



**EC Conference on
*Medical, Industrial and Research Applications of Nuclear and
Radiation Technology*, 20 – 21 March 2018, Brussels**

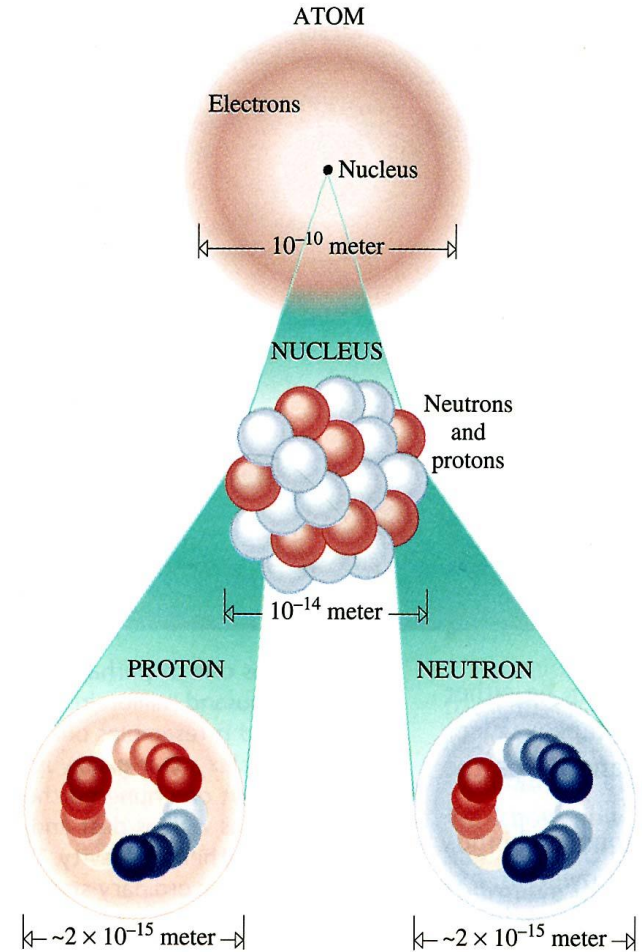
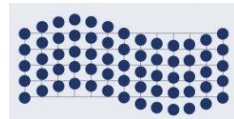
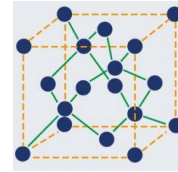
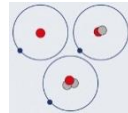
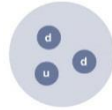
Neutrons for basic research, industry and medicine

Prof. Dr. Winfried Petry, Director FRM II and MLZ



Neutrons as a probe

- Electrically neutral
- Isotopically sensitive
- Sensitive to atomic structures
- Motion sensitive
- Magnetically sensitive
- **Neutrons give information on**
 - where atoms sit
 - how they move
 - what magnetic properties exist in materials.
 - Neutrons transform elements.





Neutrons for basic research, industry and medicine

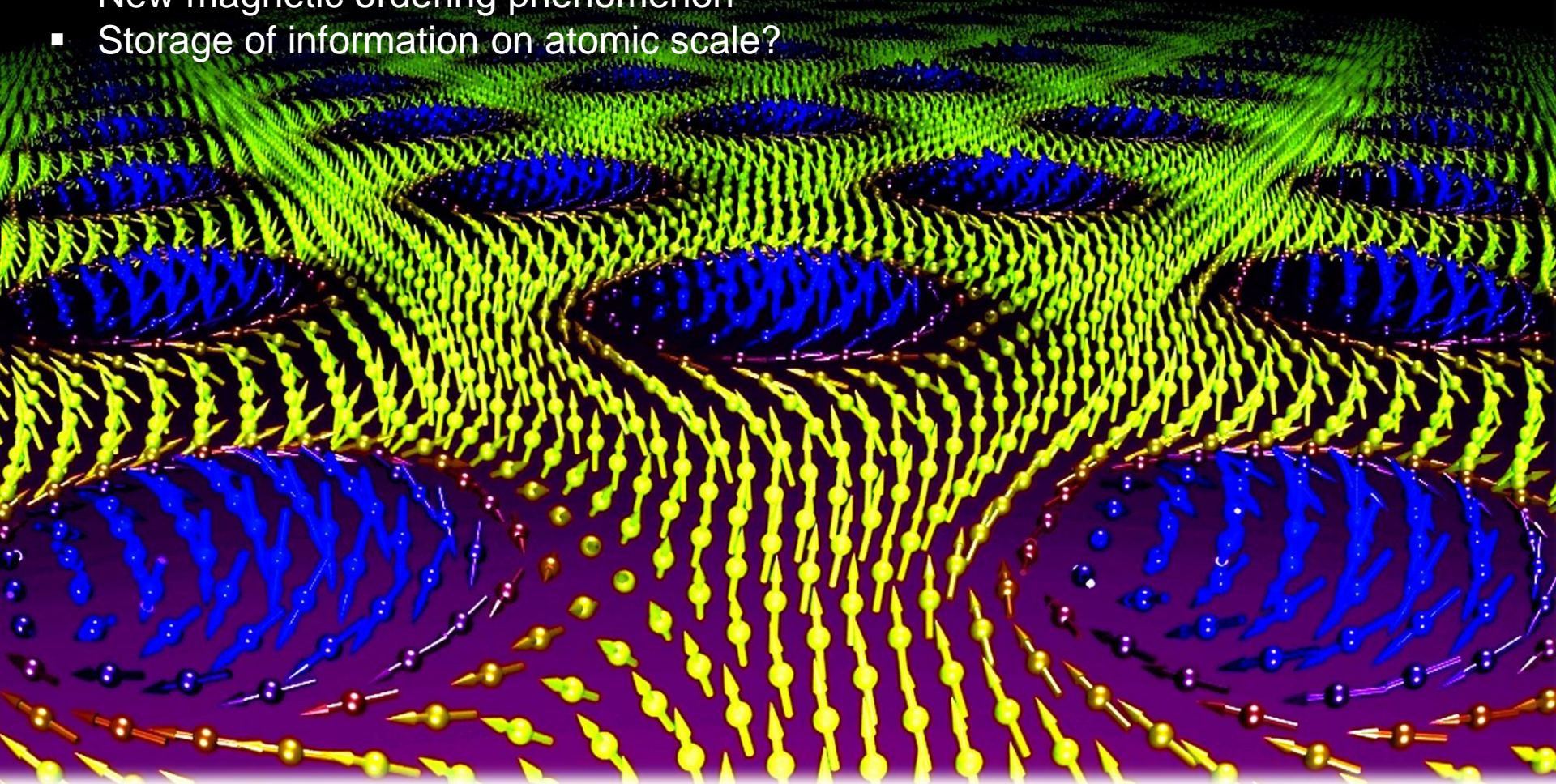
- Information technology – data storage
- Energy storage – better batteries
- Residual stresses built up during the casting process
- In-operando – make the invisible visible
- The stuff for electromobility – silicon doping

- Life science and health – bacterial antibiotic resistance
- Bipolar disorder – neutron activation analysis
- Targeted therapy – Lu-177
- Mo-99 – diagnostics: 30 Mio applications p.a.

