Neutrons versus x-ray

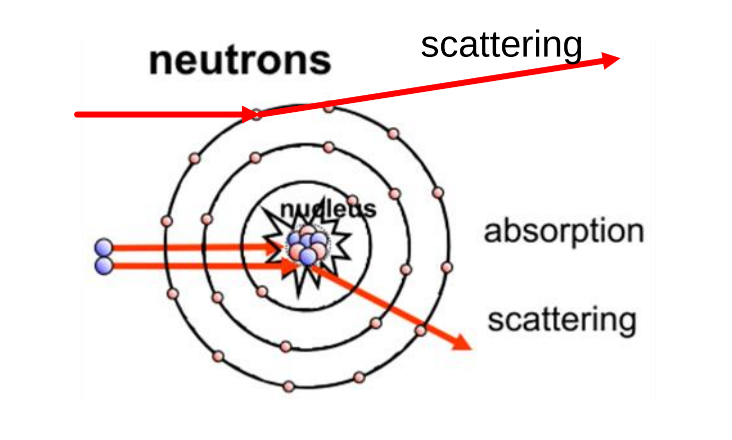




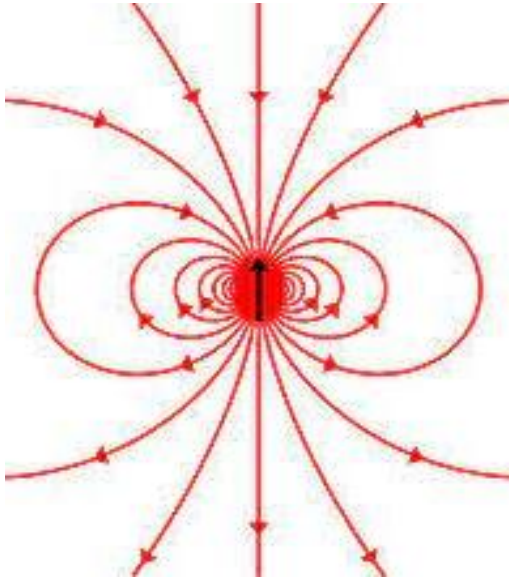
X-ray versus neutron



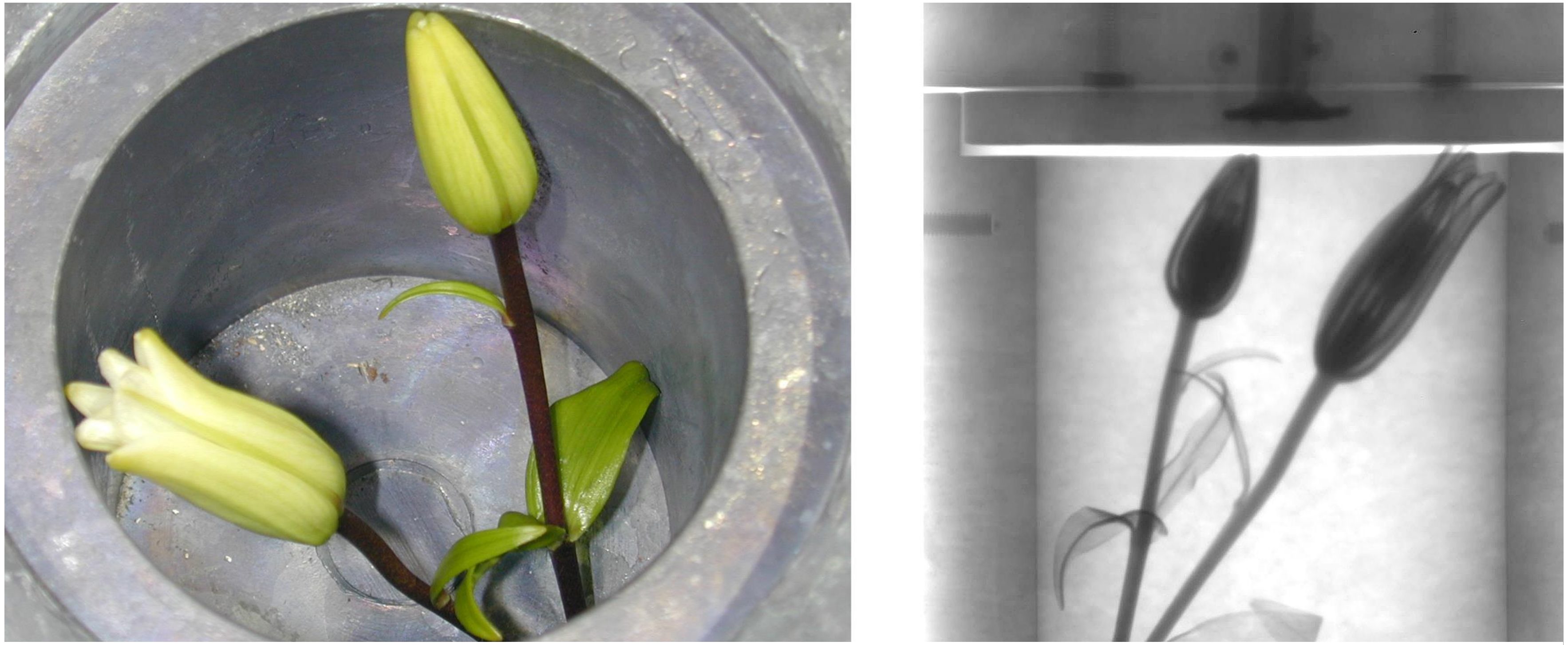
Neutrons magnetic contrast



Magnetic moment



Neutrons are remarkable probes



Hydrogen from flowers clearly visible in lead “shielding”

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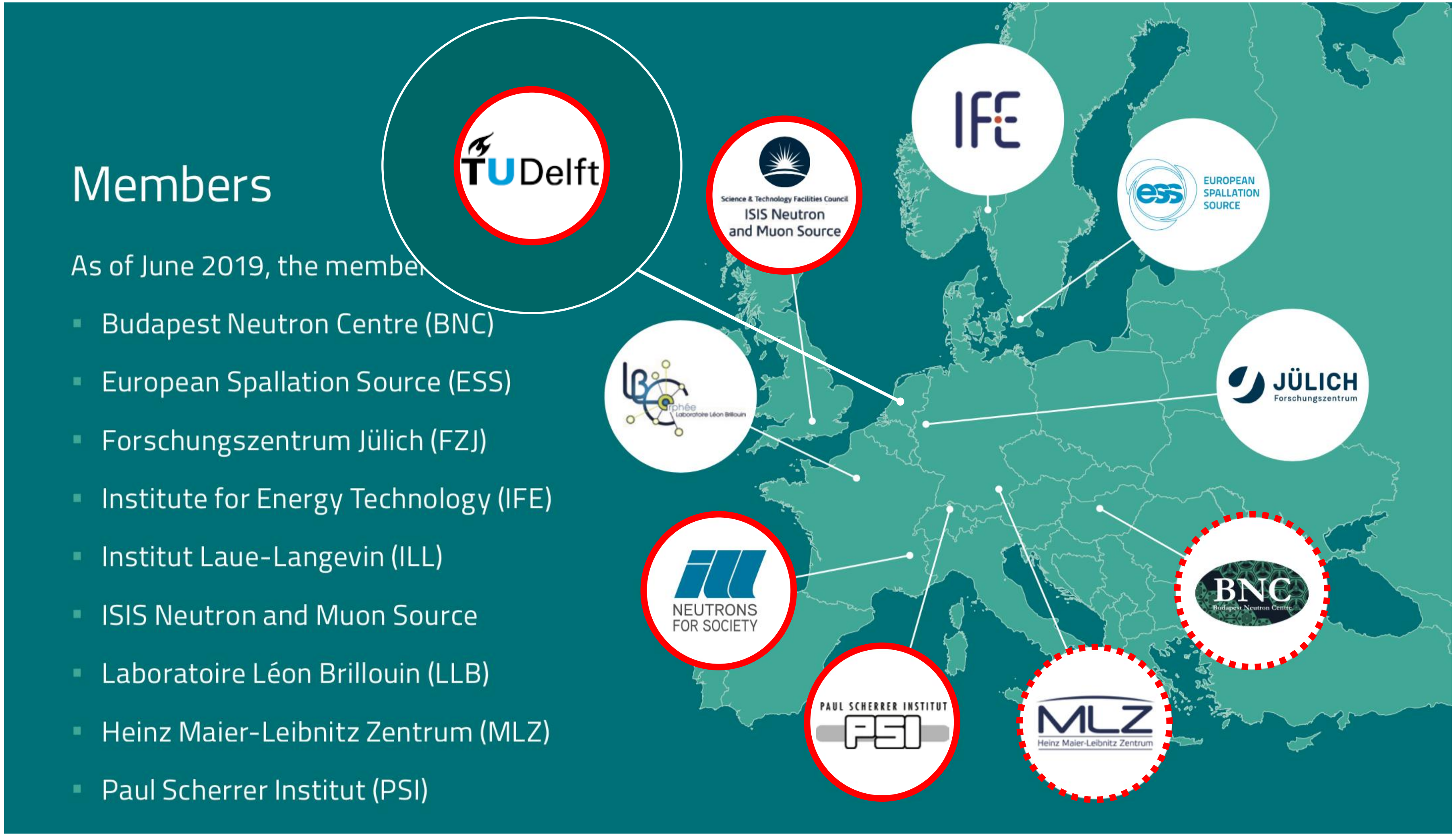
User facilities in Europe



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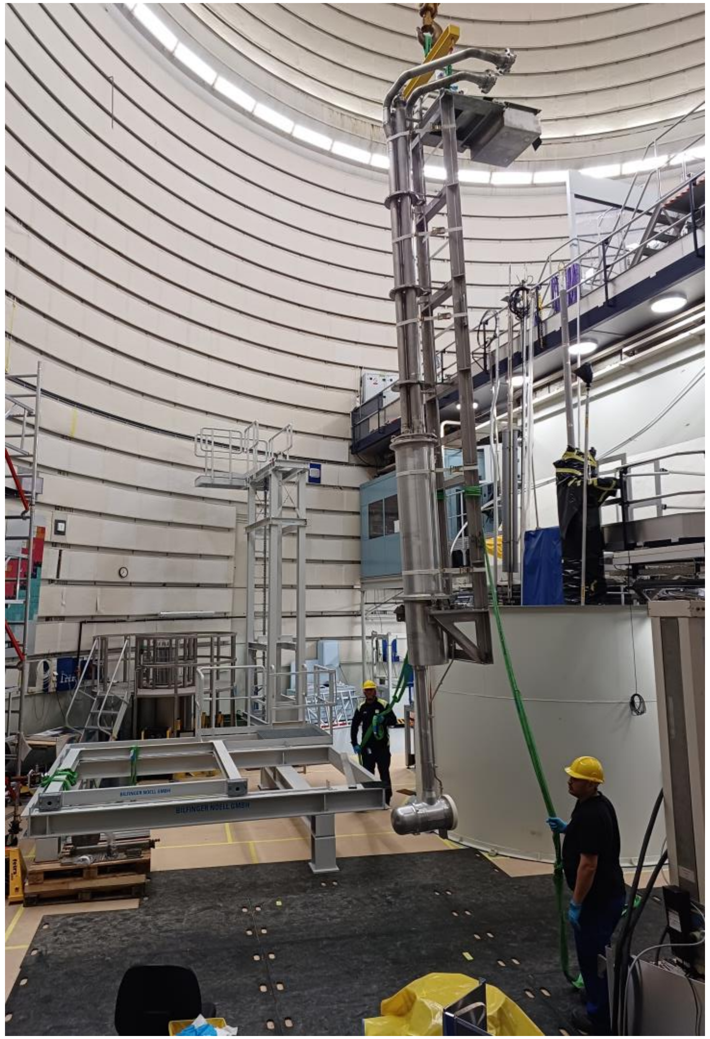
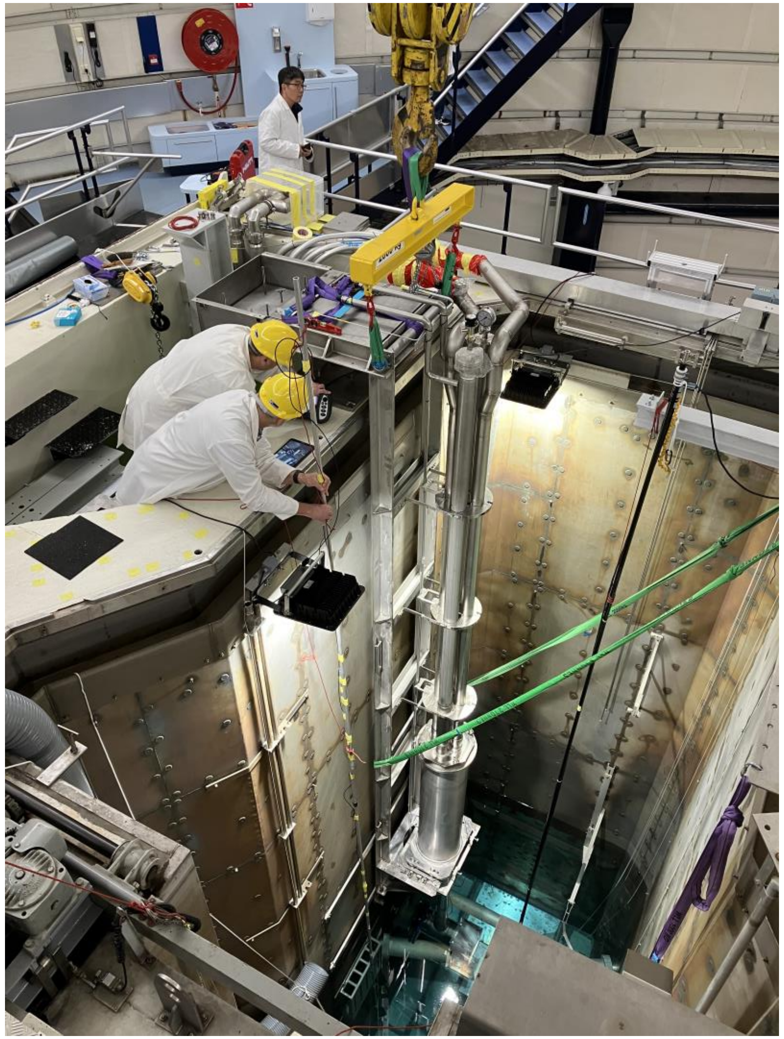
What type of field neutron users

Neutron:

- Battery materials
- Magnetism
- Colloid science
- Food science
- Polymers science
- Drug delivery systems
- Cultural heritage
- Fundamental physics
- Hydrogen economy
- CO2 storage
- Etc.

