Technische Universität München

Industrial and Commercial Applications of FRM II

Heiko Gerstenberg (and many colleagues)

Forschungsneutronenquelle FRM II,

Technische Universität München

Campus of the TUM in Garching near Munich

Motivation for the Operation of FRM II

- Basic research by means of neutron beam tube experiments
  - fundamental physics (e.g. neutron life time)
  - physics of condensed matter (solids and liquids)

- Irradiation service
  - isotope production for radiopharmaceuticals and industry
  - Si doping
  - neutron activation analysis and fission track analysis
  - target irradiation for Mo-99 (project)

- Cancer treatment by fast neutron irradiation

- Industrial applications of neutron scattering
  - determination of stress in mechanical components
  - neutron tomography

Some key numbers:

Single cylindrical compact core contained in a D_2O-moderator tank

Ø = 118~243mm, h = 700 mm

fuel: 8,1 kg U_3Si_2 , (92% U-235)

Thermal power: 20 MW

Primary coolant flow: 300 kg/s H_2O

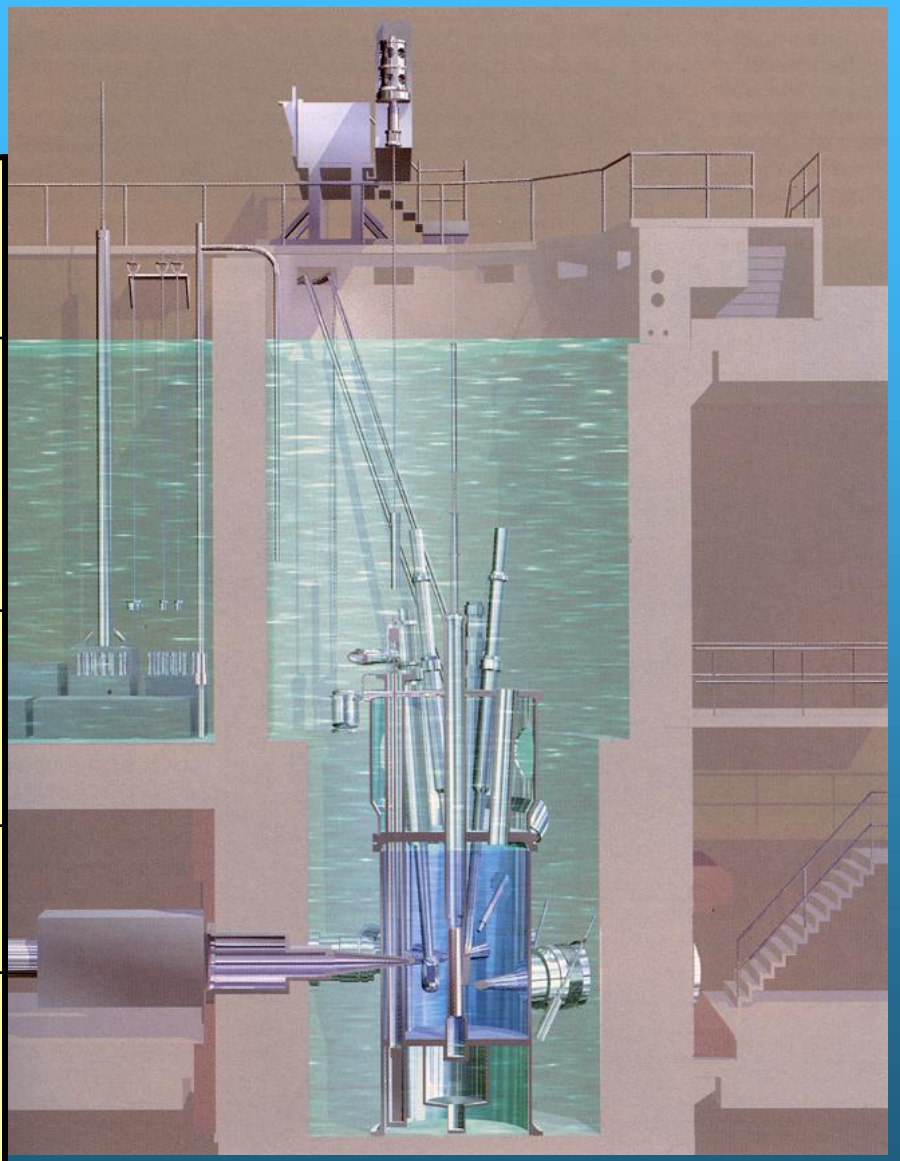
Thermal neutron flux density :

$6.5 \cdot 10^{14}$ $cm^{-2}s^{-1}$

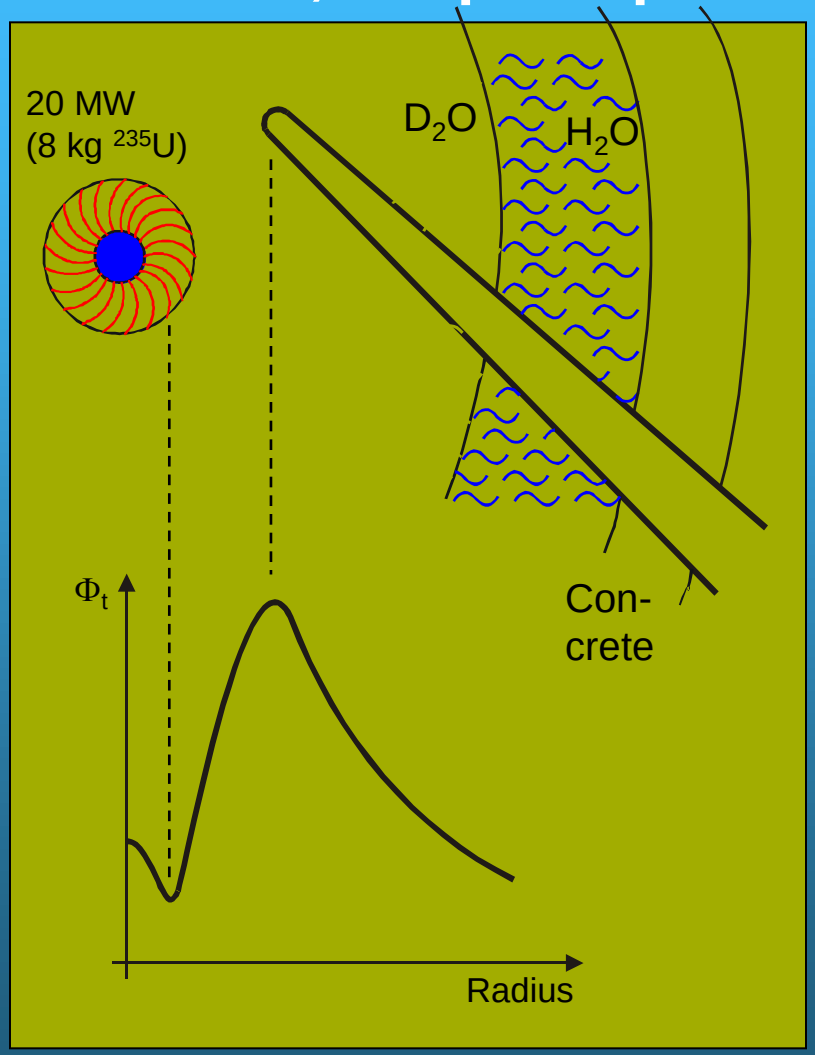
Reactor cycle:

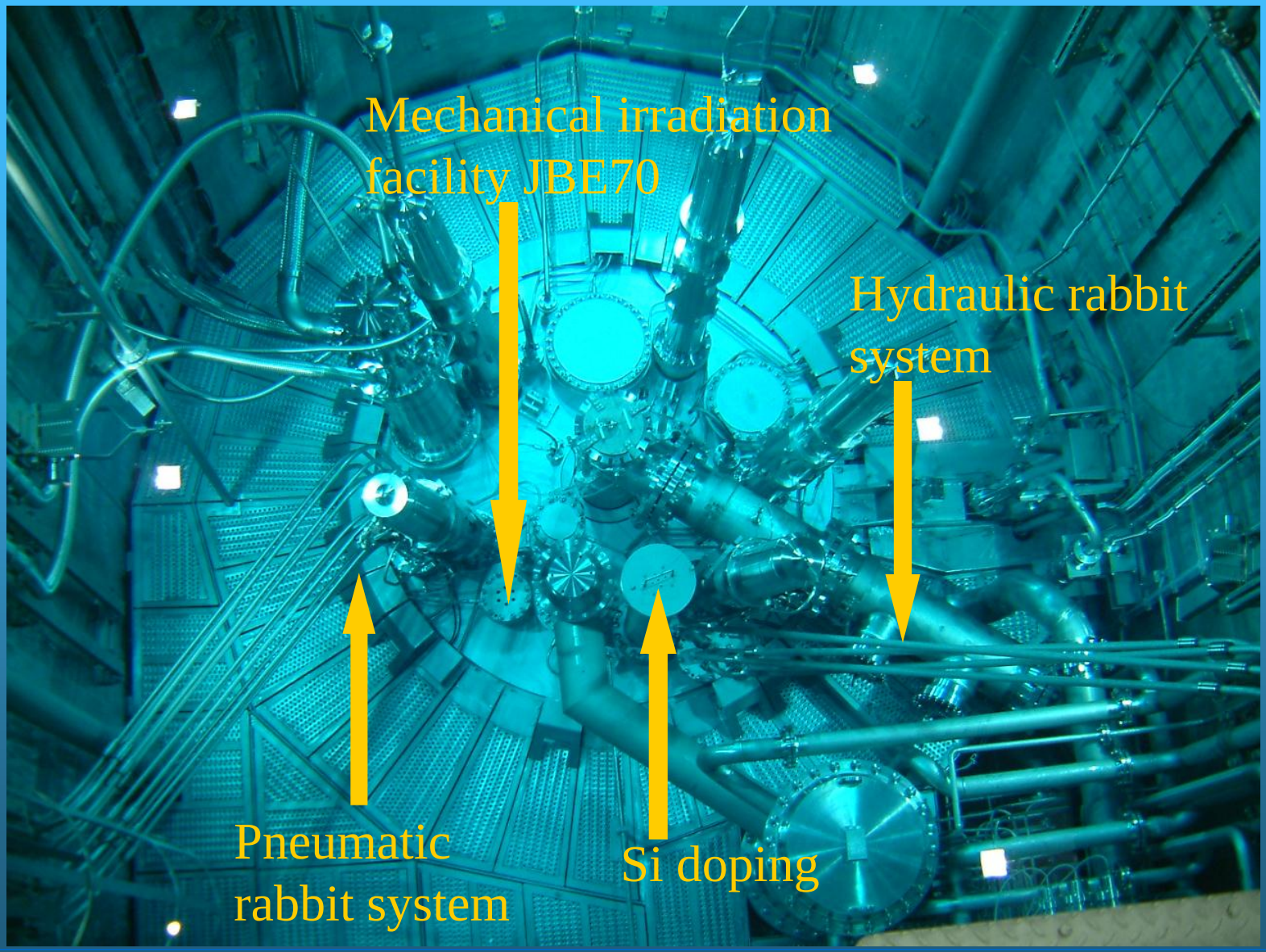
60 d/cyc (starting from 2008),

≈ 250 operational days/year



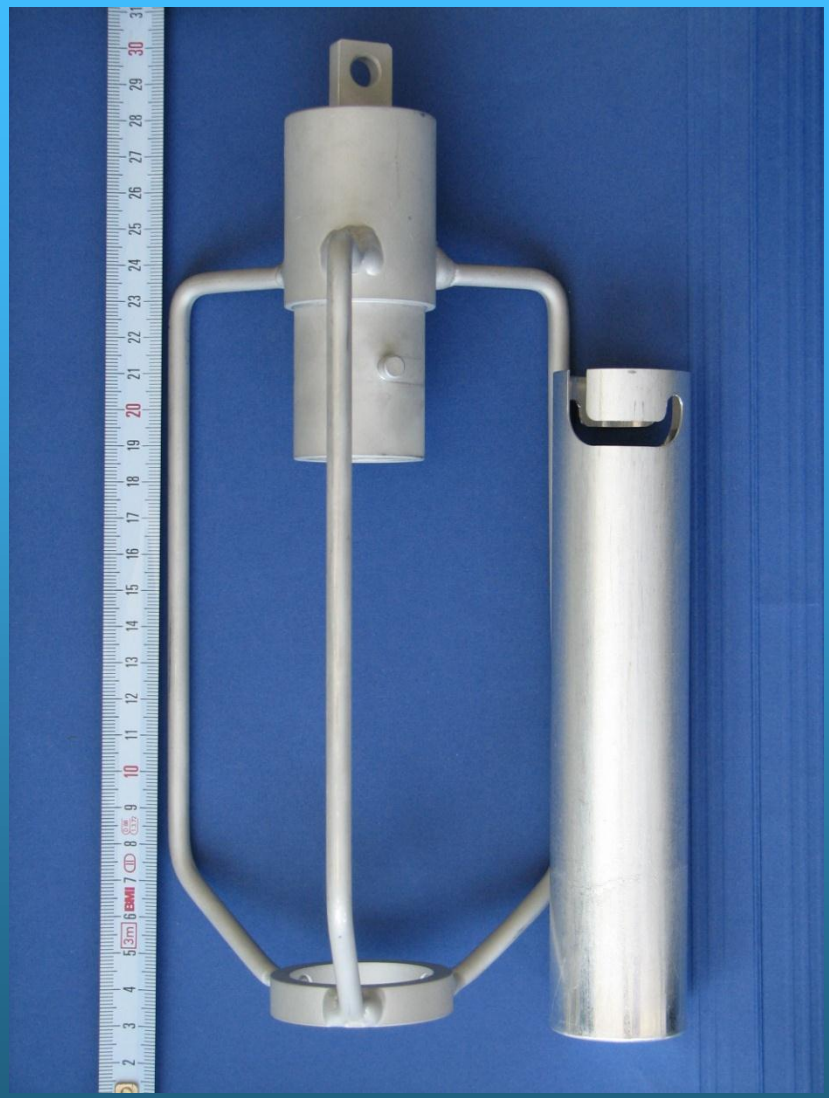
FRM II, the principle




Mechanical irradiation facility JBE70
Hydraulic rabbit system
Pneumatic rabbit system
Si doping

Mechanical irradiation facility JBE70

- Simple mechanical handling
- Simplified radiation protection measures
- Short term irradiations
- Φ_{th} = 1.2E13 $cm^{-2}s^{-1}$
- $\Phi_{th}/\ \Phi_f$ = 1200
- mainly in use for FT thermochronography, world wide customers



