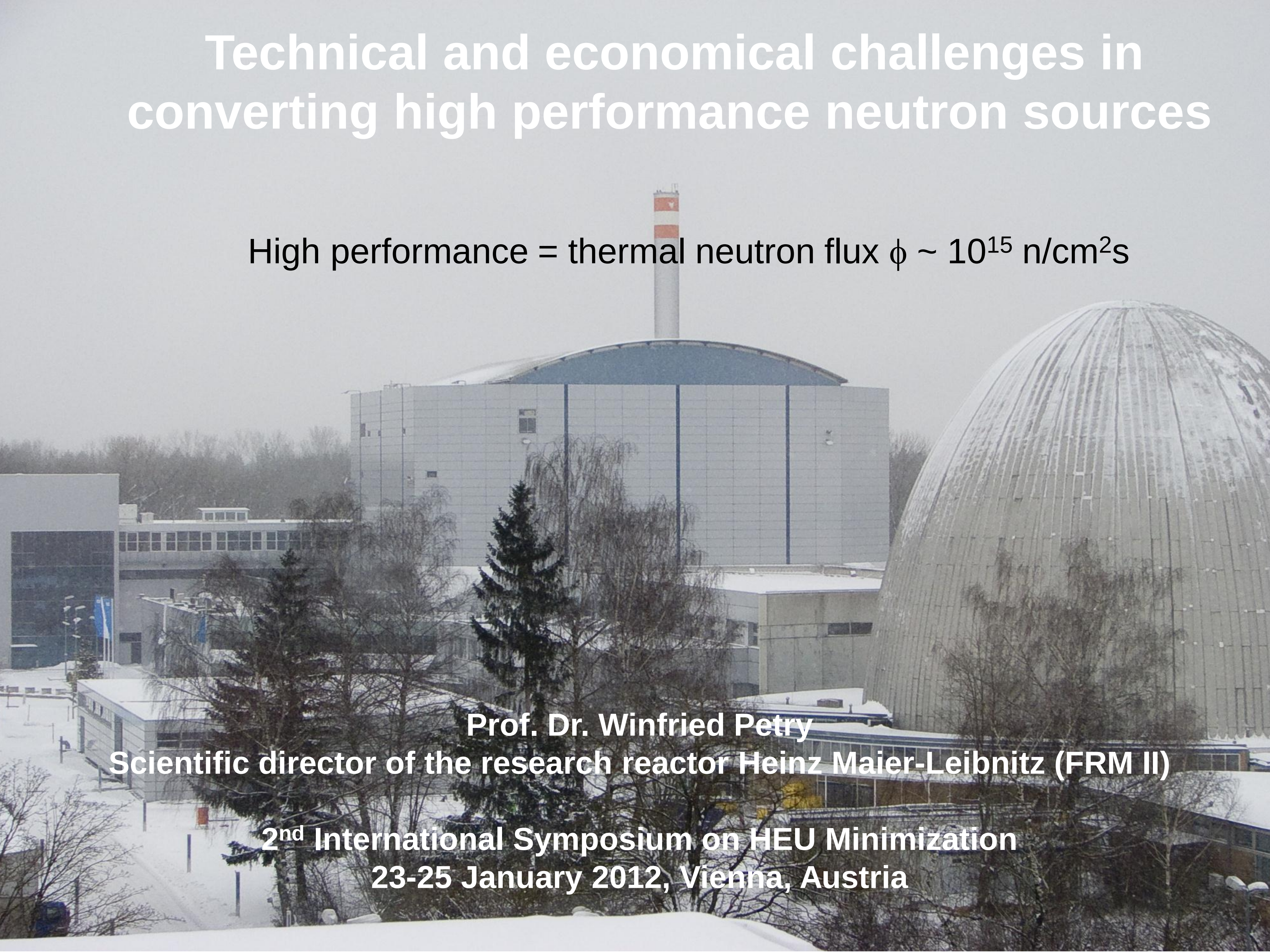
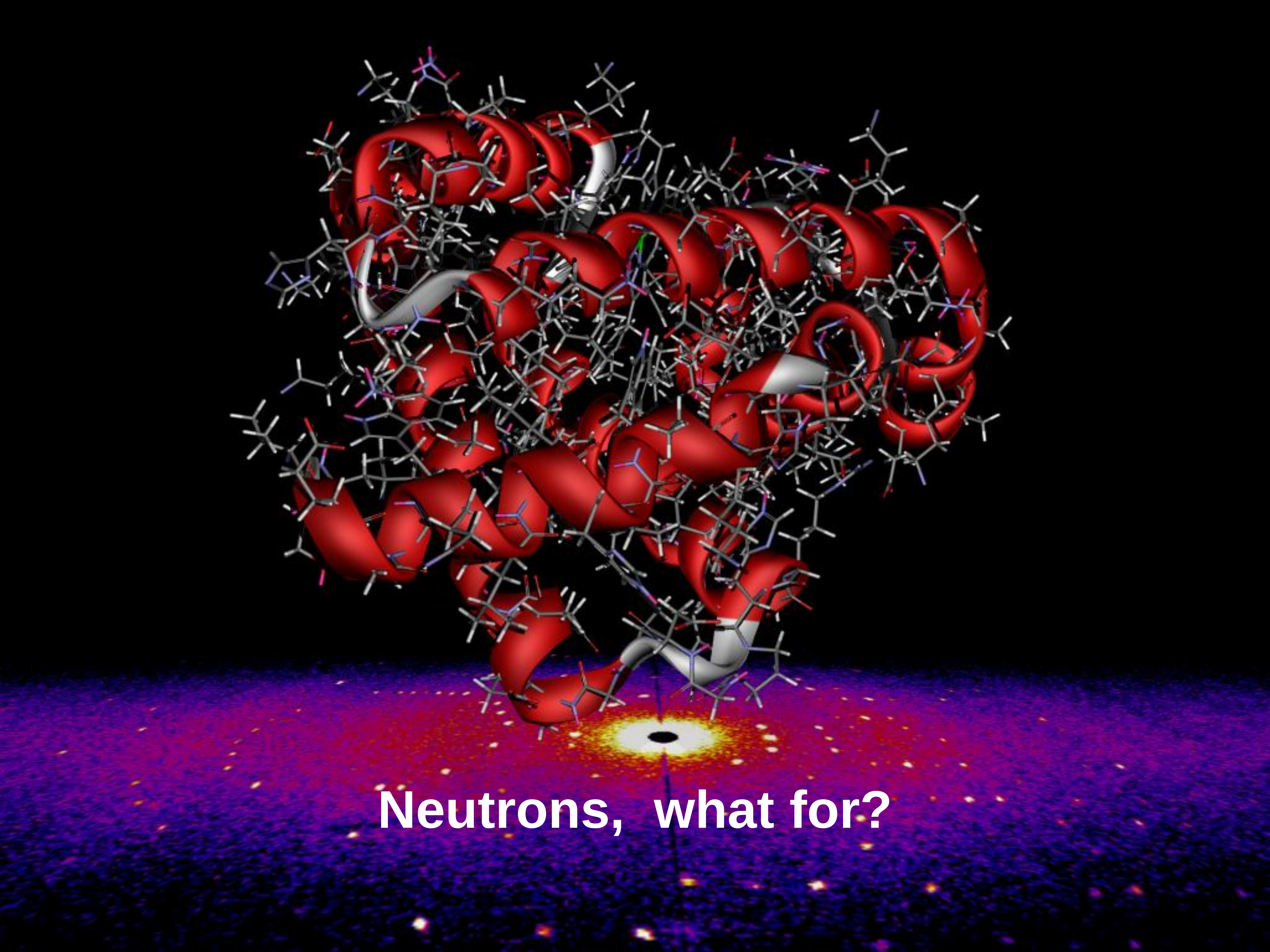
Technical and economical challenges in converting high performance neutron sources



High performance = thermal neutron flux $\phi \sim 10^{15}$ n/cm^{2}s

Prof. Dr. Winfried Petry
Scientific director of the research reactor Heinz Maier-Leibnitz (FRM II)

2nd International Symposium on HEU Minimization
23-25 January 2012, Vienna, Austria