Delft game changer, cold source project





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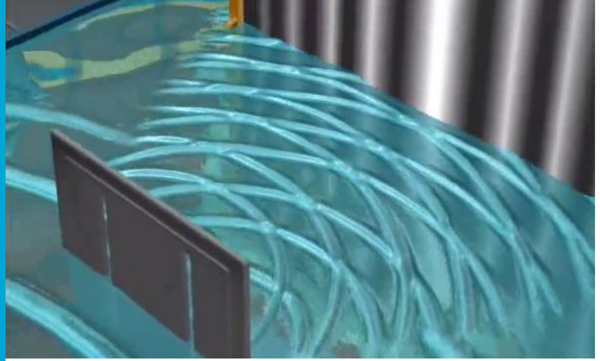

Neutron: length scale to analyse

Structure analysis length-scale:

Physics and Chemistry					Engineering		
Diffraction	Reflection	Small Angle Scattering			Radiography / Tomography		
Atoms	Layered structure	Colloids	Aggregates	Cell	Texture	Art	Engine

10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} [m]

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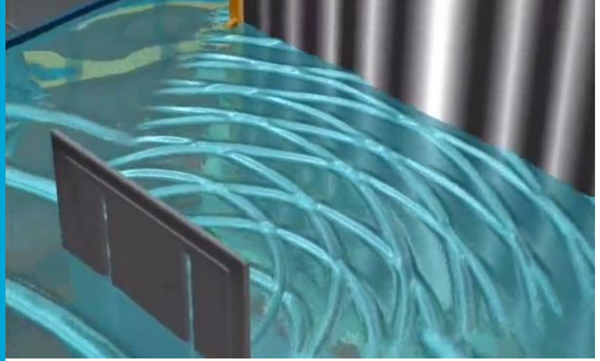
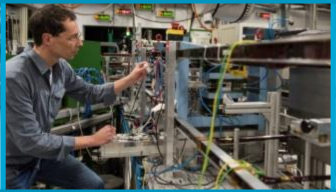
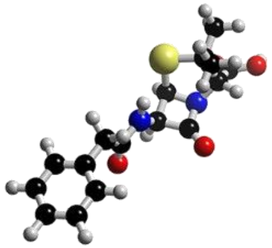
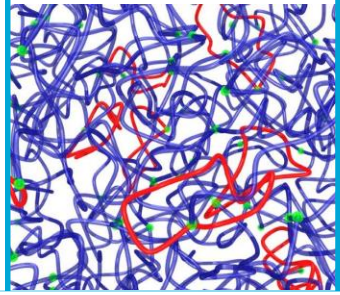
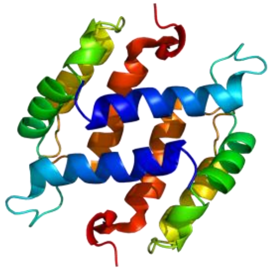
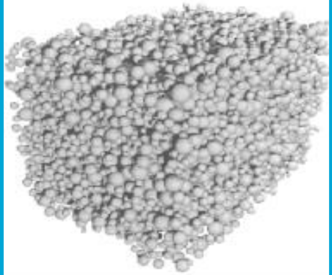
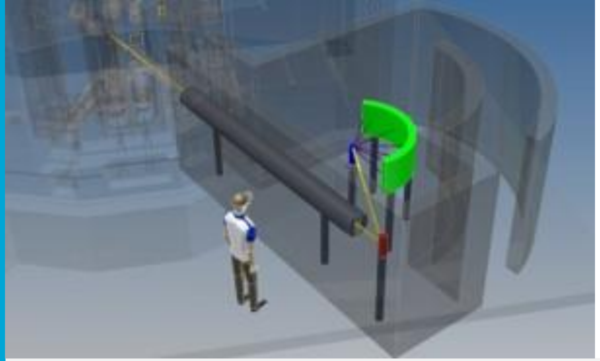
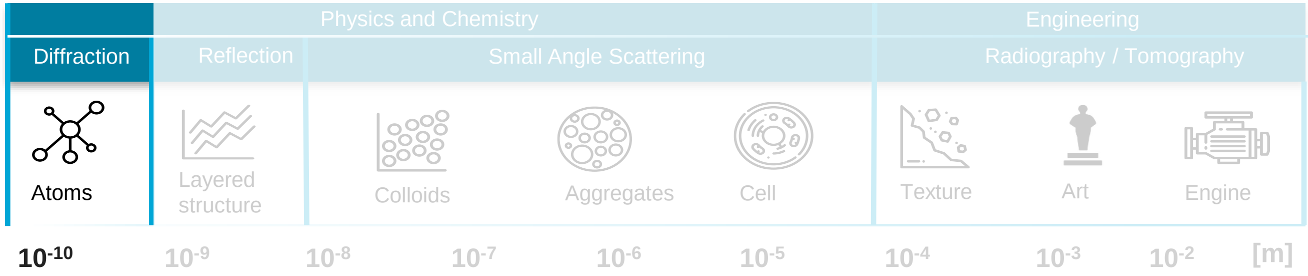


Instruments in Delft

Instruments for material research

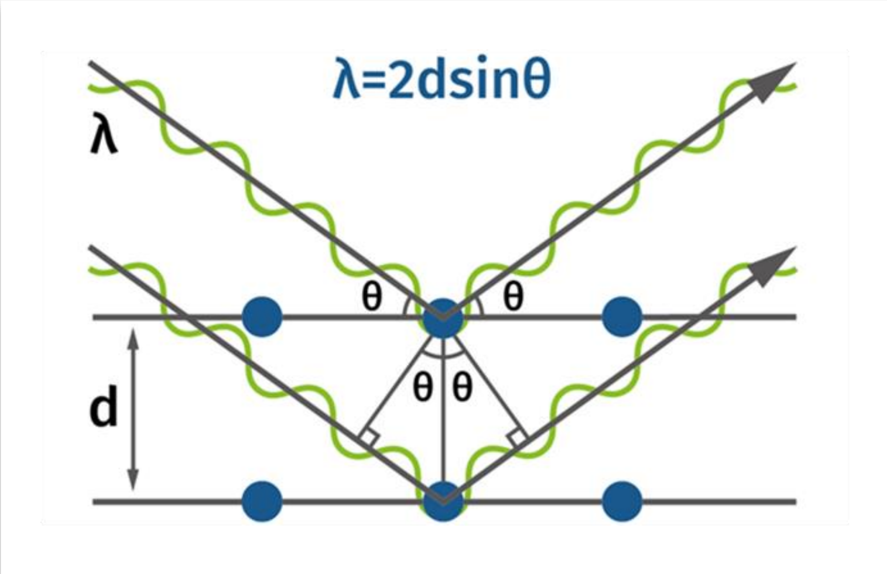
PEARL	ROG	SANS	SESANS	FISH
				
1 nm	100 nm	100 nm	10 µm	10 cm
Molecules	Polymers	Proteins	Colloids	Objects
				 

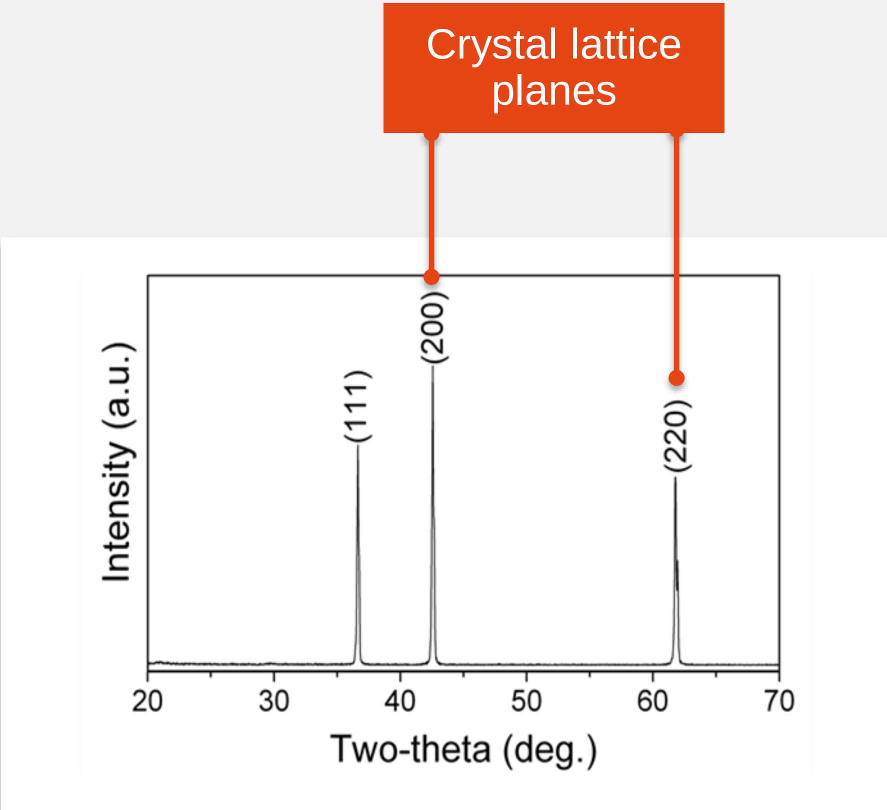




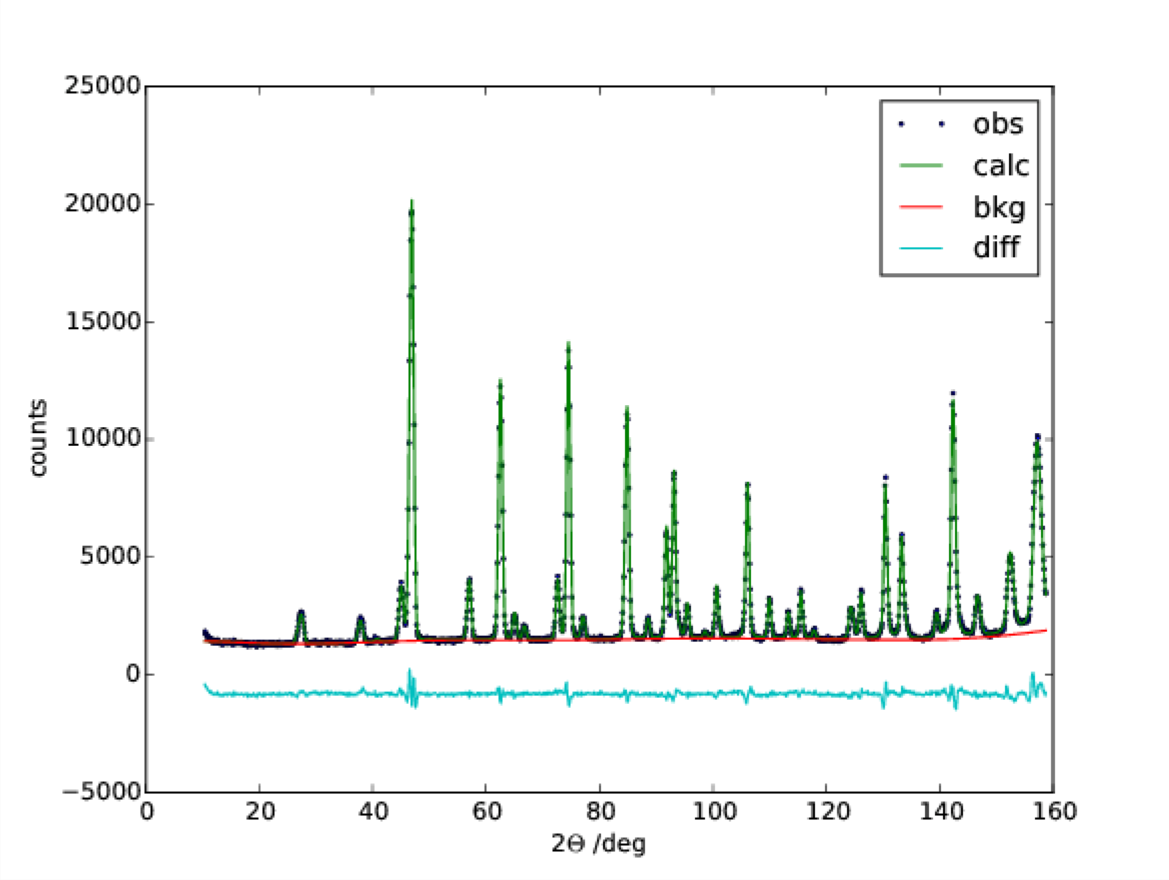
Neutron diffraction

Structure analysis length-scale 0.1 nm to 1 nm
Neutron powder diffraction, bulk





Powder diffraction, Pearl



The PEARL calibration data for the 1.67AA (533) setting at room temperature. This data was measured for 1 hour on 1.22gr of NIST sapphire.

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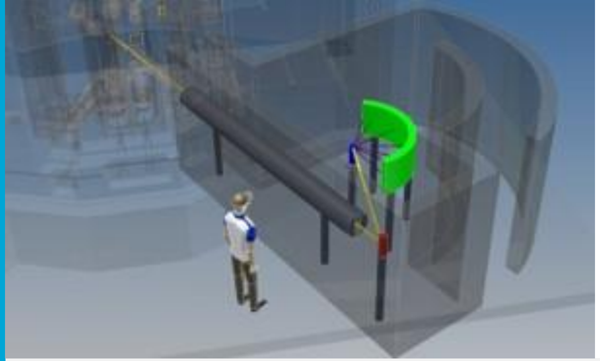
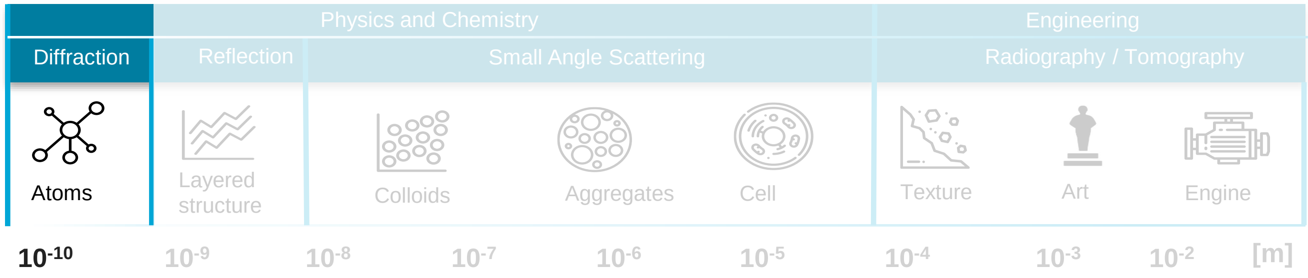
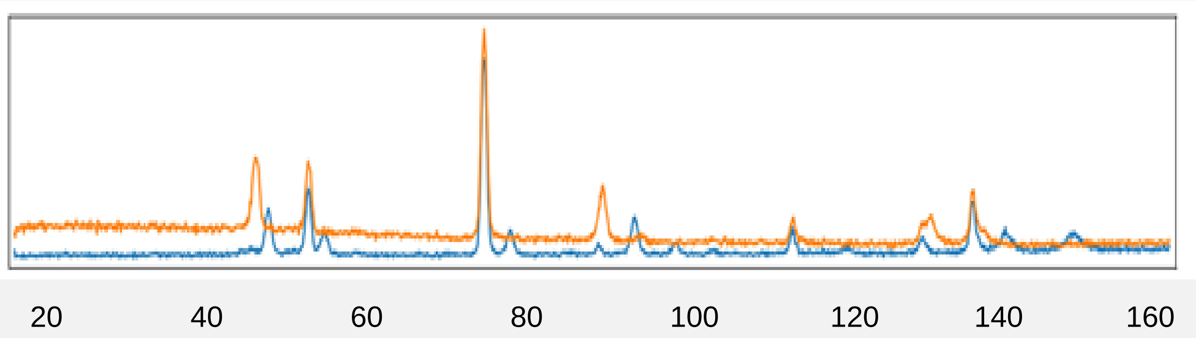