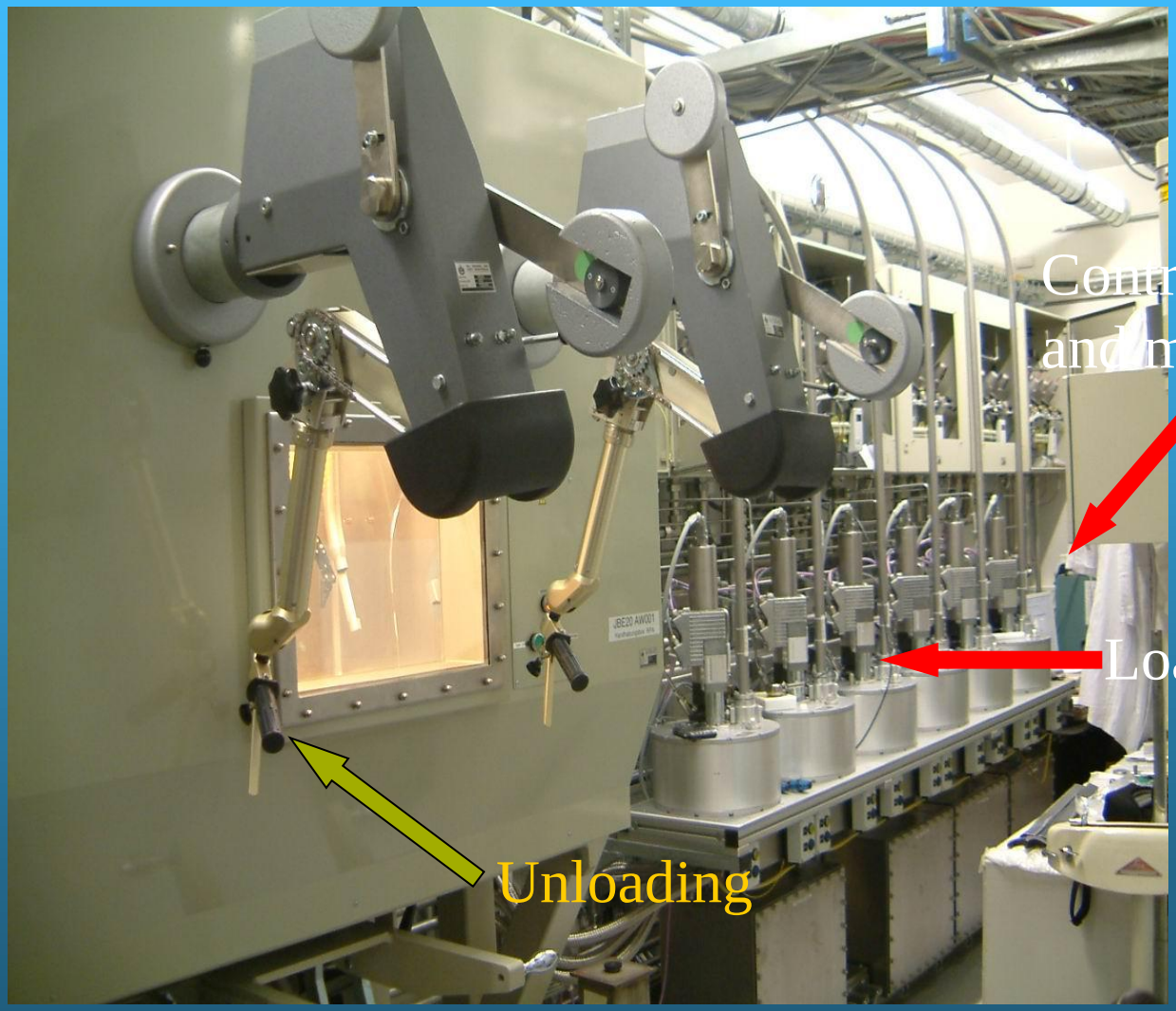
Pneumatic rabbit device

6 irradiation channels

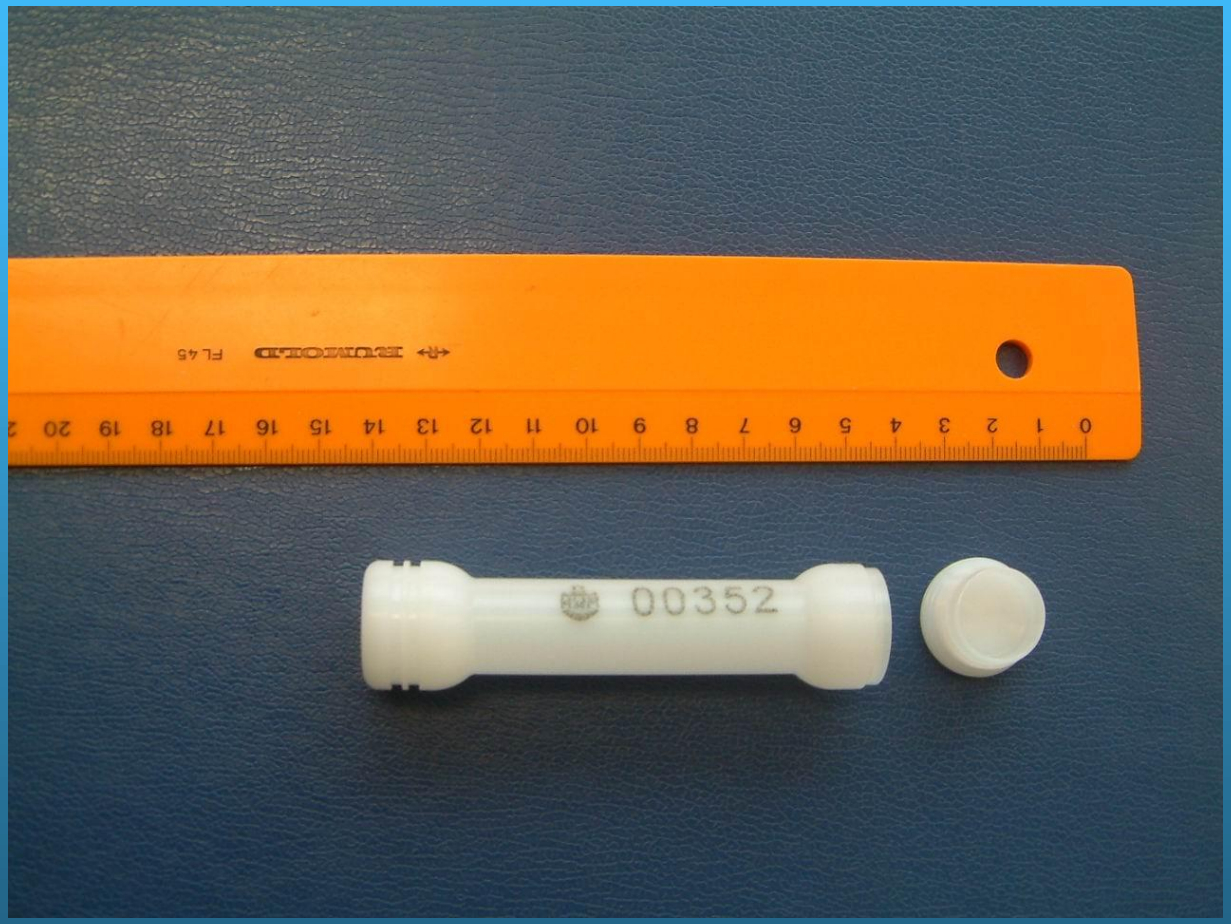
$\Phi_{th} \leq$ 7E13 $cm^{-2}s^{-1}$

$\Phi_{th}/\Phi_f >> 1000$

Mainly in use for NAA, Ir-192

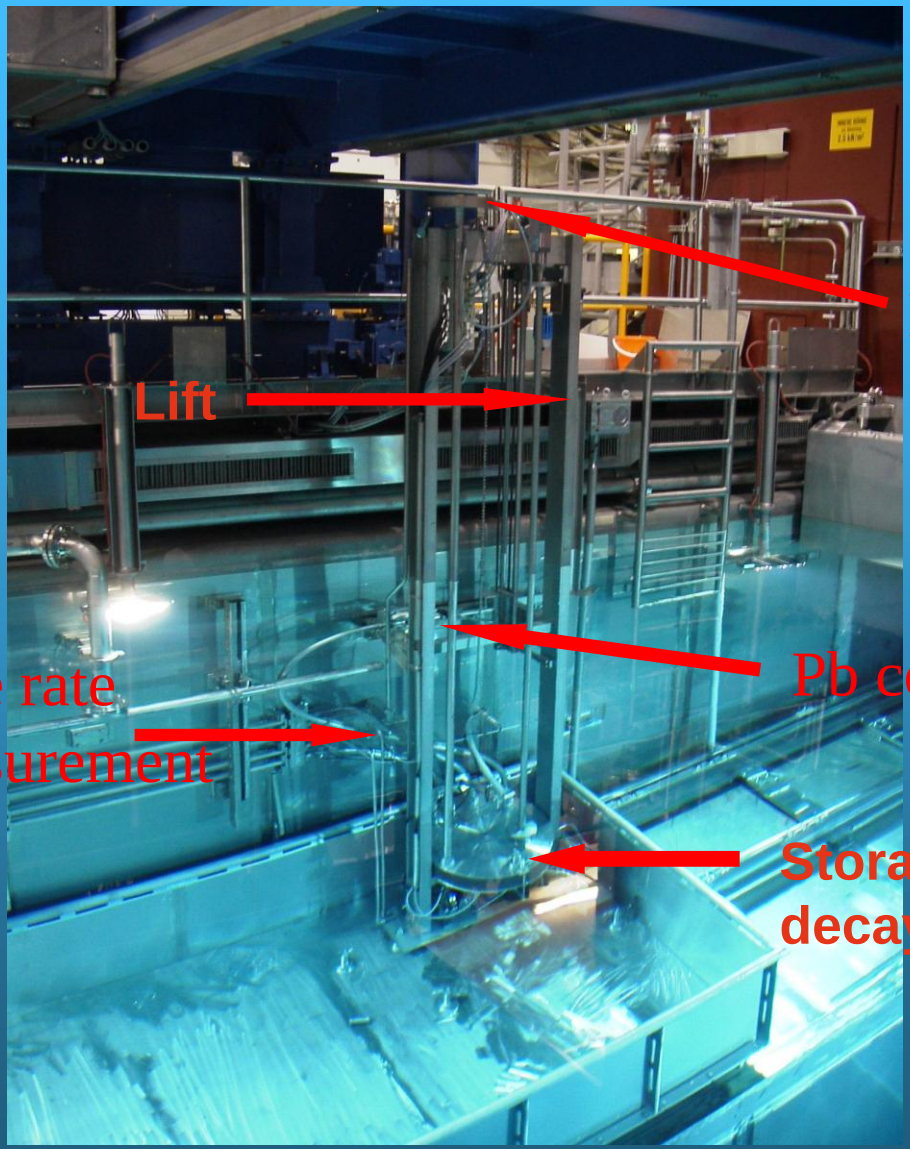


- material: PE
- mass: ≈ 10g
- max. load 10g
- max dose: 3E17 n/cm^{-2}
- Individual label
- Single use
- Connection to RCM



Hydraulic dispatch

- loading and unloading device
- Capsule management



Hydraulic rabbit system – irradiation capsules

- material: AlMg3 + Al
- mass: ≈ 48g (total)
- max. load 250g
- ø = 25 mm
- l ≈ 60 mm
- max dose: unlimited
- Water tight sealing
- Individual label
- Multiple use

Hydraulic rabbit system: Neutron flux parameters

irradiation channel	Φ_{th} ($cm^{-2}s^{-1}$)	Φ_{epi} ($cm^{-2}s^{-1}$)	Φ_{f} ($cm^{-2}s^{-1}$)	Φ_{th}/Φ_{f}
KBA1-1	1.3E14	2.6E11	3.9E11	333
KBA1-2	9.3E13	9.9E10	2.0E11	465
KBA2-1	1.1E14	7.5E10	2.1E11	524
KBA2-2	7.7E13	3.9E10	1.0E11	770

Hydraulic rabbit system: Main applications

- Production of Co-60 for industrial purposes up to 185 GBq/batch
- Production of Lu-177 nca (non carrier added) for therapy of small (range about 2 mm) neuro-endocrine tumors in cooperation with ITG GmbH, Garching. The activity is labelled to dotatate and applied to patients in 2-3 doses of 7.4 GBq each.
- Production of seeds containing I-125 for the therapy of prostata cancer in cooperation with IBT Bebig GmbH, Berlin.
- Production of tracers for e.g. the chemical industry in cooperation with Tacerco, Oldenburg.
- Irradiation of high-purity Si for NAA in cooperation with Semisol GmbH, Munich

Silicon doping facilty - Motivation

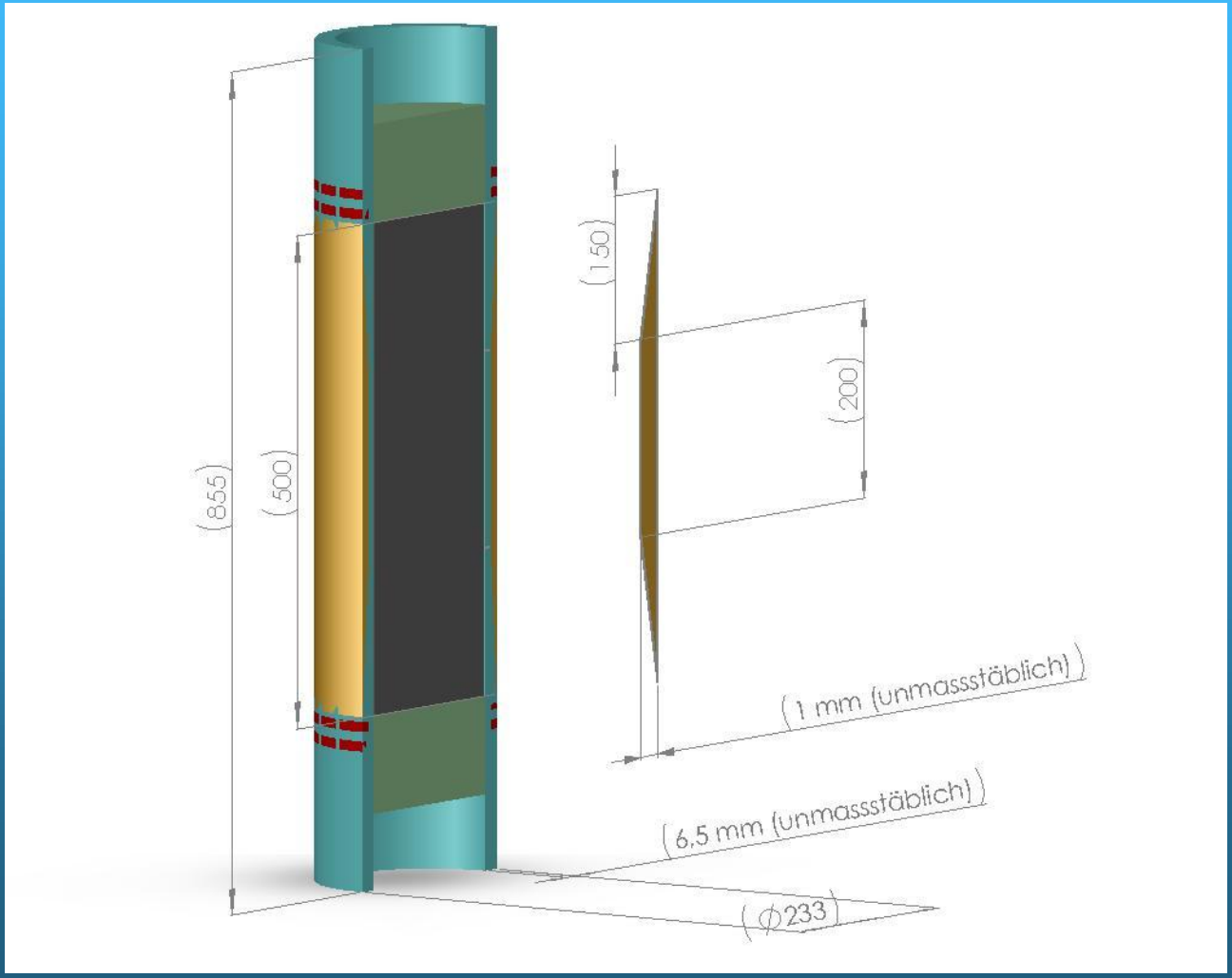
P doping of Si by neutron transmutation

$^{30}Si\ (n,\gamma)^{31}Si \longrightarrow {}^{31}P$ $\quad T_{1/2}\ (^{31}Si) = 2.62\ h$