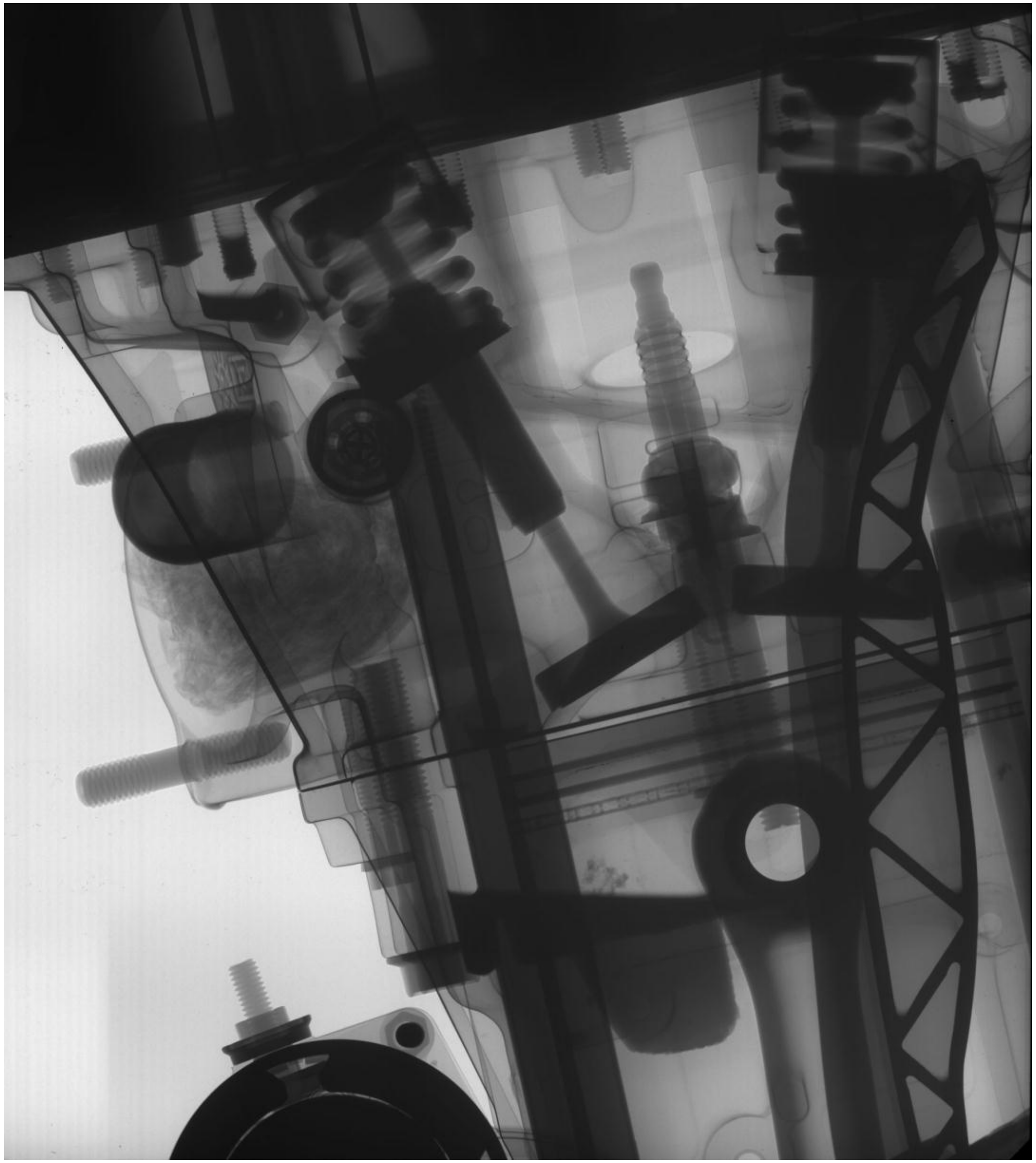
Neutrons, what for?

Neutrons give answers to the grand challenges of modern society

- information technology
- nano technology & innovative materials
- energy   (storage, transport, transformation)
- health
- mobility
- ...
- curiosity

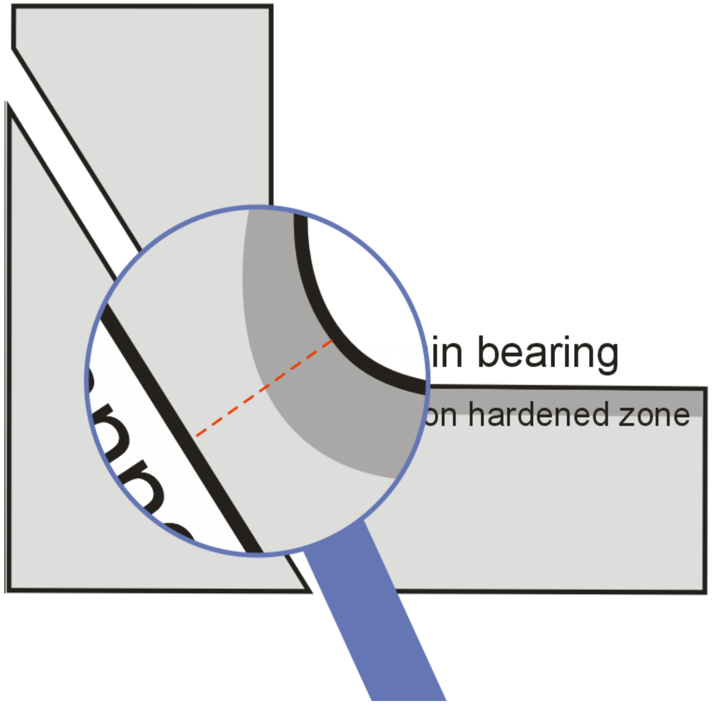
One cylinder engine

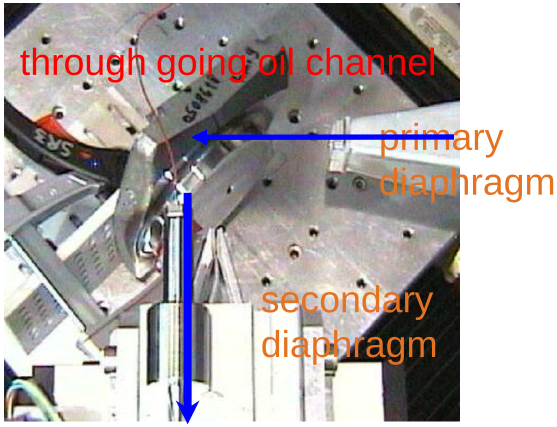
high resolution radiography

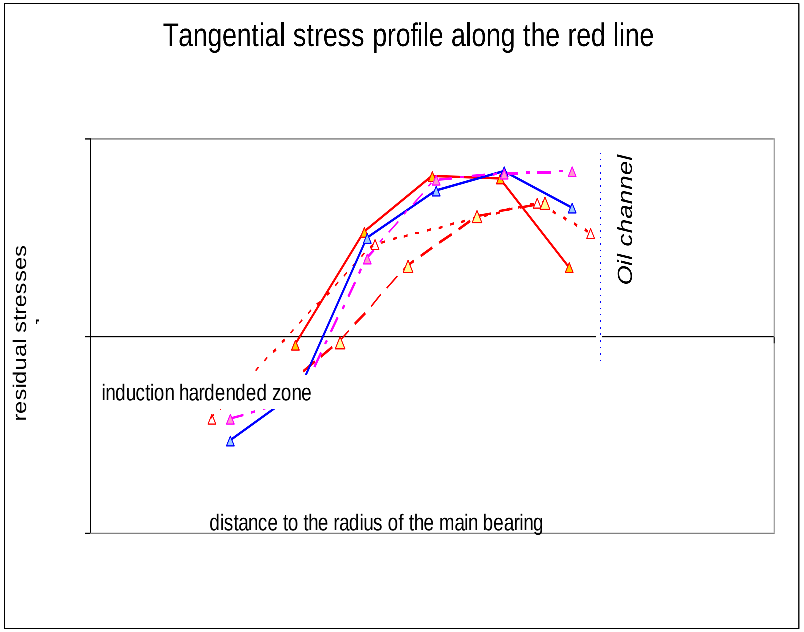


Schillinger et al, FRM II

Optimisation of a crank shaft







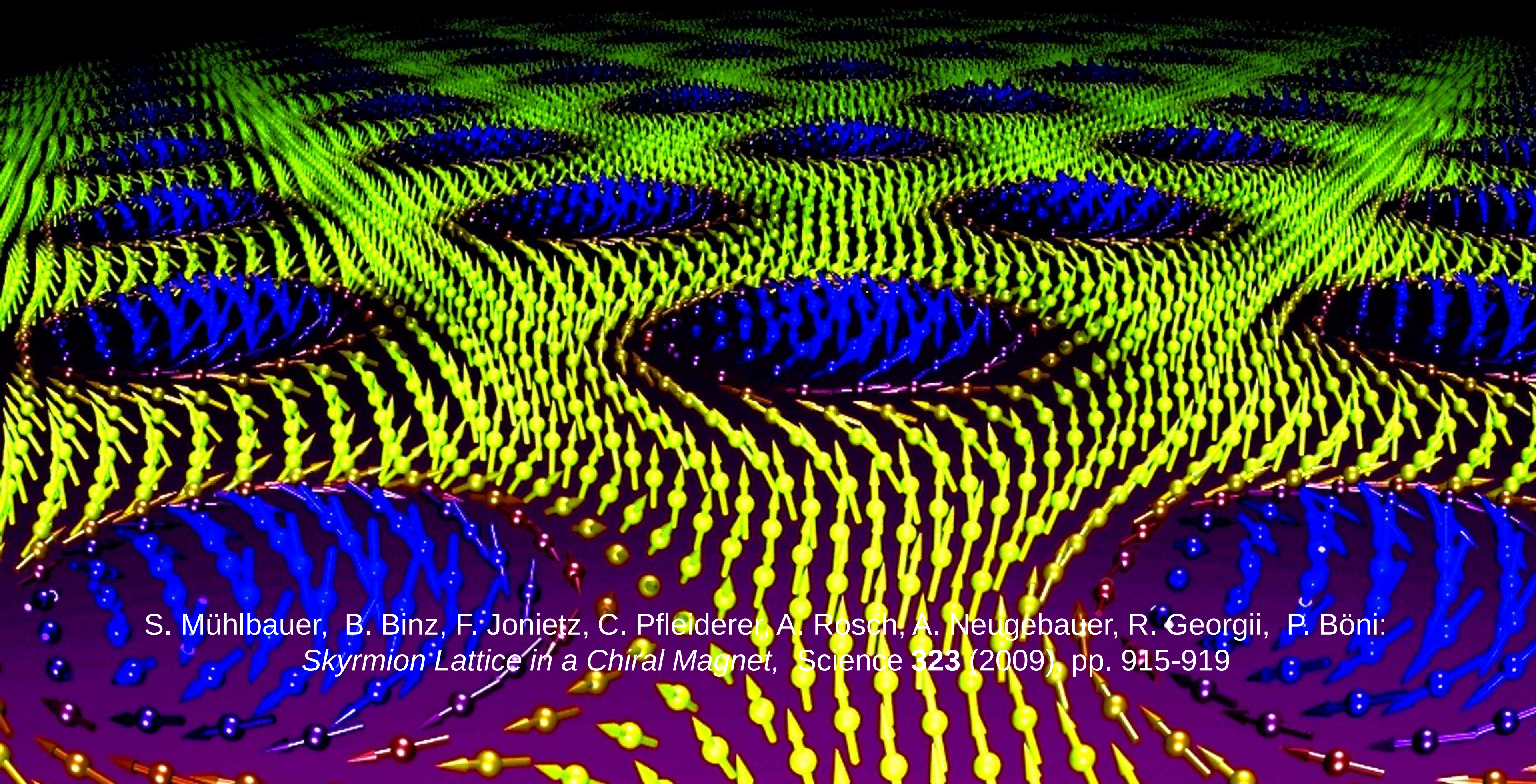
Innovative triple-axis-spectrometer at FRM II