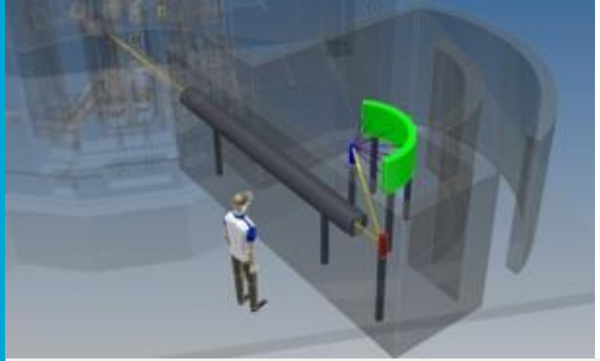
Neutron diffraction

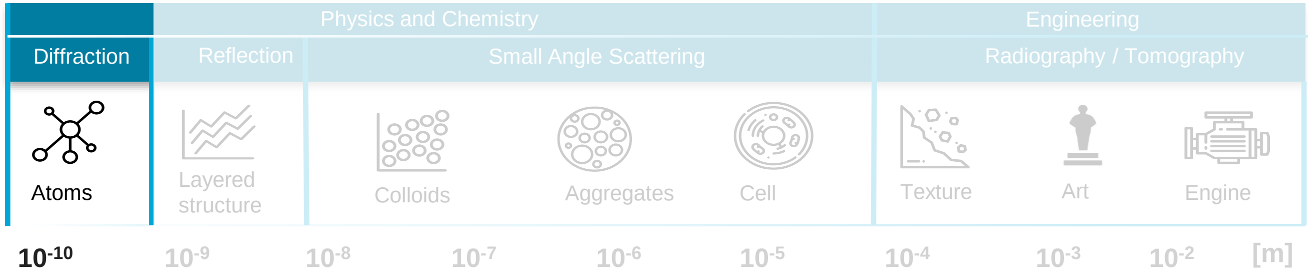
Structure analysis length-scale
0.1 nm to 1 nm

Neutron powder diffraction, bulk



Palladium

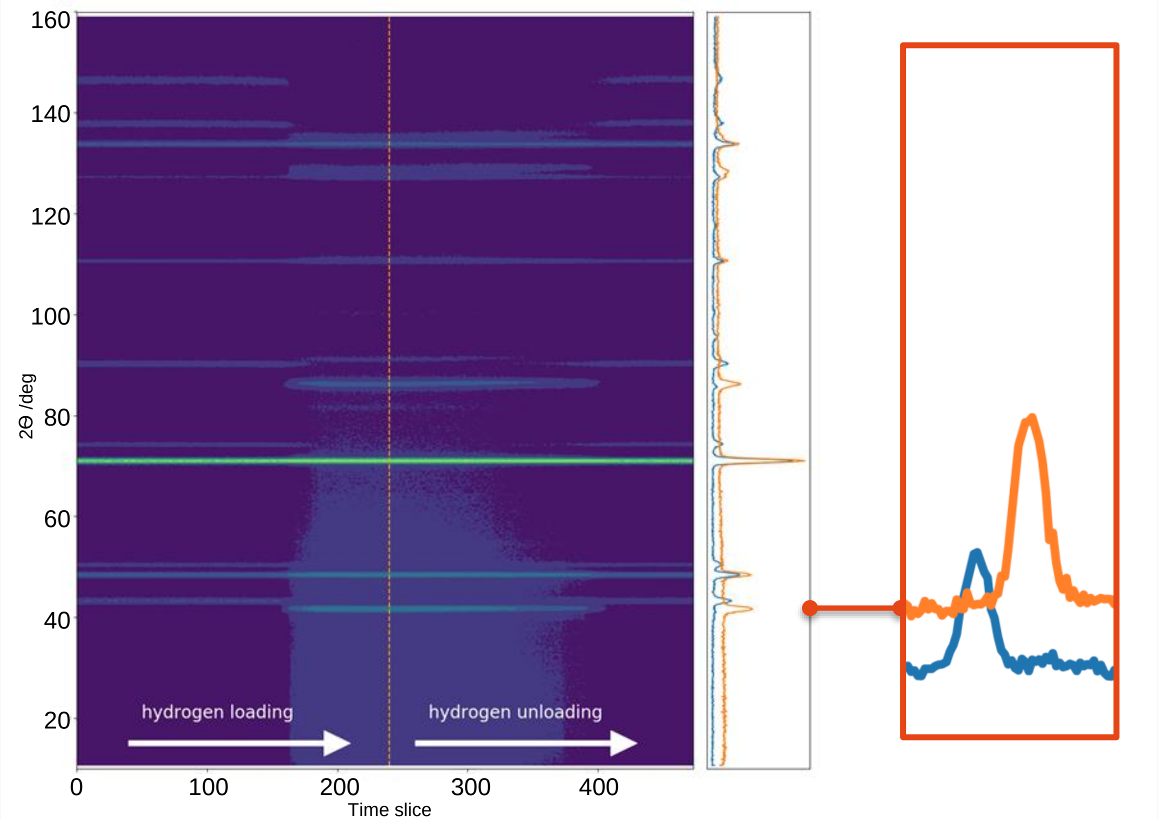




Neutron diffraction

In situ of loading and unloading of Hydrogen

Palladium



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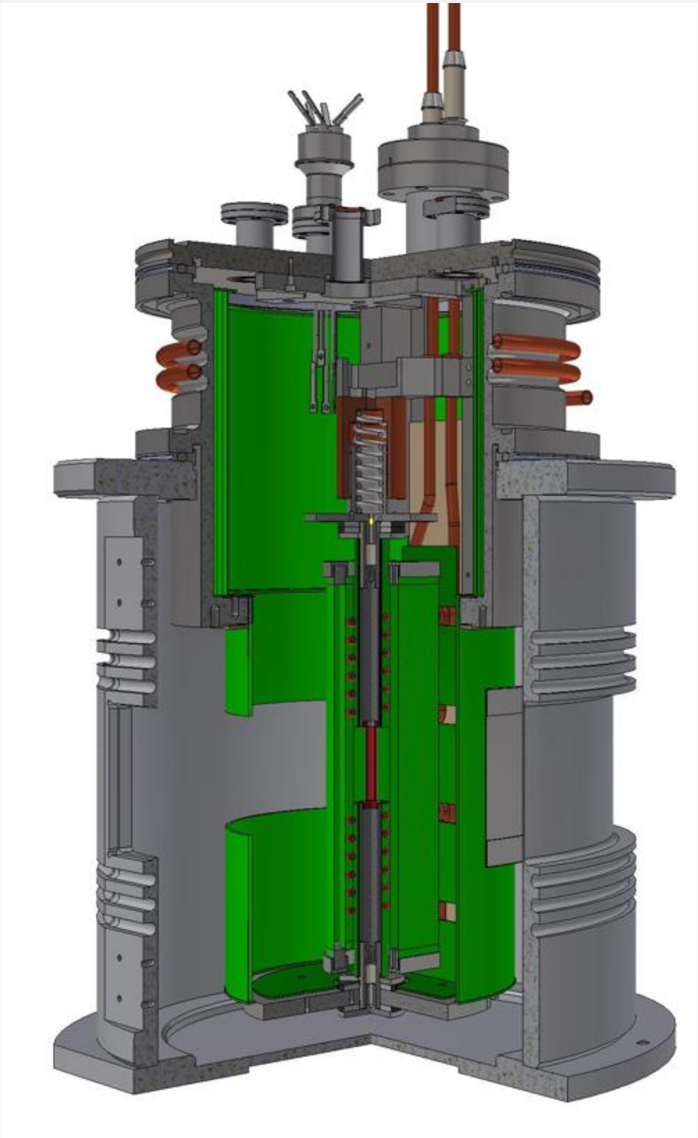
Powder diffraction, Pearl

- Induction based heating
- Standard operating range RT-1200
- Max 1800 degrees °C
- Used to study molten salts & uranium samples



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Neutron reflectometry

Structure analysis length-scale 5 nm to 150 nm
Neutron reflection, surface, layers

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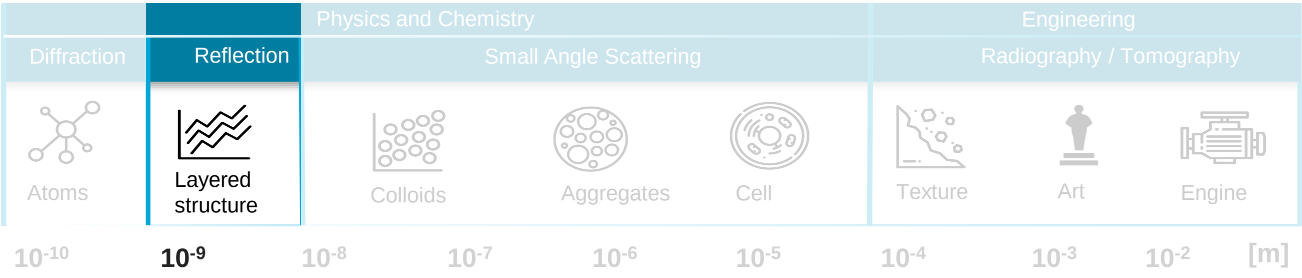
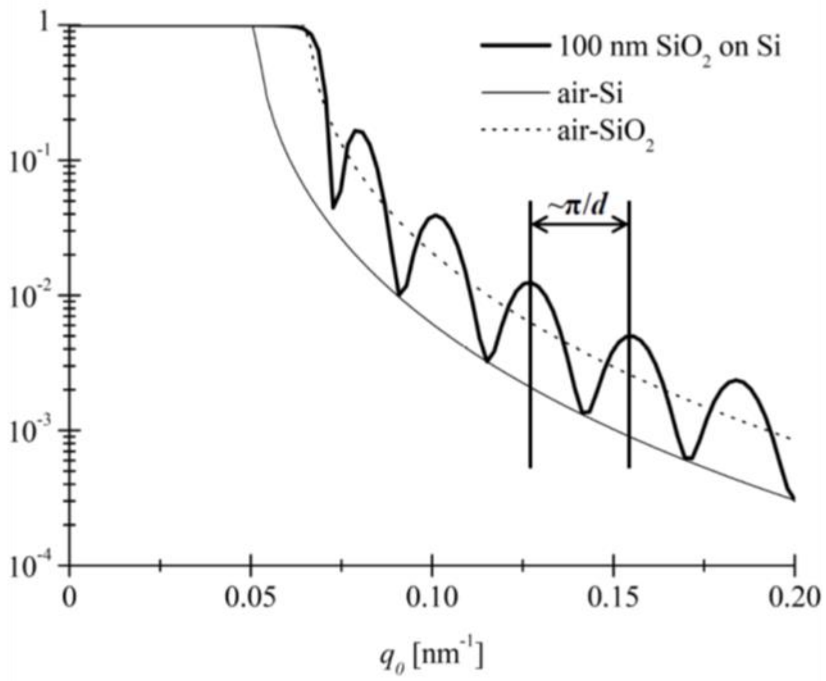


Neutron reflectometry

Structure analysis length-scale 1 nm to 200 nm
Neutron reflection, surface, layers



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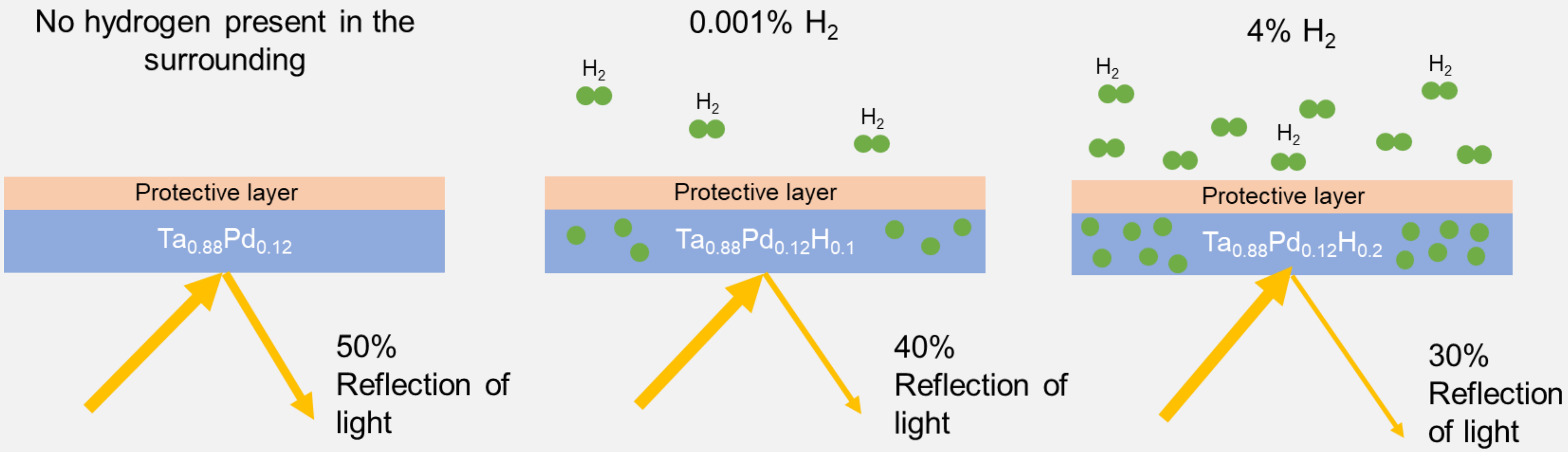
Neutron reflectometry