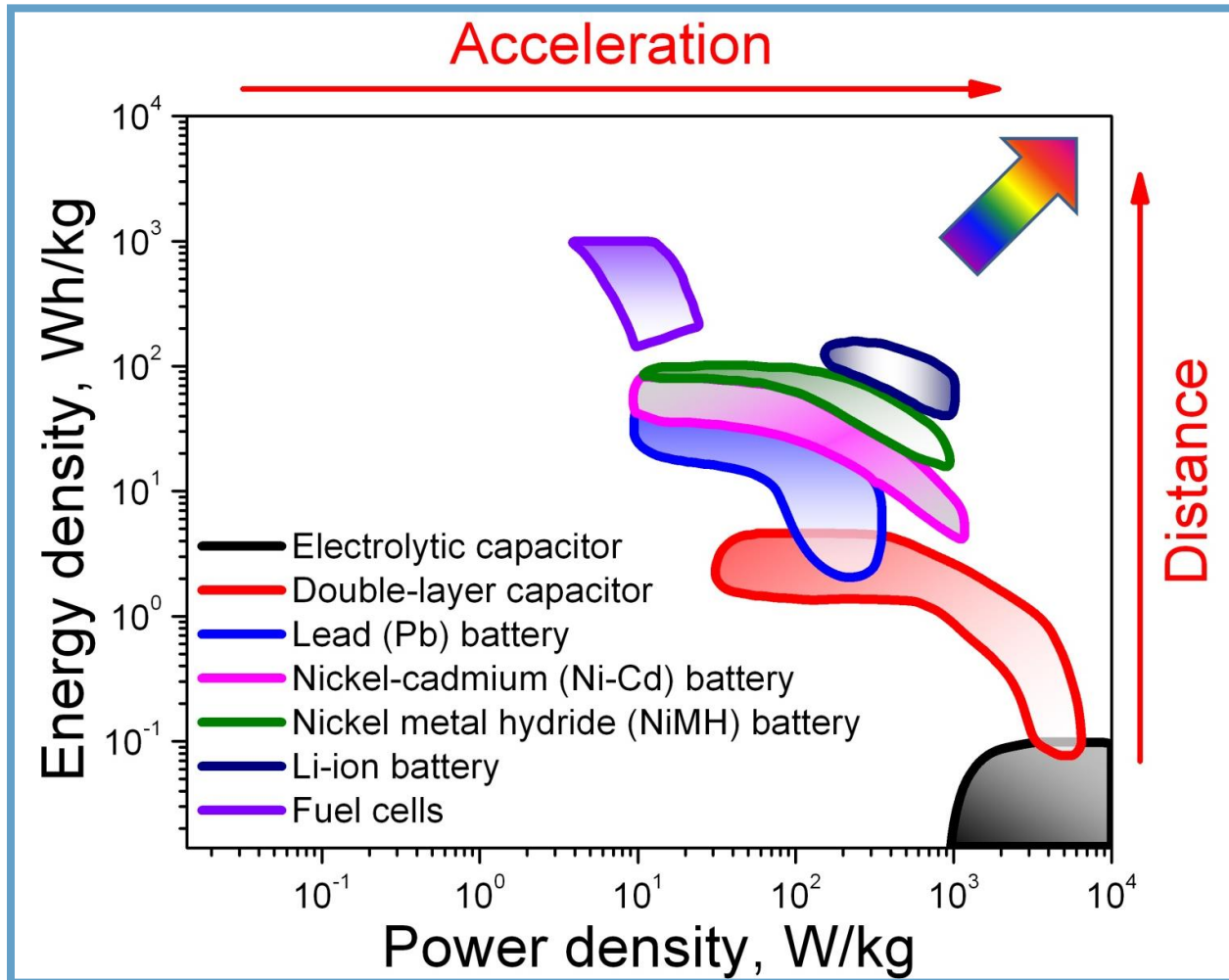
- Cultural heritage – curiosity

Information technology – data storage

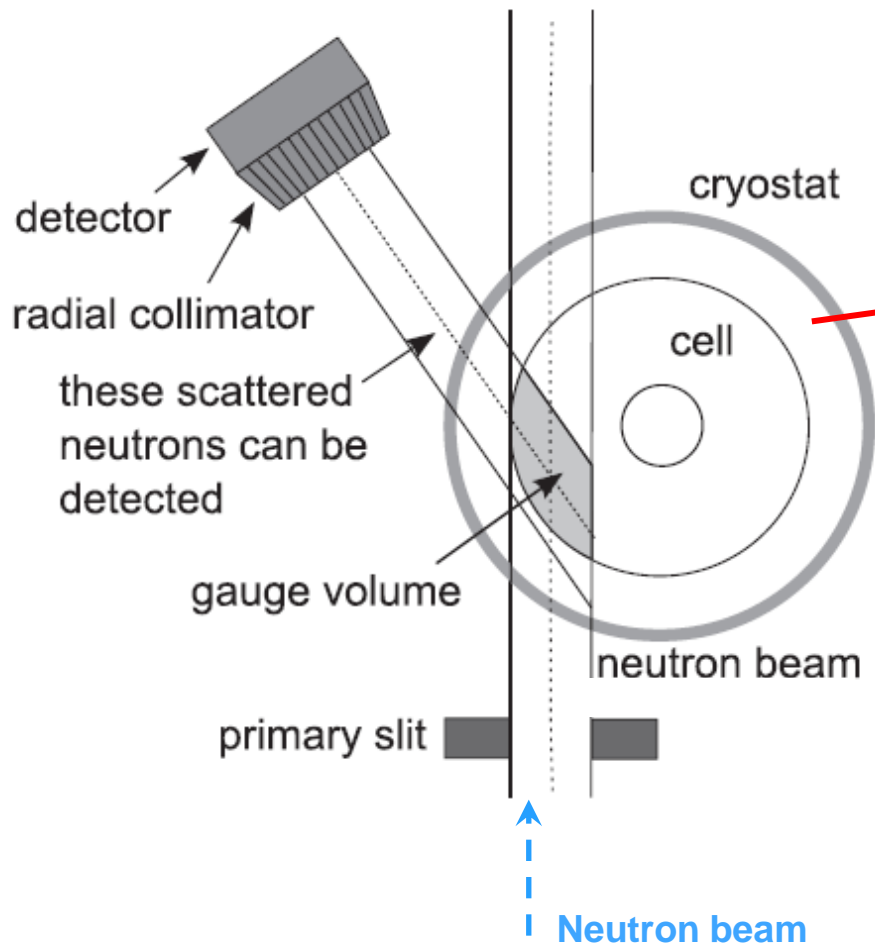
- Skyrmion lattice in MnSi
- New magnetic ordering phenomenon
- Storage of information on atomic scale?



