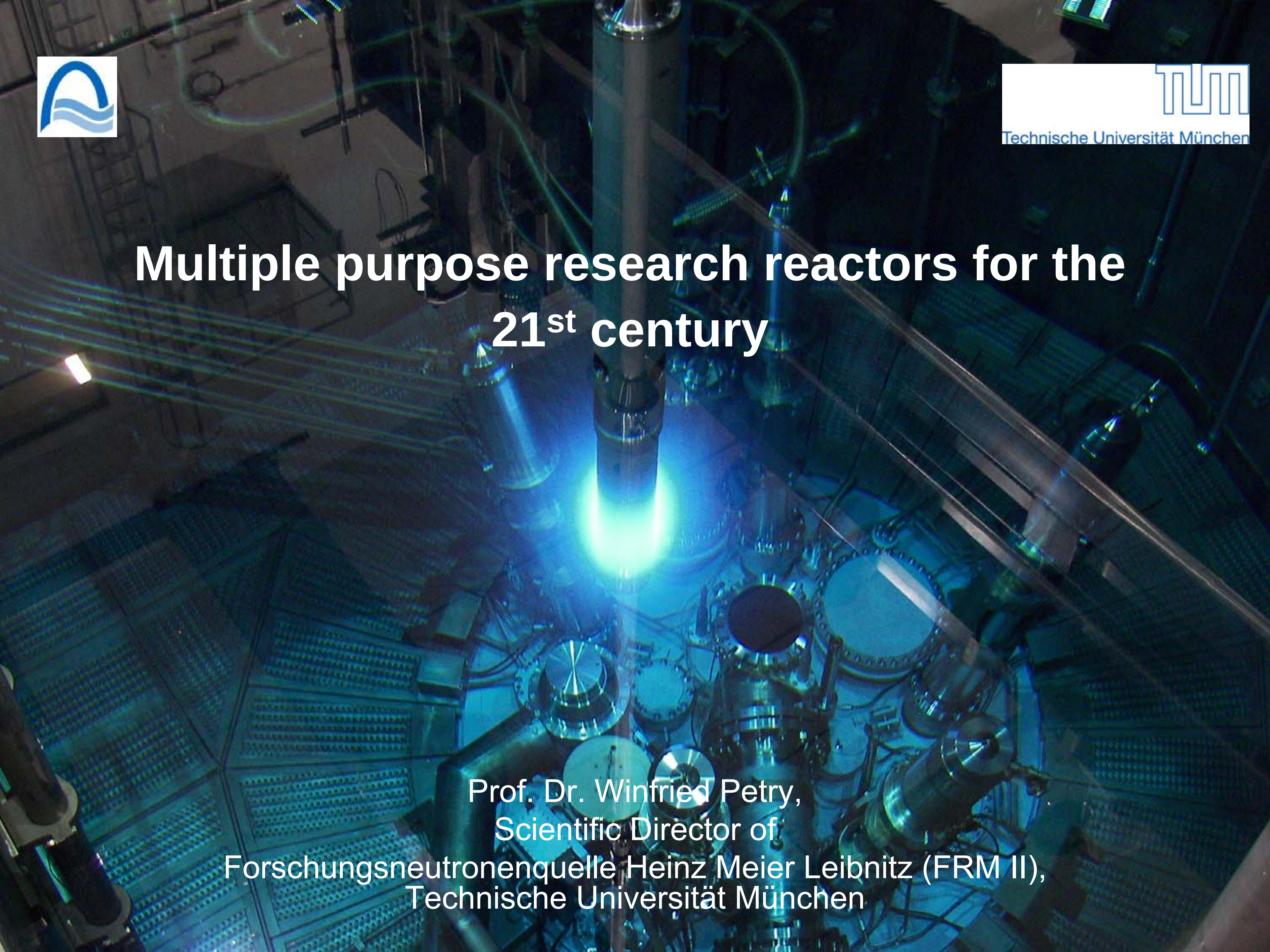
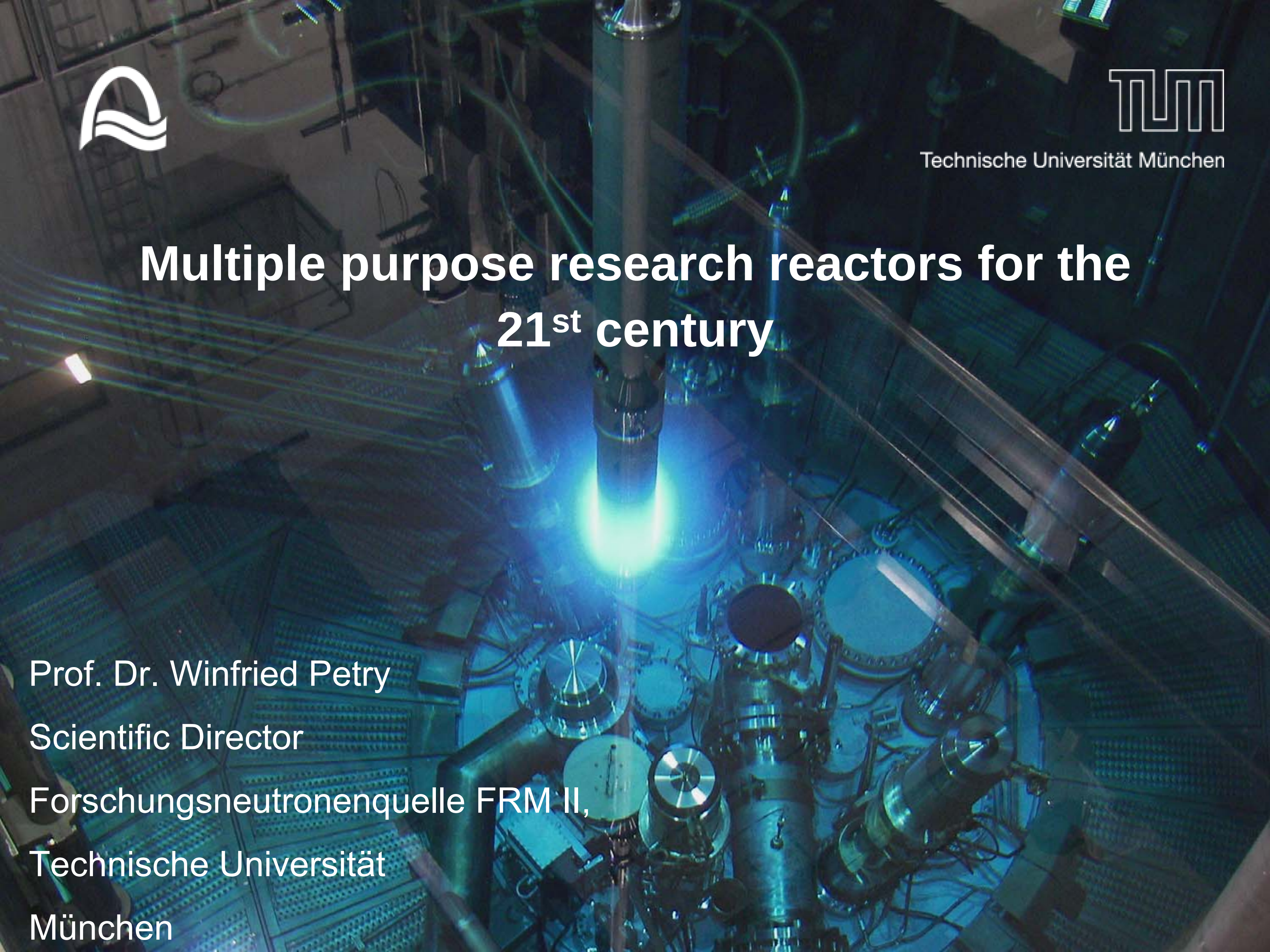


Multiple purpose research reactors for the 21st century

Prof. Dr. Winfried Petry,
Scientific Director of
Forschungsneutronenquelle Heinz Meier Leibnitz (FRM II),
Technische Universität München



Technische Universität München

Multiple purpose research reactors for the 21st century

Prof. Dr. Winfried Petry

Scientific Director

Forschungsneutronenquelle FRM II,

Technische Universität

München

Research reactors for what?

- **Materials testing, fuel development, components testing**
- **Zero power reactors**
- **Generation IV**
- **Training**
- **Radiosotopes**
- **Irradiations, Si-doping, NAA, PGAA, ...**
- **Gain, enlarge (or keep) knowledge in nuclear technology**
- **Beam tube experiments, fundamental & science**
- **........**

Answer depends on the particular needs!

- **Country with mature nuclear industry playing on the world market**
- **Developing country, which wishes to build nuclear power plants**
- **Country steps out of nuclear power**
- **Nuclear medicine needs isotopes**

In any case a well maintained research reactor is an investment for > 40 years!

- During > 40 years needs may change
- Structural materials will suffer under irradiation, fatigue ...
- The construction has to foresee changes ...
- A RR must be reparable, easily, each part!
- An environment for handling strong radioactive sources is needed

Involve your future users in the definition, construction, operation ...

- Build the RR near to your users, near to universities, scientific laboratories, ...
- Is there a suitable infrastructure to reach the RR and to transport strong radioactive sources?

Involve the greater public, explain, be transparent, ...

- RRs reactor must be accessible to the larger public at (almost) any time!
- Make all problems of the nuclear facility public, immediately, don‘t hide anything!

A multiple purpose RR may satisfy most of your needs

... without sacrifices on the performance of the different tasks.

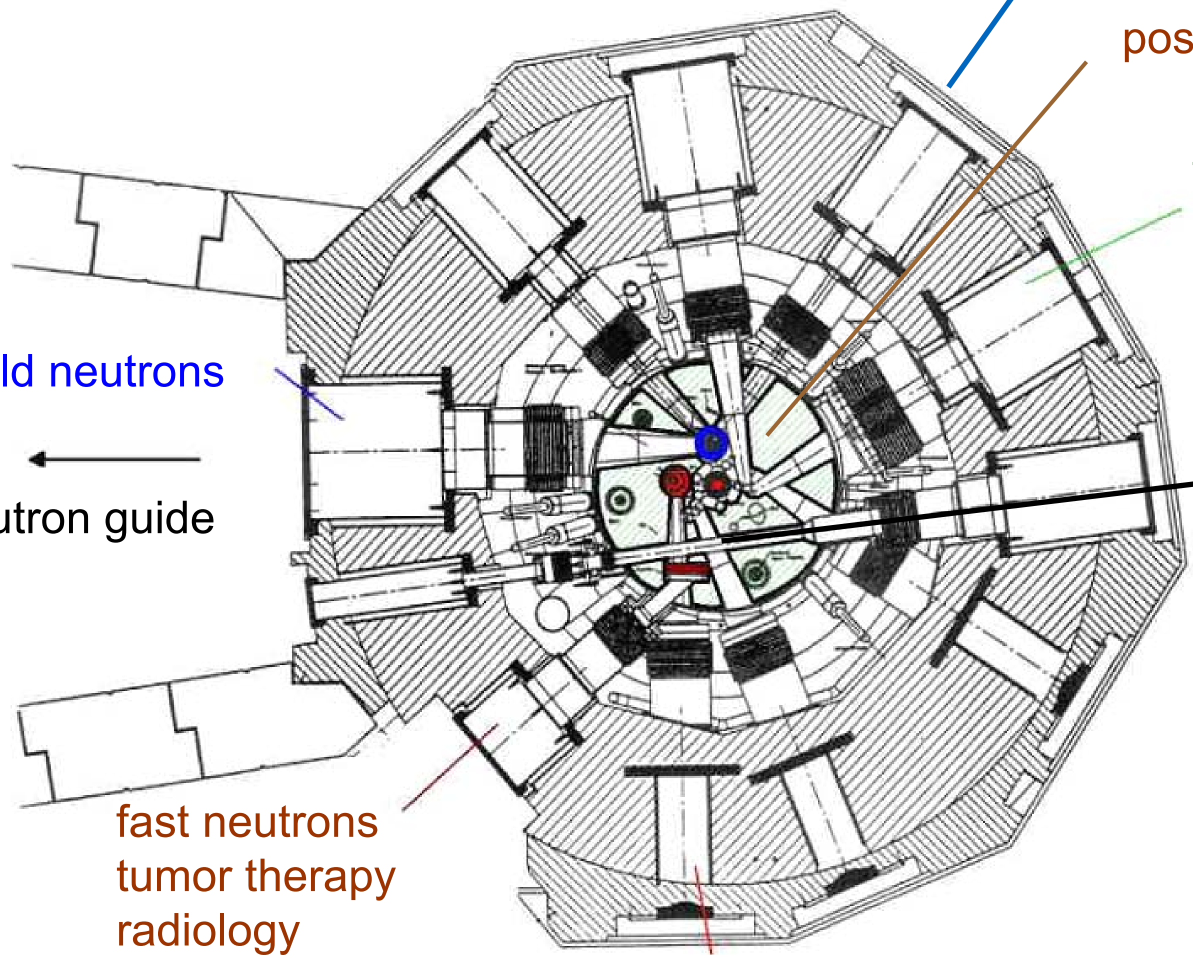
- Diversity!
- A multiple purpose RR should be a user facility.