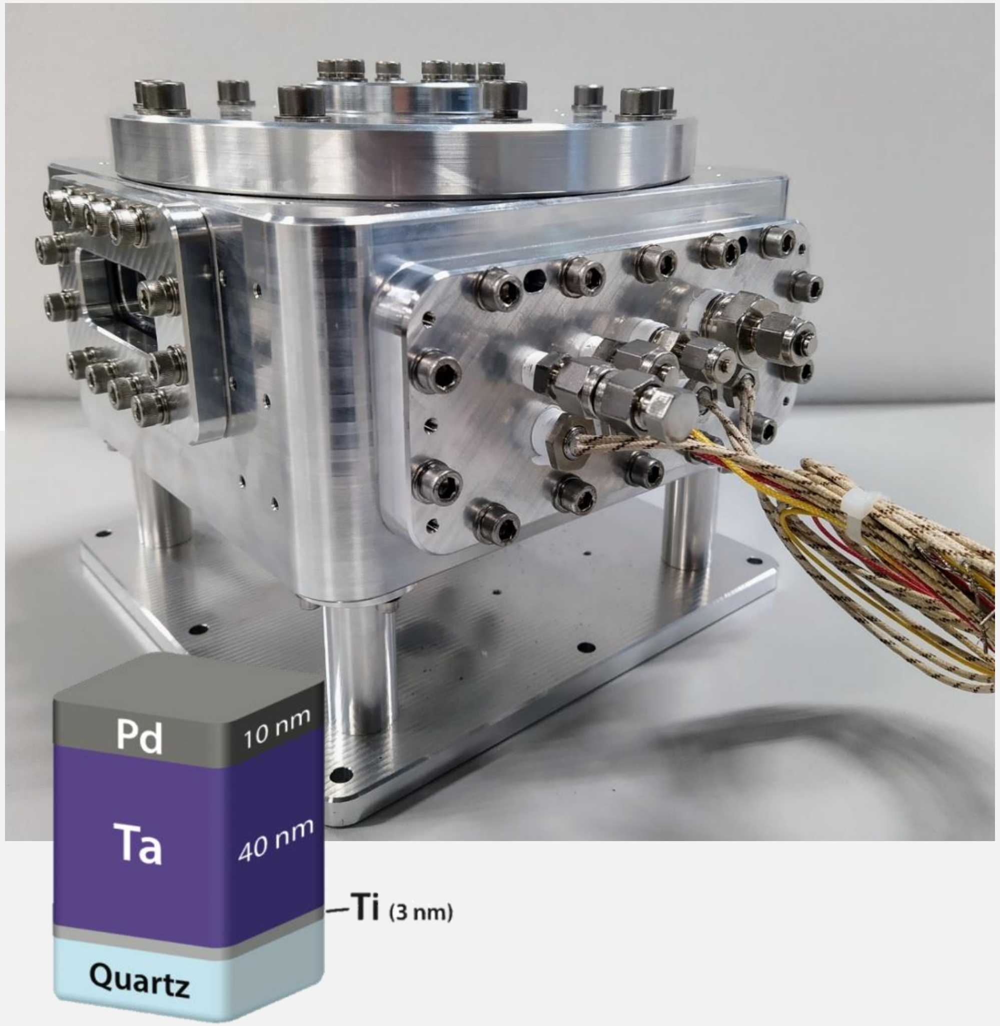
Example: Hydrogen sensing materials

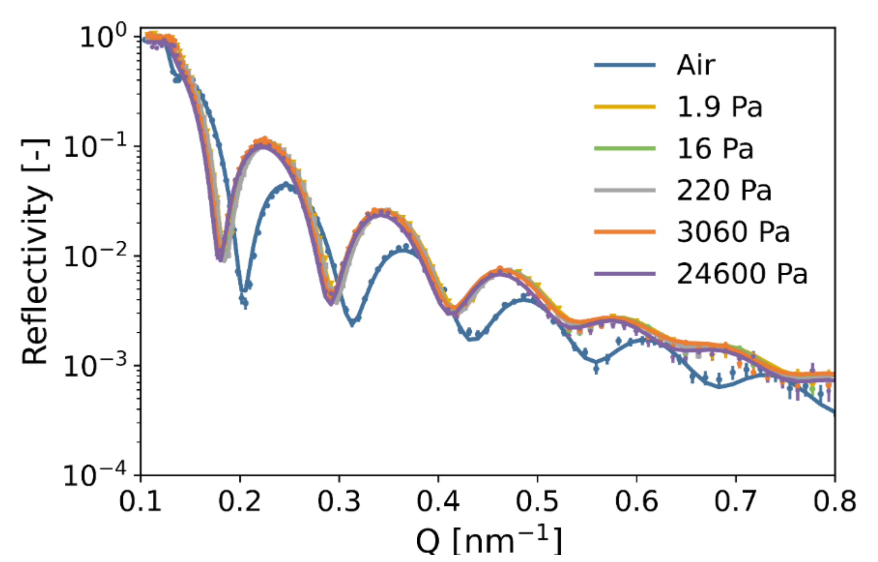


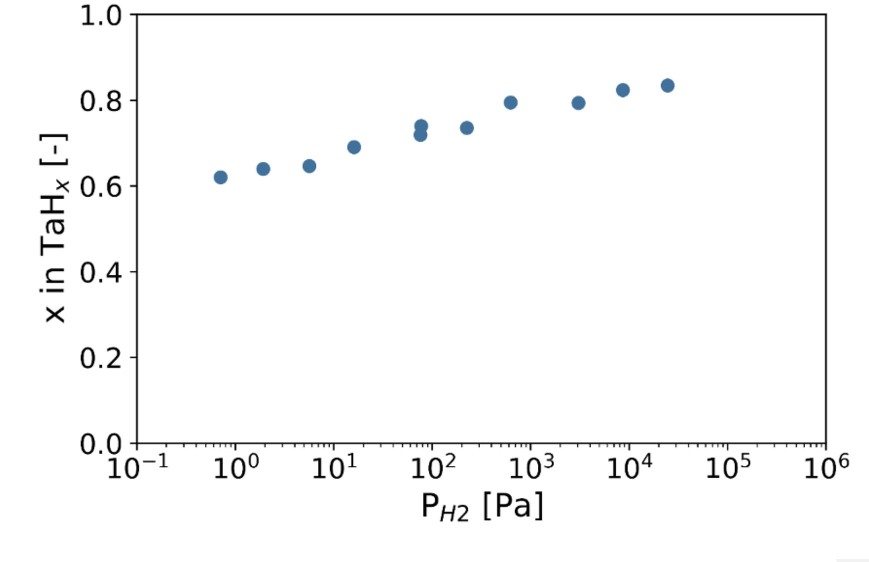
→ Key to understanding the thermodynamics and sensor response is to know the hydrogen concentration in the sensing layer

Neutron reflectometry

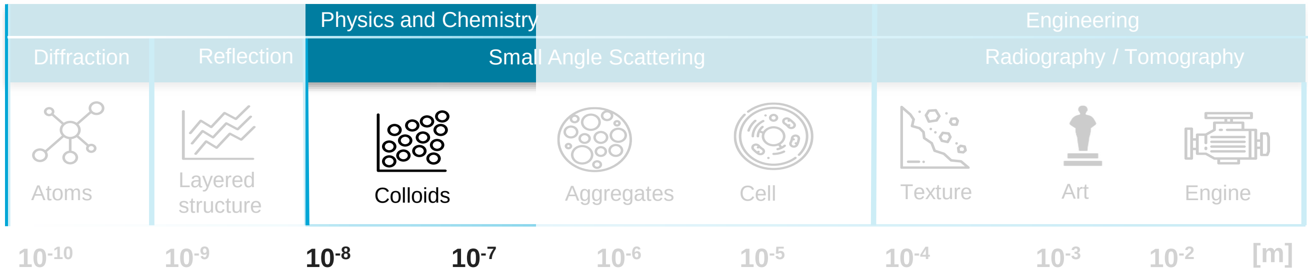
Example: Hydrogen sensing materials





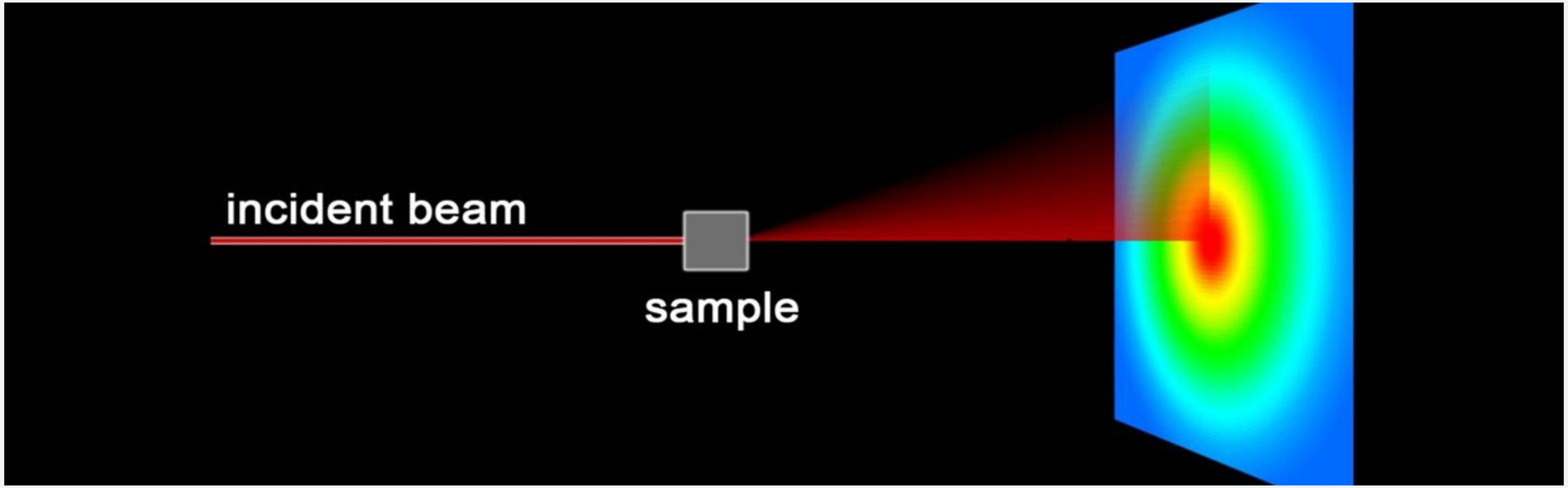


Bannenberg, L. J., Blom, L., Sakaki, K., Asano, K., & Schreuders, H. (2023). Completely elastic deformation of hydrogenated Ta thin films. *ACS Materials Letters*, *5*, 962-969.



Small Angle Neutron Scattering (SANS)

Structure analysis length-scale 1 nm to 500 nm



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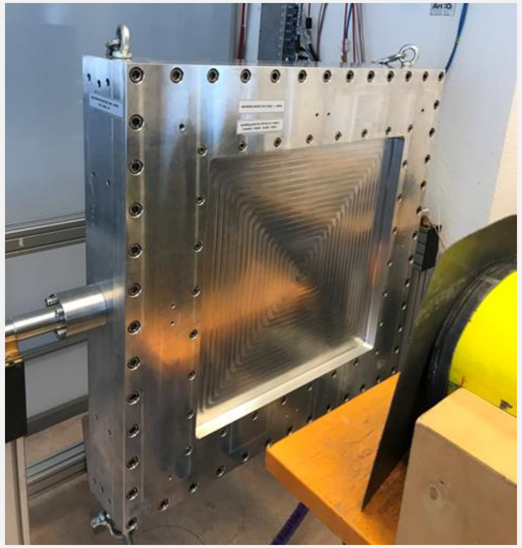
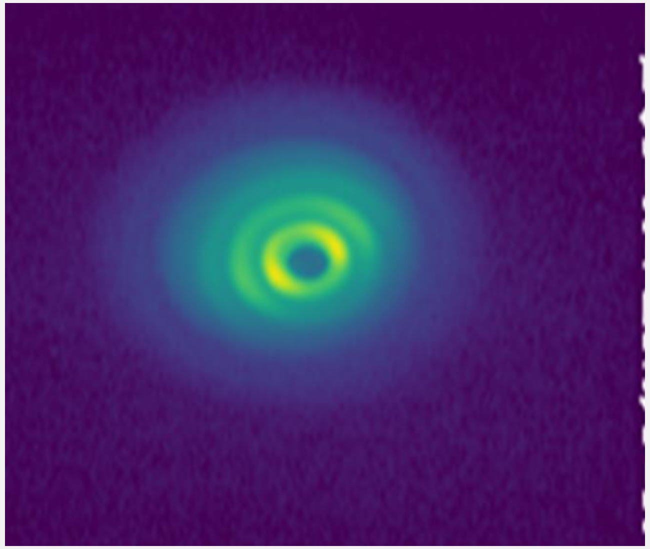
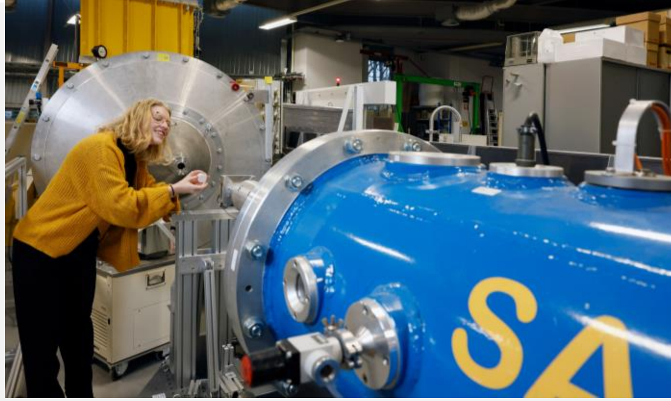
Small Angle Neutron Scattering

- Commissioning
- New detector and electronics (50x50cm -> 60x60cm)
- New funded projects – Steels (PhD Started)
- Development of battery cell
- New software (epics)
- Reduction software under development







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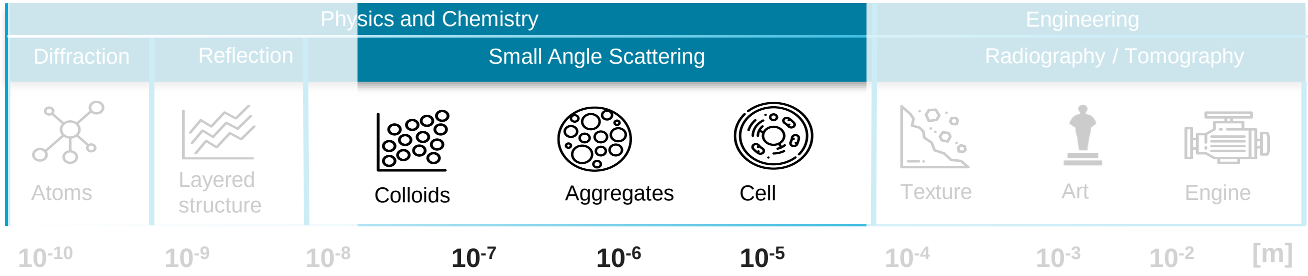
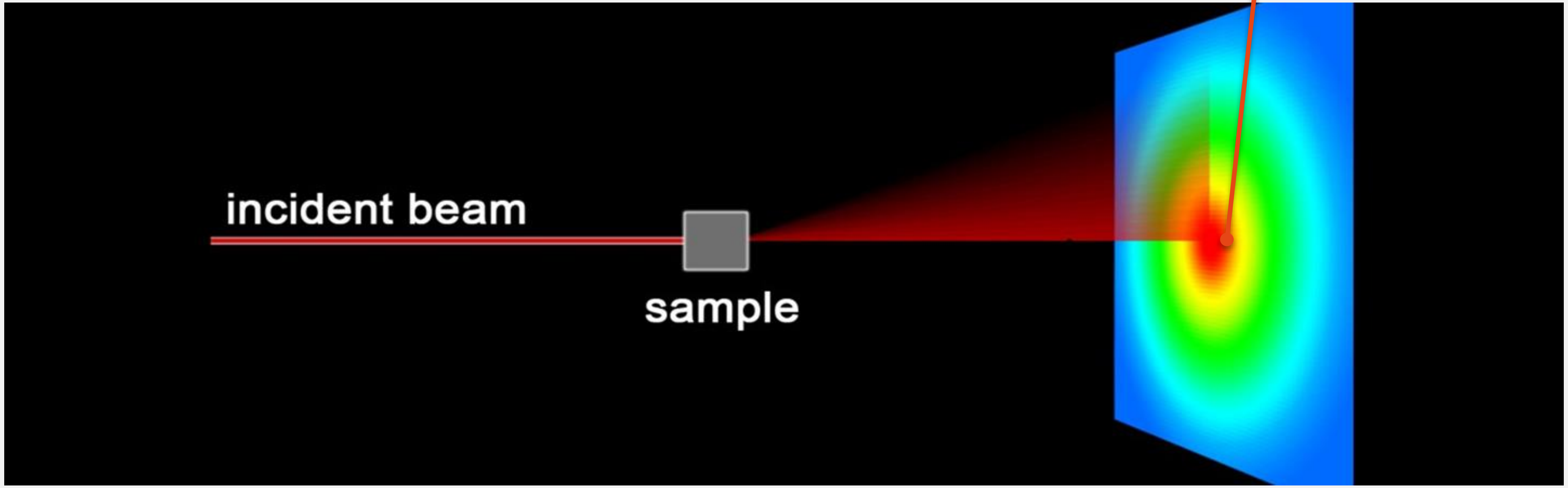


Spin Echo Small Angle Neutron Scattering

Structure analysis length-scale 50 nm to 20 µm

SESANS signal !