Energy storage: Li-ion battery technology



In situ – in operando

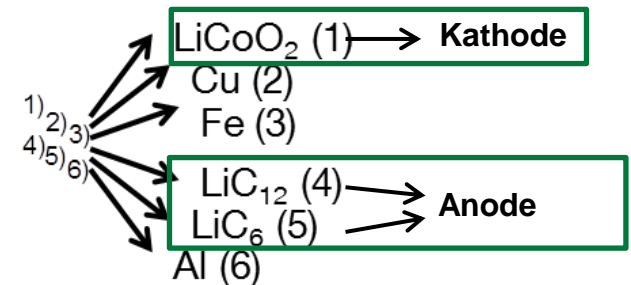
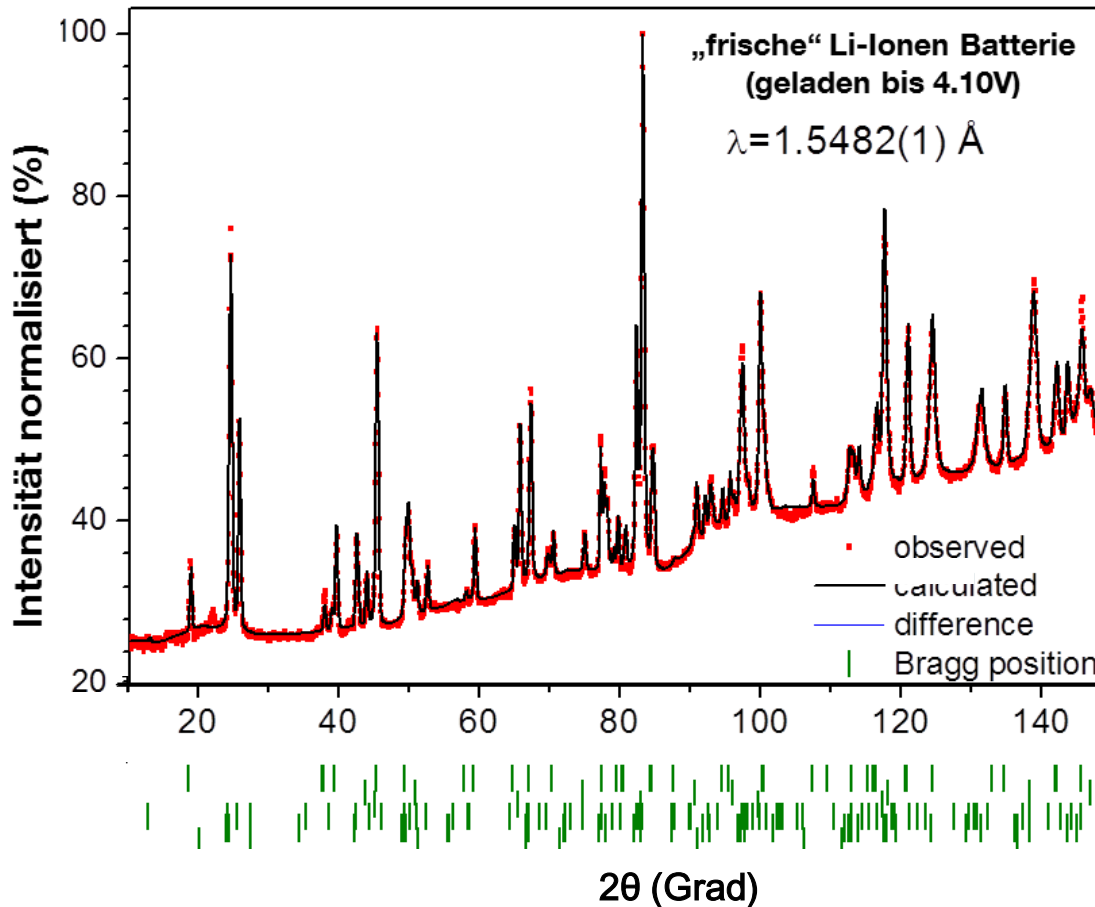


Detector Primary slit

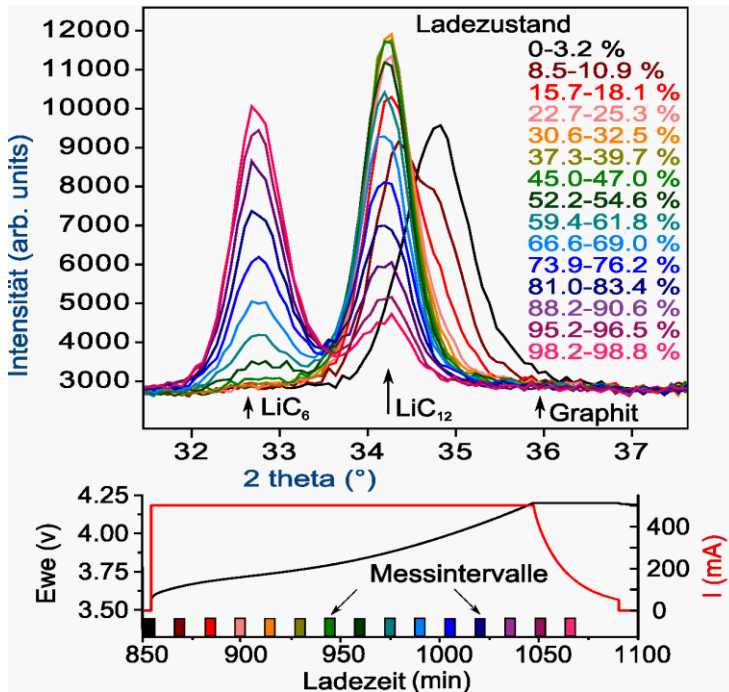


Neutron rays

Typical diffraction measurement of a 18650 Li-ion-battery



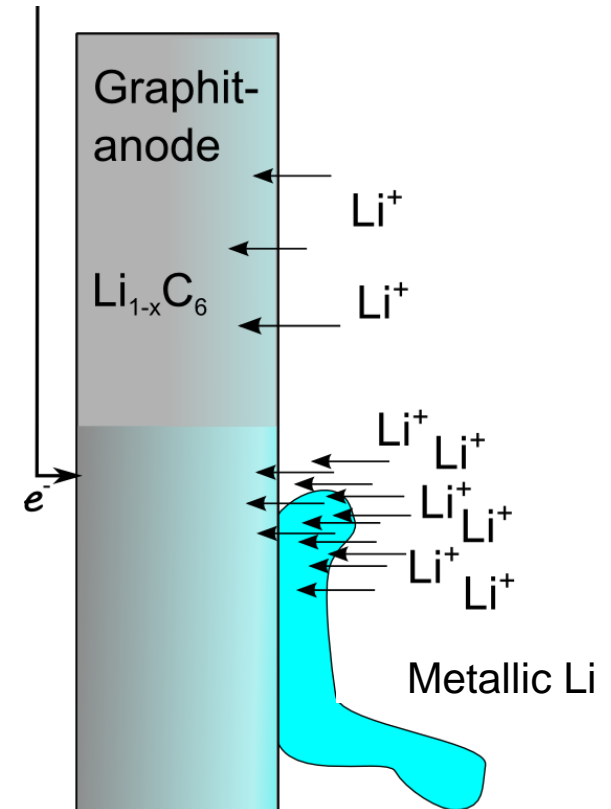
How molecules move



When charging too fast >

Li Plating:
segregated Li
diffuses into the
anode

Effect reinforced
at low temperatures:
-40 °C to -10 °C



→ Risk 'Li plating': reduces the capacitance and destroys the cell

Insights by neutrons

Destructive effects don't appear during isolated examination.