A few decisions have to be taken

- Φ_{th} > or < 3×10^{14} $cm^{-2}s^{-1}$?
- Inverted geometry?
- D_2O moderator or H2O/Be reflector?
- D_2O much more expensive, Tritium emission!

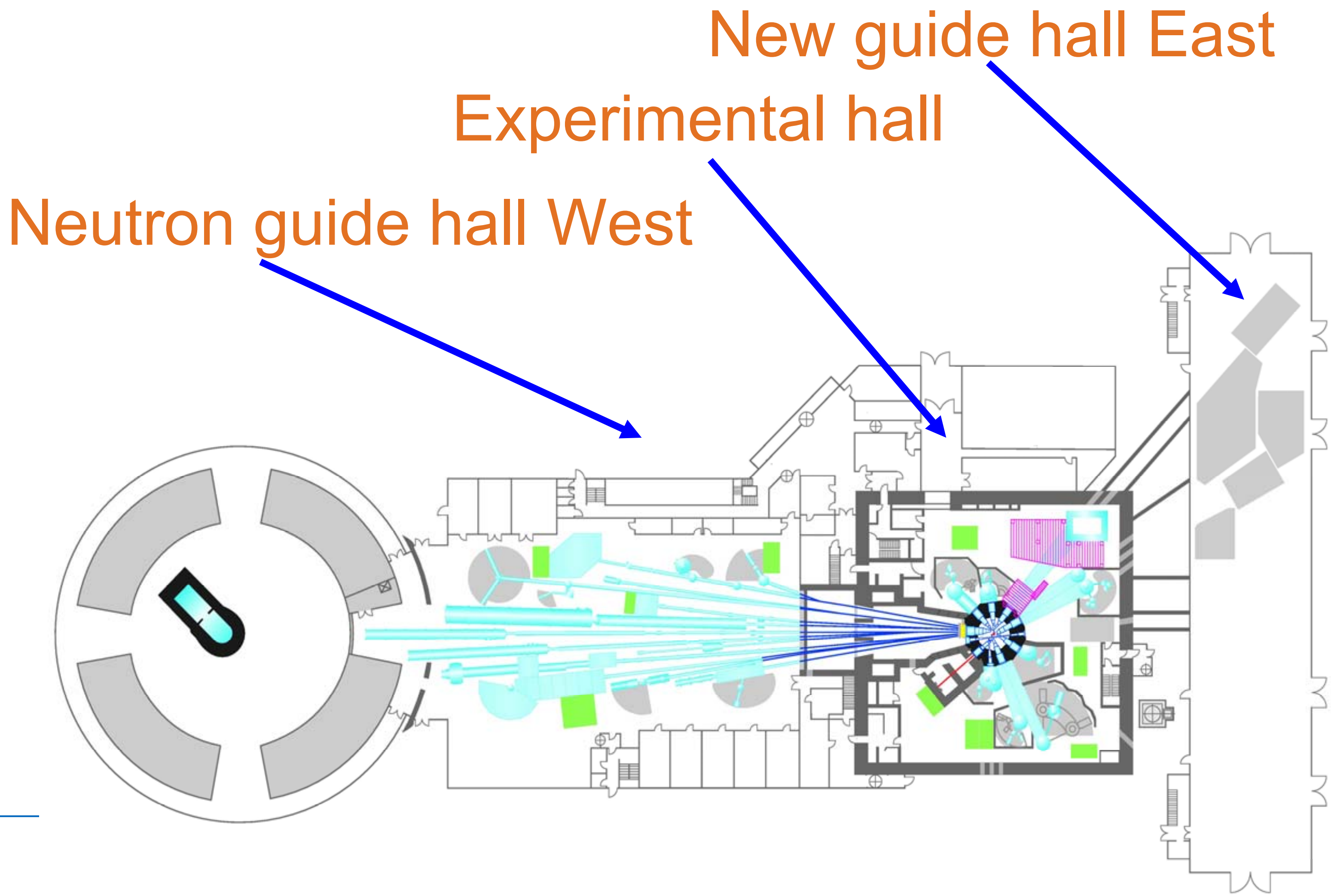
Campus of the TUM in Garching near Munich

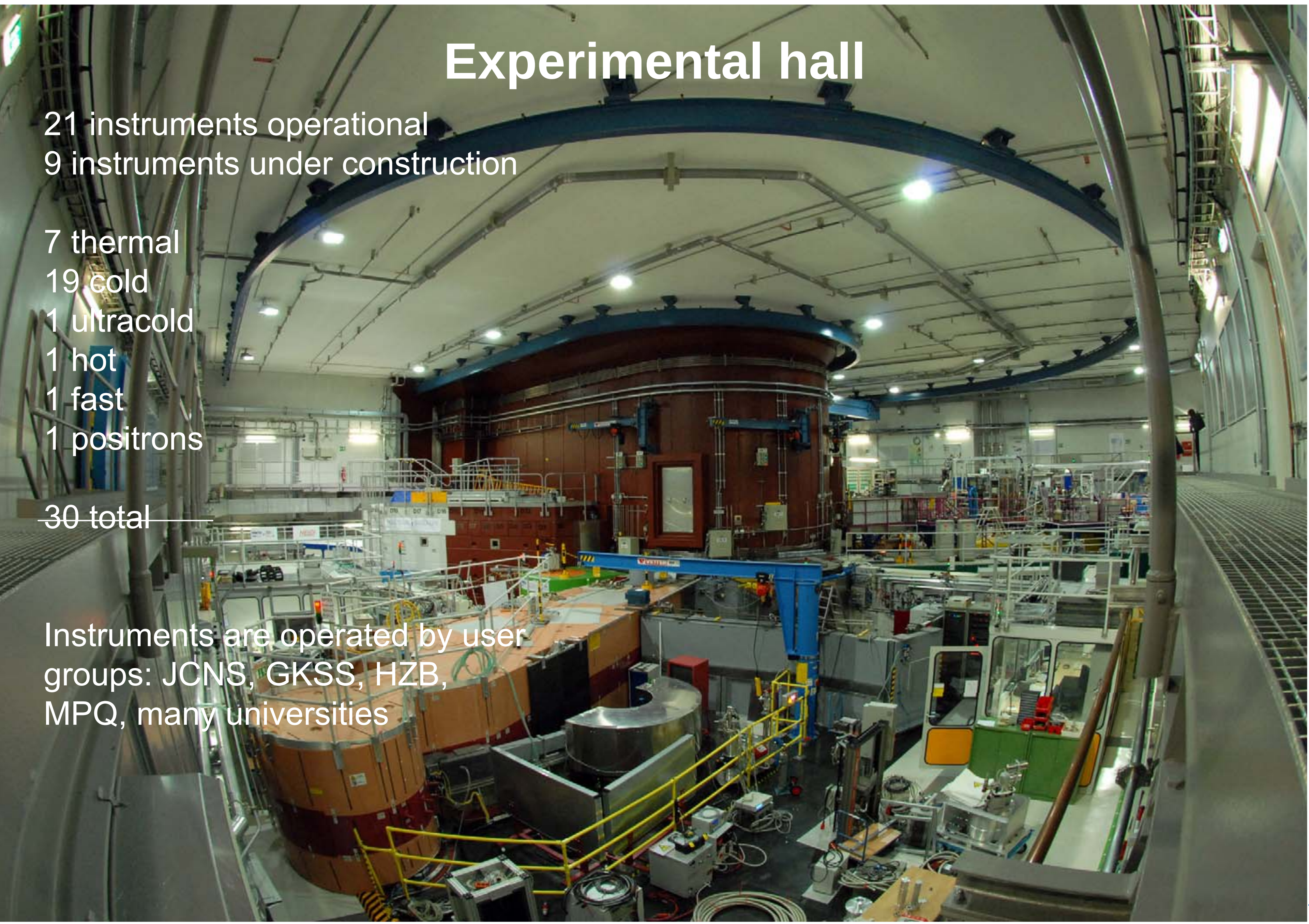
Neutrons of different wavelengths



Unperturbed thermal flux:
8 x 10^{14} n/cm^2/s
perturbed
6.4 x 10^{14} n/cm^2/s

Foresee plenty of possibilities for extensions





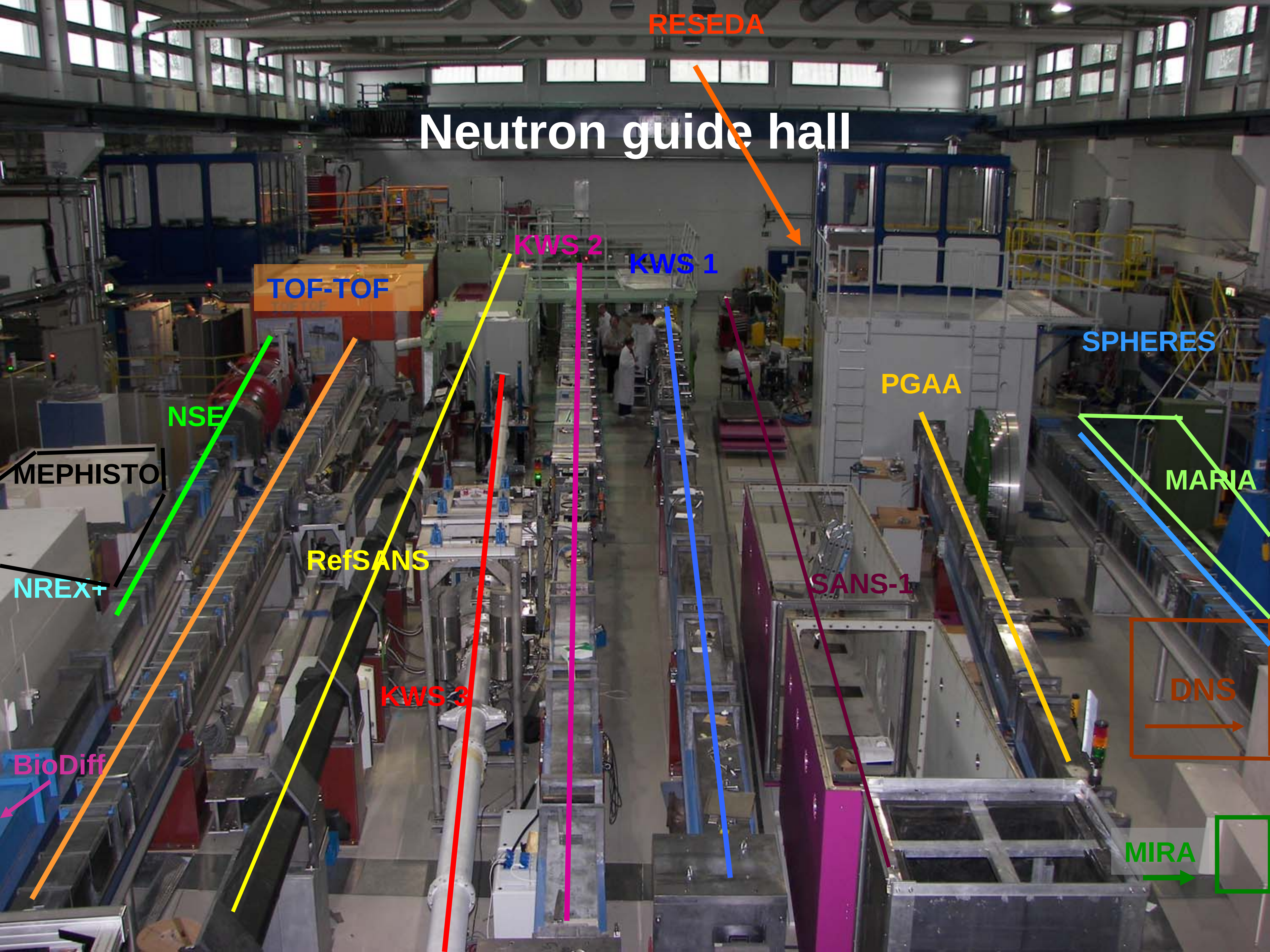
Experimental hall

21 instruments operational
9 instruments under construction

7 thermal
19 cold
1 ultracold
1 hot
1 fast
1 positrons

30 total

Instruments are operated by user groups: JCNS, GKSS, HZB, MPQ, many universities


Neutron guide hall
RESEDA
KWS 2
KWS 1
TOF-TOF
SPHERES
PGAA
NSE
MEPHISTO
MARIA
RefSANS
NREX+
SANS-1
DNS
KWS 3
BioDiff
MIRA