- → 100 times better than others
- → enables answering completely new questions
- → like understanding supra conductivity

Keller, Buchner, Keimer, MPI-Stuttgart

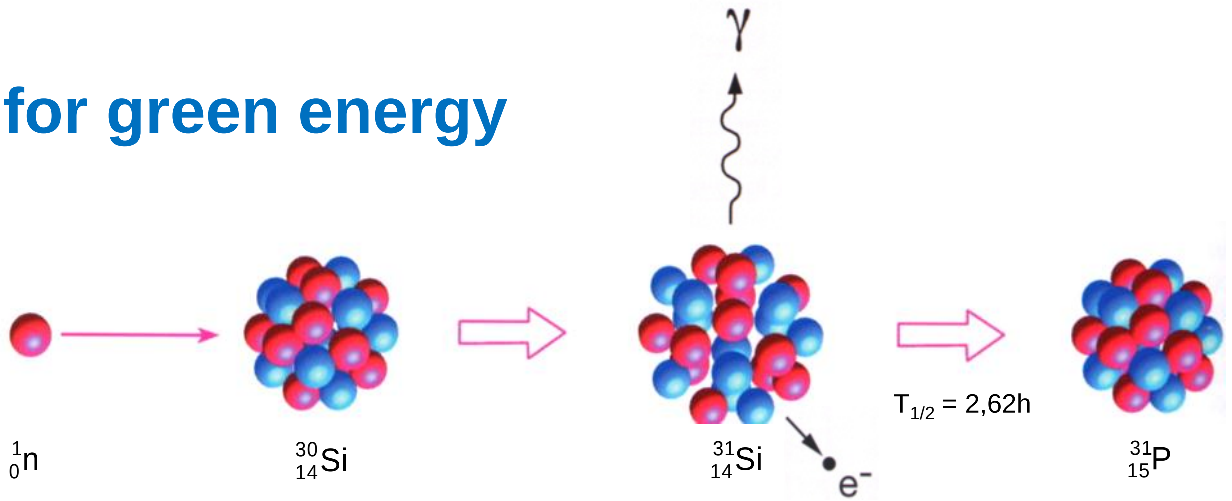
New kind of magnetic storage on a nanoscopic scale

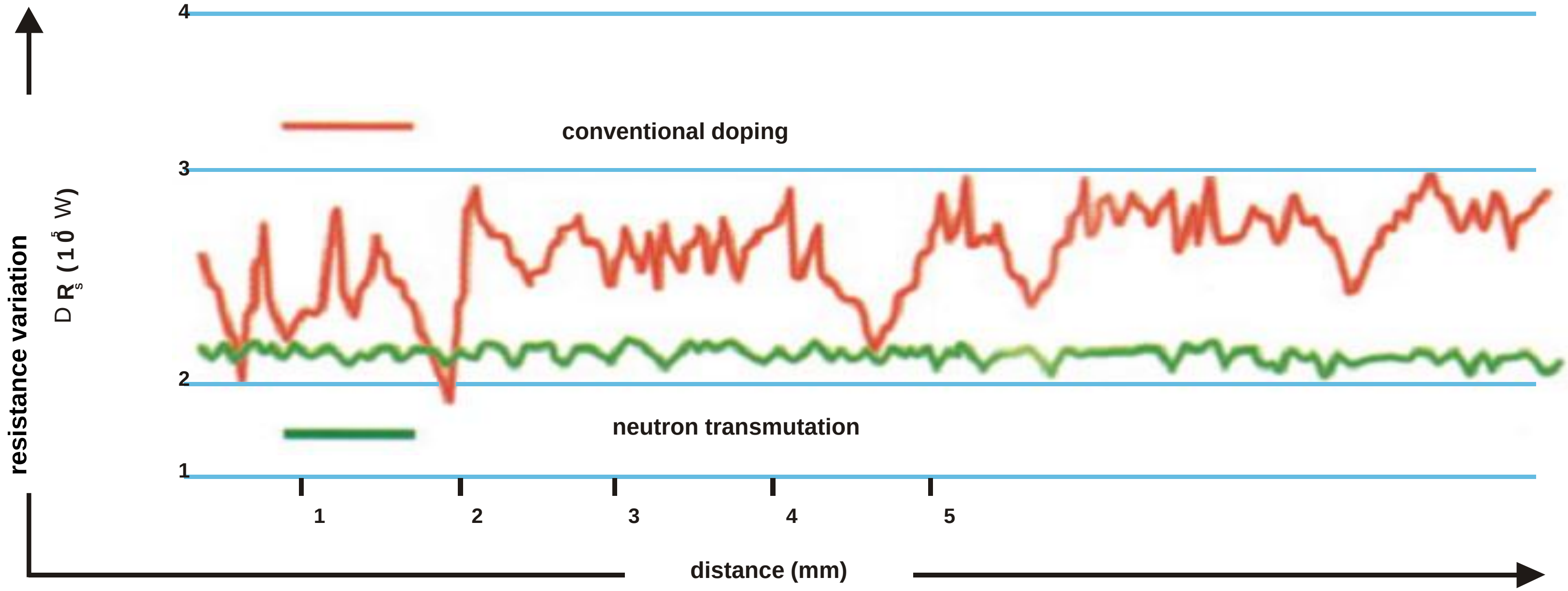
Skyrmion lattice in MnSi



S. Mühlbauer, B. Binz, F. Jonietz, C. Pfleiderer, A. Rosch, A. Neugebauer, R. Georgii, P. Böni: *Skyrmion Lattice in a Chiral Magnet,* Science **323** (2009), pp. 915-919

Silicon doping for green energy

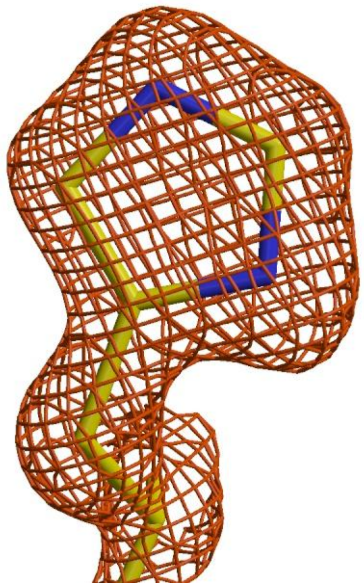




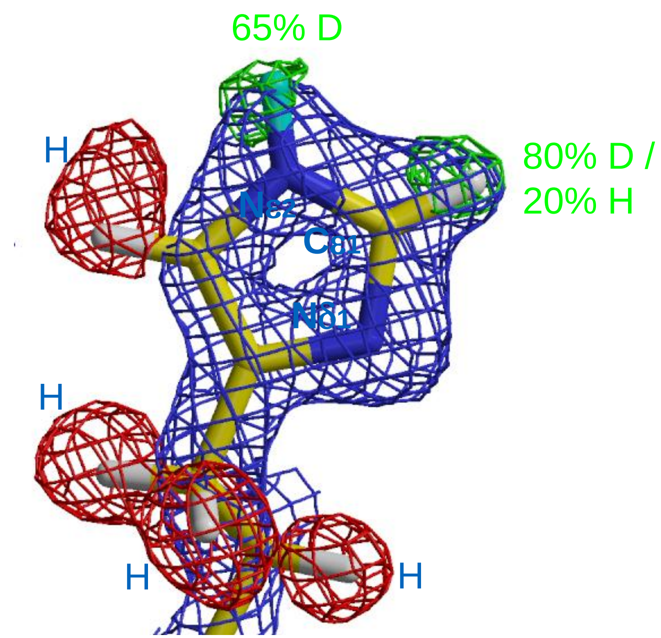
Neutron structure analysis: where are the H-atoms in proteins?