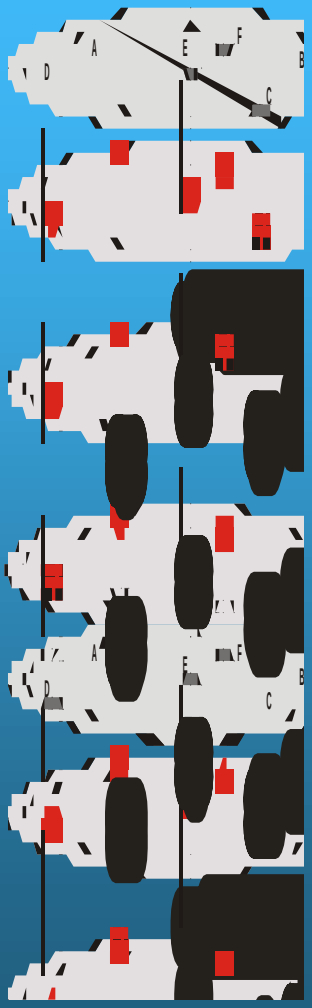
Typical Specifications

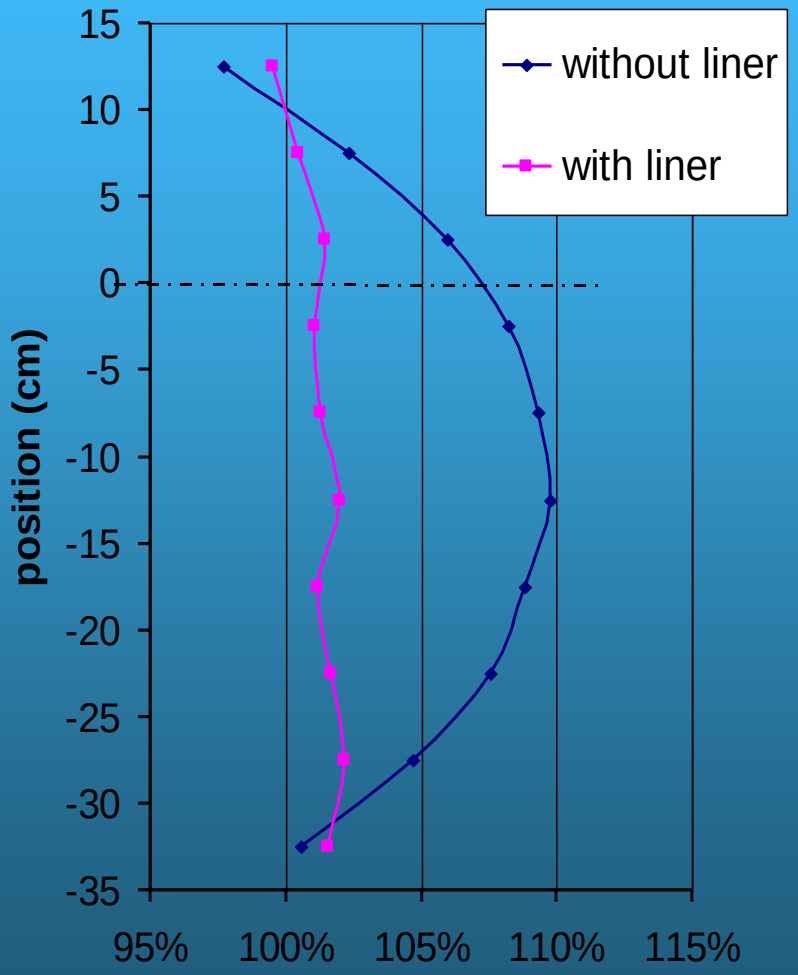
Accuracy:	$\rho_{meas.} = \rho_{target} \pm 5\%$
Homogeneity:	axial: $\Delta\rho < 5\%$
	radial: $\Delta\rho < 3.5\%$
Residual radioactivity:	$A/m < 0.09\ Bq/g$
Residual contamination:	$A/S < 0.5\ Bq/cm^2$

Smoothening of neutron flux density by a Ni compensation layer

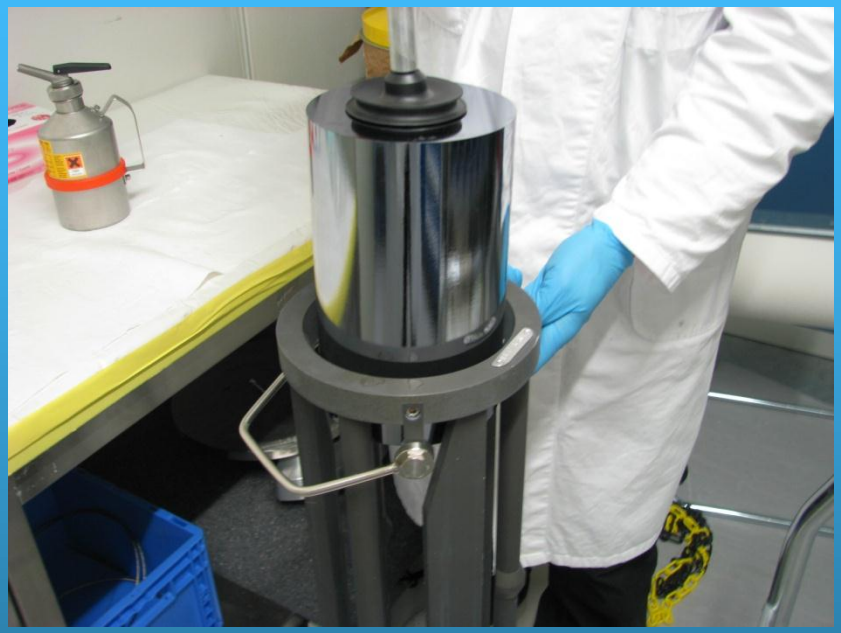


Effect of smoothening



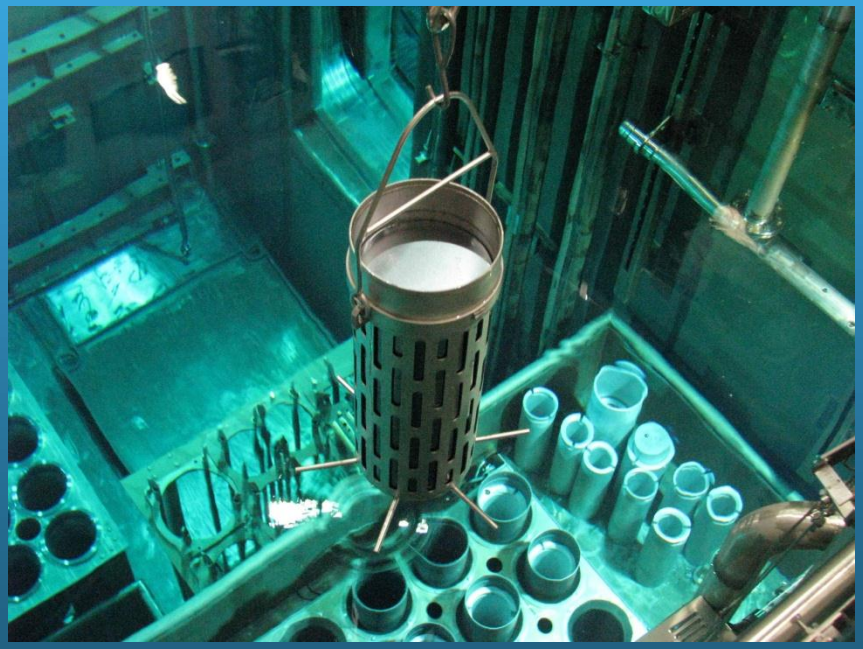


Main handling steps (1)