In-situ / in-operando studies reveal the degradation mechanism, namely Li-plating



Tesla burning after internal short circuit
(<http://www.cnet.com>)
Screenshot by Wayne Cunningham/CNET)



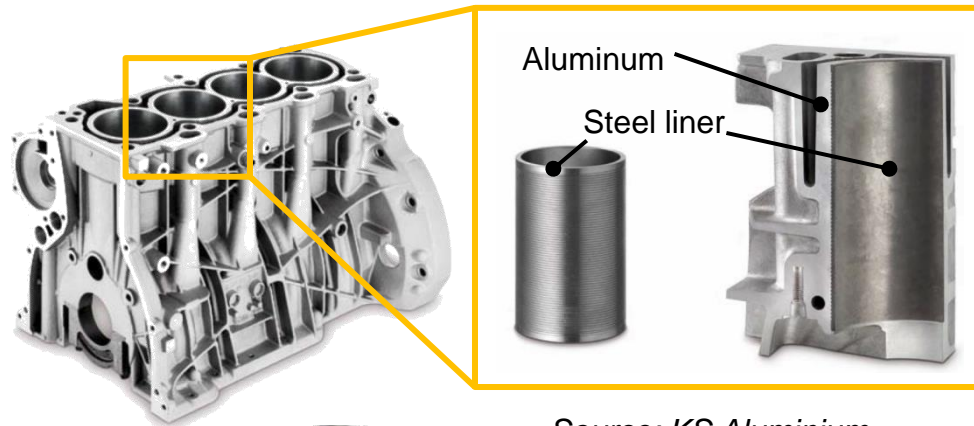
Also cause for Samsung Galaxy Note 7 ?
(Quelle: Tham Hua)



Boeing Dreamliner after internal short circuit
(<https://en.wikipedia.org/wiki>)

Residual stresses built up during the casting process

- Measurement of residual stresses in cast part up to now only in the finite state without knowledge how they develop
- Knowledge on residual stresses important for design of cast parts (e.g. engine blocks)
- Behaviour during casting needed as input for FEM simulations



Source: KS Aluminium-Technologie AG



Aluminium
(cast part)

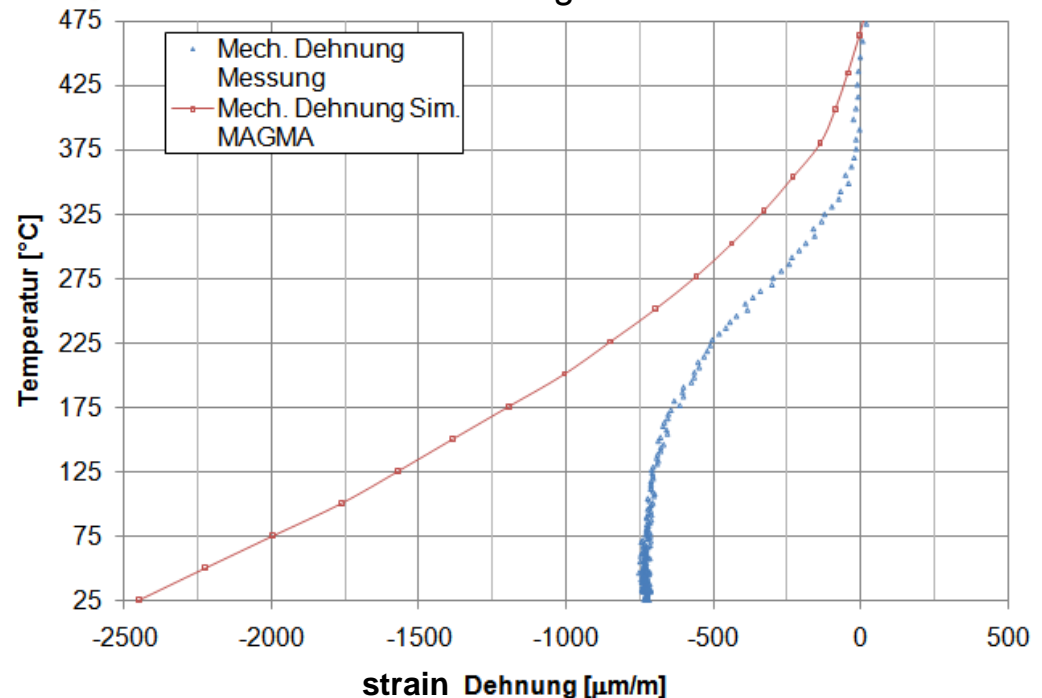
Mock-up sample for neutron diffraction experiment at STRESS-SPEC