X-ray d_{min}= 1.5Å:

Neutrons d_{min}= 1.5Å:



▭ 2Fo-Fc Mappe; +1.5σ



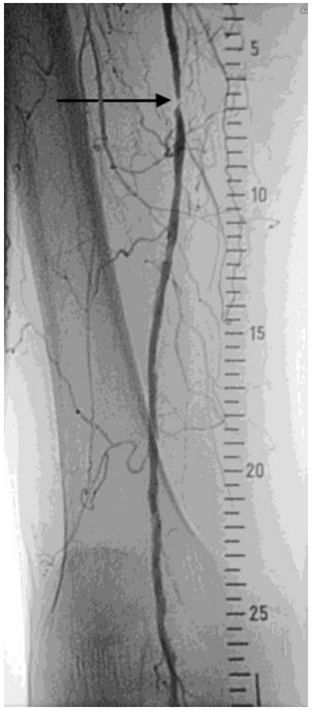
▭ 2Fo-Fc Mappe; +1.5σ

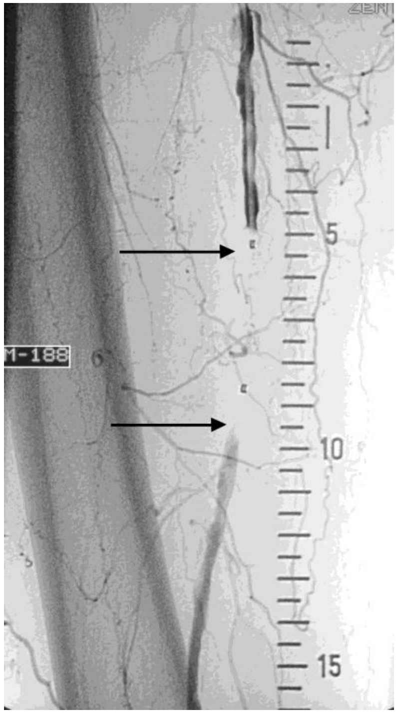
▭ Fo-Fc omit-Mappe; -3.0σ

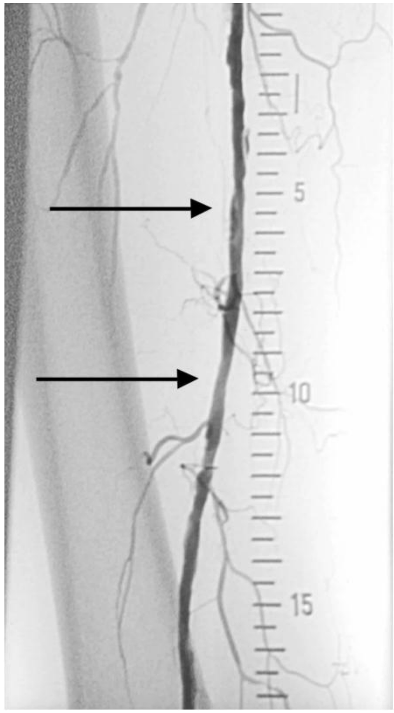
▭ Fo-Fc omit-Mappe +3.0σ

Ostermann A, Tanaka I, Engler N, Niimura N, Parak F (2002) Biophys. Chem. 95:183

^{188}Re for better radiopharmaceuticals



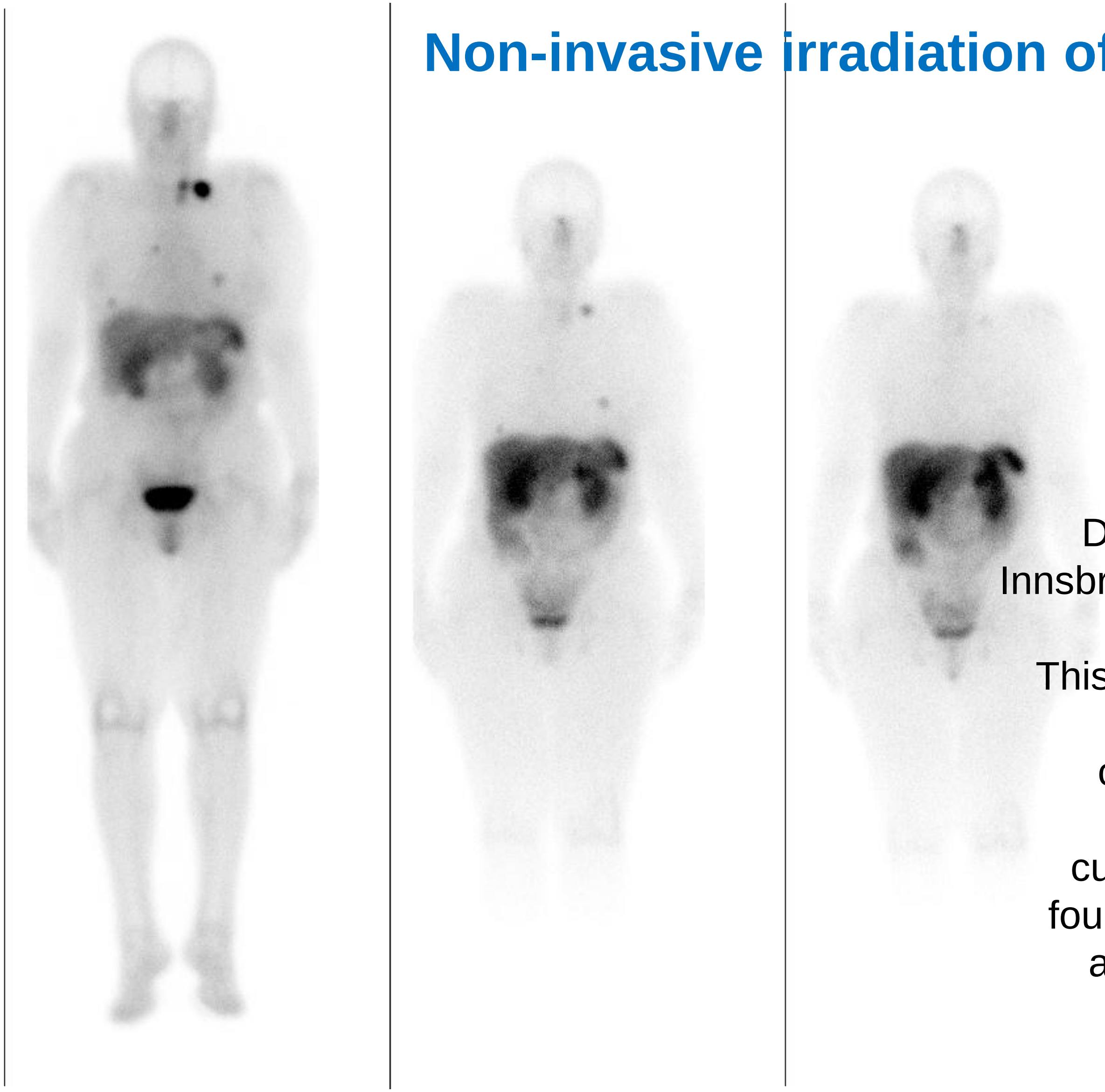




→ Klinikum Augsburg, brachytherapy of a vein contraction

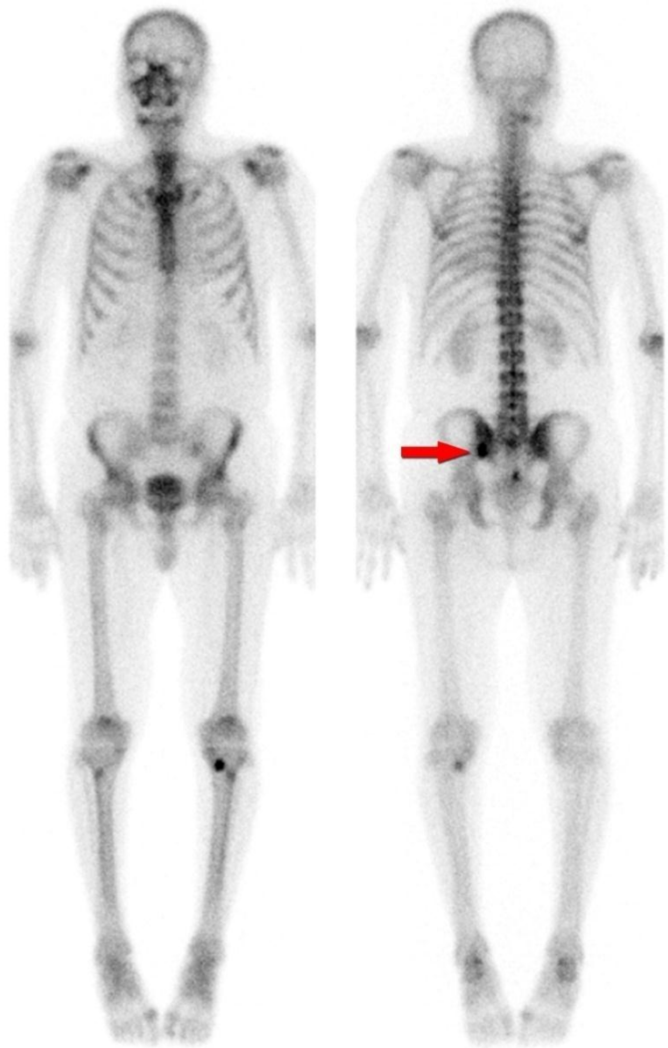
^{177}Lu for better radiopharmaceuticals