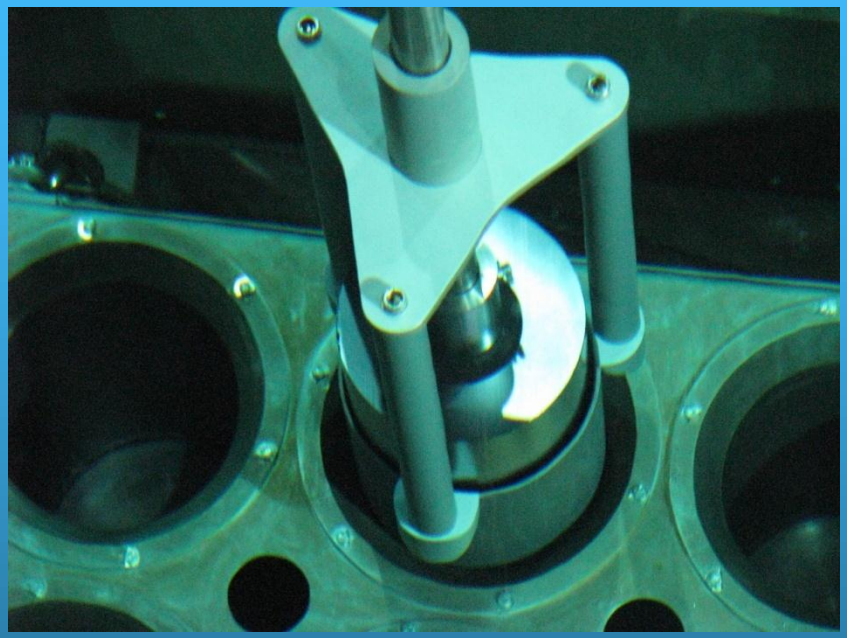


Insertion of Si ingots into the loading basket

Lowering the Si into the reactor pool

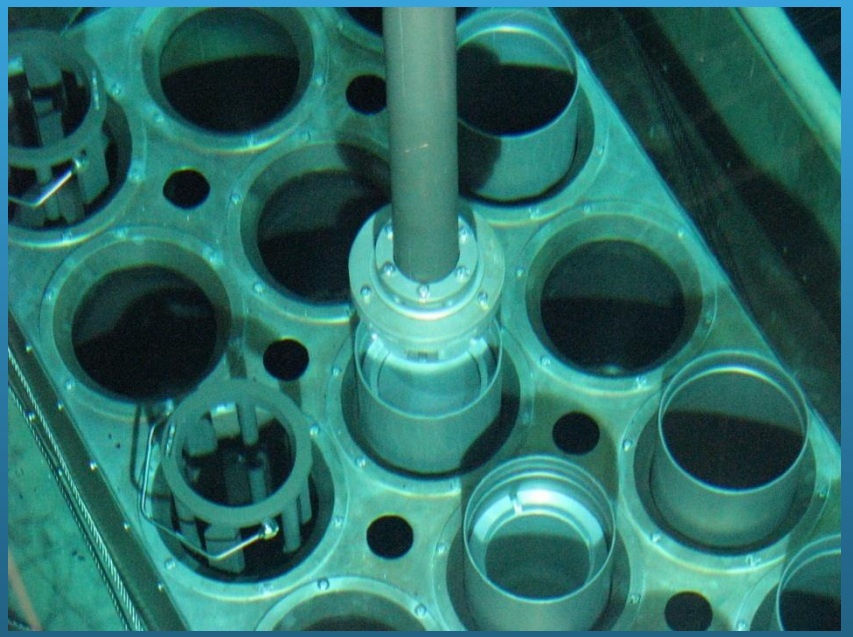


Main handling steps (2)

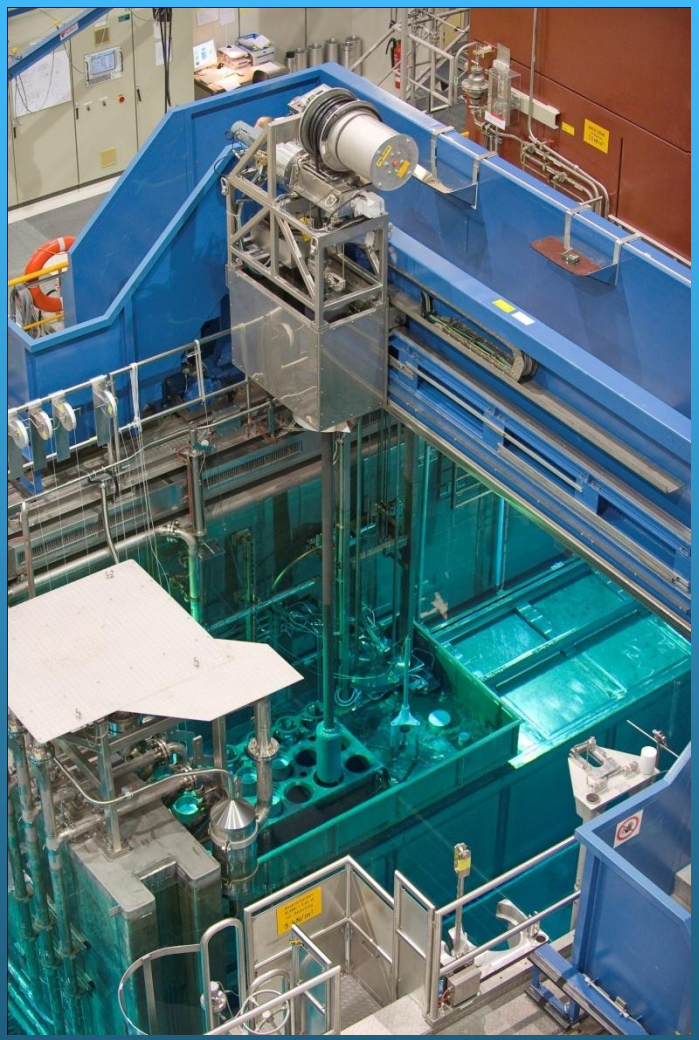


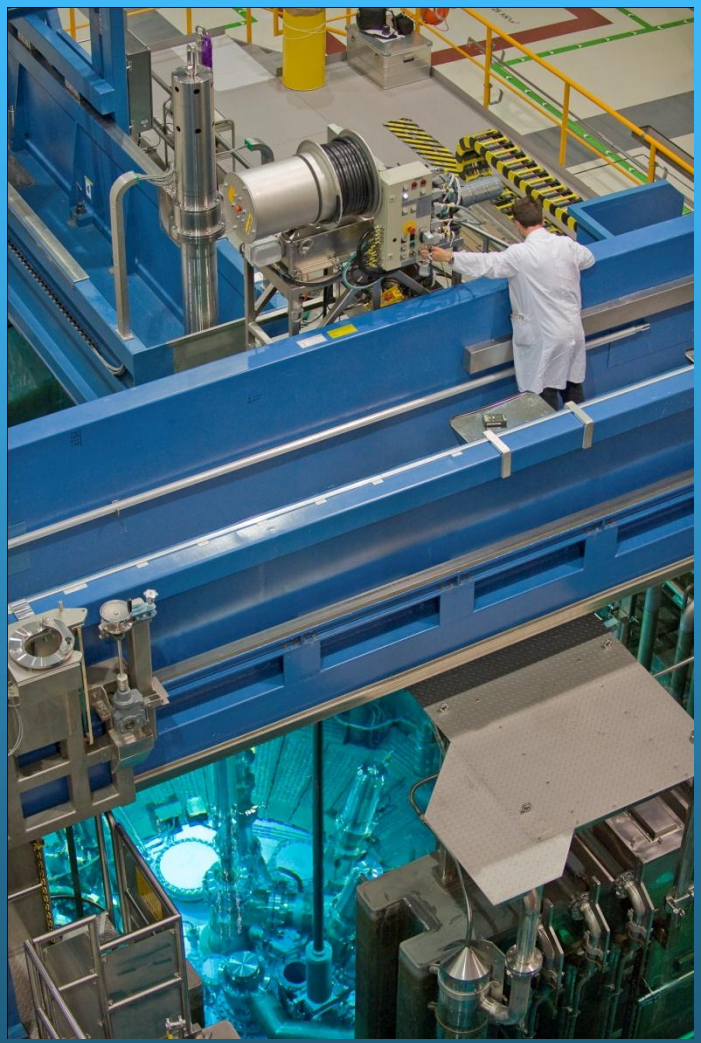
Loading Si ingots into the irradiation basket

Coupling the basket to the irradiation device



Main handling steps (3)





ZERTIFIKAT ◆ CERTIFICATE ◆ 認証書 ◆ СЕРТИФИКАТ ◆ CERTIFICADO ◆ CERTIFICAT

TÜV SÜD Management Service

ZERTIFIKAT

Die Zertifizierungsstelle
der TÜV SÜD Management Service GmbH
bescheinigt, dass das Unternehmen

Technische Universität München
Forschungsneutronenquelle
Heinz Maier-Leibnitz (FRM II)
Lichtenbergstraße 1, D-85747 Garching

für den Geltungsbereich

Dotierung von Reinstsilizium
mittels Neutronenbestrahlung

ein Qualitätsmanagementsystem
eingeführt hat und anwendet.
Durch ein Audit, Bericht-Nr. **70716021**
wurde der Nachweis erbracht, dass die Forderungen der

ISO 9001: 2000

erfüllt sind. Dieses Zertifikat ist gültig bis **2010-03-11**
Zertifikat-Registrier-Nr. **12 100 30803 TMS**

München, 2007-03-13

QMS-TGA-ZM-07-92

TÜV SÜD Management Service GmbH • Zertifizierstelle • Ridlerstraße 65 • 80339 München • Germany