The cold neutron source

Liquid deuterium moderator

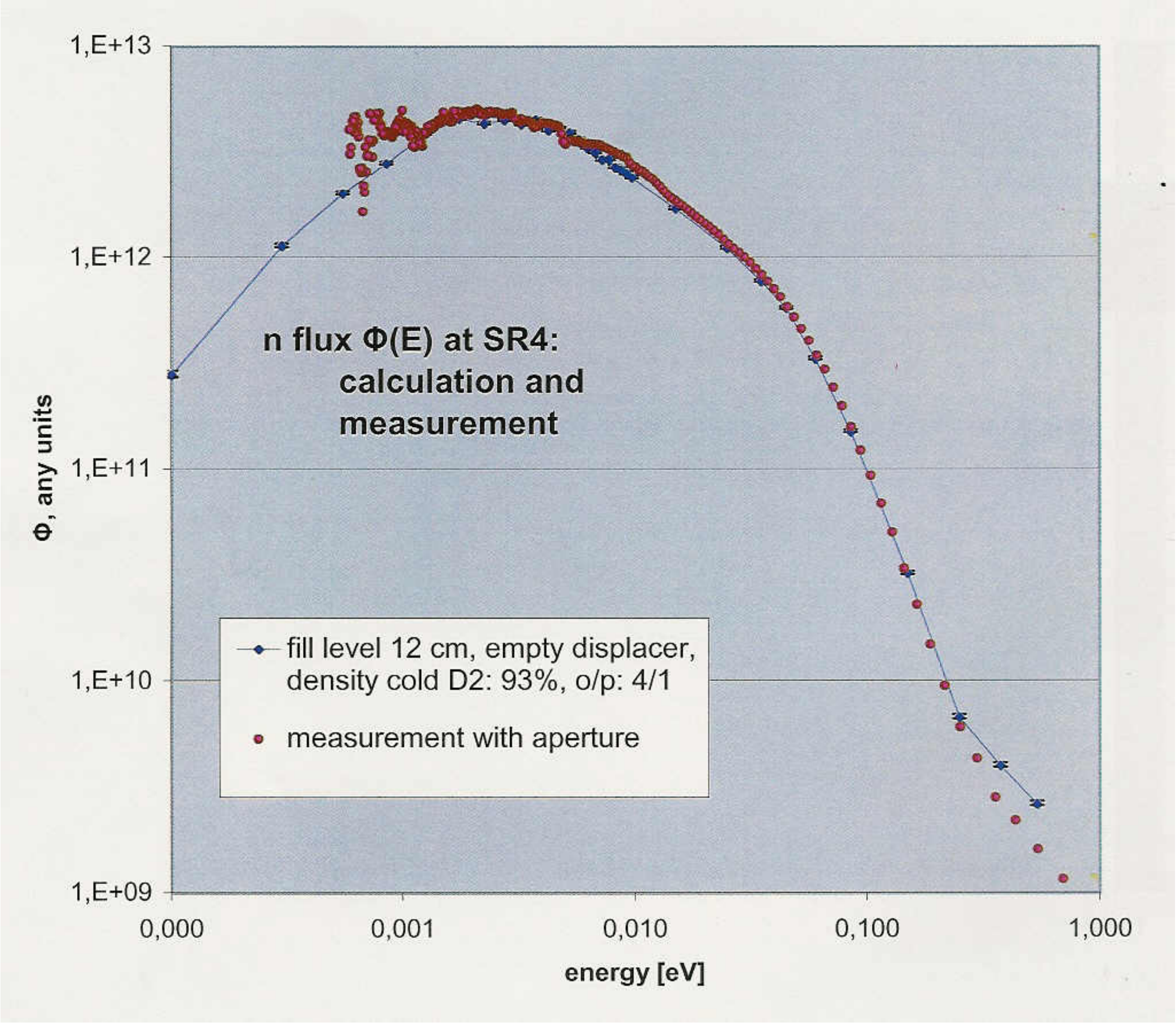
Volume moderator vessel		25 liters
Volume of liquid D_2	~	13 liters
Temperature		25 K

3 beam tubes
for cold neutron experiments

1 vertical beam tube is not in use

Cooling power total	~ 6 kW
in liquid D_2	2.7 kW

Measurement of the cold neutron spectral Flux at 20 MW



Perfect agreement between measurement and calculation

A. Röhrmoser, K. Zeitelhack

The hot source

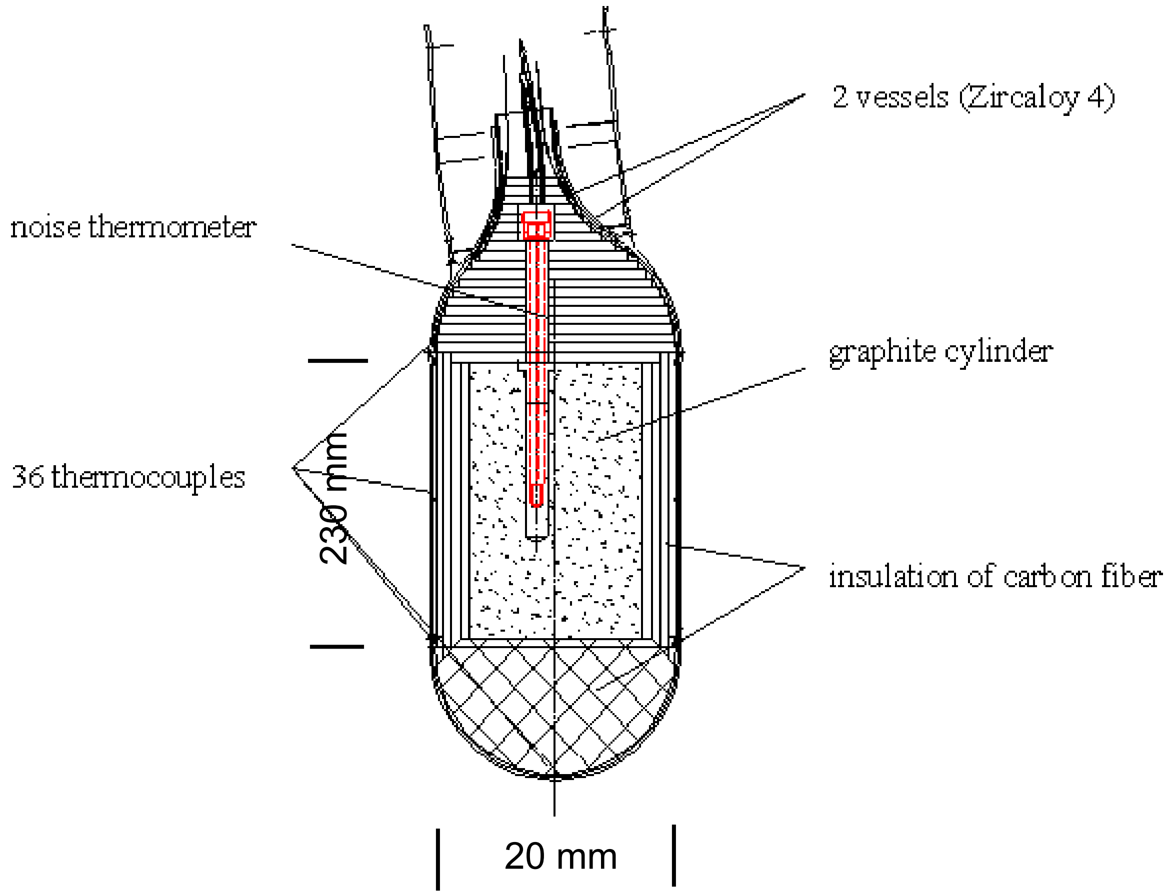
Hot graphite moderator heated by gamma radiation

Distance from center source to center of core 42 cm

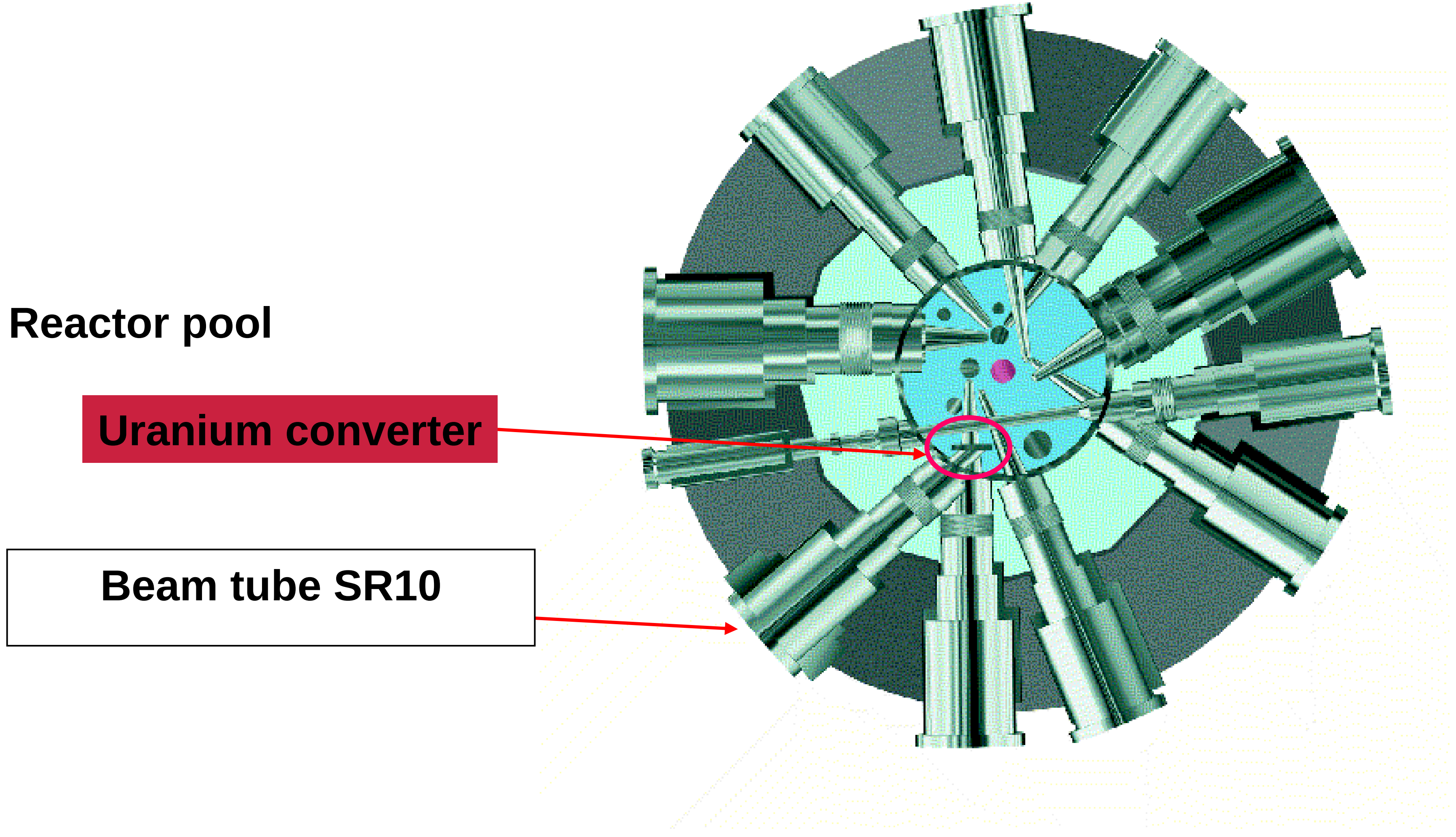
1 beam tube with neutron energies 0.1 – 1 eV

T = 2000°C (measured + calculated)

Graphite moderator of hot source



Use of fission radiation in life sciences and materials characterisation

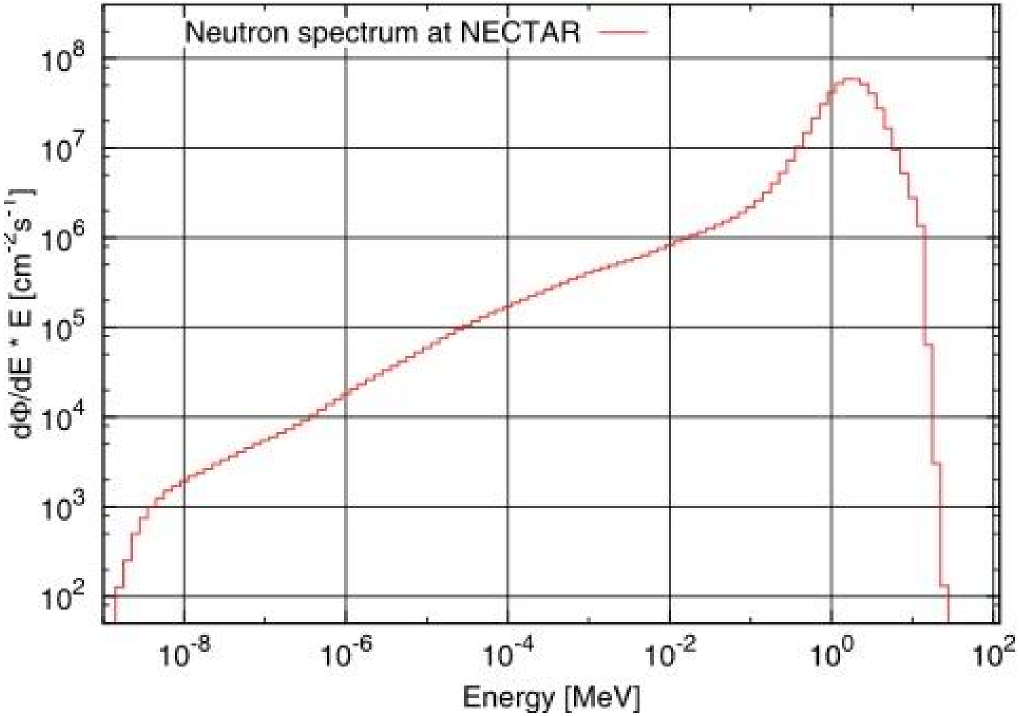


Beam quality: Fast neutron spectrum

- Thermal neutrons (without converter)
- Beam area: 23x18 cm²
- Φ_{th} : 3.9 x10^9 $s^{-1}cm^{-2}$