Build-up of internal strain during cooling of the cast

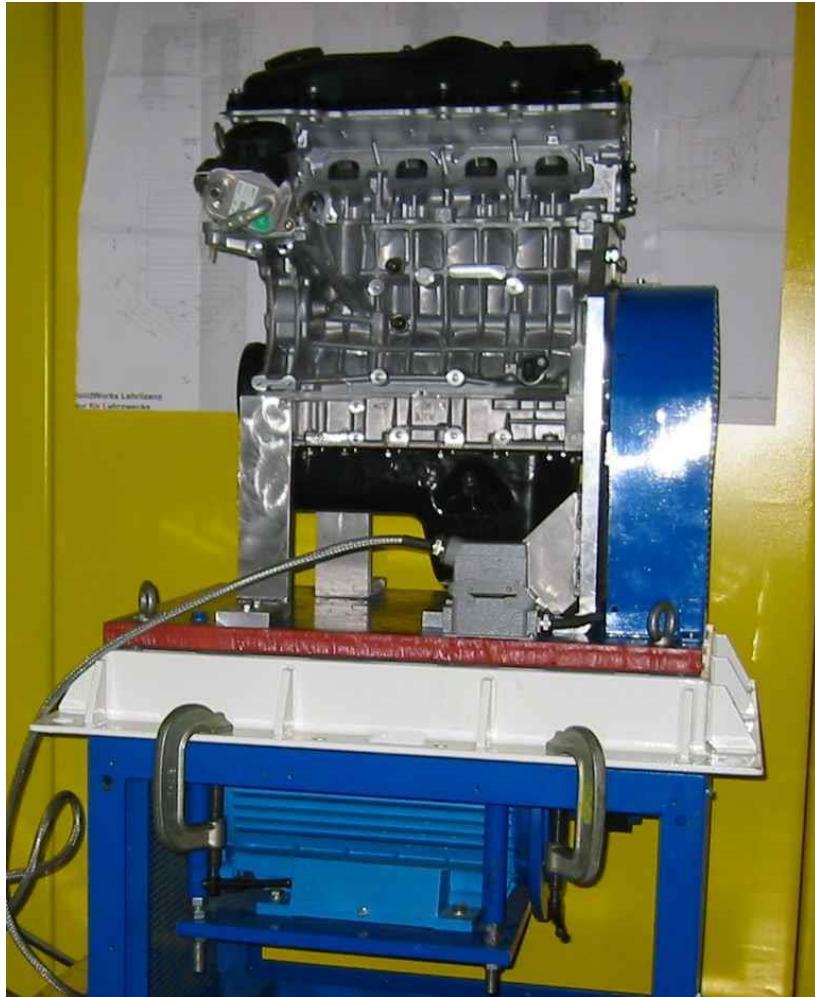


Build-up of residual stress in the steel liner during cooling of the cast



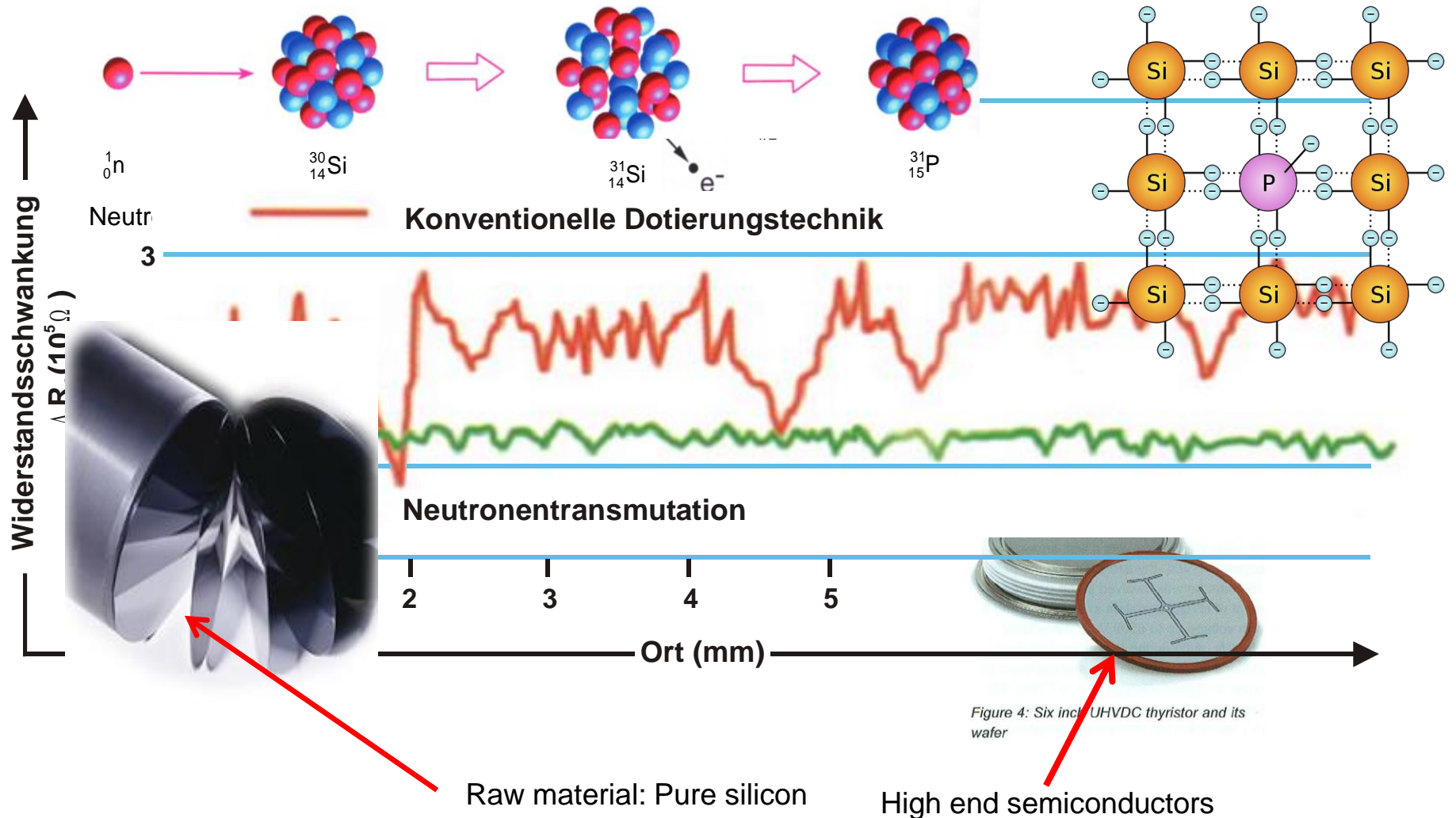
- Variables: alloy composition, strain in Al, strain in liner, different moulds, cooling speed,
- Drastically improved Finite-element-simulation of the casting process

In-operando: Make the invisible visible



BMW engine – electrically driven

The stuff for electromobility – silicon doping by neutron transmutation (15t/a at FRM II)





High voltage – direct current (HVDC) power transmission High performance electronic devices for e-mobility



TUM E-car Visio.M: Prof. Lienkamp



Thyristor towers:
96 thyristors 250 KV – 2000 A



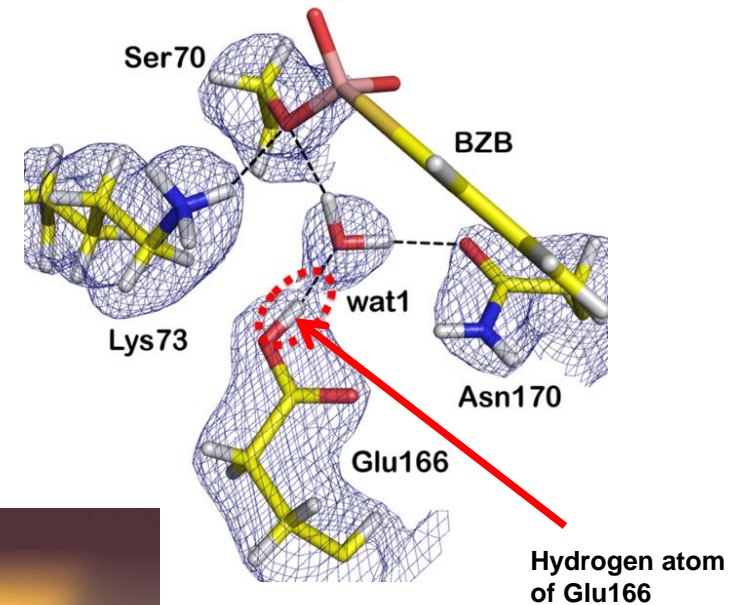
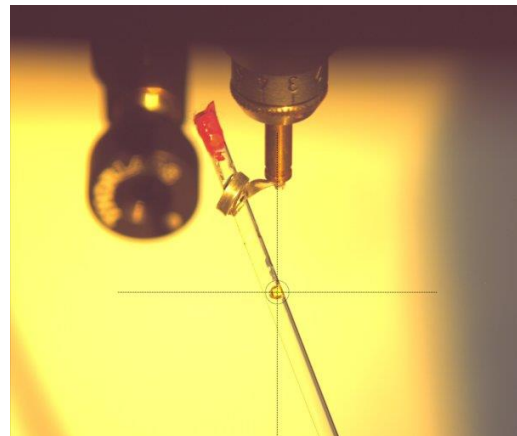
Siemens:
Thyristors for HVDC transmission –
undersea cable Tasmania – Australia