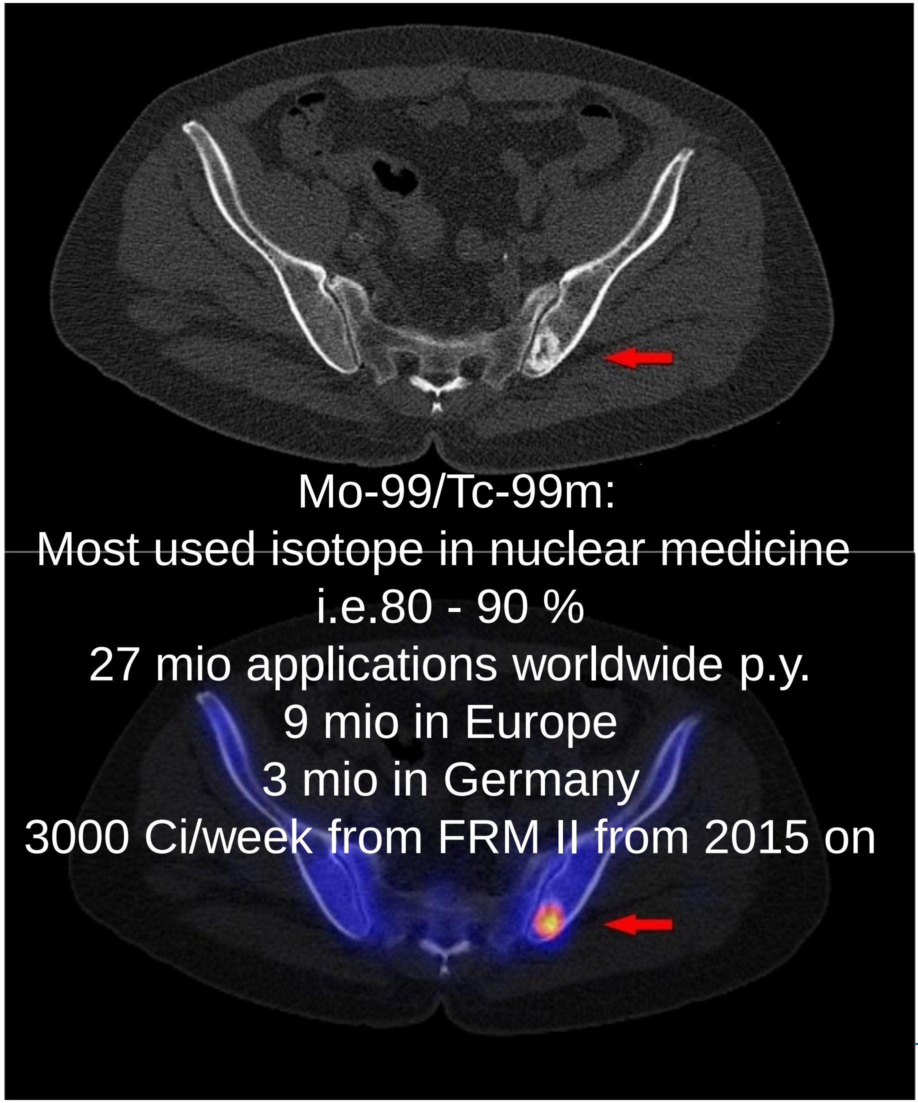
Non-invasive irradiation of metatasis by ^{177}Lu



Department of Nuclear Medicine; Innsbruck Medical University; Austria"
.
This 71-year old female patient with a metastatic medullary thyroid carcinoma was treated by ^{177}Lu-DOTA-TATE five times with a cumulative dose of 37GBq. It was found excellent response on PRRT as documented also by the post-therapy scans 24 hours p.i.”

Scintigraphy of tumors

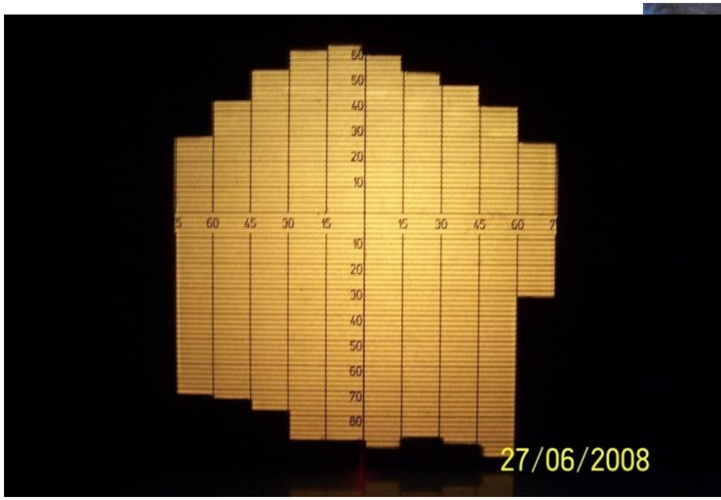




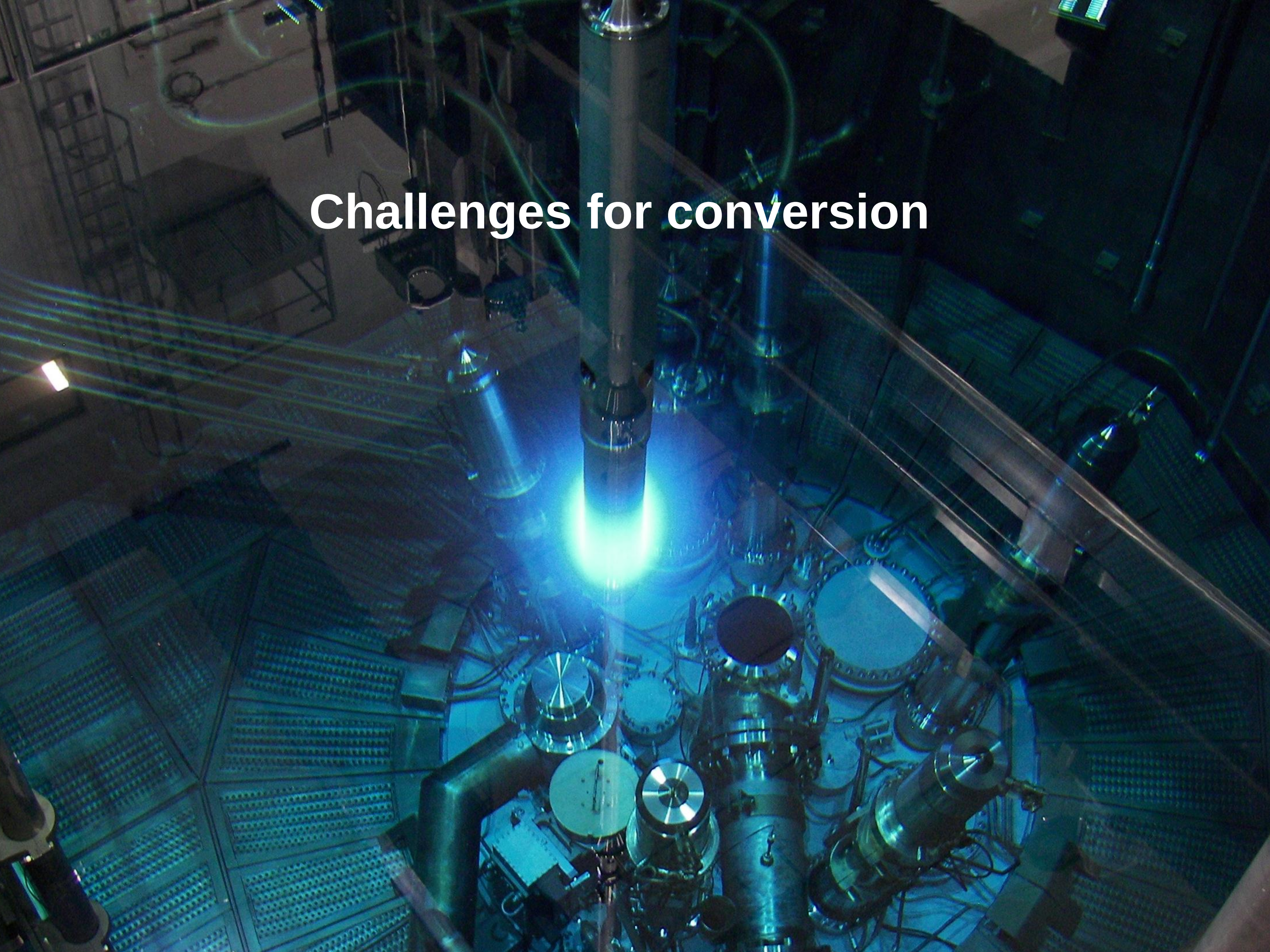
Mo-99/Tc-99m:
Most used isotope in nuclear medicine
i.e.80 - 90 %
27 mio applications worldwide p.y.
9 mio in Europe
3 mio in Germany
3000 Ci/week from FRM II from 2015 on