- Fast neutrons (with converter)
- Beam area up to 30x20 cm (multi leaf collimator)
- Φ_f: 3.2 x10^8 $s^{-1}cm^{-2}$
- Very small thermal neutron fraction
- Filters for adjustment of the n/ γ -fraction

Unfolded spectrum



⟹ Watt spectrum plus intermediate neutrons

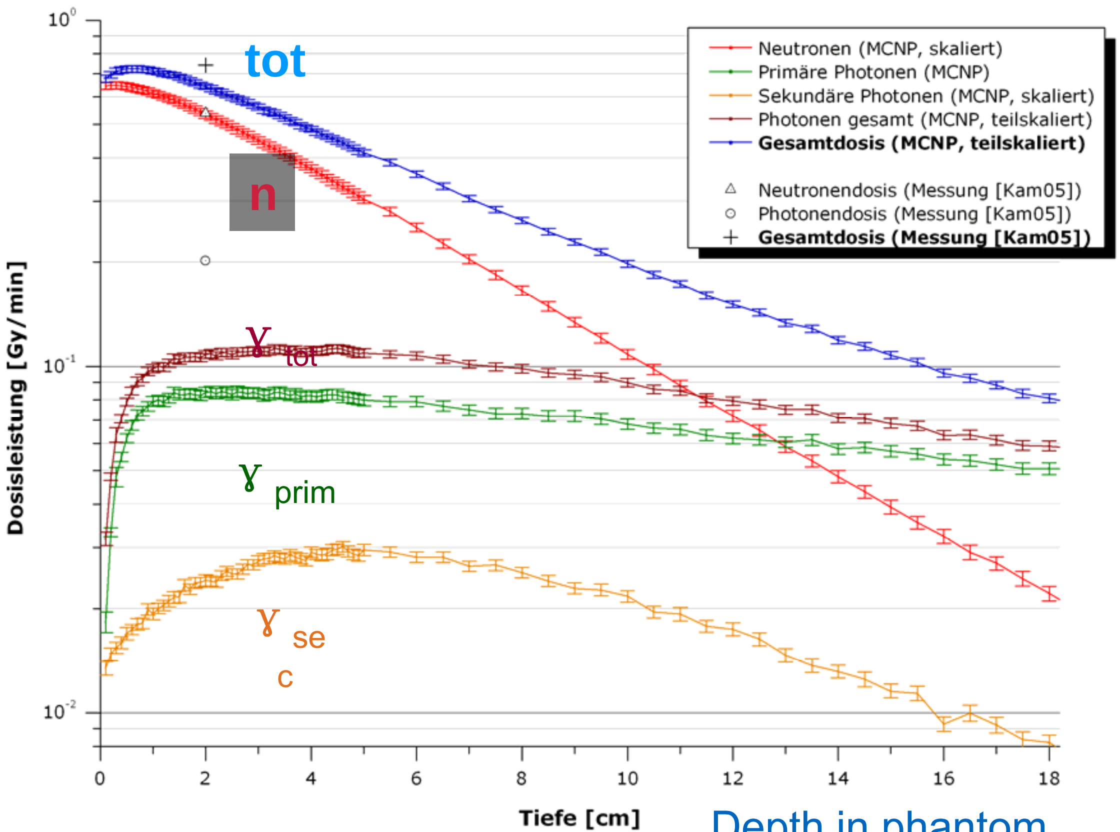
F.M. Wagner, B. Loeper-Kabasakal, H. Breitkreutz, Th. Bücherl, S. Garni

Medical irradiation facility at FRM II

Photo: Gert von Hassel

PE-Phantom: Calculated depth dose curves

Dose rate 10^{-1} Gy/min

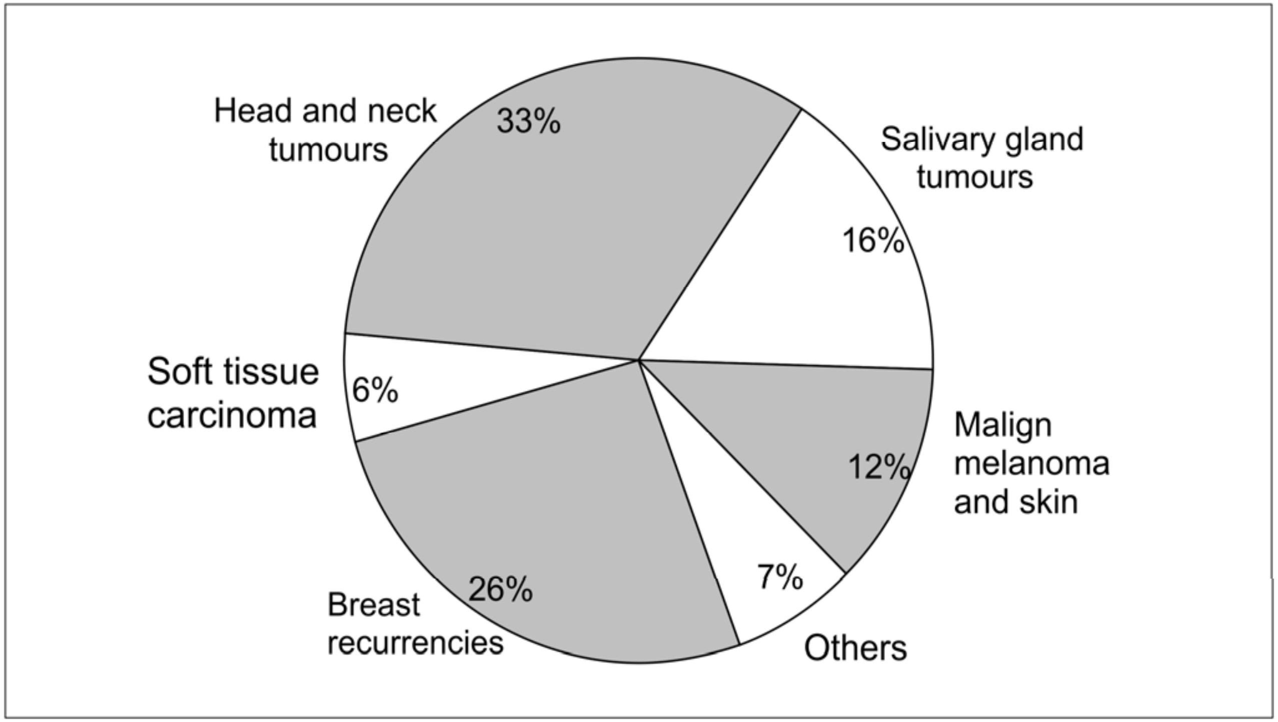


Depth in phantom

⟹ Surface and near-surface tumours only (head and neck, breast, skin)

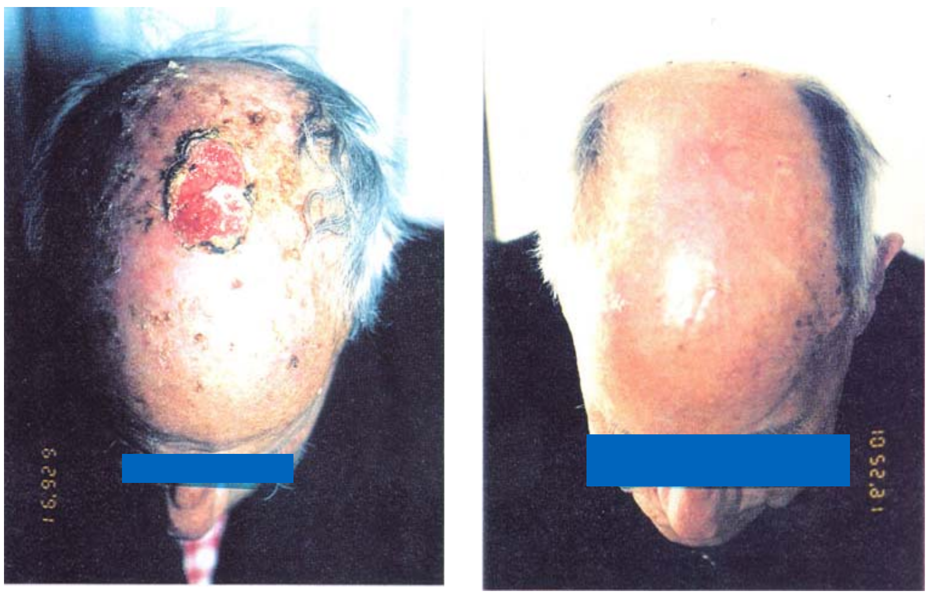
H. Breitkreutz ,F.M. Wagner, B. Loeper-Kabasakal,

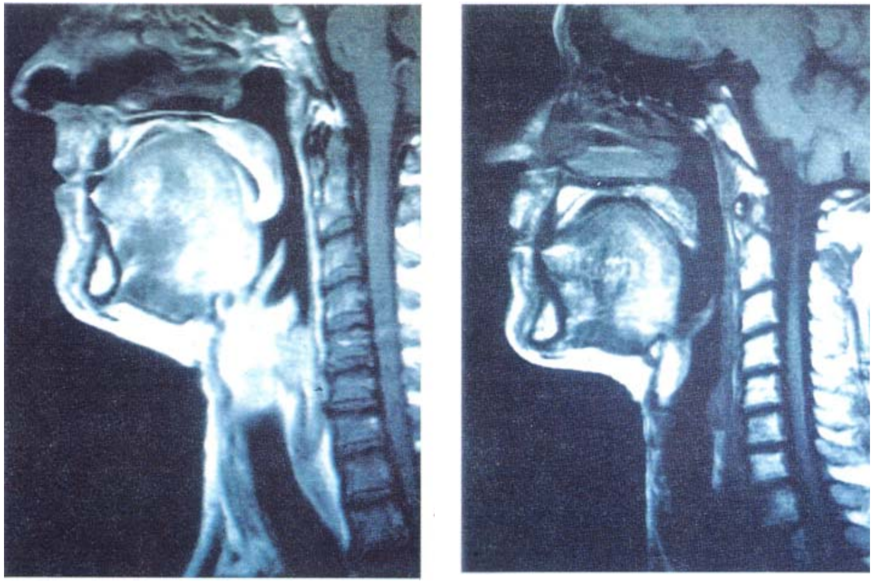
Applications of the fast reactor neutron beam
Medical applications (“MedApp”)



- FRM (1985-2000): 715 patients, about 2300 fields
- FRM II (since June 2007): 41 patients, about 230 fields (40% curative)
  MedApp needed a CE-mark + accordance to „Medizin-Produkte“ legislation

MedApp: Irradiation response





Figs.: Th. Auberger, Hospital for radiotherapy, TUM

Malignant melanoma, elder patient

Laryngeal tumour, 39-year old patient

Th. Auberger, M. Molls, F.M. Wagner, B. Loeper-Kabasakal

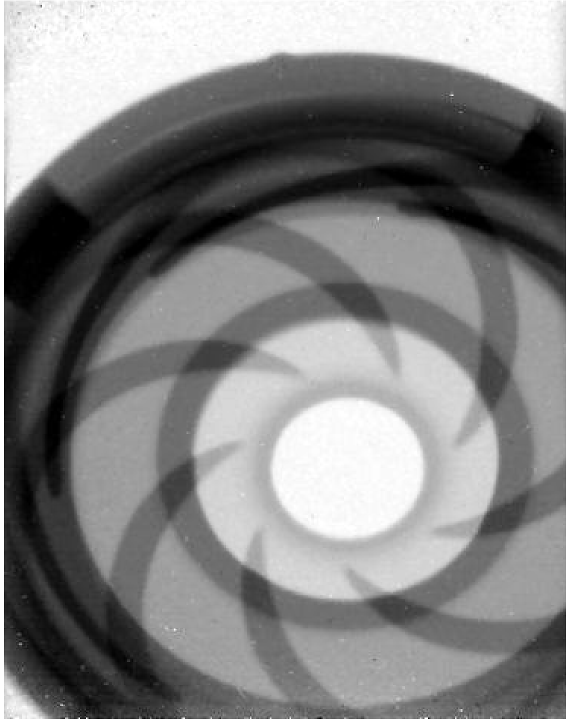
Neutron computed tomography and radiography (NECTAR)