Life Science & Health: Neutrons reveal mechanism of bacterial antibiotic resistance

- Bacteria antibiotic resistance due to secreted enzymes (β -lactamases) that digest β -lactam antibiotics
- **Better understanding of the catalytic mechanism of this enzymes (hydrogen positions!) with help of neutrons.**
- Amino acid Glu166 acts as the general base during the catalytic action of the enzyme.

→ **Design better antibiotics**

The enzyme crystal examined at BioDiff in a capillar

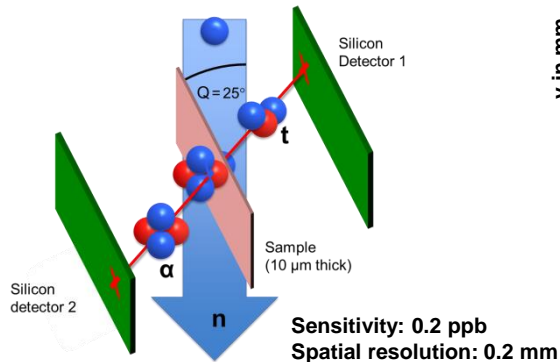


Bipolar disorder - Neutron activation analysis

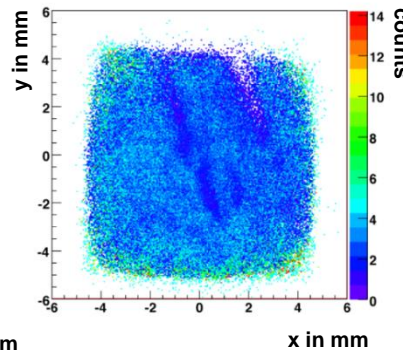
Material testing from an alternative point of view: Lithium Traces in Human Brain Samples

- Bipolar disorder (manic depression) is a relatively common disease with an overall lifetime incidence of **1%**
- Lithium is an effective antimanic agent.
- Still it is not clear how Lithium works in the brain.
- Generate a Lithium map of the human brain!

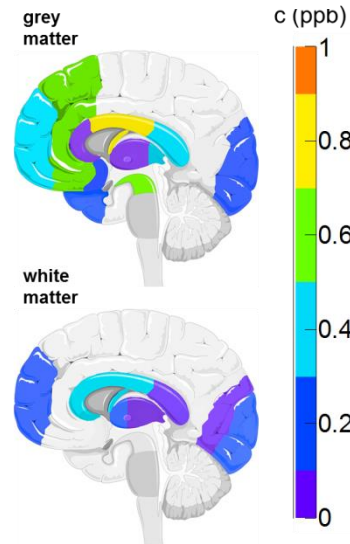
Special detector setup



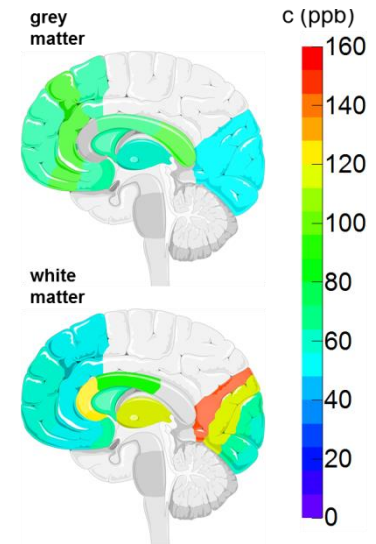
2D Lithium sample



Victim of suicide



Person with Li-treatment

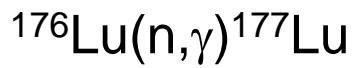


→ **Li accumulation in white matter observed in a number of depressive patients treated with Li**

→ **Li does work, in contrast to other psychotropic drugs, within the nerve tracts themselves**

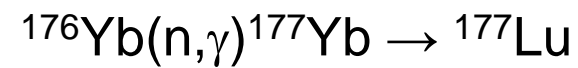
Lutetium-177: General information

Therapeutic Lutetium-177 can be obtained on two different ways:



Hf 176 5.206	Hf 177 18.60		
Lu 175 97.41	Lu 176 2.59	Lu 177	
σ 8	σ 2 + 2100	160.1 d β^-	6.647d β^-
Yb 174 31.8	Yb 175 4.2	Yb 176 12.7	Yb 177 1.9 h
σ 68	β	σ 3	β

Carrier added (c.a.) Lu-177



Hf 176 5.206	Hf 177 18.60		
Lu 175 97.41	Lu 176 2.59	Lu 177	
σ 8	σ 3 + 2070	160.1 d β^-	6.647d β^-
Yb 174 31.8	Yb 175 4.2 d β	Yb 176 12.7	Yb 177 1.9 h β
σ 68		σ 3.1	

No carrier added (n.c.a.) Lu-177

Patient with metastatic prostate cancer (mCRPC)