TÜV SÜD ISO 9001

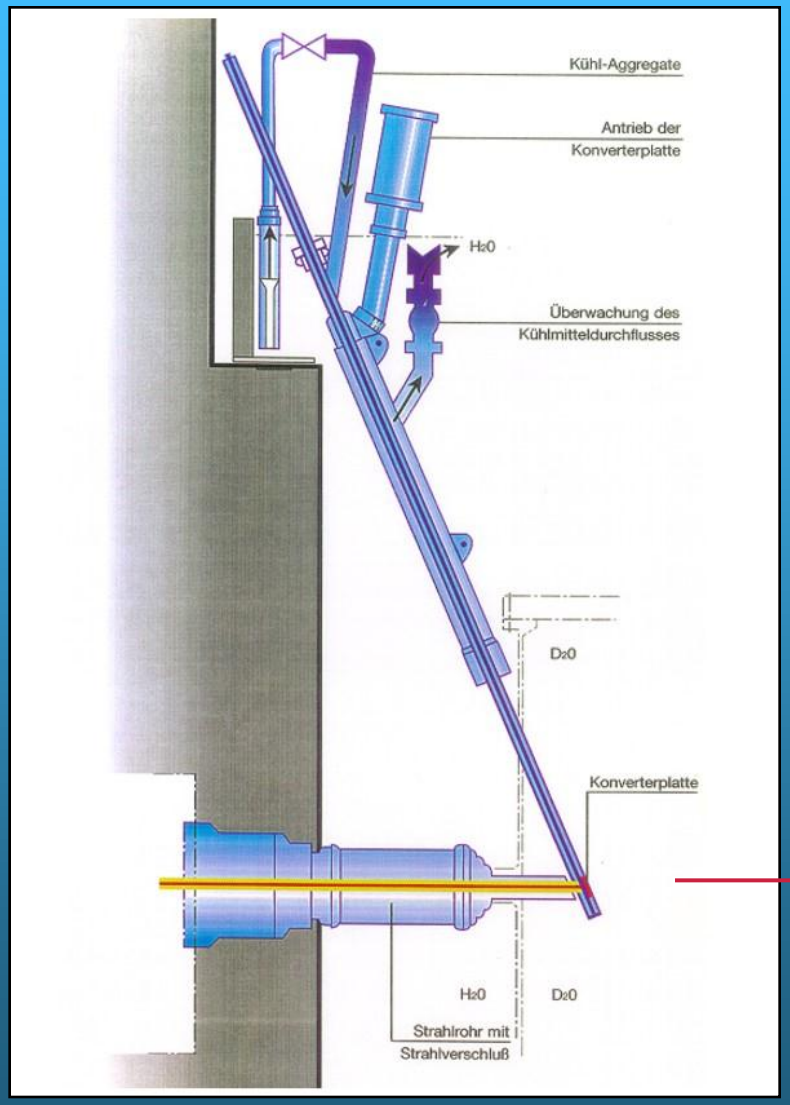
Si doping at FRM II

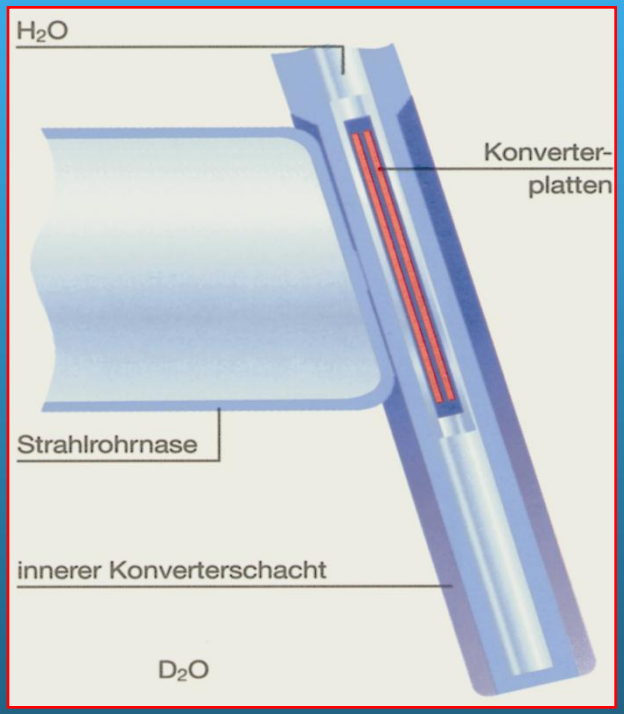
Throughput in 2009: 15 t

5 customers from Europe + Asia

Staff: 6 technicians/2 shifts
1 engineer
2 physicists

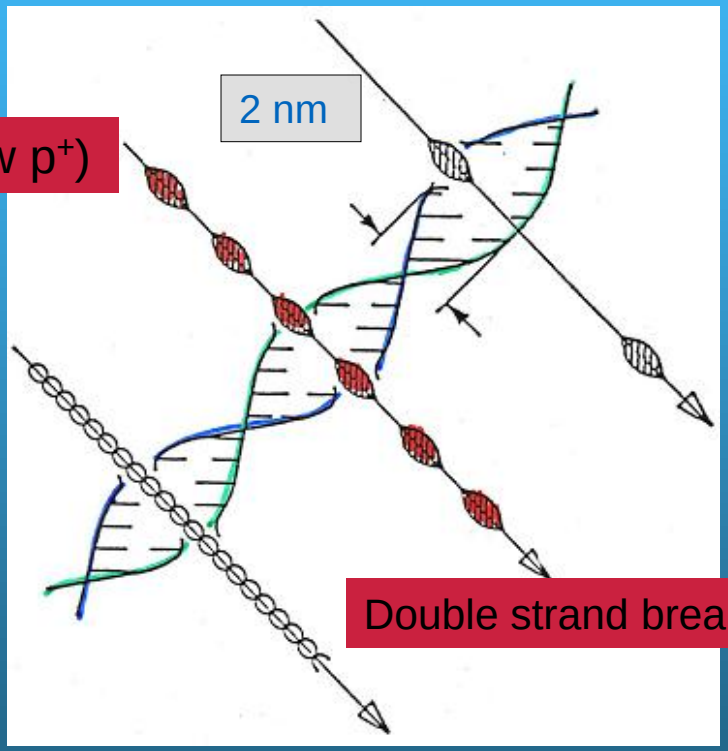
Converter facility - Neutron production for cancer therapy



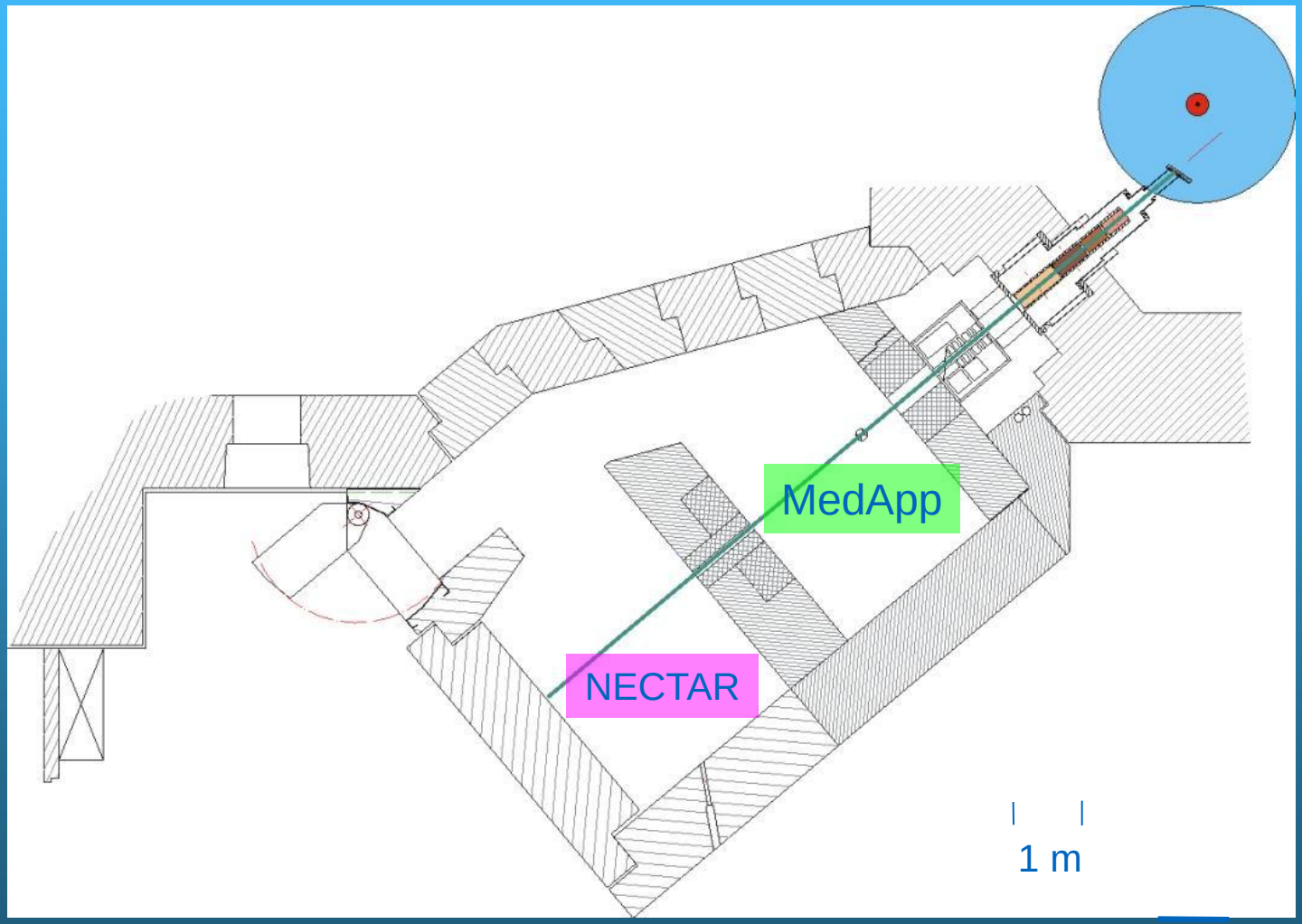


Linear energy transfer (n_f: up to 100 keV/µm)