Hadron therapy with neutrons

Neutrontherapy for breastwall-metas; breast-Ca



Challenges for conversion



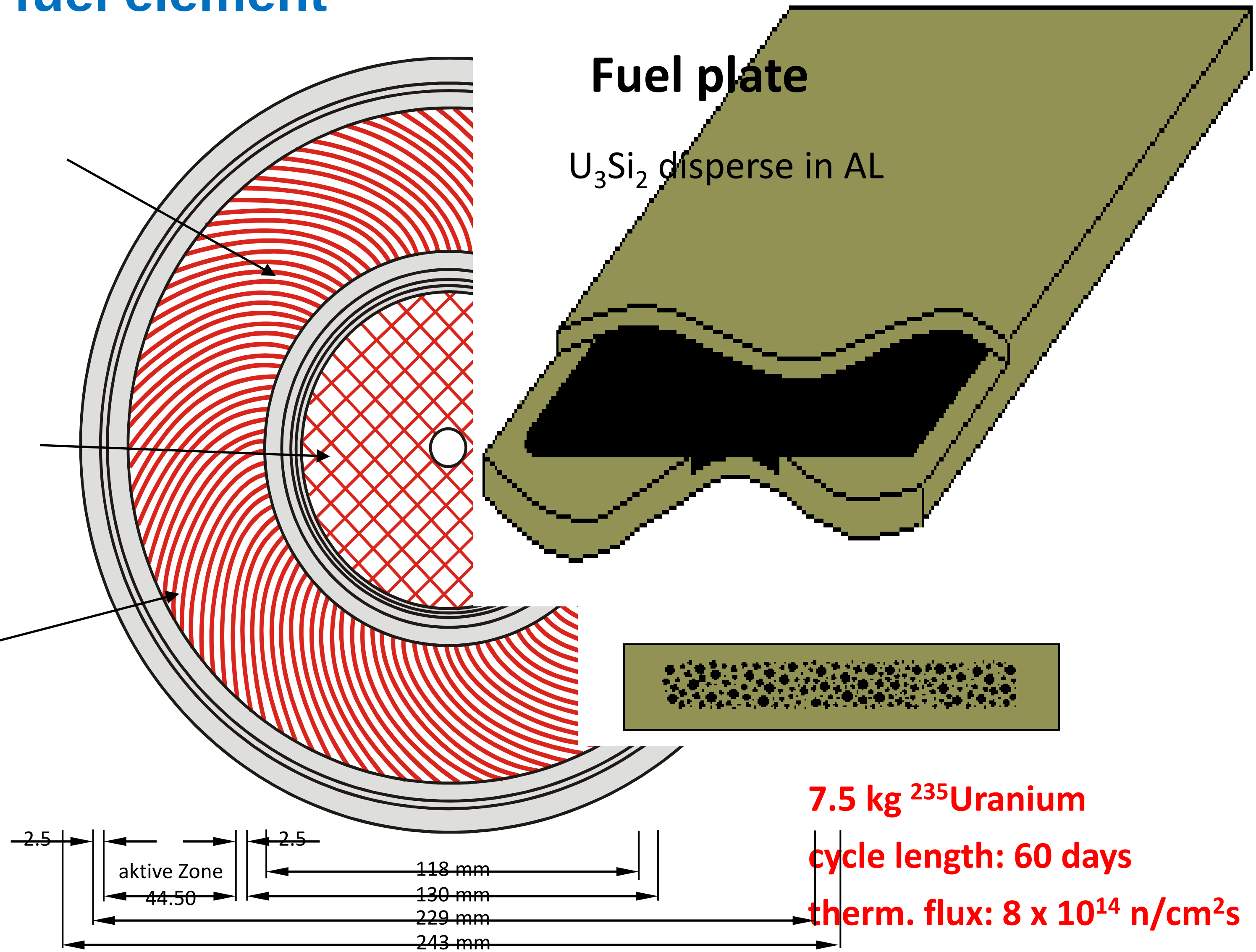
High performance neutron sources in West-Europe

Compact fuel element of FRM II

Fuel plates

Control rod

Cooling channel

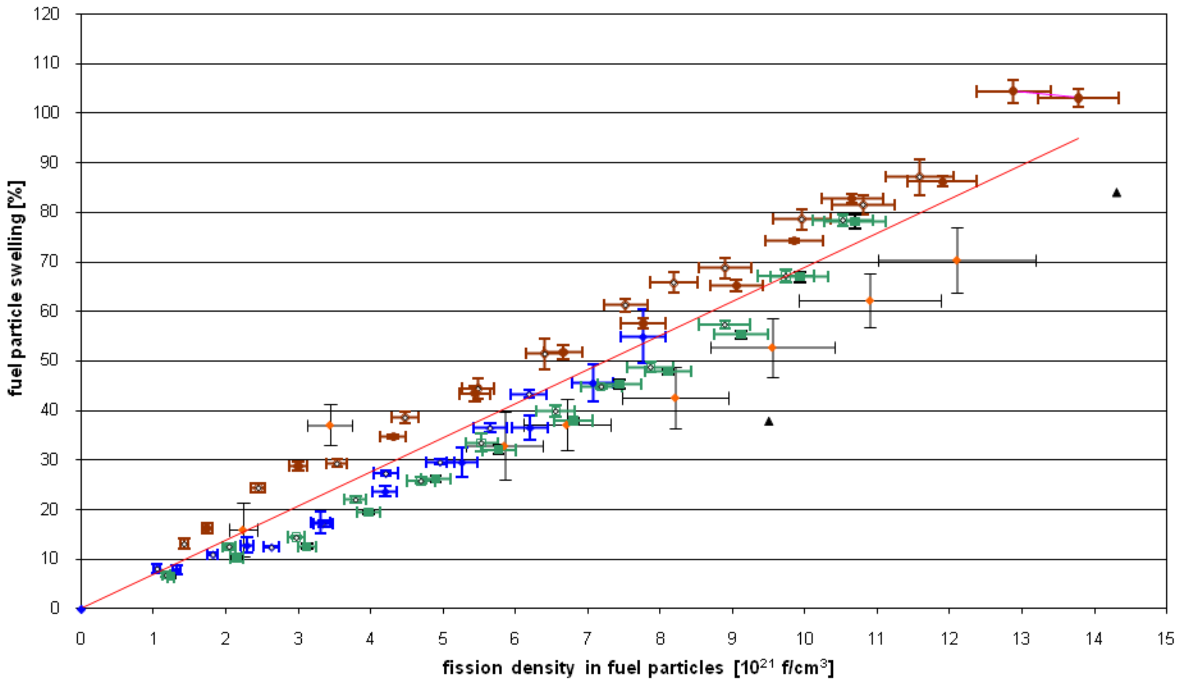


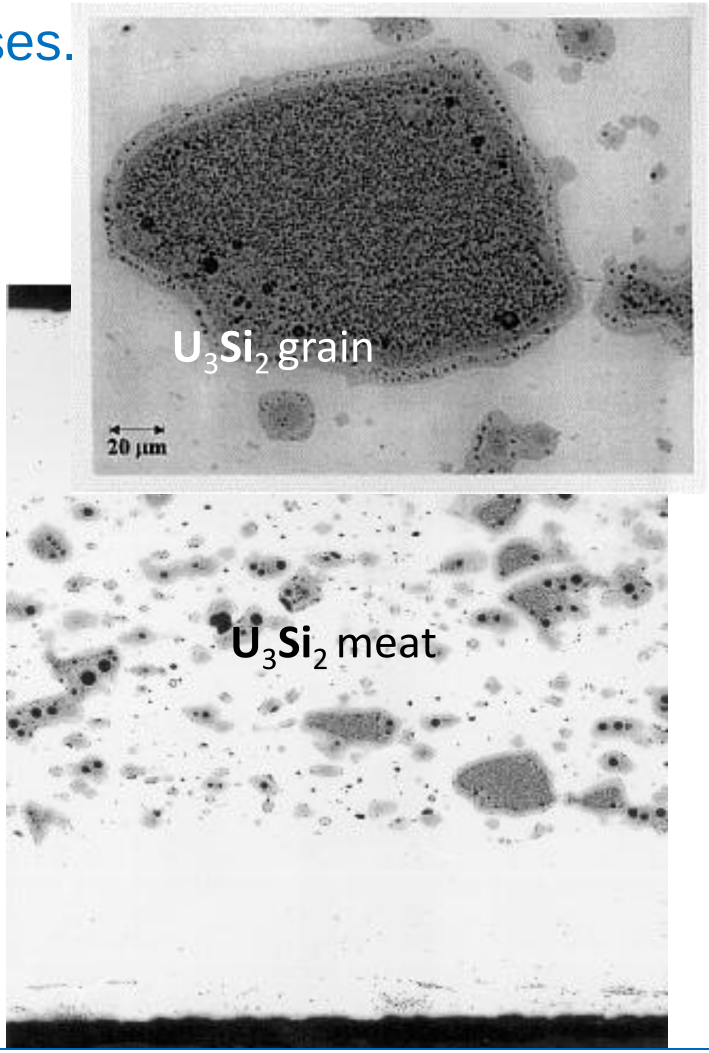
7.5 kg ^{235}Uranium

cycle length: 60 days

therm. flux: 8 x 10^{14} n/cm^{2}s

U_3Si_2 is an approved and reliable alloy for high performance research reactors.
It accommodates huge amounts of fission gases.