4 therapy cycles; 6 Gbq Lu-177-PSMA/cycle



8/2015
Ga-68-PSMA PETCT
prior to
Lu-177-PSMA therapy

PSA: 453 ng/ml

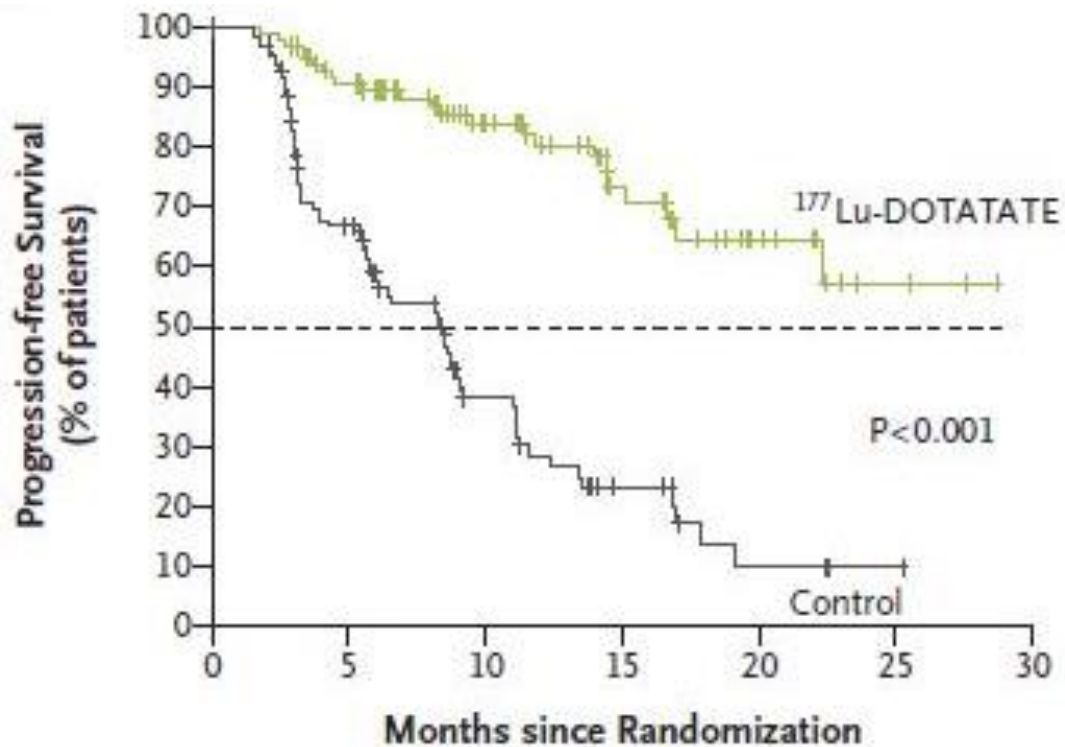


2/2016
Ga-68-PSMA PETCT
Two therapy cycles completed:
Lu-177-PSMA
PSA: 1,77 ng/ml



7/2016
Ga-68-PSMA PETCT
Four therapy cycles completed:
Lu-177-PSMA
PSA: 0,85 ng/ml

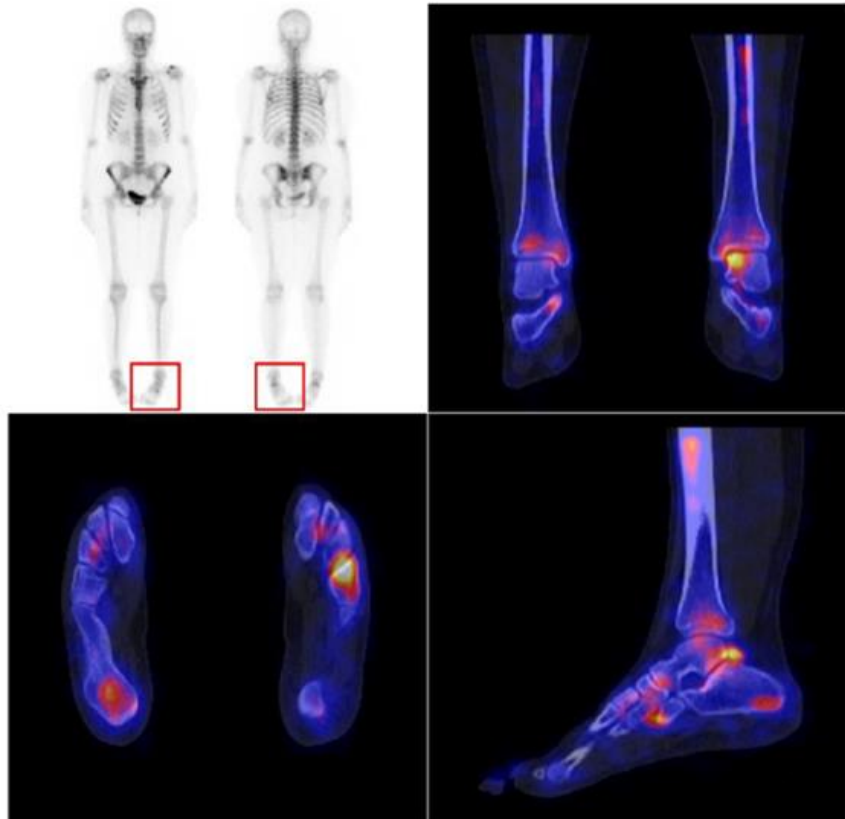
Lu-177-DOTATATE Therapy of neuroendocrine tumors (NET) Phase 3 Study of Lu-177-DOTATATE (NETTER1-trial, N=229)



Strosberg et al. *N Engl J Med.* 2017; 376(2):125-135

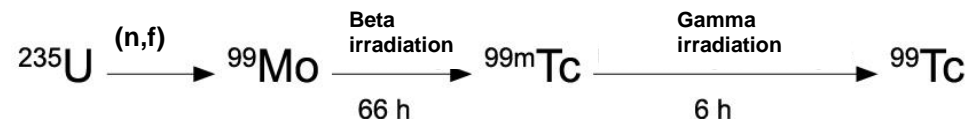
Diagnostics: Most common used isotope Mo-99/Tc-99m

- Sustainable supply with Mo-99 is mandatory for millions of patients worldwide
- Most efficient and mostly used method to produce Molybdenum-99 is by irradiation of U-235 targets
- → **30 mio examinations per year**
 - Investigation of thyroid function
 - Diagnosis of diseases of
 - lungs
 - heart
 - liver,
 - skeletal apparatus,
 - Inflammation, etc.



Bone scintigraphy of an ankle joint by means of Tc-99m

→ bright areas show an abnormally increased bone metabolism indicating an inflammation



Diagnostics: Reliable Mo-99 supply in future ?

- Challenges due to decay of Mo-99:
 - No storage of Mo-99 possible
 - Transport logistics within supply chain needs to be well coordinated
- Yesterday's production: **mainly 8 reactors** worldwide (with 5 > 40 yrs old)



© Mallinckrodt
Pharmaceuticals

- **Risks of unplanned outages** as well as planned maintenance periods and **shut downs** between 2015-2025

Diagnostics: Reliable Mo-99 supply in future ?

- Challenges due to decay of Mo-99:
 - No storage of Mo-99 possible
 - Transport logistics within supply chain needs to be well coordinated
- Current production: **mainly 6 reactors** worldwide



Diagnostics: Reliable Mo-99 supply in future ?