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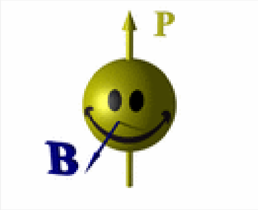
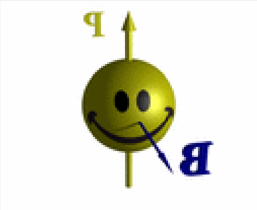
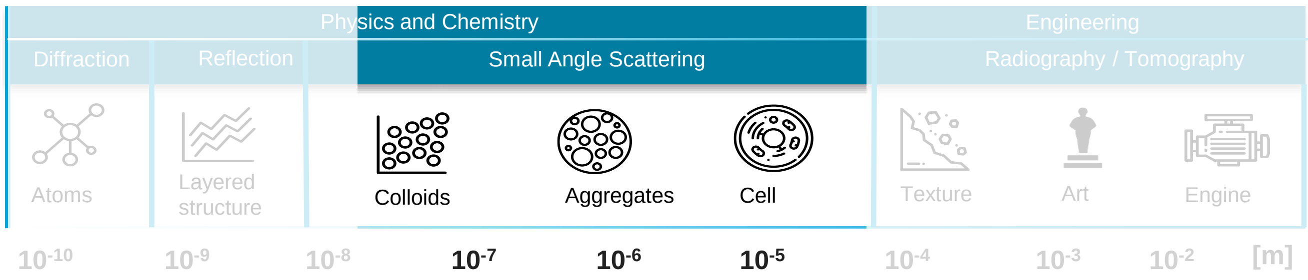
Small Angle Neutron Scattering (SESANS)

Structure analysis length-scale 50 nm to 20 µm
Spin Echo Small Angle Neutron Scattering

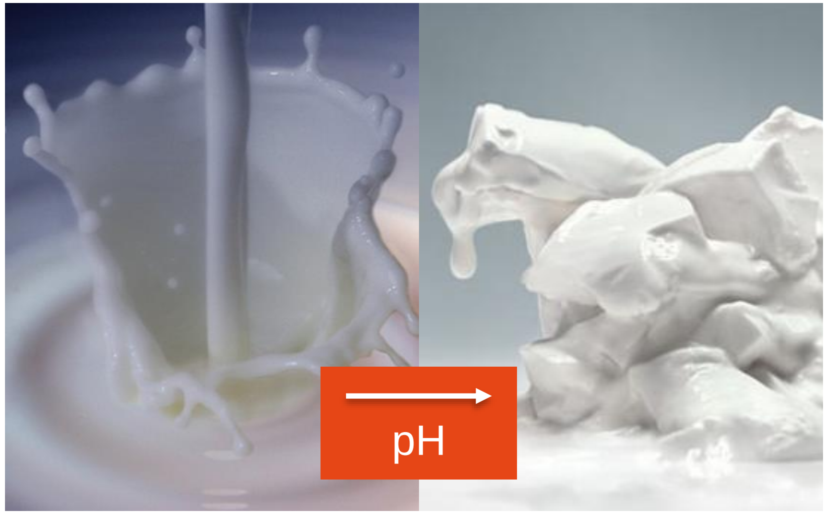


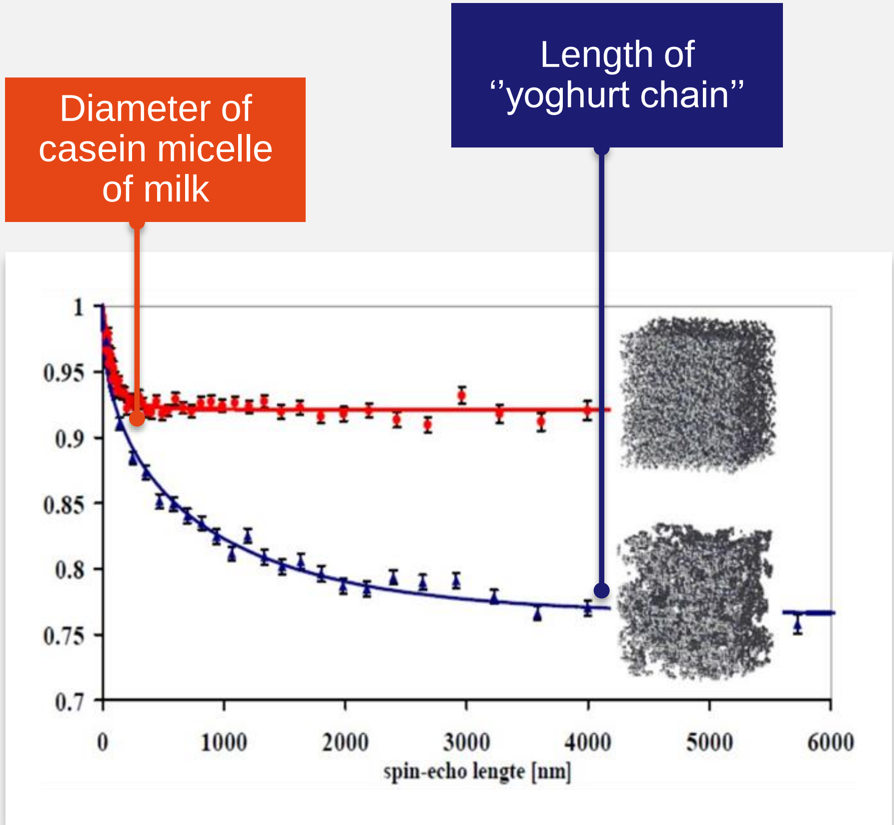


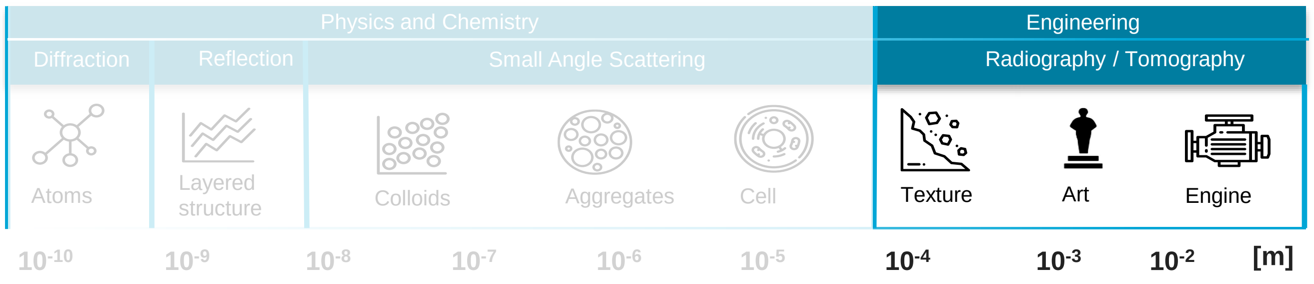


SESANS example

Structure analysis length-scale 50 nm to 20 µm

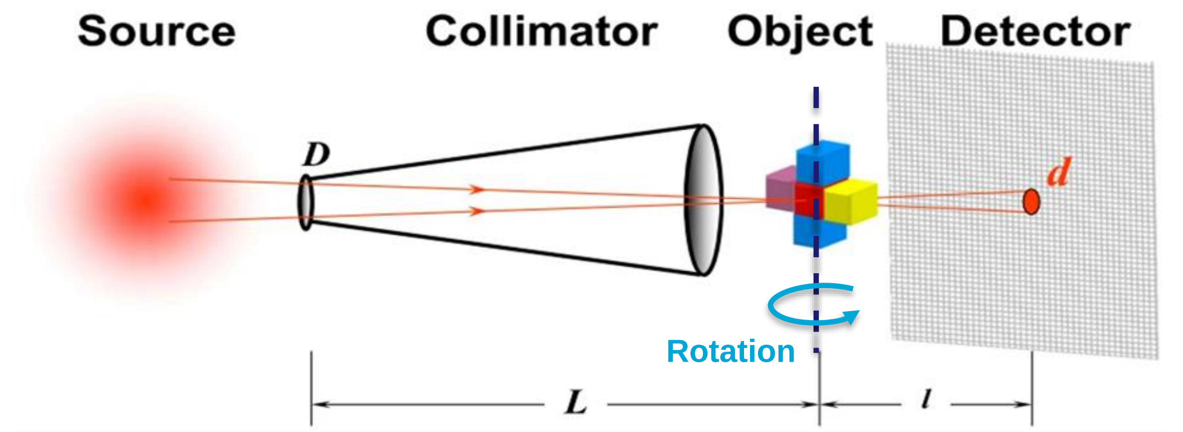




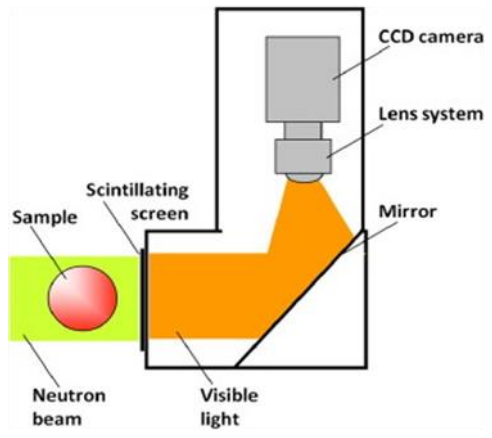


Neutron imaging

Structure analysis length-scale 50 µm to cm level
Radiography and tomography



Tomography



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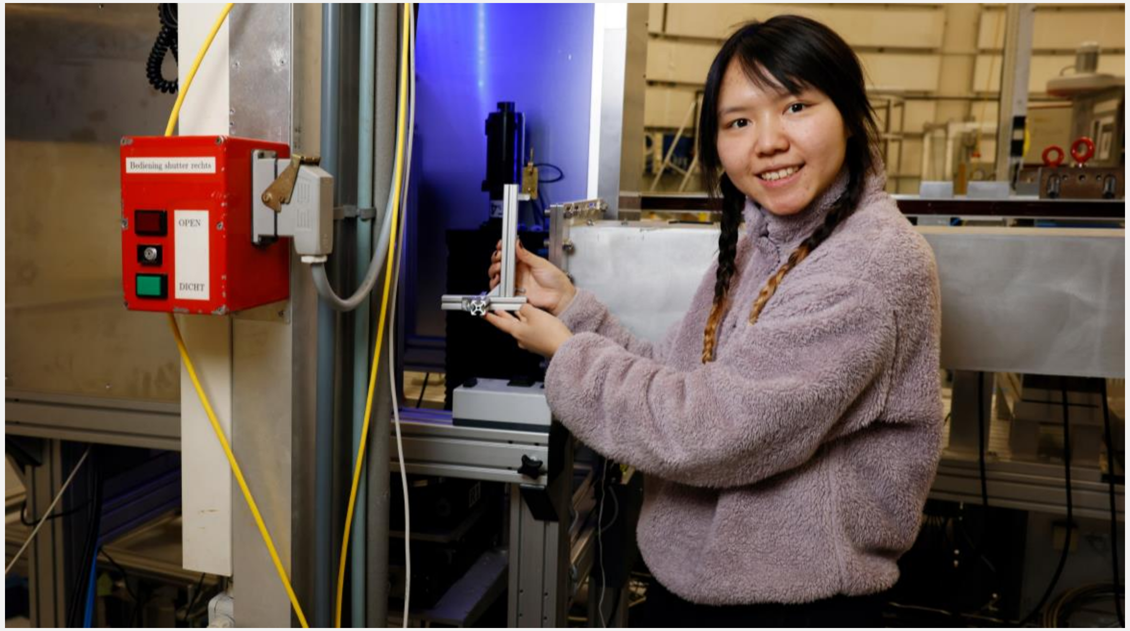
Neutron Imaging, FISH 2x

Structure analysis length-scale 50 µm to cm level

Radiography and tomography



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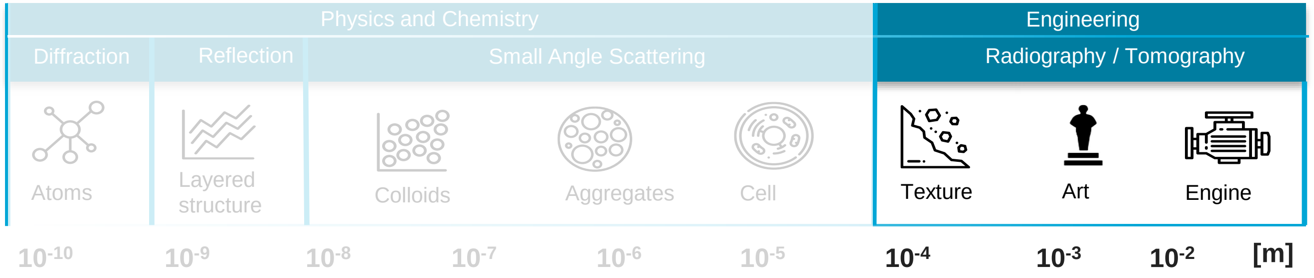
Zhou, Zhou & Plomp, Jeroen & Eijck, Lambert & Vontobel, Peter & Harti, Ralph & Lehmann, Eberhard & Pappas, Catherine. (2018). FISH: A thermal neutron imaging station at HOR Delft. Journal of Archaeological Science: Reports. 20. 369-373. 10.1016/j.jasrep.2018.05.015.