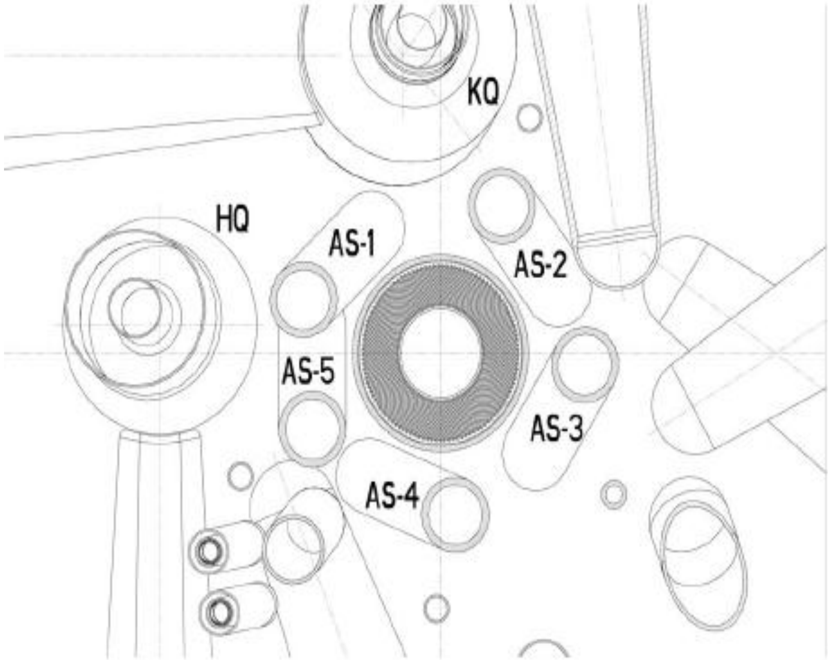


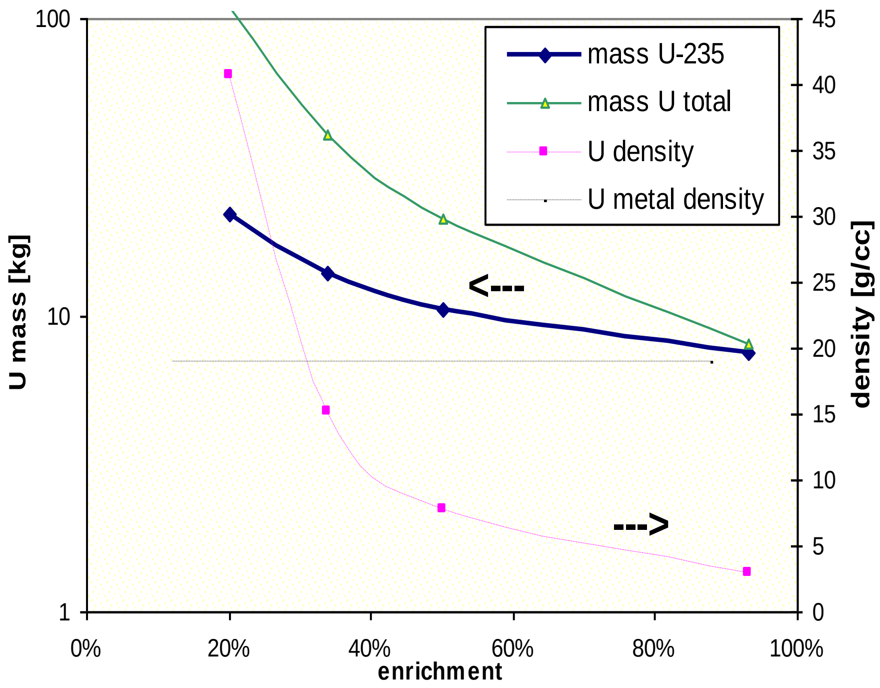


Linear swelling of the fuel plates as function of burn-up !

⇒ U_3Si_2 dispers in Al is a save fuel!

Limits for fuel depletion (at FRM II)





Safety rods very near to the core.

The compact geometry is optimised for a max. neutron flux at lowest thermal power.

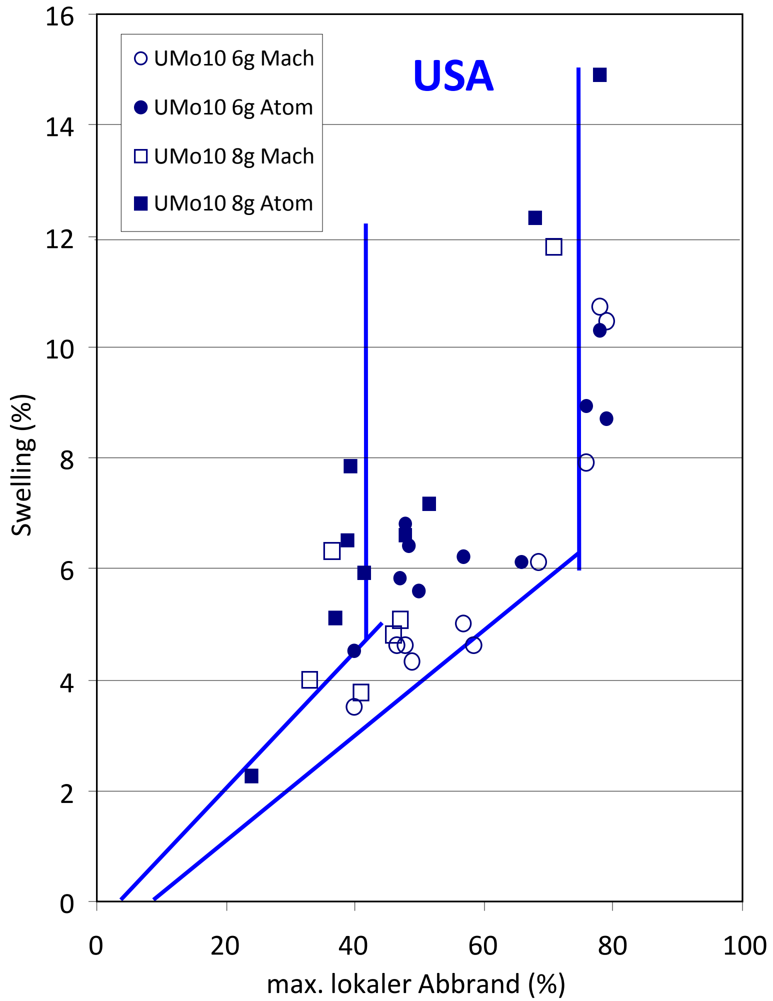
⇒ No change in geometry possible !

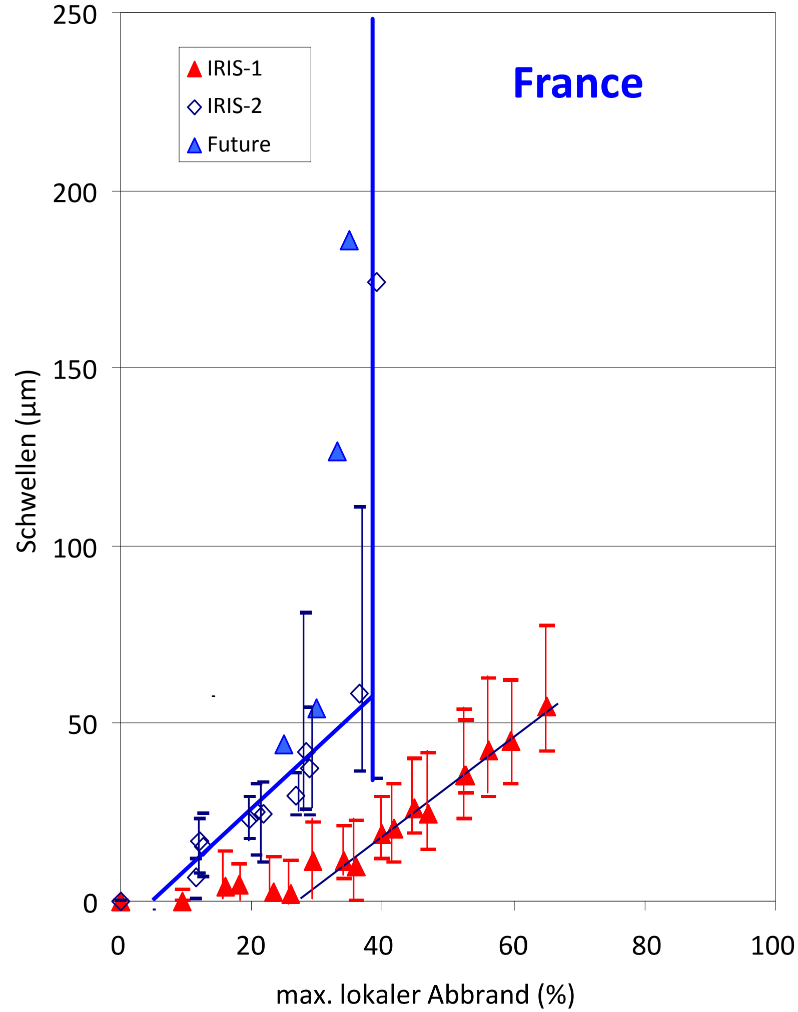
⇒ Reduction of enrichment only by increase in density of Uranium !