Photo: Wenzel Schürmann

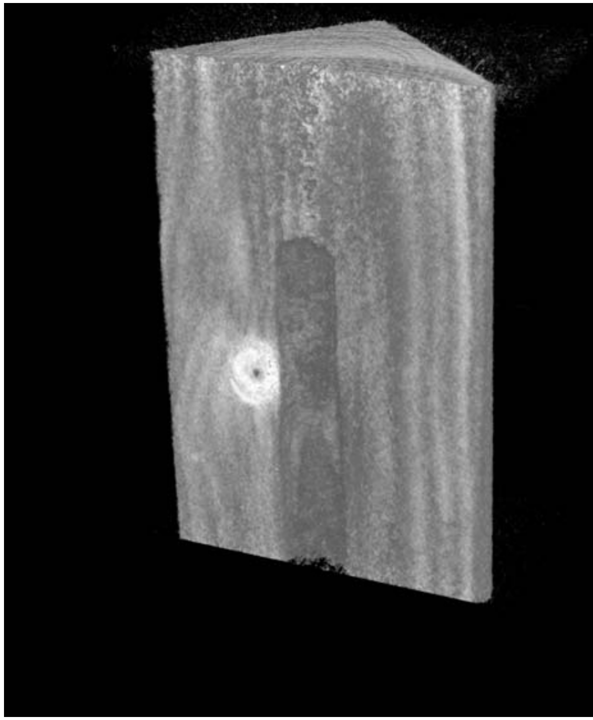
Max. object dimension:
80 cm x 80 cm x 80 cm³
Max. burden: 400 kg