Electrons/X, **γ**



Beam SR10

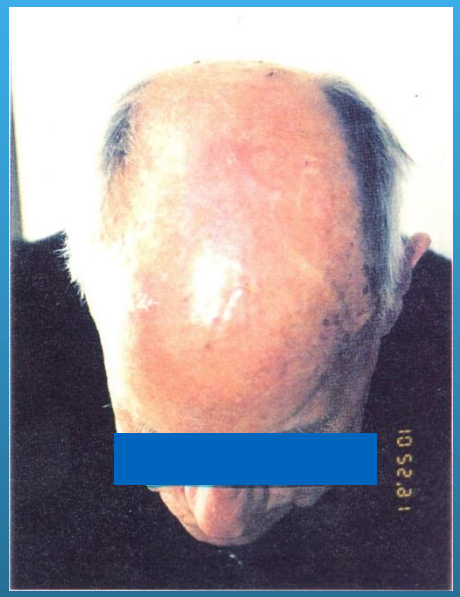


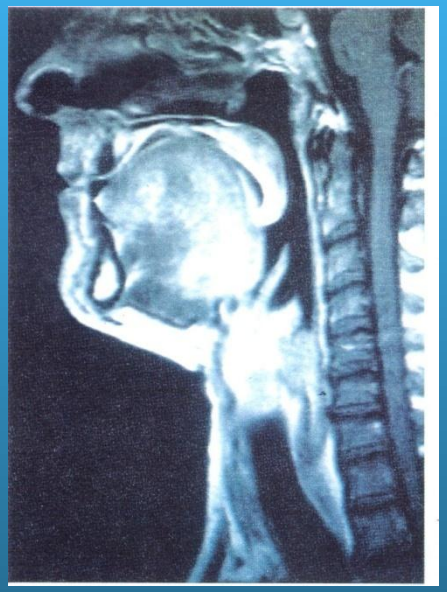
Irradiation rooms

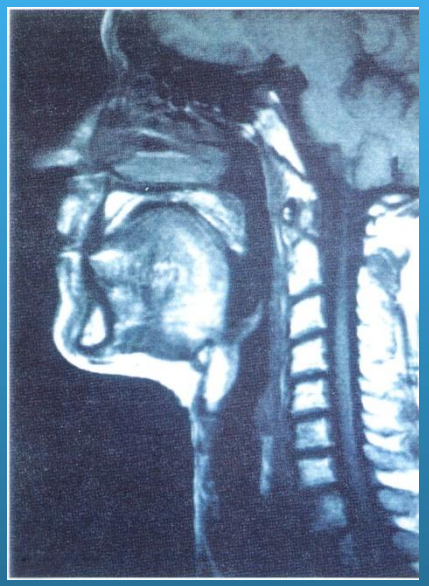
High-flux irradiation room

Radiography room

MedApp: Irradiation response





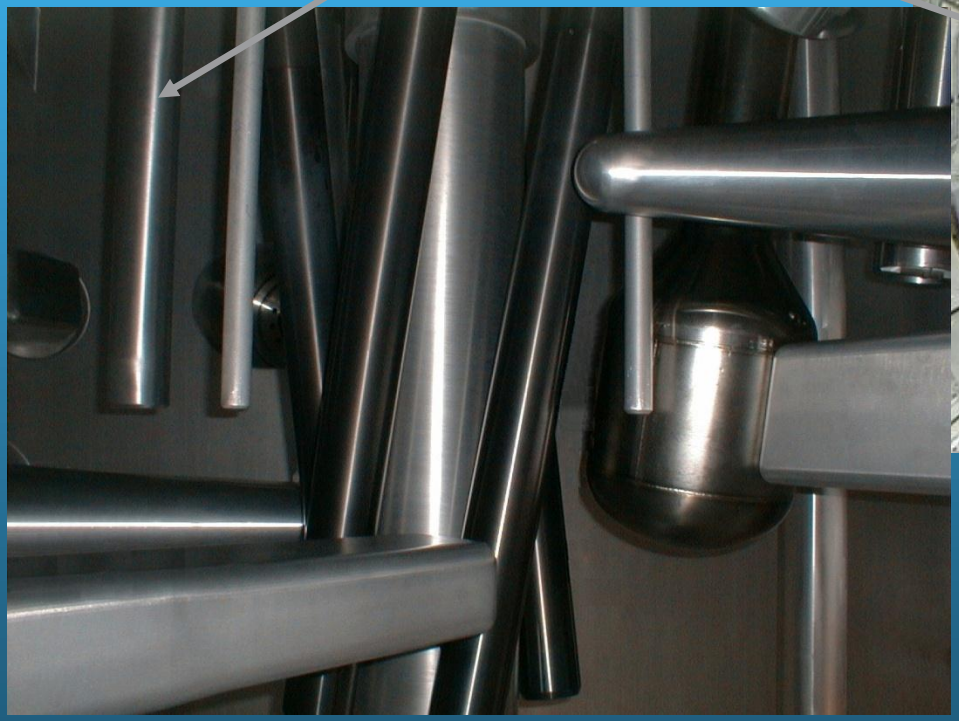


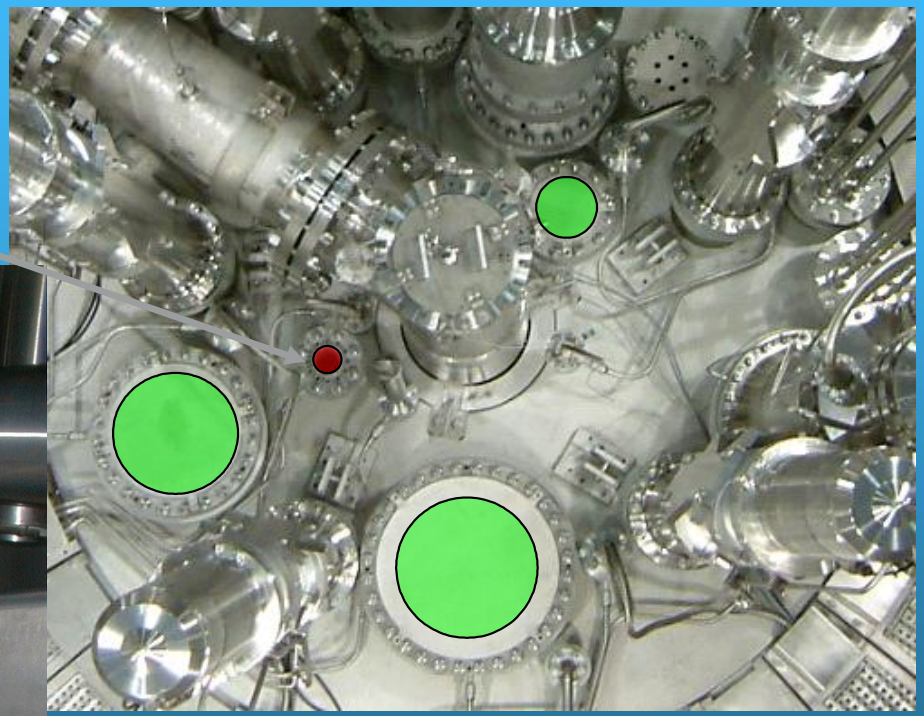
Malignant melanoma, elder patient

Laryngeal tumour, 39-year old patient

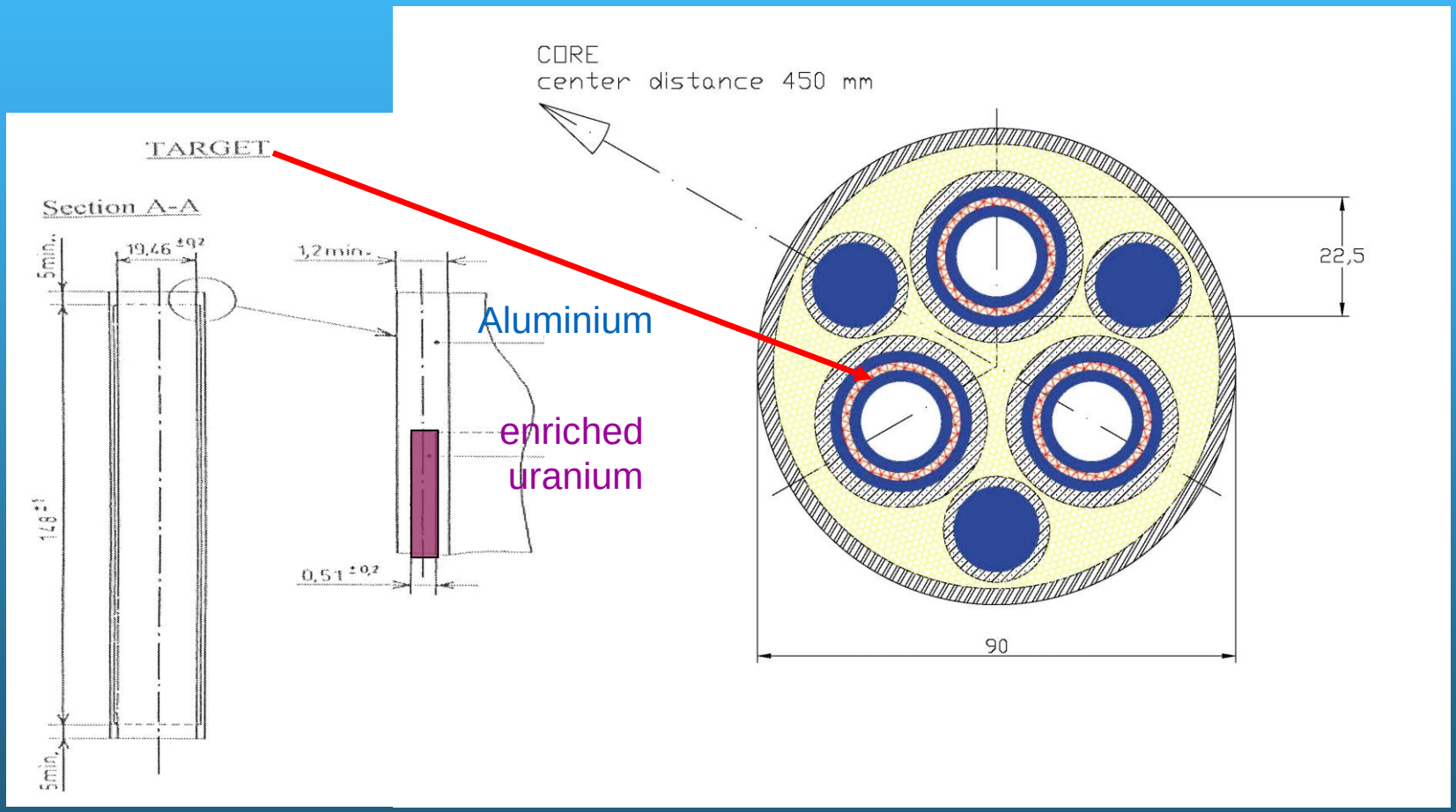
Figs.: Th. Auberger – Klinik für Strahlentherapie, TUM

Project: Target irradiation for Mo-99 production (2010-2014)