- Challenges due to decay of Mo-99:
 - No storage of Mo-99 possible
 - Transport logistics within supply chain needs to be well coordinated
- Tomorrow: **mainly 8 reactors** worldwide (with 3 brand new)



- **Outlook: Routine operation of Mo-99**
 - at FRM II in 2019,
 - at Jules Horowitz in 2021

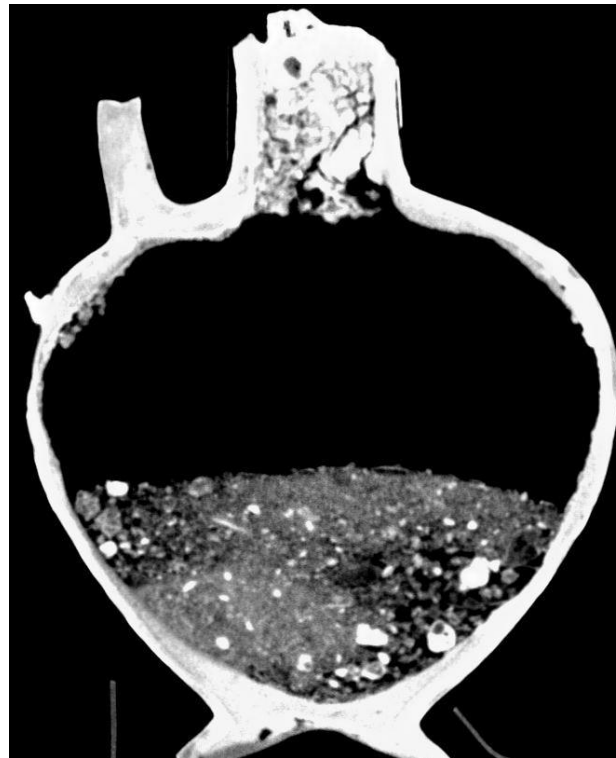
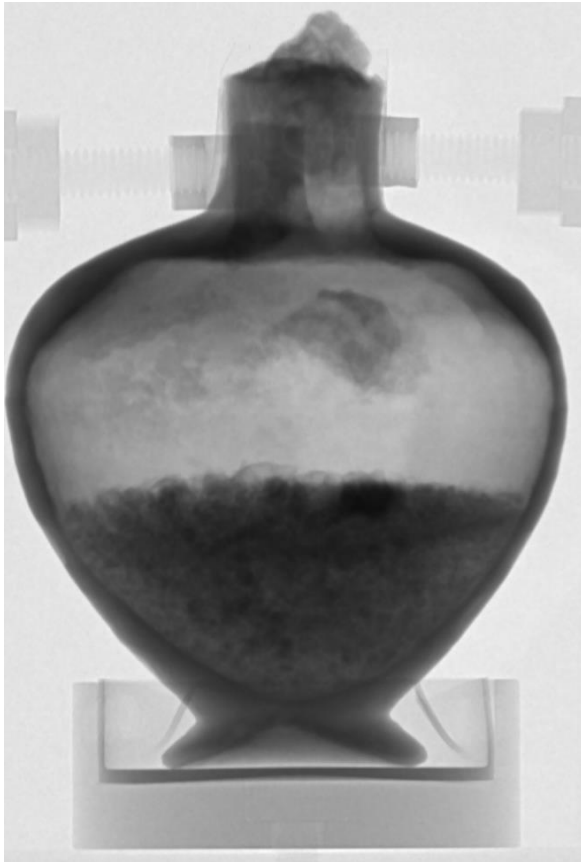
Curiosity: Cultural heritage

Sealed Roman vase/amphora, presumed empty

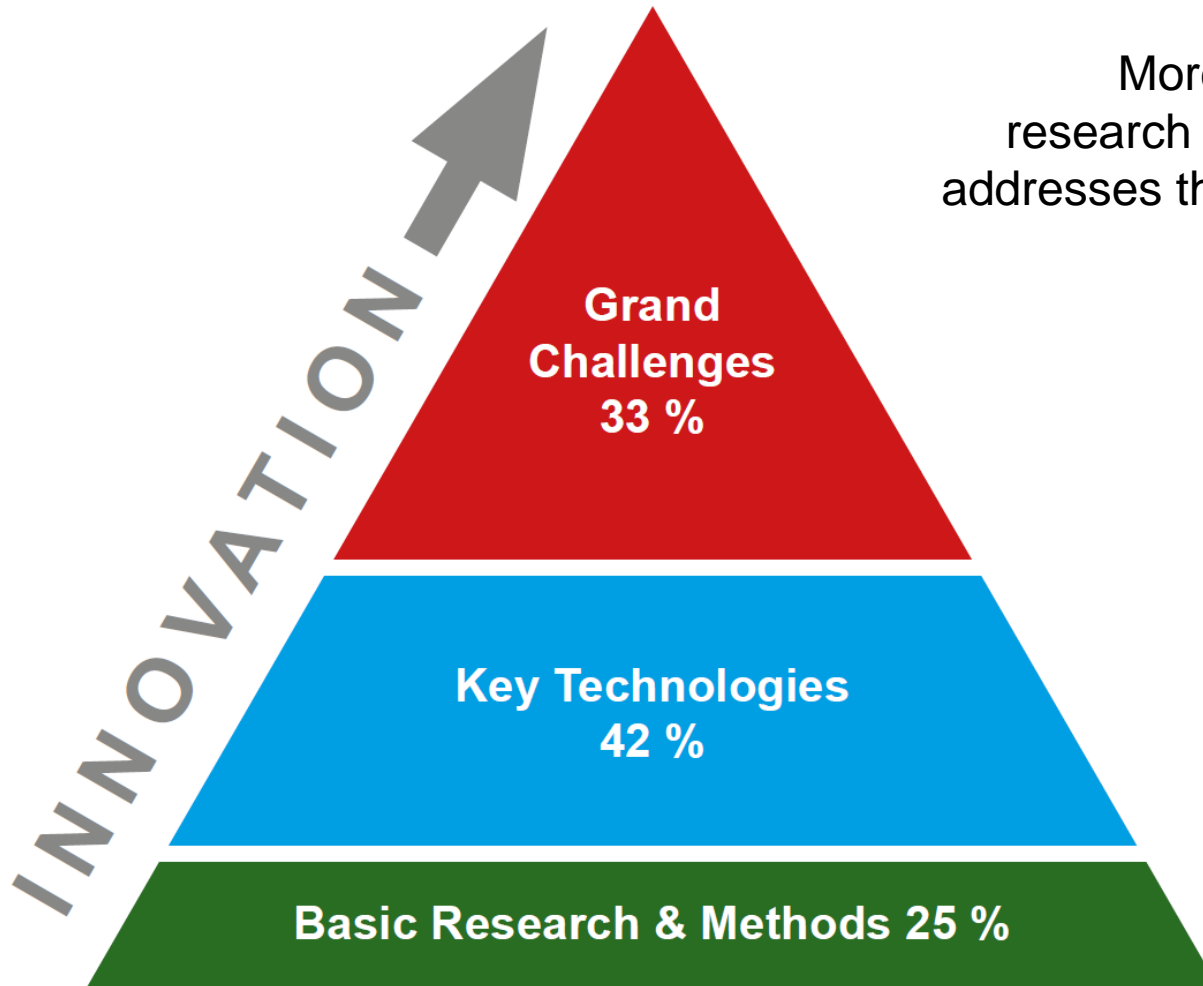


Curiosity: Cultural heritage

Neutron tomography reveals plant seeds!



Neutrons for innovation – example MLZ



More than one third of the research performed at the MLZ addresses the **Grand Challenges** of today's society.

Basic Research & Methods are required to tackle the **Key Technologies**.

**Neutrons in the heart
of the campus of Garching**