F.M. Wagner, Th. Bücherl

NECTAR: Examples

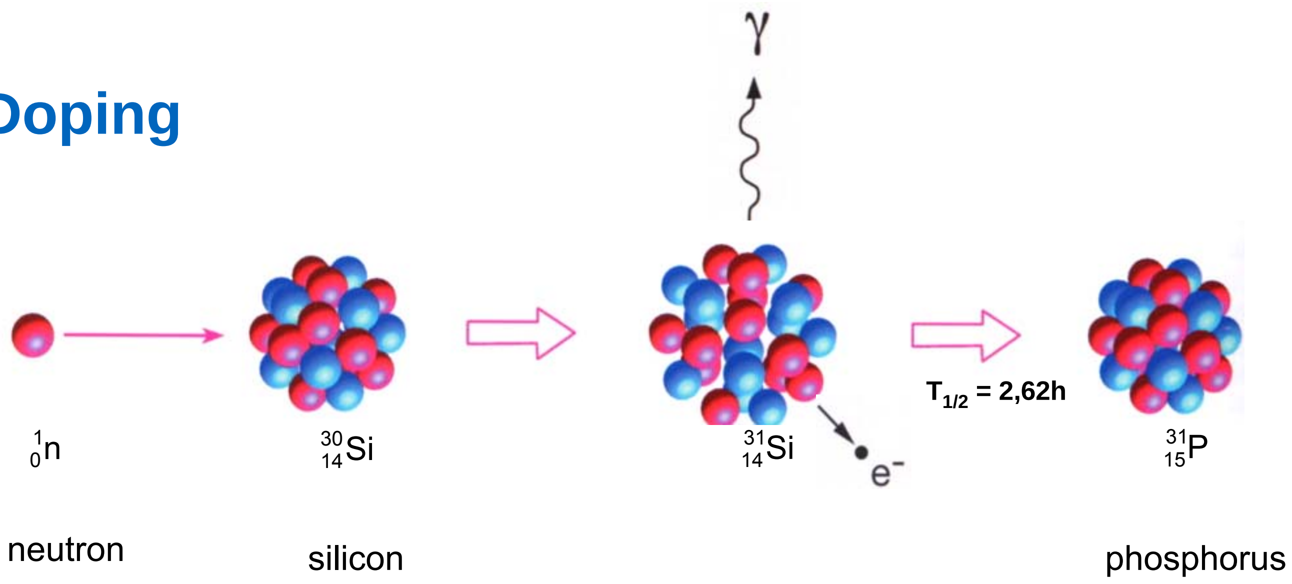


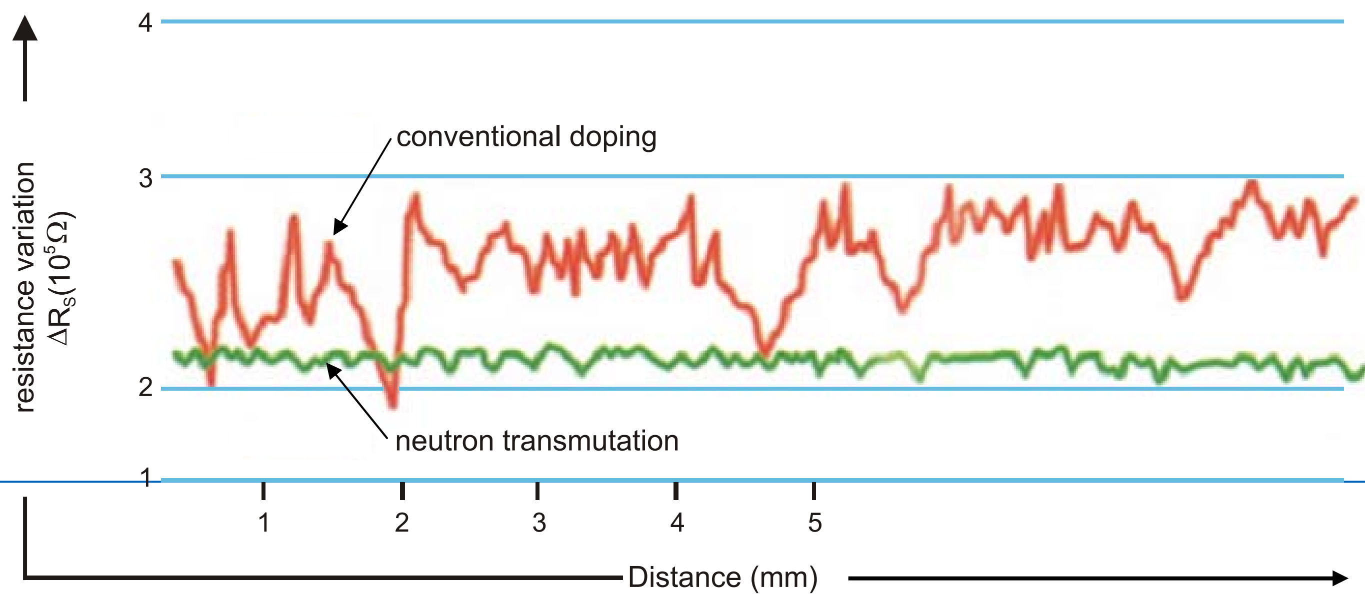
Radiography with n_{fast} of a diffuser

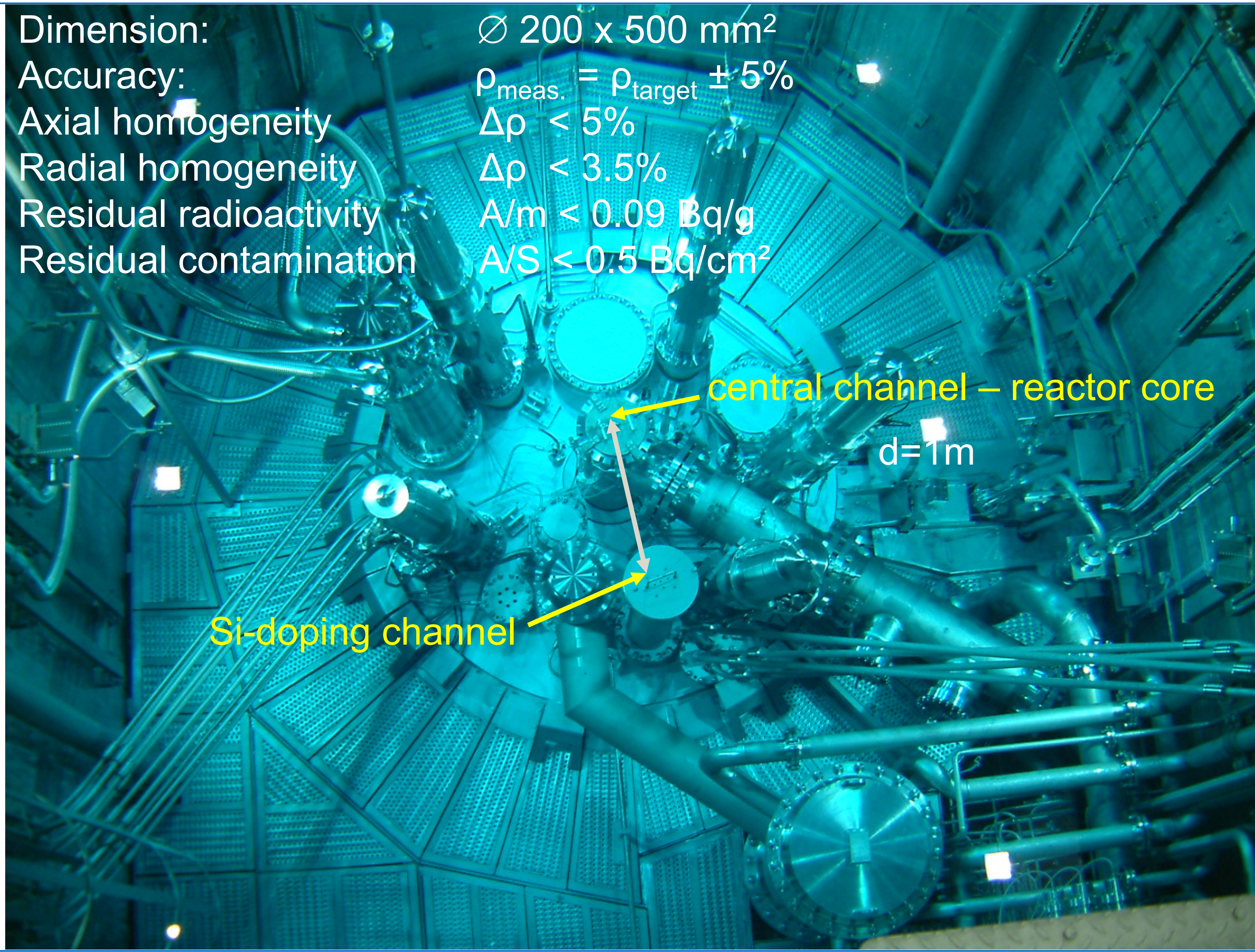


Cut through a 3D-CT of a timber using a collimated neutron beam

Silicon Doping

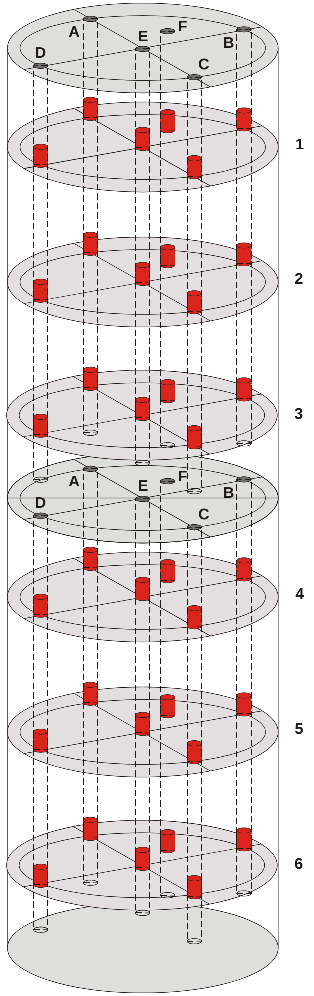


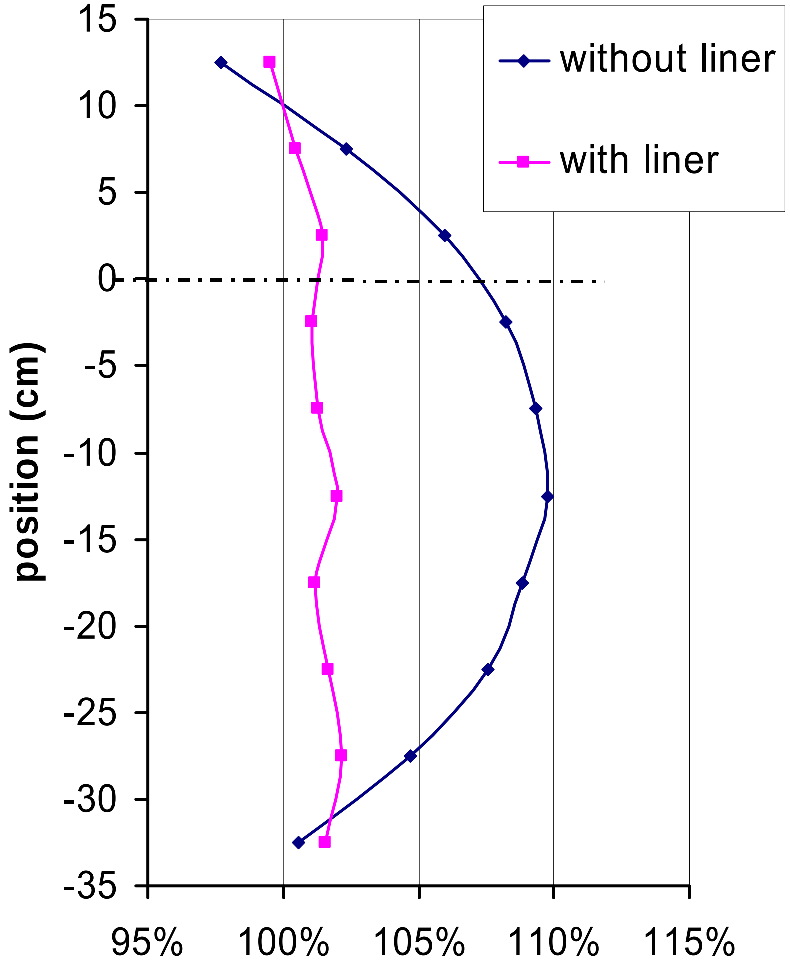




H. Gerstenberg, X. Li, I. Neuhaus

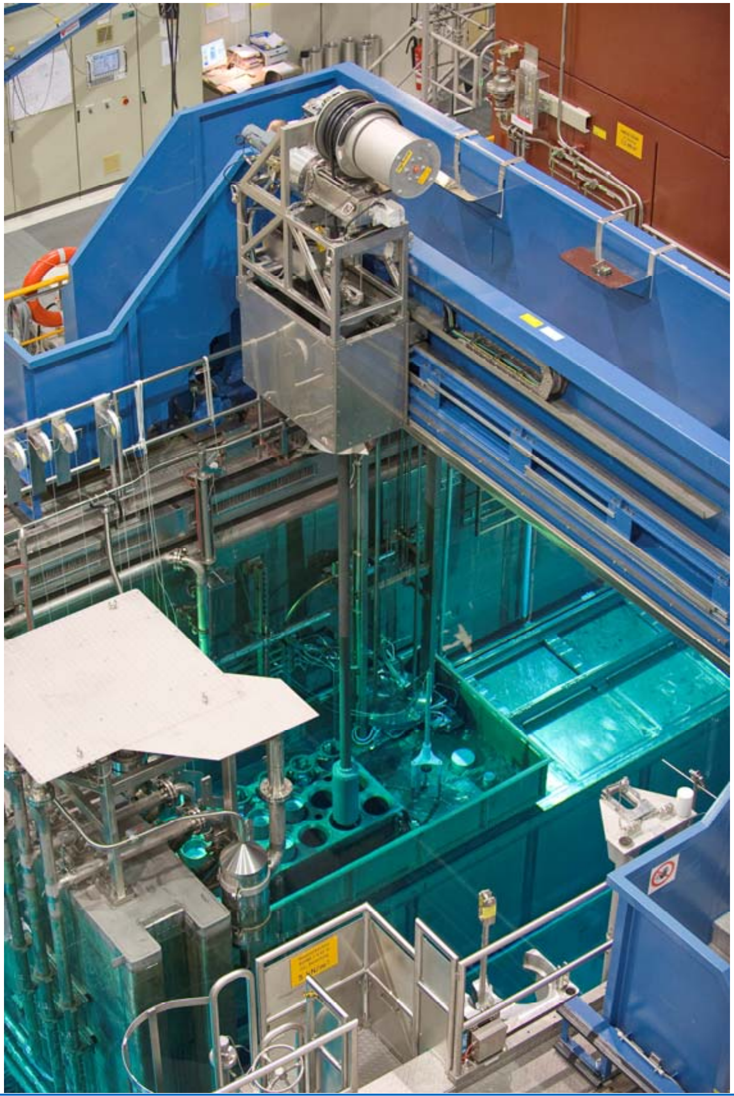
Smoothening of the neutron flux density by a Ni liner