Neutron imaging

Structure analysis length-scale 50 µm to cm level with radiography and tomography

What does the lens look like?

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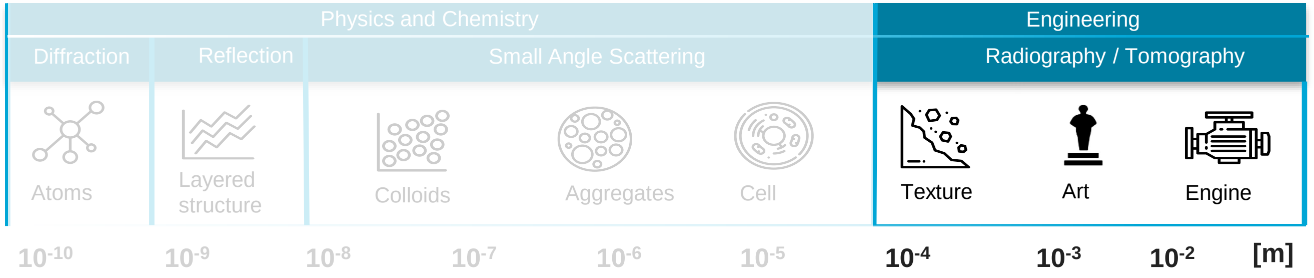
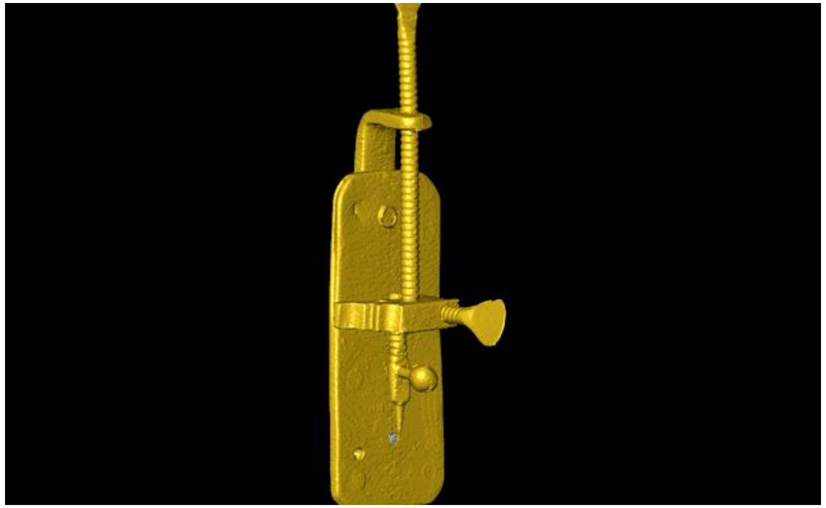
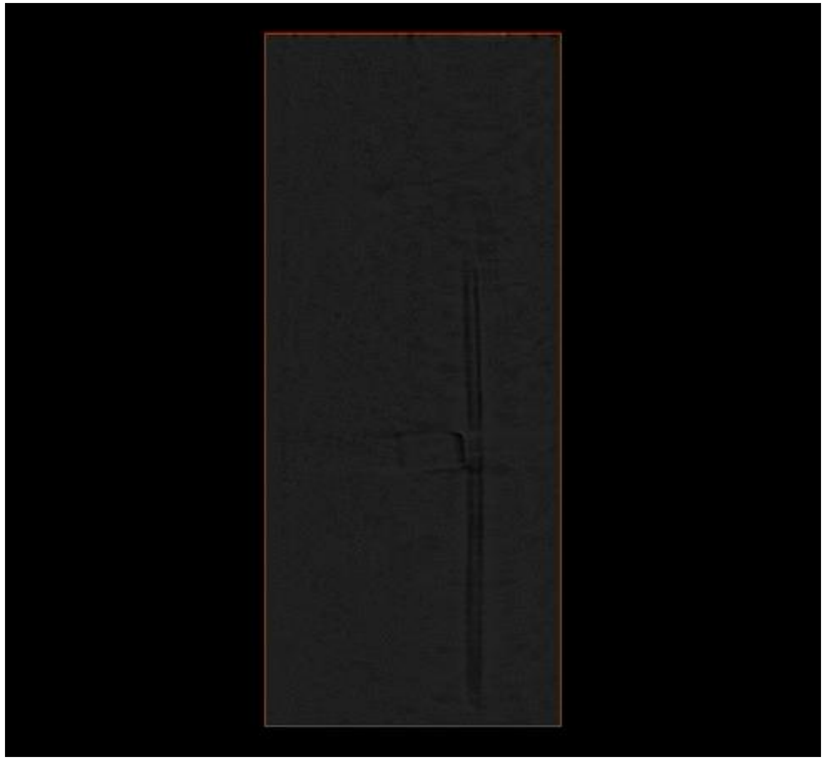


Neutron imaging

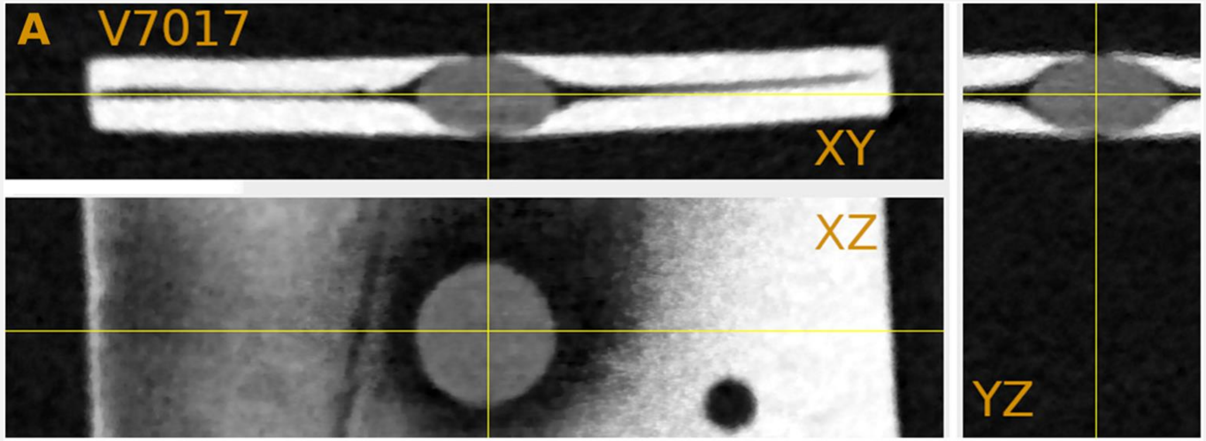
Structure analysis length-scale 50 µm to cm level
Radiography and tomography





Neutron imaging

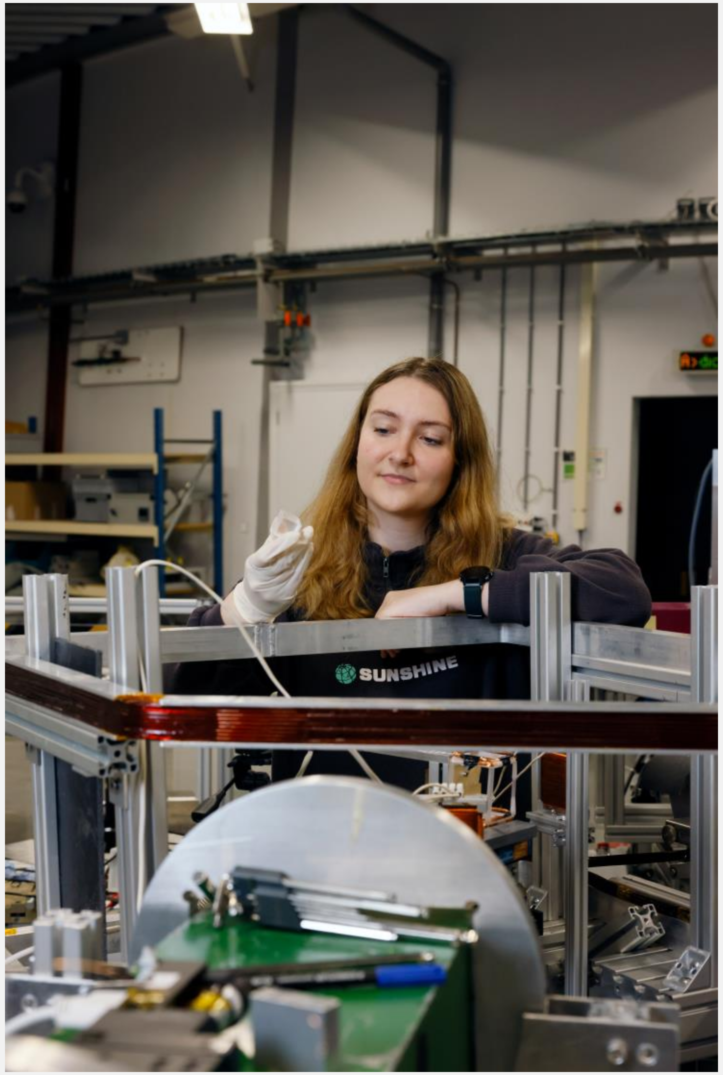
- Example: Antoni van Leeuwenhoek (1632 –1723)



Cocquyt, Tiemen, Zhou Zhou, Jeroen Plomp and Lambert van Eijck. “Neutron tomography of Van Leeuwenhoek’s microscopes.” Science Advances 7 (2021): n. pag.

Cold Test beam (2x)

Measuring with, monochromatic, polarised beam. Instrument development or student practical. Detector testing (V17 Berlin)



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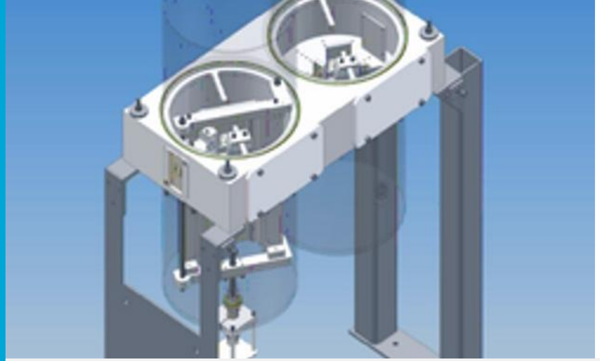
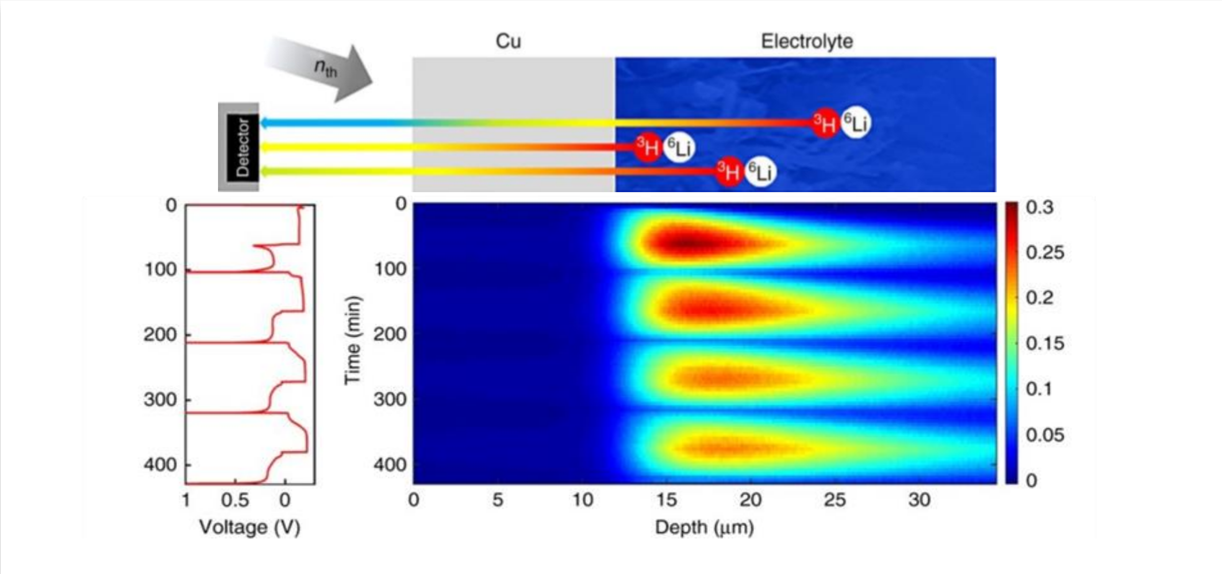
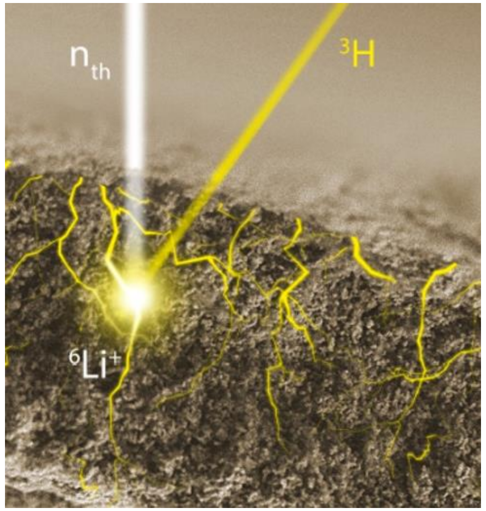


Neutron depth profiling

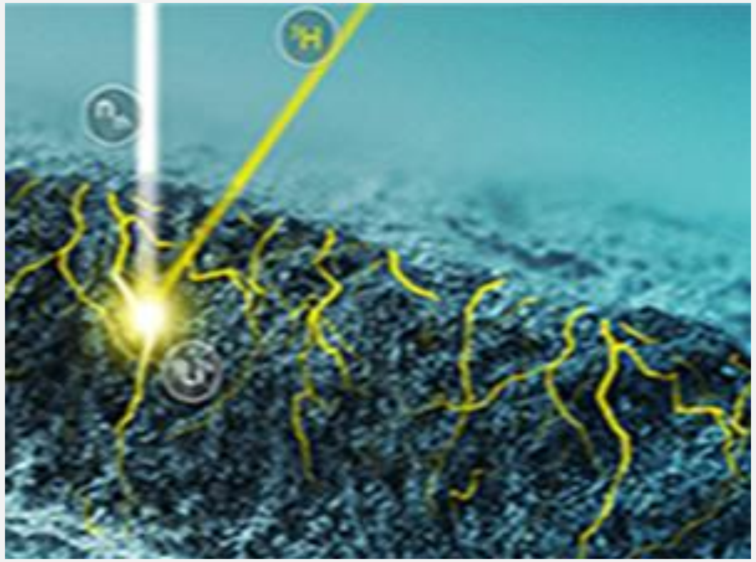
Measuring the concentration of e.g. He, Li, B or N as a function of depth in various substrates. Measuring the absolute amount of isotopes like ^{3}He, ^{6}Li, ^{10}B or ^{14}N per cm^2.