Scenarios for depleted fuel at FRM II

enrichment [%]	93	50	34	20
fuel	U_3Si_2 dispers	U8Mo disperse	U8Mo monolithic	fictive, impossible
meat density [g/cm^3]	3	8	15	40,5
neutron loss [%]	0	8	>10	>>10
total U mass [kg]	8	21,4	41	110
^{235}U mass [kg]	7,5	10,7	14	22
Pu production [g]	13,8	87,7	137,3	253,8
used ^{235}U in [%]	20	14	10,7	6,8
increase of the radioactive inventory after 500 years decay	-	6,3	10	~ 20

U8wt%Mo as potential fuel with densities ρ ≤ 15g $^{235}U/cm^3$



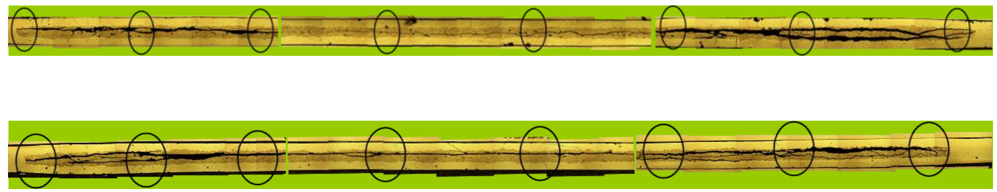


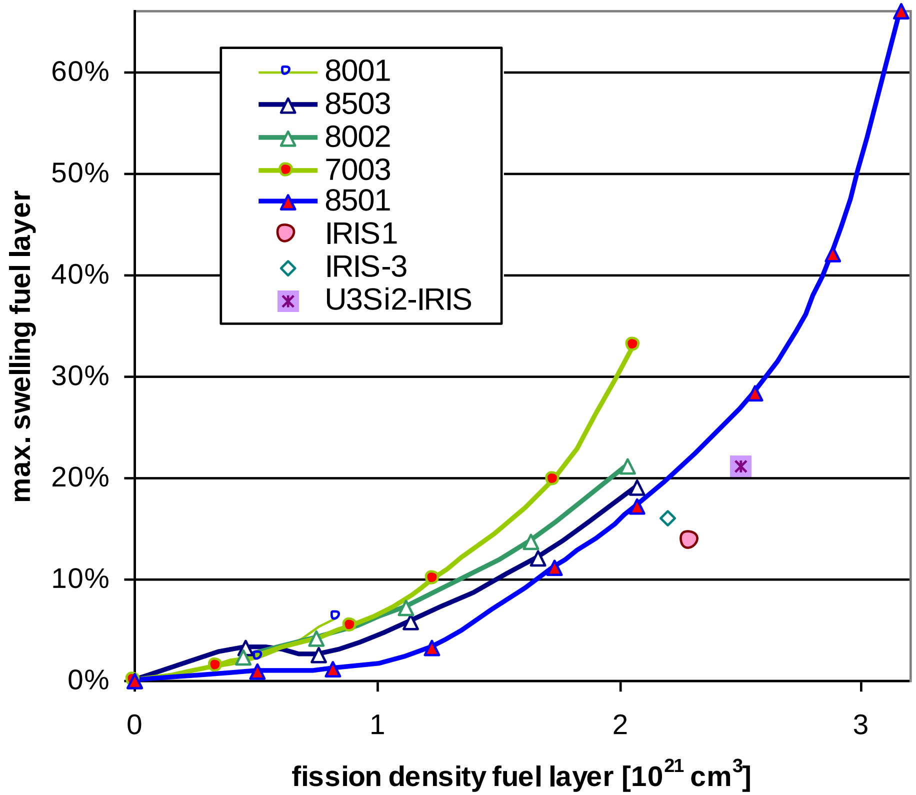
⇒ **swelling of US RERTR mini plates and full size French plates**

UMo dispers, IRIS-TUM

8002T

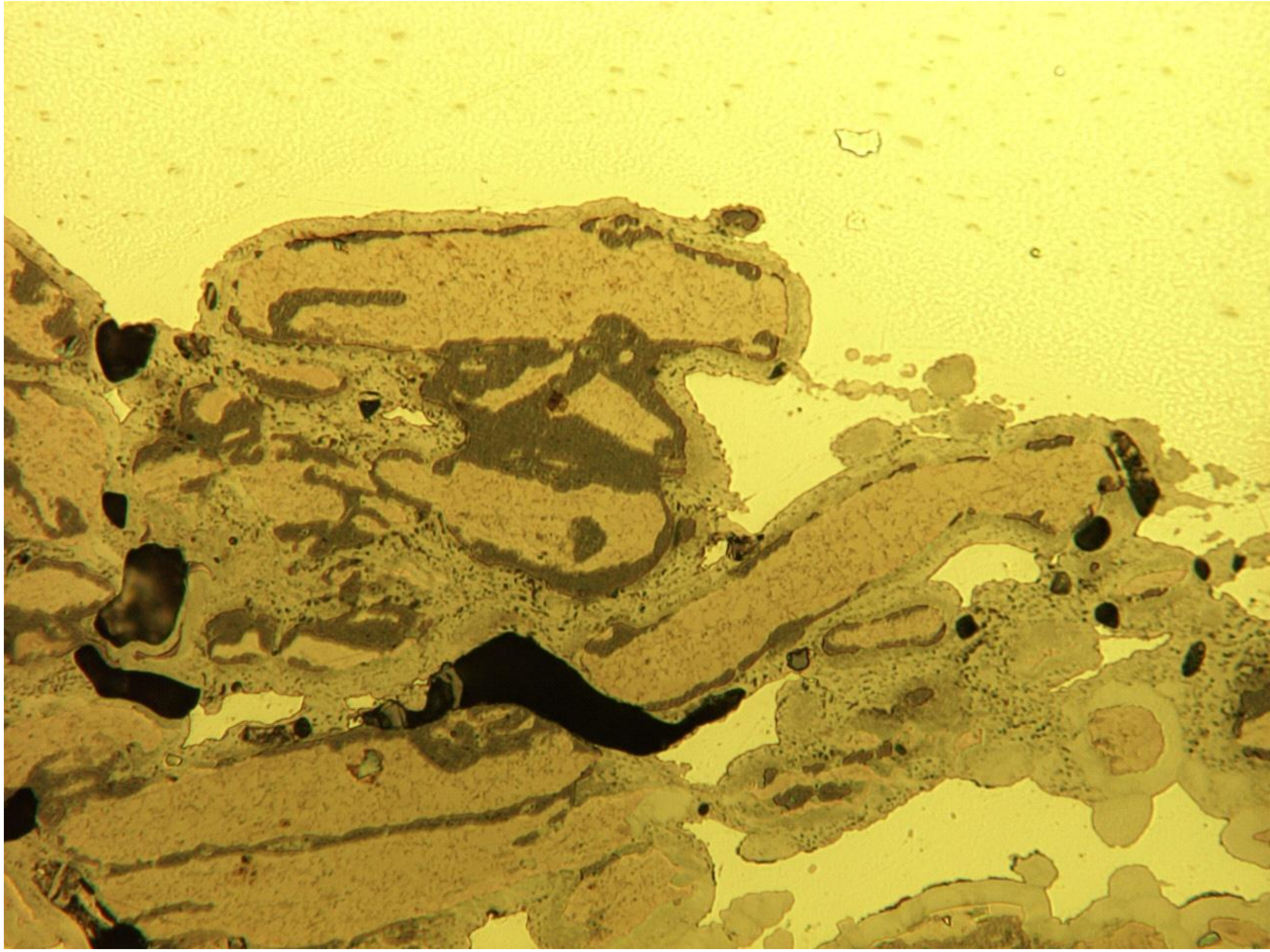
8503T





heat load 270 Watt/cm^2
80% LEU equivalent burn up
⇒ no break away, but non-linear swelling

UMo dispers, IRIS-TUM



Typical SEM picture:

⇒ Formation of an irradiation induced diffusion layer (IDL)

⇒ Pore formation at the outer interace of the IDL responsible for critical swelling

Development of high density fuels - current status at an international level

- U8wt%Mo powder dissolved in Al, disperse, ρ = 8 gU/cm^3,
  - advantages: industrial maunfacuring processes established, failure tolerant,
  - challenges: formation of an interdiffusion layer IDL during in-pile irradiation, IDL does not accomodate fission gases $\Rightarrow$ break-away-swelling, blistering, non linear swelling,
  - solution: coating of particles with diffusion barrier,
  - allows conversion of most high performance reactors, FRM II reaches 50% enrichment.

- U8wt%Mo monolithic, ρ = 15 g^{235}U/cm^3,
  - advantage: no problems with IDL due to coating,
  - challenges: failure intolerant, no cost efficient industrail production available,
  - allows to reach LEU for almost all reactors, FRM II reaches ~ 35% enrichment.

- The 2 alternative alloys/techniques are still waiting for qualification.
- Once qualification reached, each country has to run through its own nuclear safety analysis.
- Industrial fabrication has to be established in USA and Europe.
- USA intend to convert all 6 high performance RR to UMo monolitic.
- After the failure of the last test irradiation E-FUTURE the conversion of West Eurpean reactors is scheduled for 2018/2019

Current status - TUM

UMo dispers:

- Test irradiation IRIS-TUM finished.
- Qualification of manufacuterer to produce UMo powder
- Materials development ,
- Simulation of in-pile irradiation by heavy ion bombardement.

UMo monolithic:

- Qualification of CERCA to manufacture UMo monolithic fuel plates, TUM Sputtertechnik, CERCA hotrolling, monolithic foils from USA
- Test irradiations of those in USA and Europe

Materials down selection

- Strong collaboration between TUM, CERCA, CEA, SCK-CEN, DOE
- Simulation of in-pile radiation damage by irradition with heavy ions
- Measurement of thermal conductivity of UMo,

Calculations of possible future high density cores for FRM II including cooling properties

Back end – where to put the spent fuel

- Spent fuel of research reactors should be reprocessed,
  $\Rightarrow$ minimisation of nuclear waste,
  $\Rightarrow$ feeding back of ^{235}U into fuel cycle, no proliferation risk !

- UAl_x spent fuel can be reprocessed.

- UI_3Si_2 may be reprocessable ?

- Up to now no knowledge about reproccessing UMo including Si or other coatings !

- Spent fuel handling will dominate the total cost of the fuel cycle, i.e. of operating research reactors!


conversion working group at FRM II:
today 15 persons + students;
2 coworkers detached to french laboratories, 1 person detached to US lab
Since 2004 52 publications, PhD thesis, Diploma thesis.


Neutrons in the heart of the Garching campus –