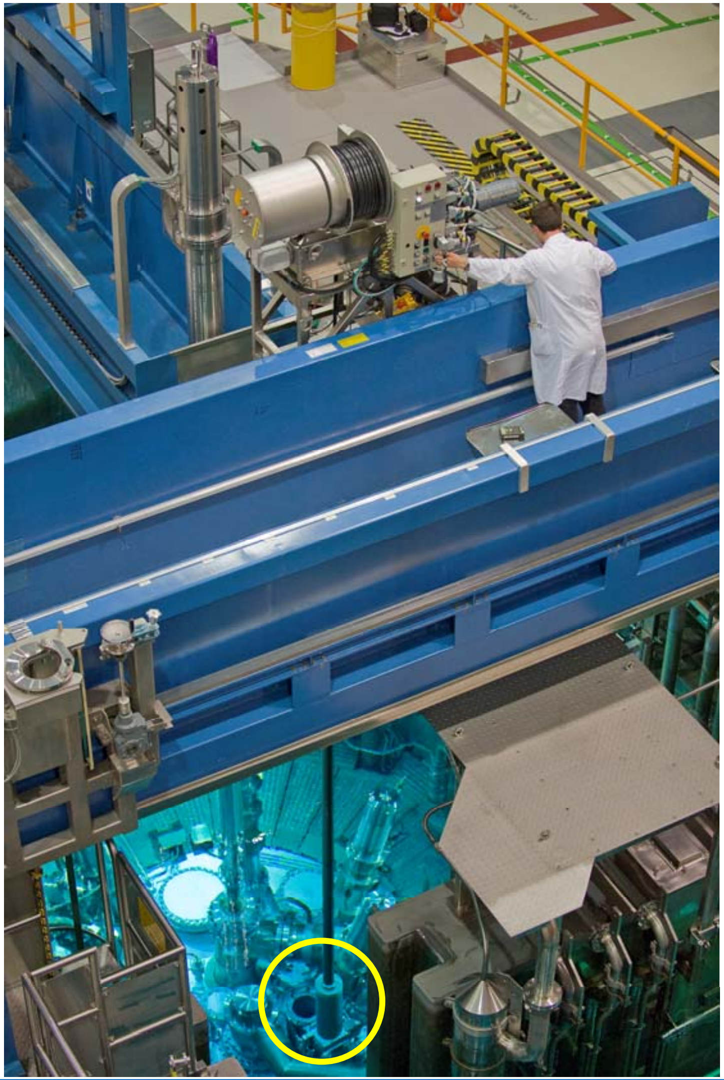




H. Gerstenberg, X. Li, I. Neuhaus

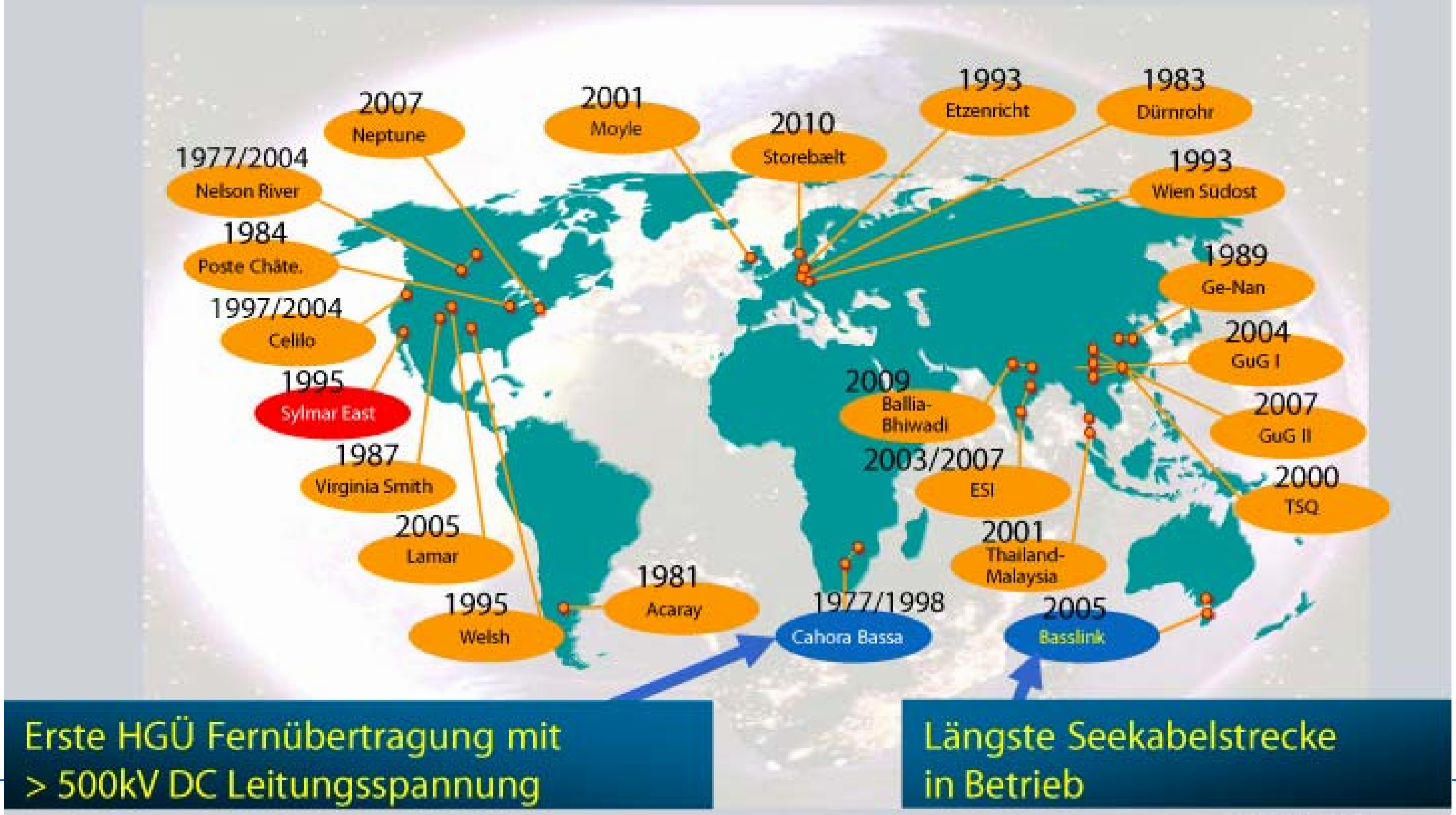
Handling – semiautomatic irradiation





H. Gerstenberg, X. Li, I. Neuhaus

High voltage DC current transport over lang distances

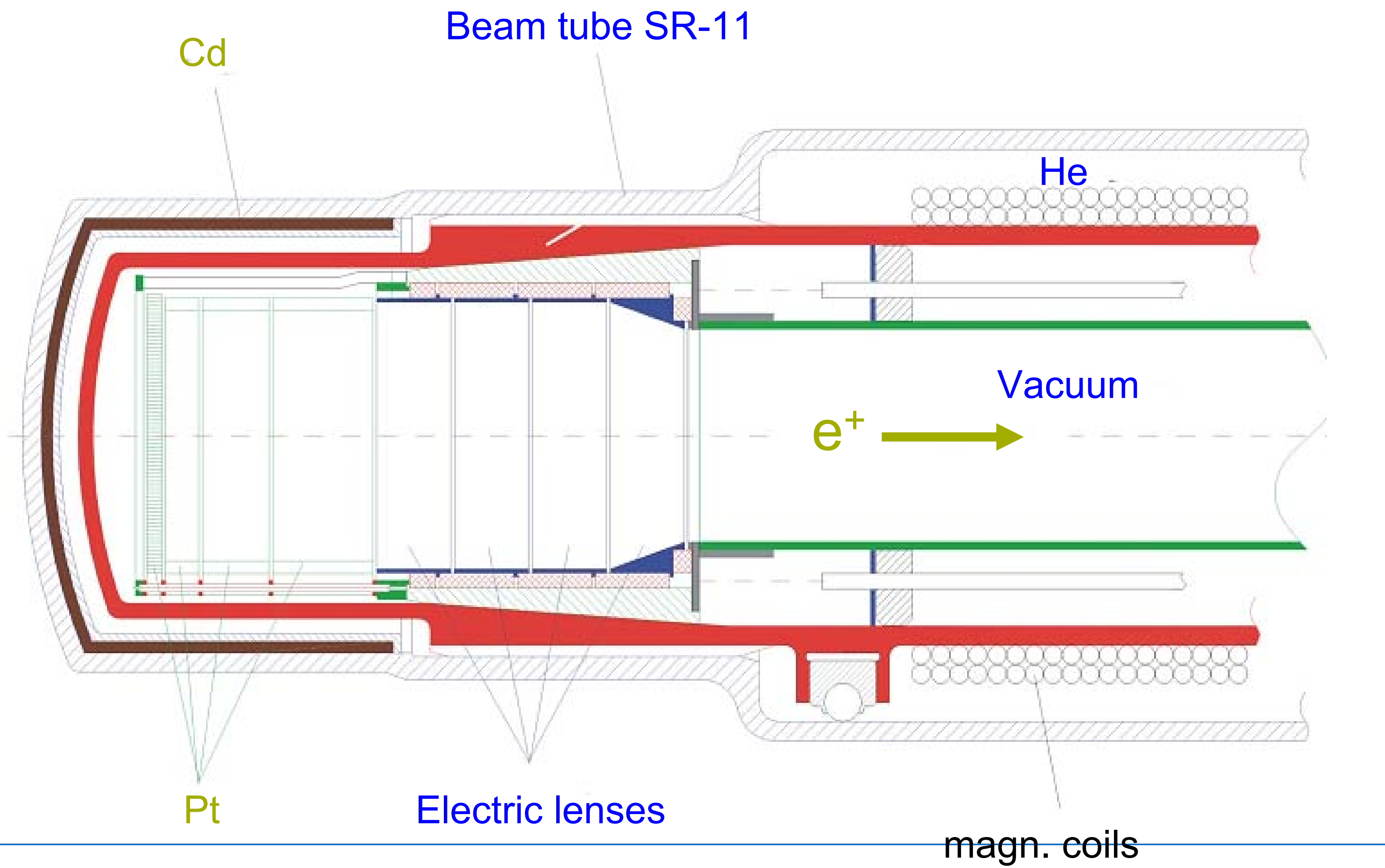


Wilfried Breuer, Siemens AG, Power Transmission and and Distribution

Irradiation services

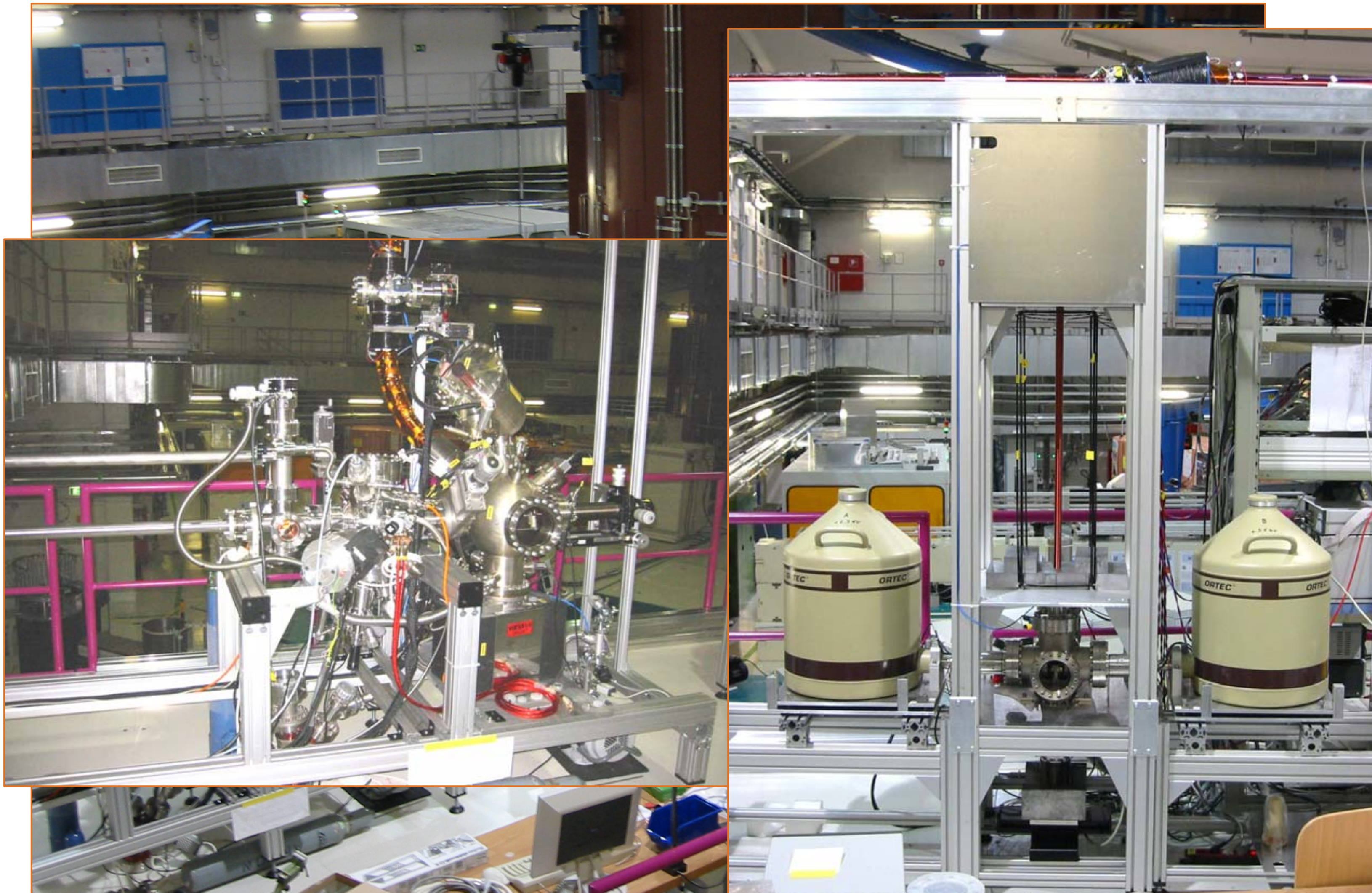
Facility	Sample Conveying	Φ_{th} (cm^{-2} ·s^{-1})	Φ_{th}/Φ_f	Irradiation Period	Positions
Fishing line	manually	$1.2 \cdot 10^{13}$	$1.2 \cdot 10^{3}$	10 minutes … days	1
Standard Rabbit Irradiation System RPA	pneumatic (CO_2)	4.8×10^{12} 7.3×10^{13}	6.66×10^{4} 1.3×10^{3}	30 seconds … hours	2 × 3
Capsule Irradiation Facility KBA	hydraulic (pool water)	$7.7 \cdot 10^{13}$ $1.3 \cdot 10^{14}$	$7.7 \cdot 10^{2}$ $3.3 \cdot 10^{2}$	minutes … days	2 x 5
Silicon Doping Installation SDA	mechanically automatized	2×10^{13}	?	10 minutes … 1 day	1
control rod position	isotope production	6×10^{14} fast	-	52 days	1

The world‘s most brillant thermal positron source



K. Schreckenbach, C. Hugenschmidt

$\Phi_{th.\ pos.} = 9 \times 10^8\ cm^{-2}s^{-1}$ at $E_{pos.} = 0 \ldots 30$ keV



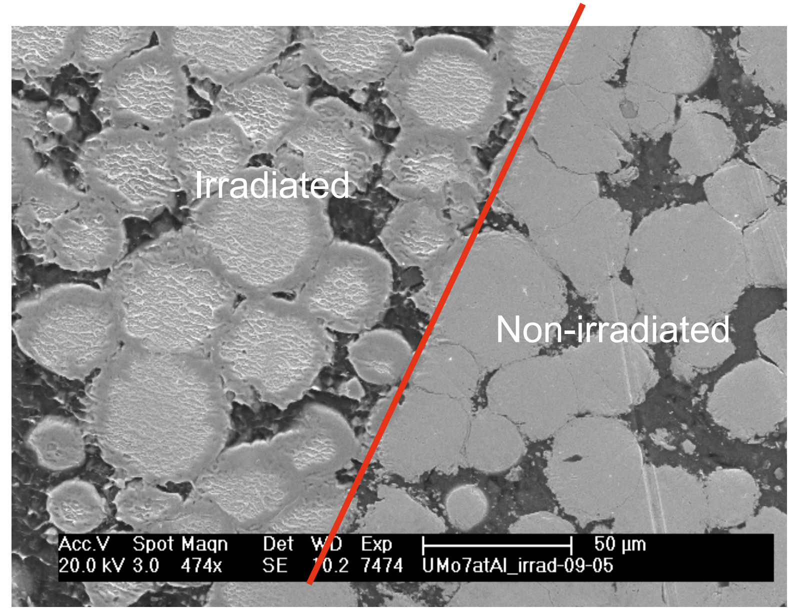
K. Schreckenbach, C. Hugenschmidt

Testing new high density fuel by ion beams

Maier-Leibnitz Beschleuniger Laboratorium heavy ion accelerator

• Irradition with 70 MeV Iodine ions

U7wt%Mo-Al

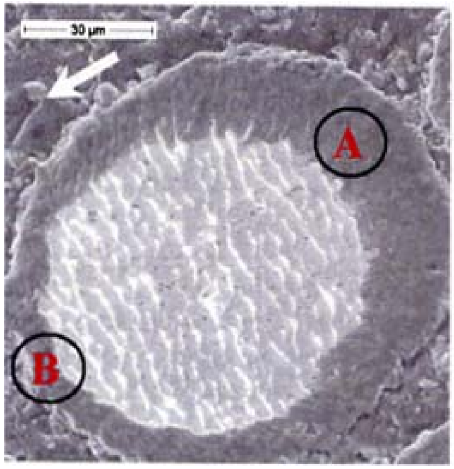


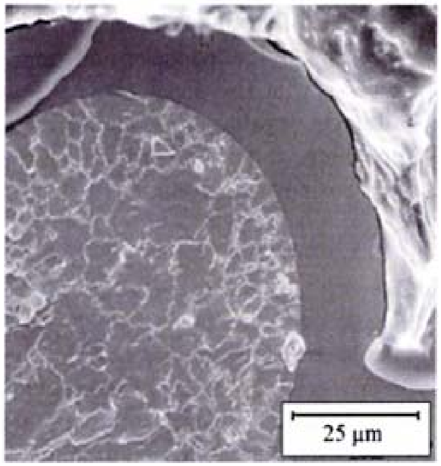
• Heavy ion irradiation induces the growth an UMo/Al interaction layer

• Average thickness of interdiffusion layer: 7.6 µm

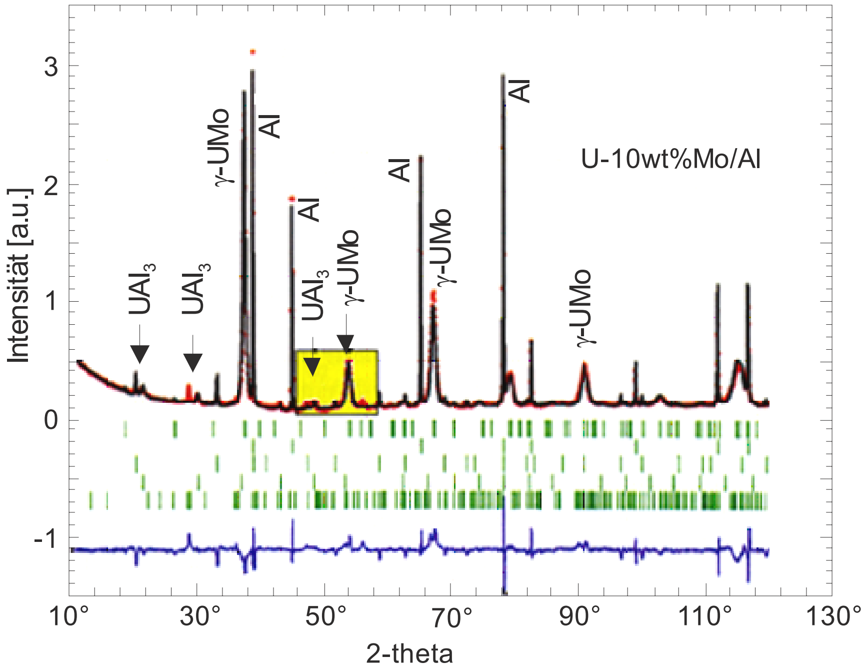
R. Jungwirth, A. Röhrmoser, W. Schmitt, N. Wiechalla, H. Breitkreutz, Palancher

Identification of the UAl_3 interdiffusion layer





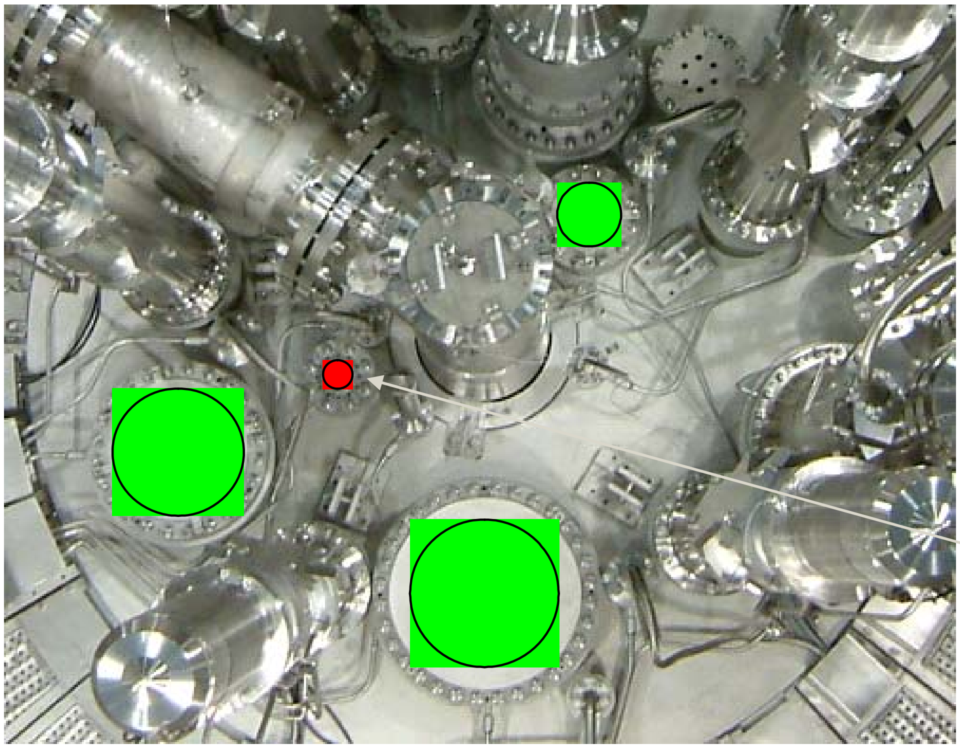
Heavy ion irradiation simulates the metallurgical processes during in-pile irradiation