Neutron Depth profiling

Gain factor of 20 for cold neutrons



$^{6}Li + n \rightarrow {}^{4}He$ (2055keV) + ^{3}H(2727keV)

^{4}He max depth 7μm, resolution 10nm
^{3}H max depth 40μm, resolution 50nm

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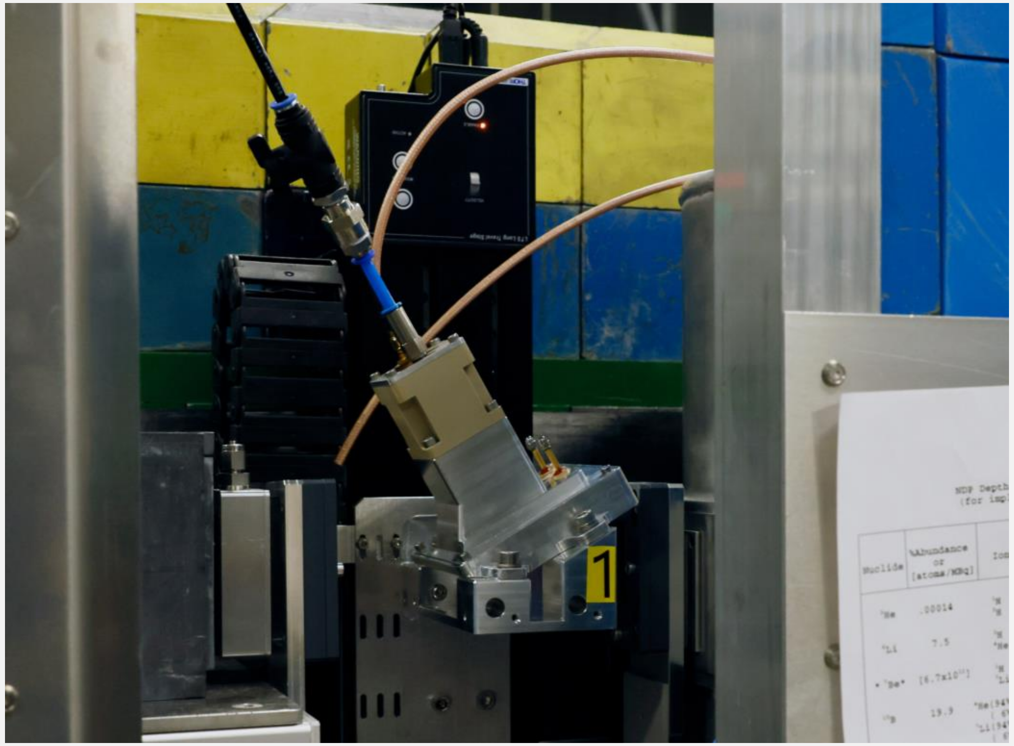
Neutron Depth profiling

Small compact system developed for thin film battery, can be taken to labspace in glovebox if needed



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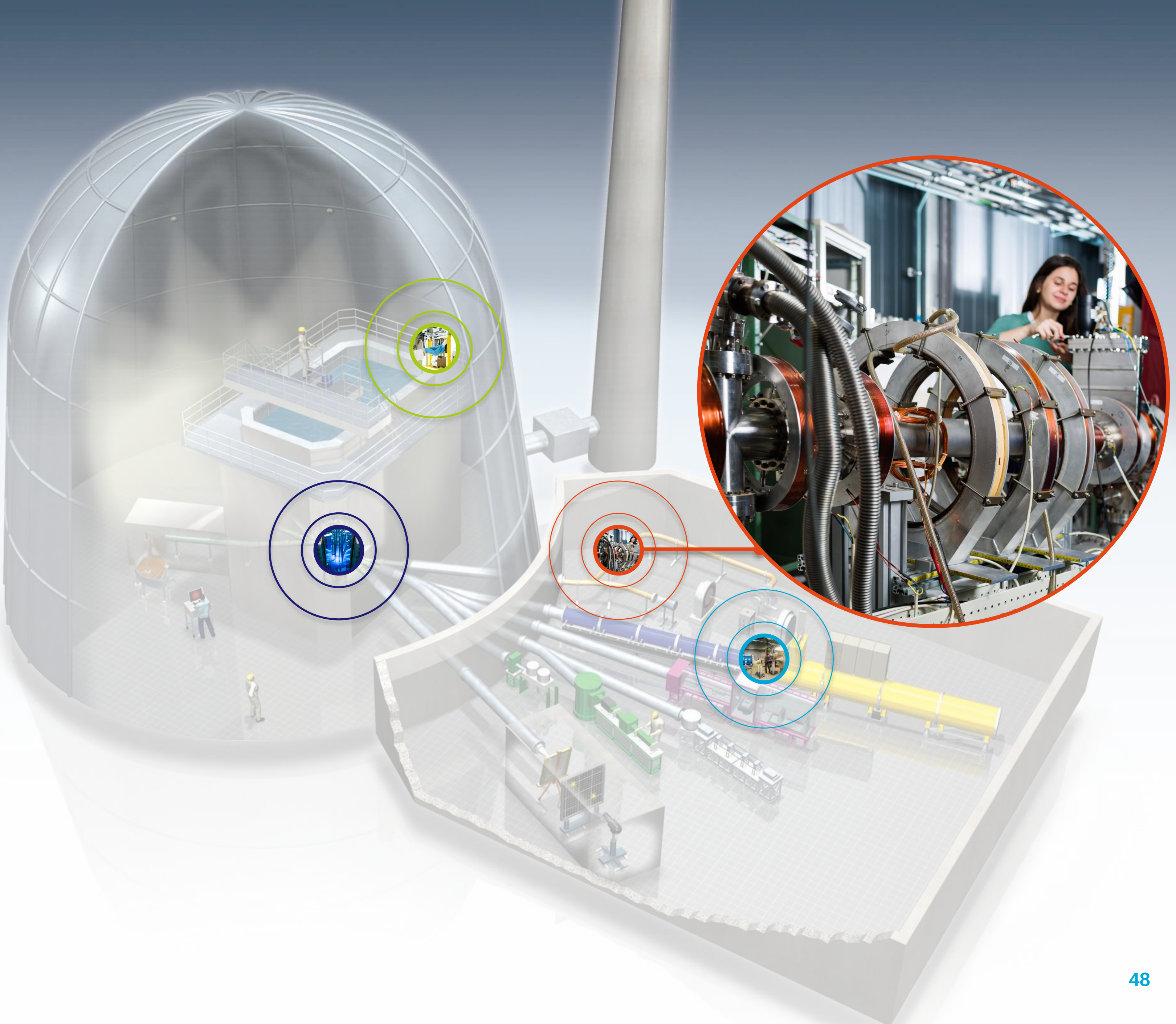

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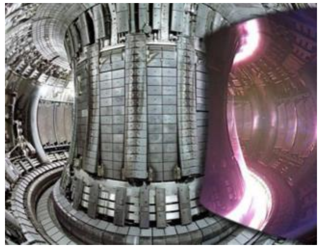
Positrons: application fields

- With Self-Healing properties (aluminium and steel alloys)

- For efficient Hydrogen storage (low weight, high capacity)

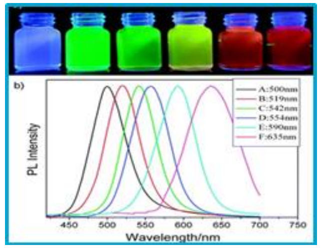
- For efficient conversion of light into electricity (solar cells)

- For fusion reactor walls facing the hot plasma



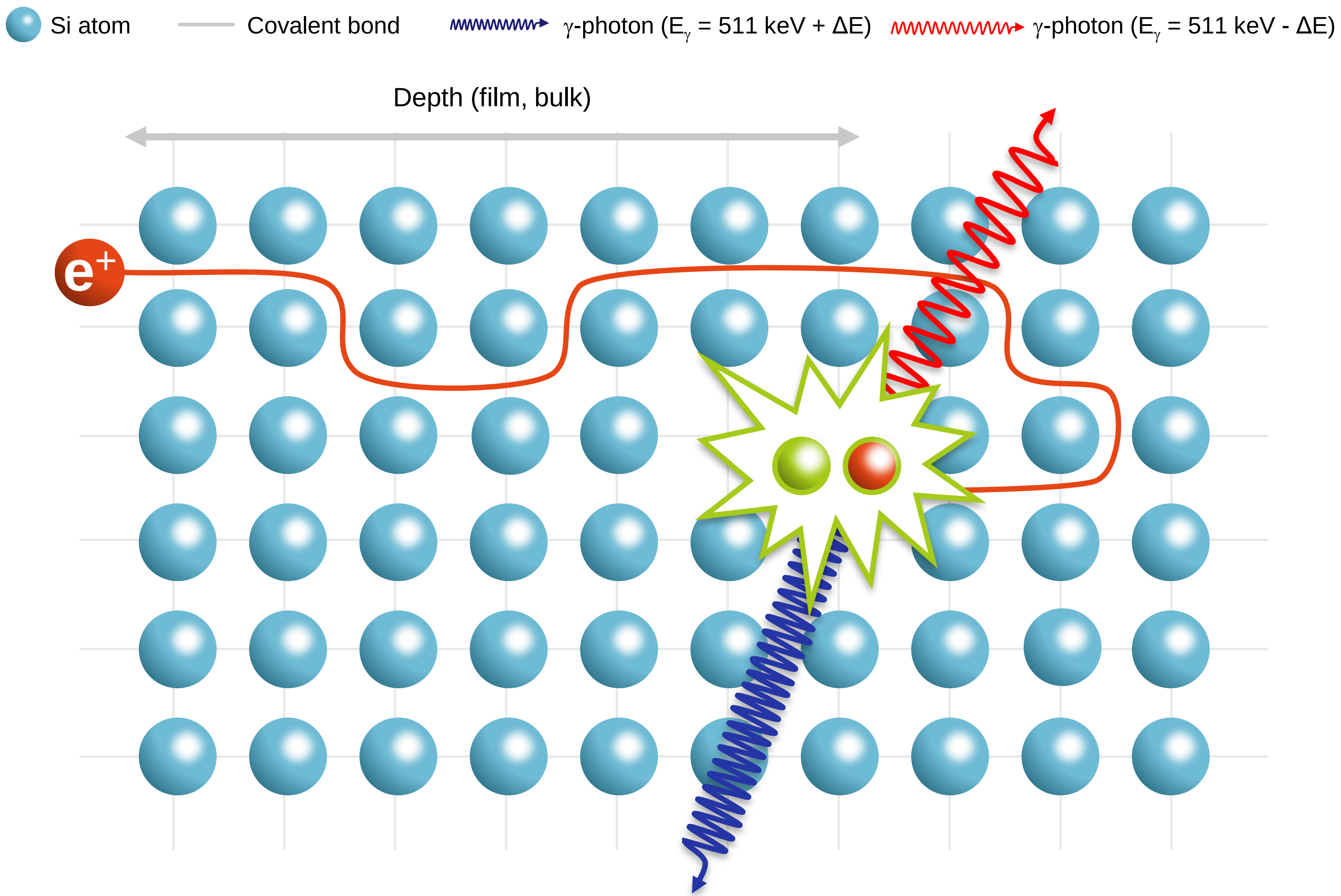
- For fission reactors used as moderator and fuel

- Of nano-meter scale



…….. and more

Positrons are remarkable probes



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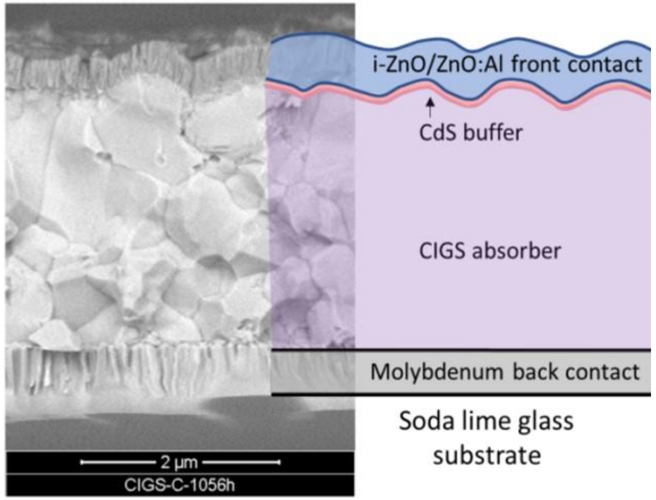
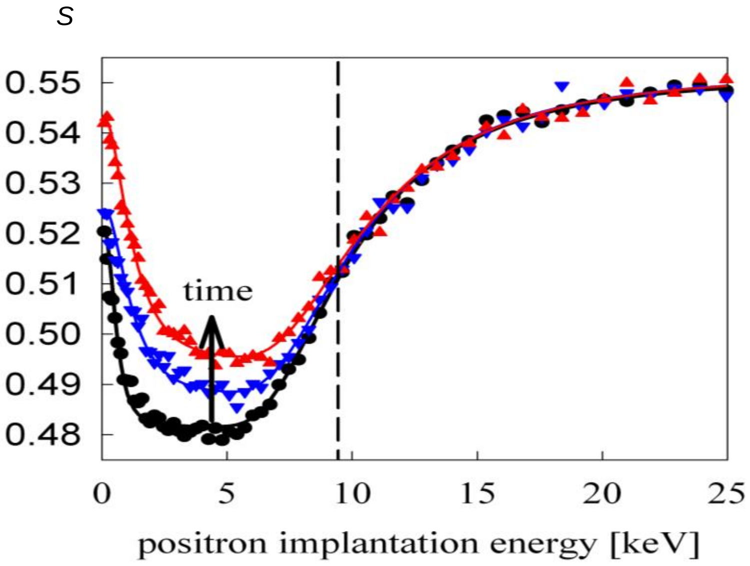
Thin Film studies,10 nm – 2 µm thickness