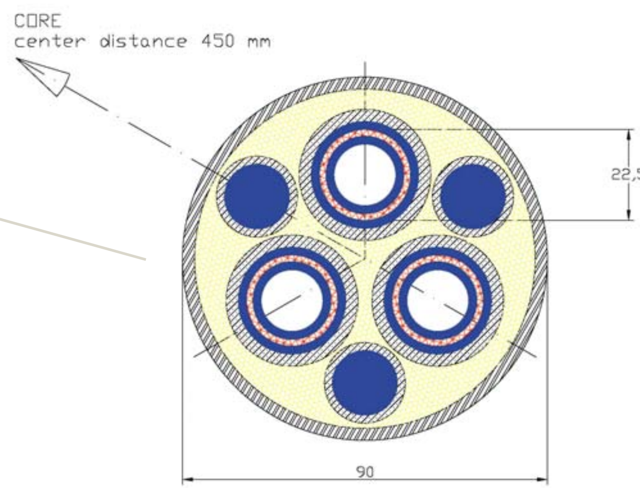
Identification of the metallurgical composition

R. Jungwirth, A. Röhrmoser, W. Schmitt, N. Wiechalla, H. Breitkreutz, Palancher

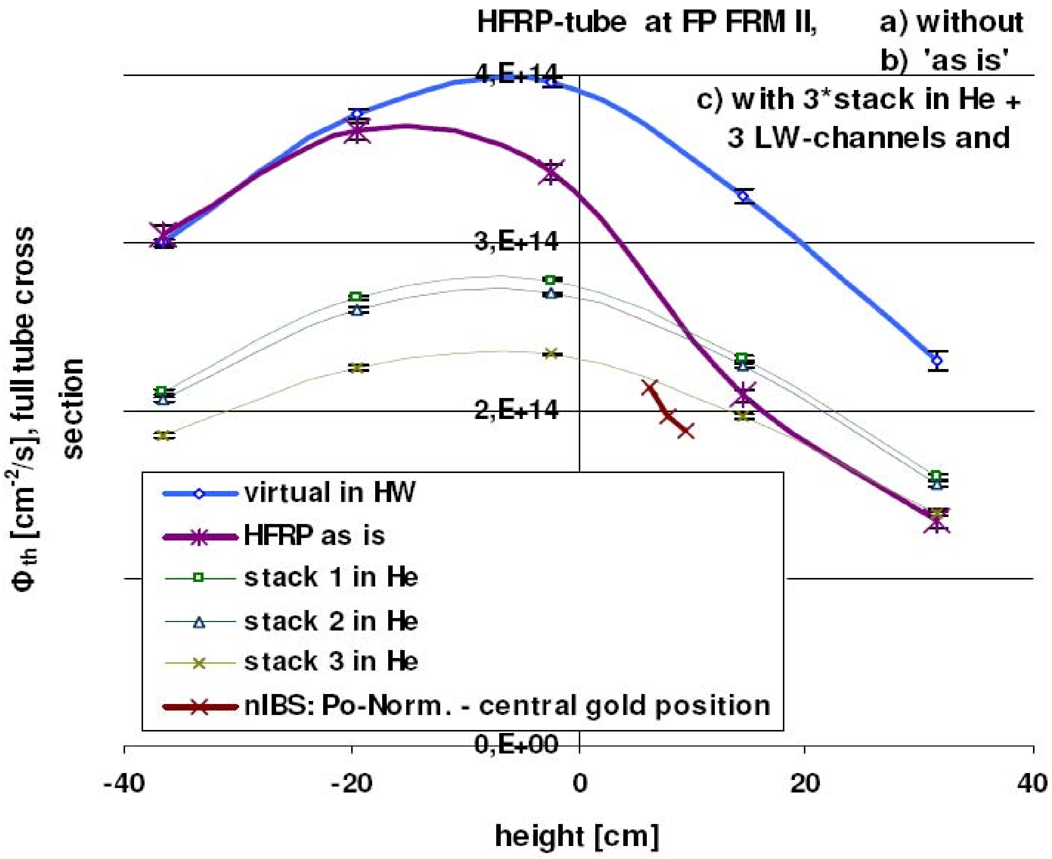
Feasability study Mo-99 production at FRM II



Definition of the most suitable irradiation channel



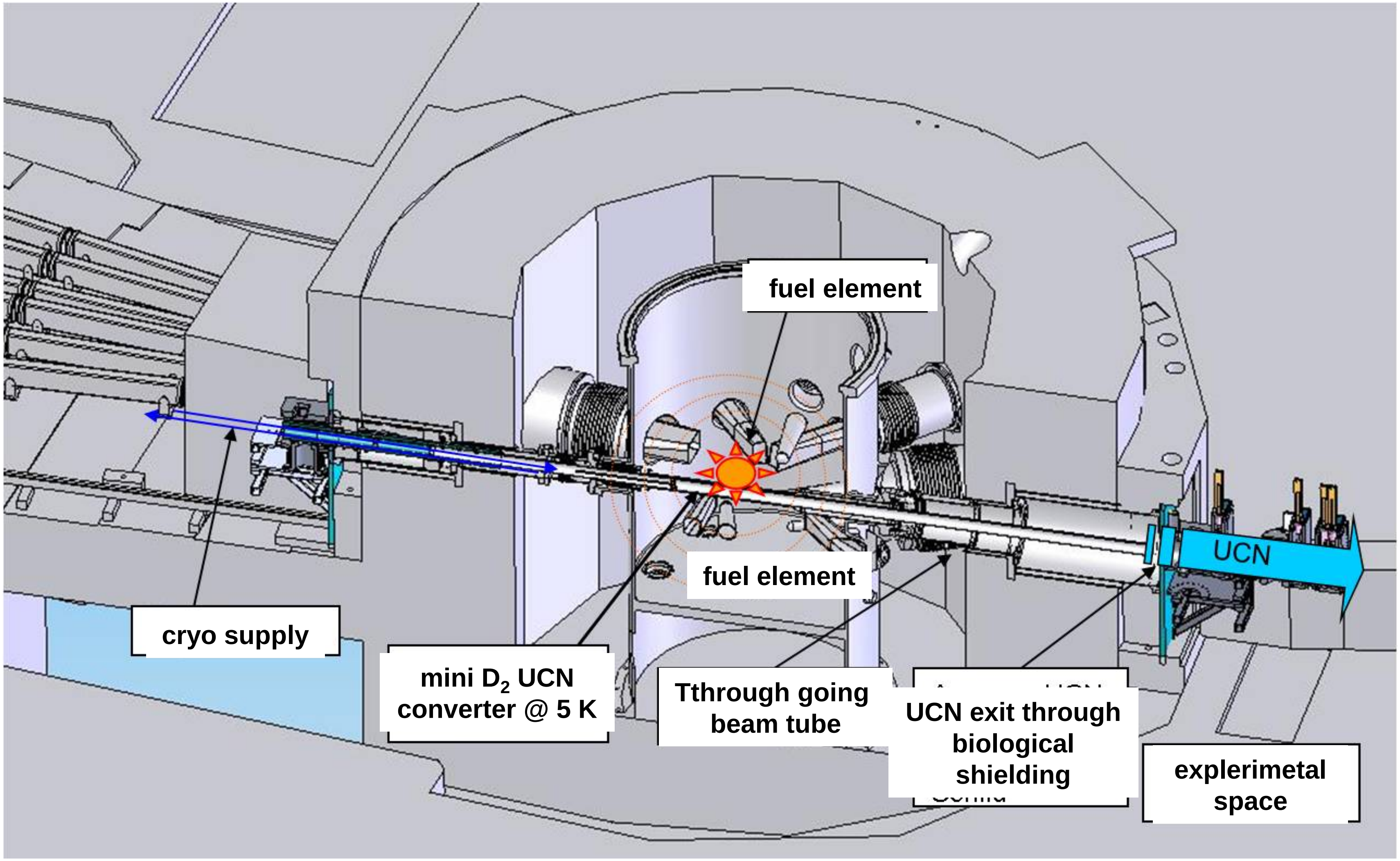
Thermal neutron fluxes at HFRP-tube



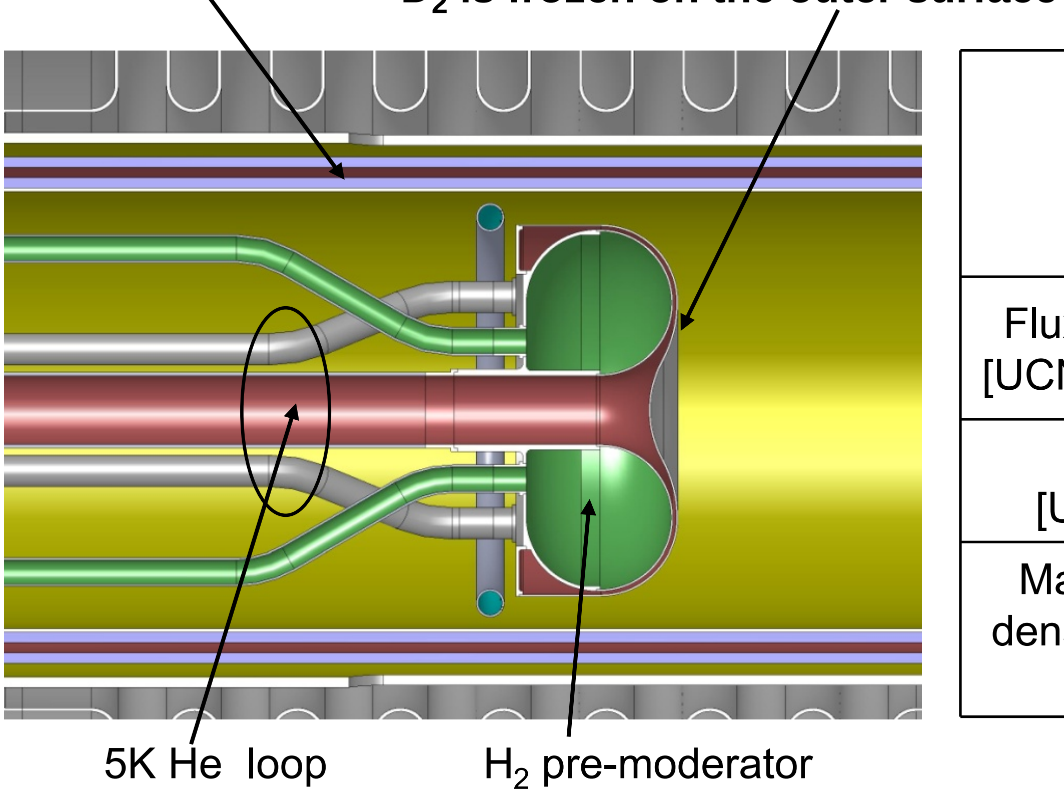
- Averaged Φ_{th} 2.0 x 10^{14} $cm^{-2}s^{-1}$
- Saturation activity of Mo-99 8.0 x 10^{14} s^{-1}

  equivalent 22 kCi
- After 6 d irradiation 17 kCi
- ... and 6 d decay time 4 kCi

Ultra Cold Neutron source @ FRM II



Expected performance of UCN source



	UCN source FRMII Exit of beam port	Experimental hall PENeLOPE
Flux density [UCN cm^{-2} s^{-1}]	$7.0 \cdot 10^4$	$6.2 \cdot 10^4$
Flux [UCN s^{-1}]	$8.0 \cdot 10^6$	$7.0 \cdot 10^6$
Max. UCN density [UCN cm^{-3}]	$1.2 \cdot 10^4$ (V = 100 dm^3)	$3.0 \cdot 10^3$ (V = 700 dm^3)

Names to be mentioned

- **Prof. Dr. Wolfgang Gläser**
- **Prof. Dr. Klaus Böning**
- **D. Anton Axmann**
- **Gert von Hassel**
- **Prof. Dr. Klaus Schreckenbach**
- **Guido Engelke**
- **Dr. Ingo Neuhaus**
- **........**