Low energy positrons: e^+ beams

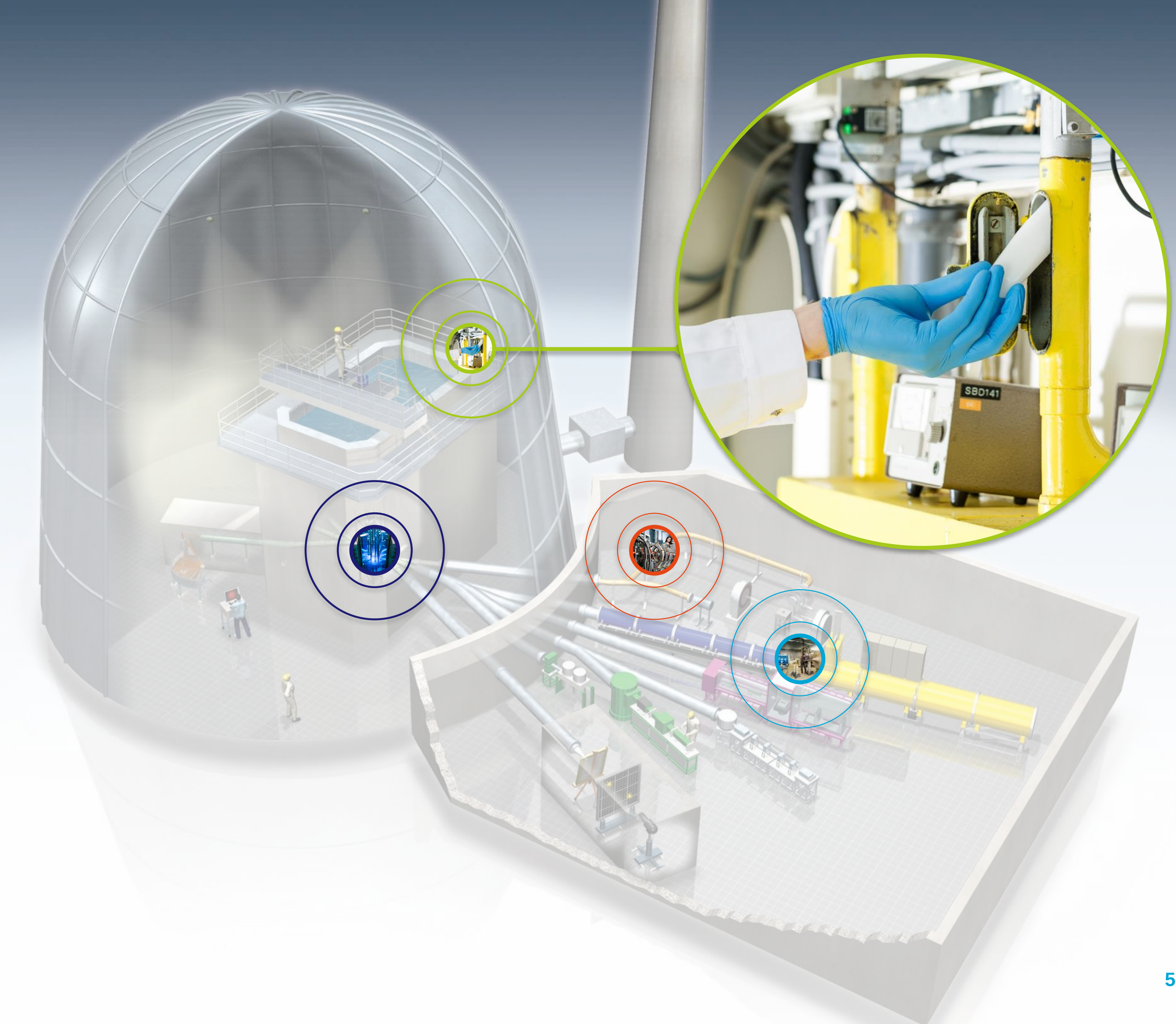


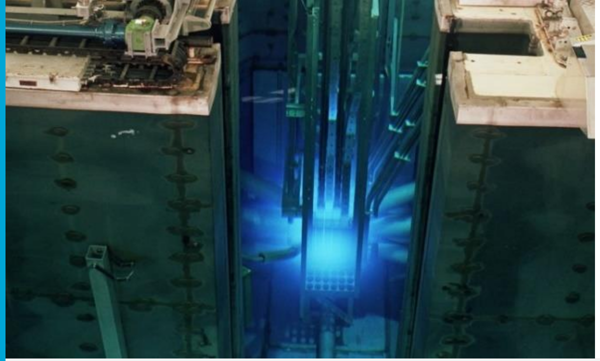
Solar cell

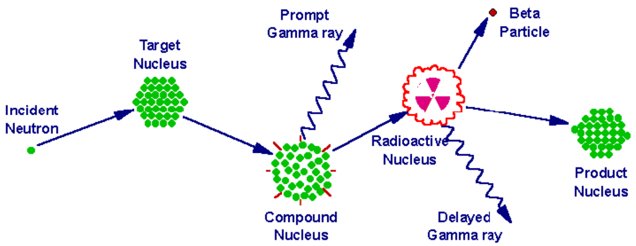


average depth 250 nm

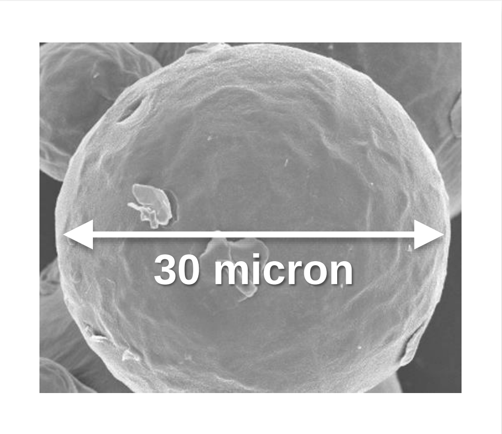
With TNO Soliance


SBD141





Isotopes treatment



Tc-99m in a tumor-seeking compound as tracer

UMC Utrecht

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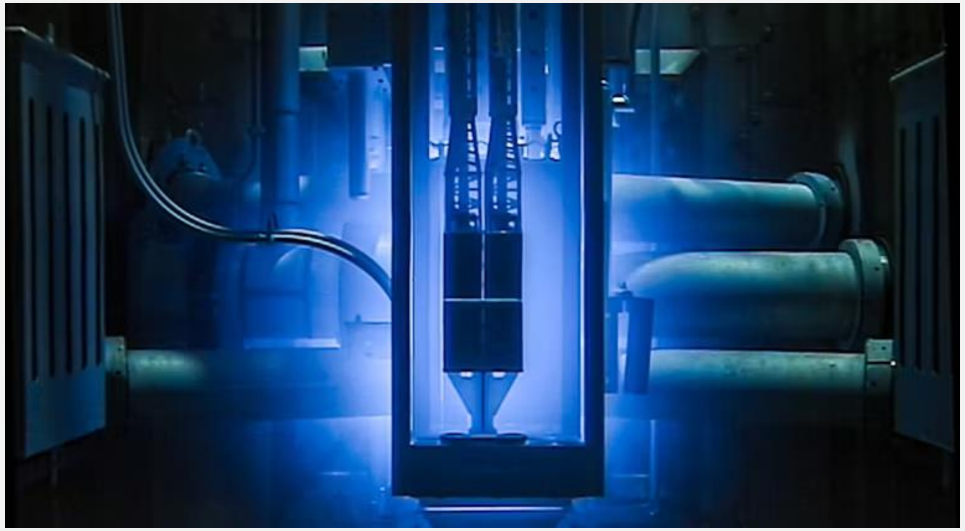
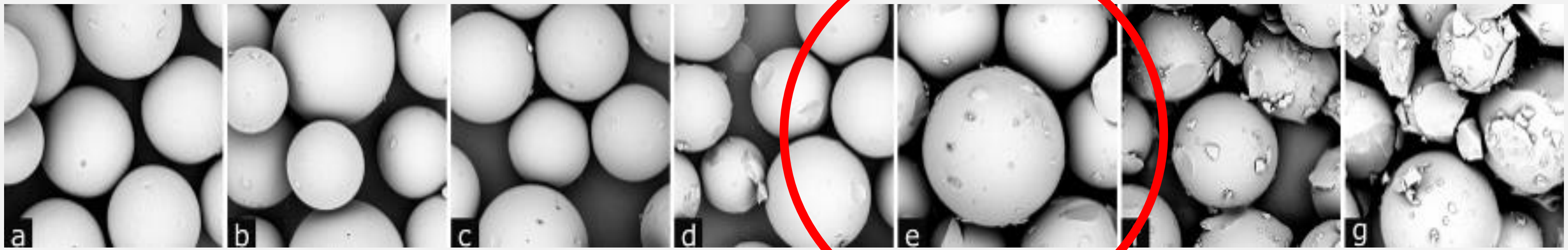
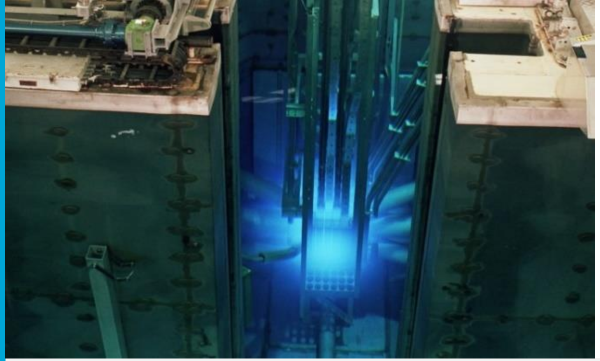
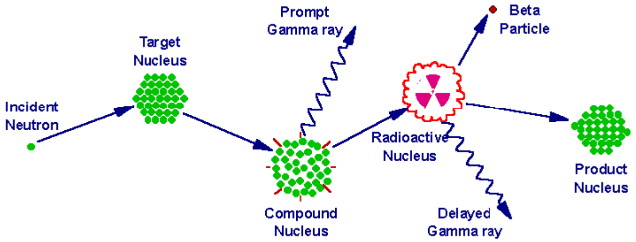
Holmium

- Higher activity possible by Pb shielding and lower level of radiation damage

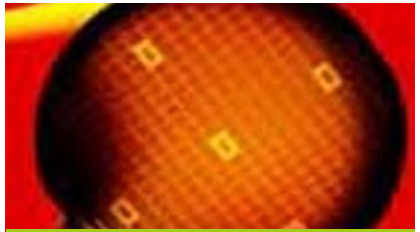








Instrumental Neutron Activation Analysis (INAA)



Ultra high purity materials

Nails

Lichens, mosses

Rock and sediment

Glass

Food

Air particulates on filter

Catalysts, zeolites

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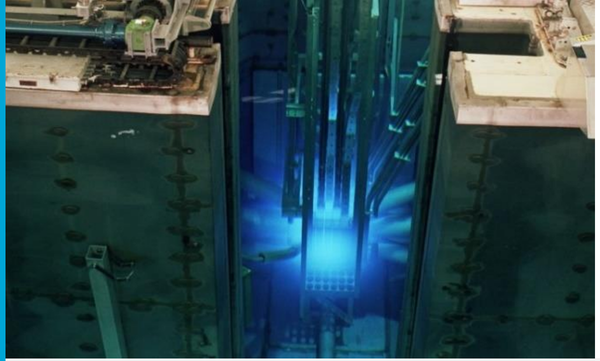
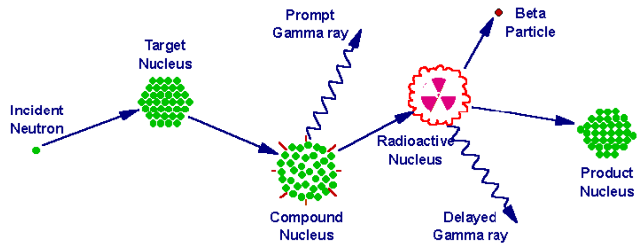
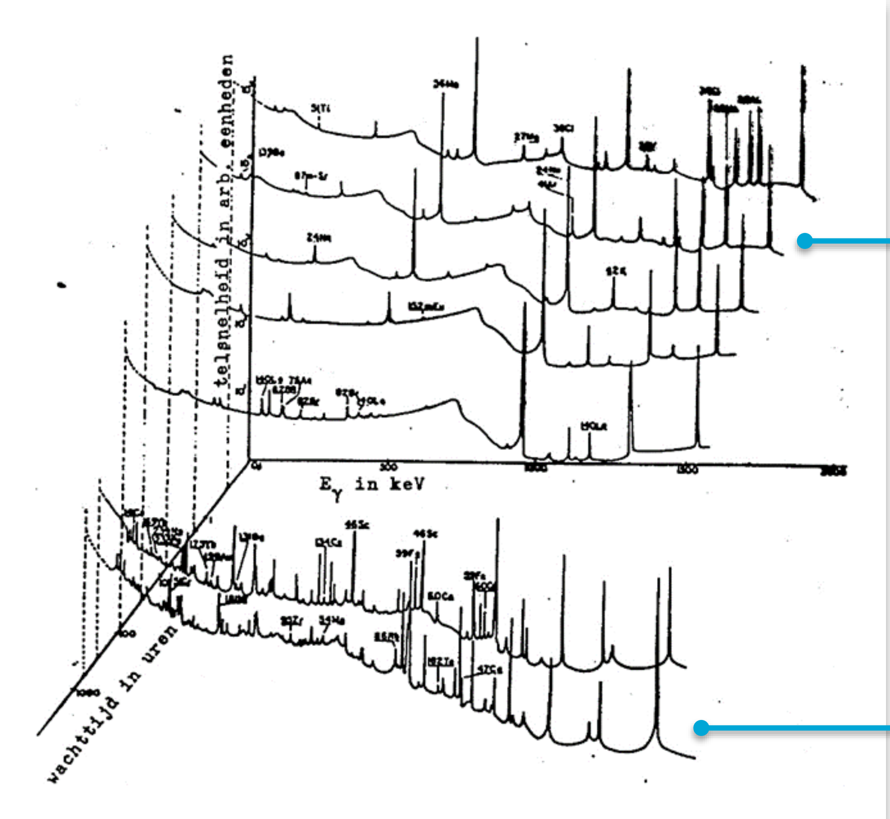




INAA



- Change of the gamma-ray spectrum due to decay of radionuclides

Measured 30 s after irradiation

- The shape of the spectrum changes with time…
- Consecutive measurements provide complementary information

Measured 1 month after irradiation

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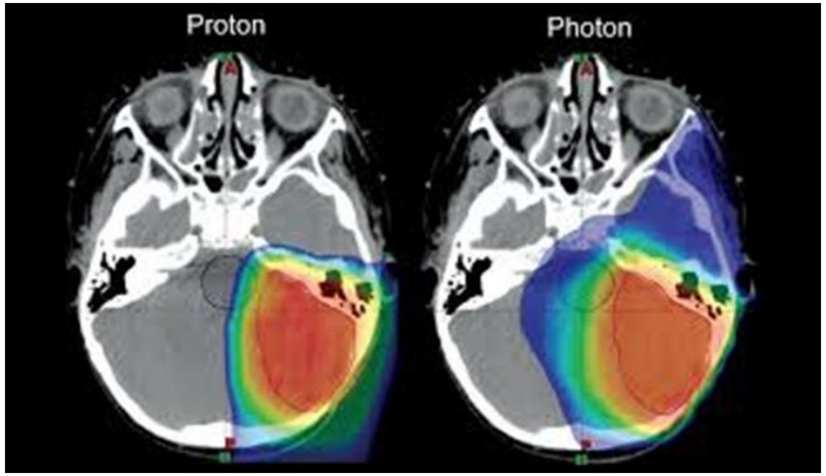
Protons, therapy and research

Laboratory facilities:

- 150 m^2 research bunker with R&D proton beam line (clinical grade)
- 70 m^2 laboratory space for technology development
- 30 m^2 laboratory space for radiochemical research
- 30 m^2 biological laboratory space



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Any questions?