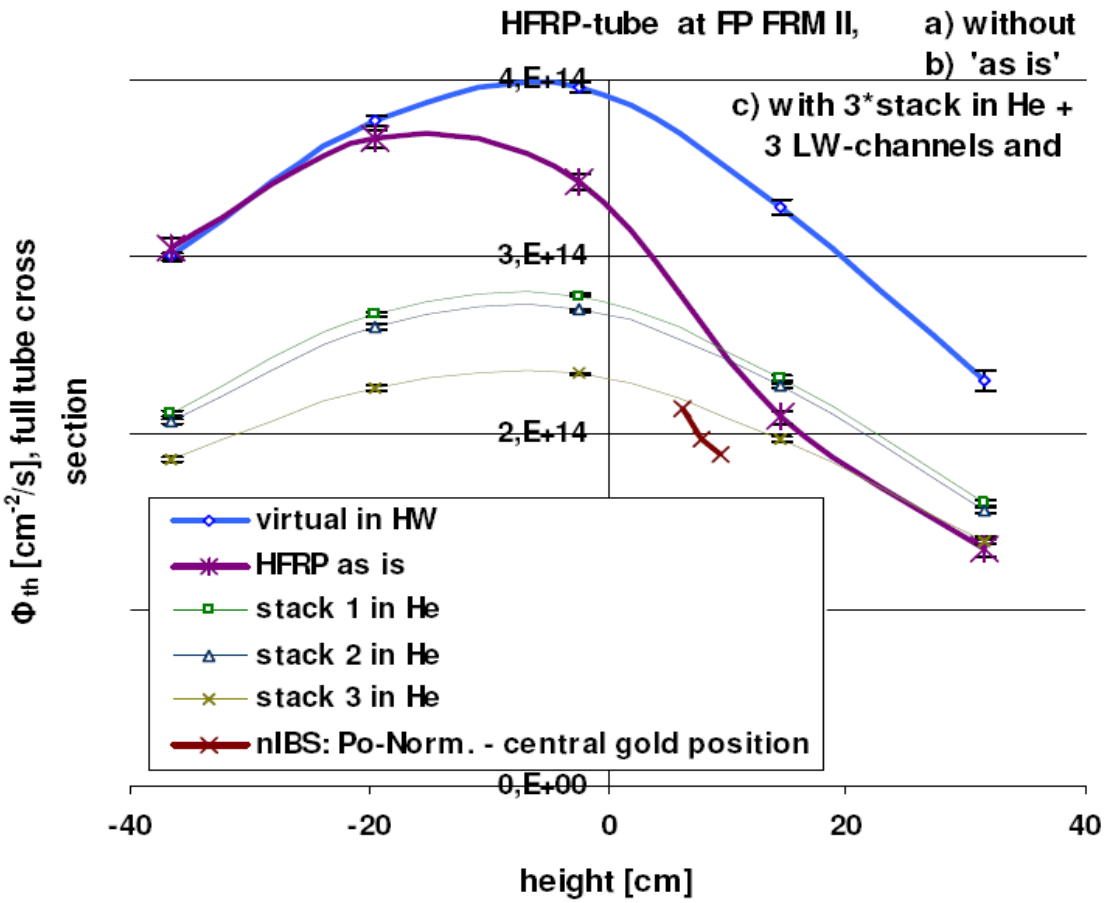




Top View to Future Irradiation Rig including Target Positions



Neutron Flux Density in Irradiation Channel for U-Targets



comparison of thermal flux axial profile for position HFRP/FRM II

Basic data for 15 targets JBE46 / FRM II

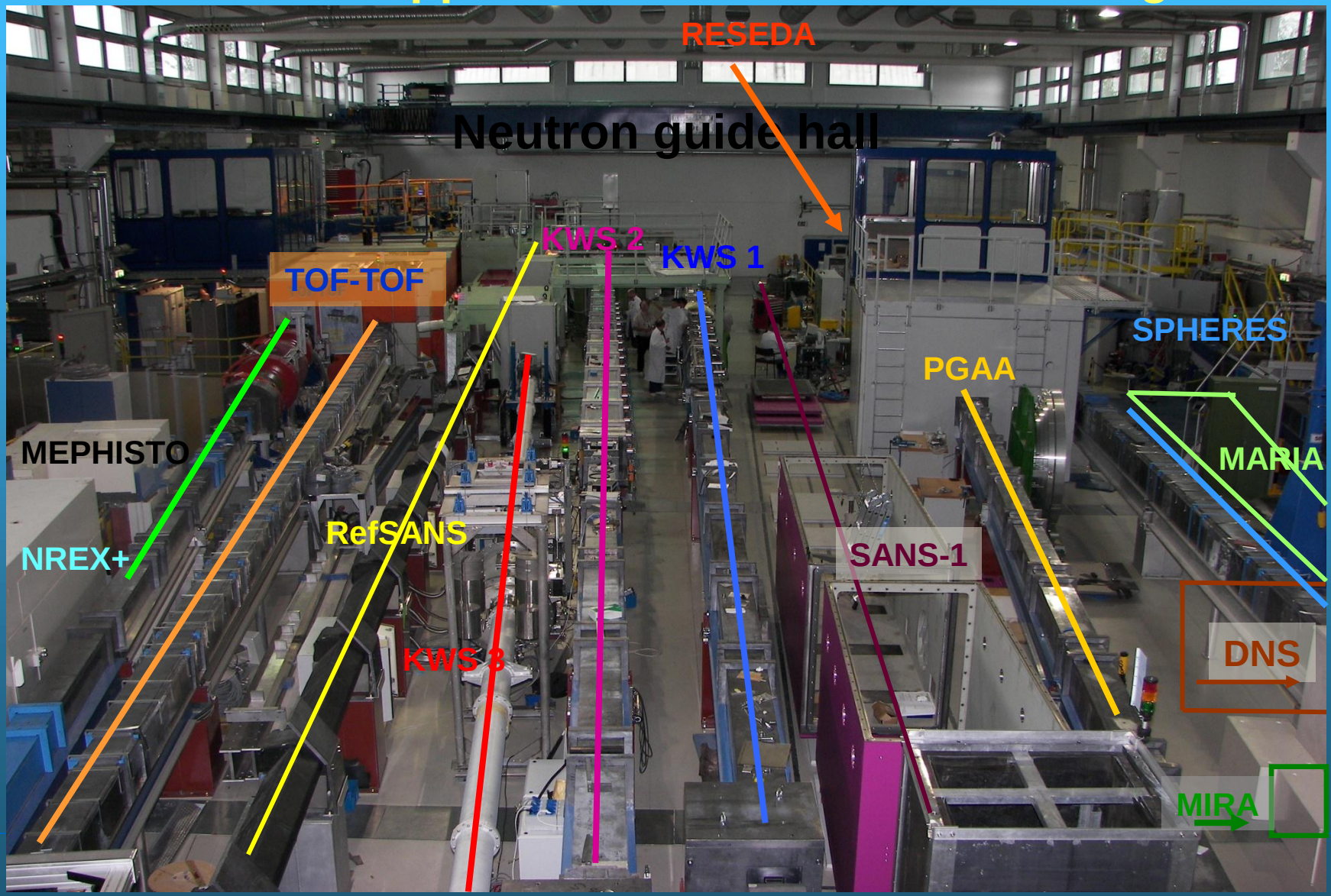
power

• flux at target position (undisturbed)	$2.2*10^{14}$	cm^{-2}/s
• flux at target position (disturbed)	$1.9\text{-}2.0*10^{14}$	cm^{-2}/s
• fission cross section (rate averaged)	470	barn
• power of target per fission event	< 193	MeV
• target amount, U-235	15*4	g
→ total power in target stacks	< 430	kW

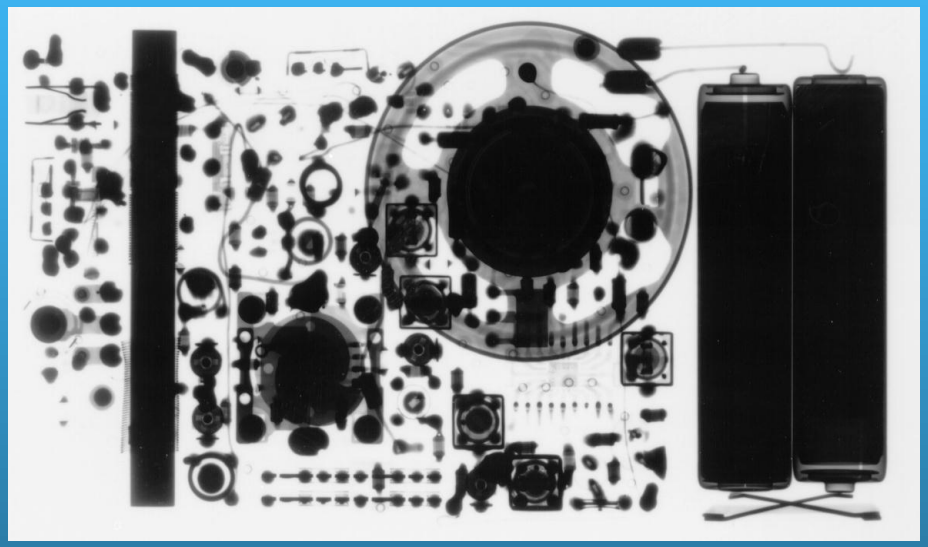
activity

• fission yield, 99-isomer chain	6.1	% / fission
• flux depression at targets due to Xe-135 build up	4	%
→ total saturation activity M0-99	8.0 E14	1/s or
	22	kCi
at 6 days of irradiation (=78% of saturation)	17	kCi
at 10 days of irradiation (=92% of saturation)	20	kCi

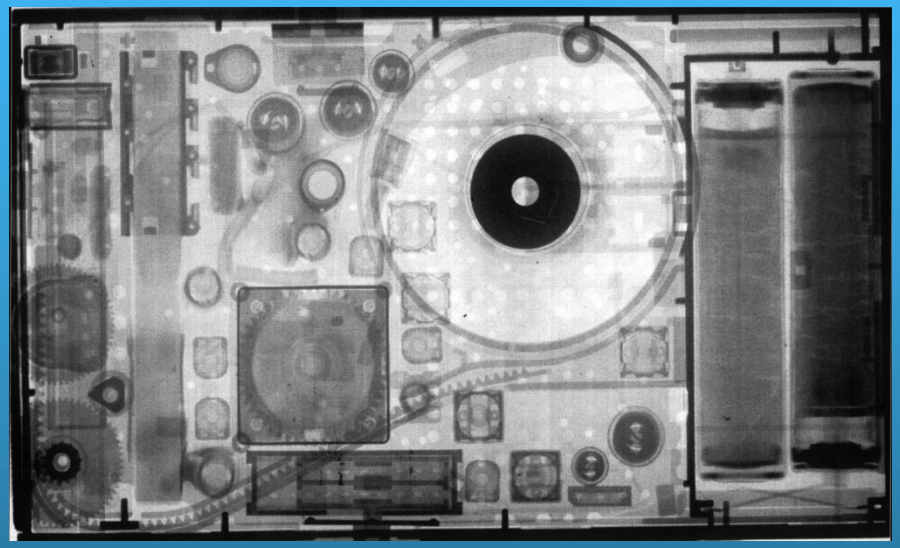
Industrial applications of neutron scattering



Radiography: comparison between X-rays und neutrons



X-rays

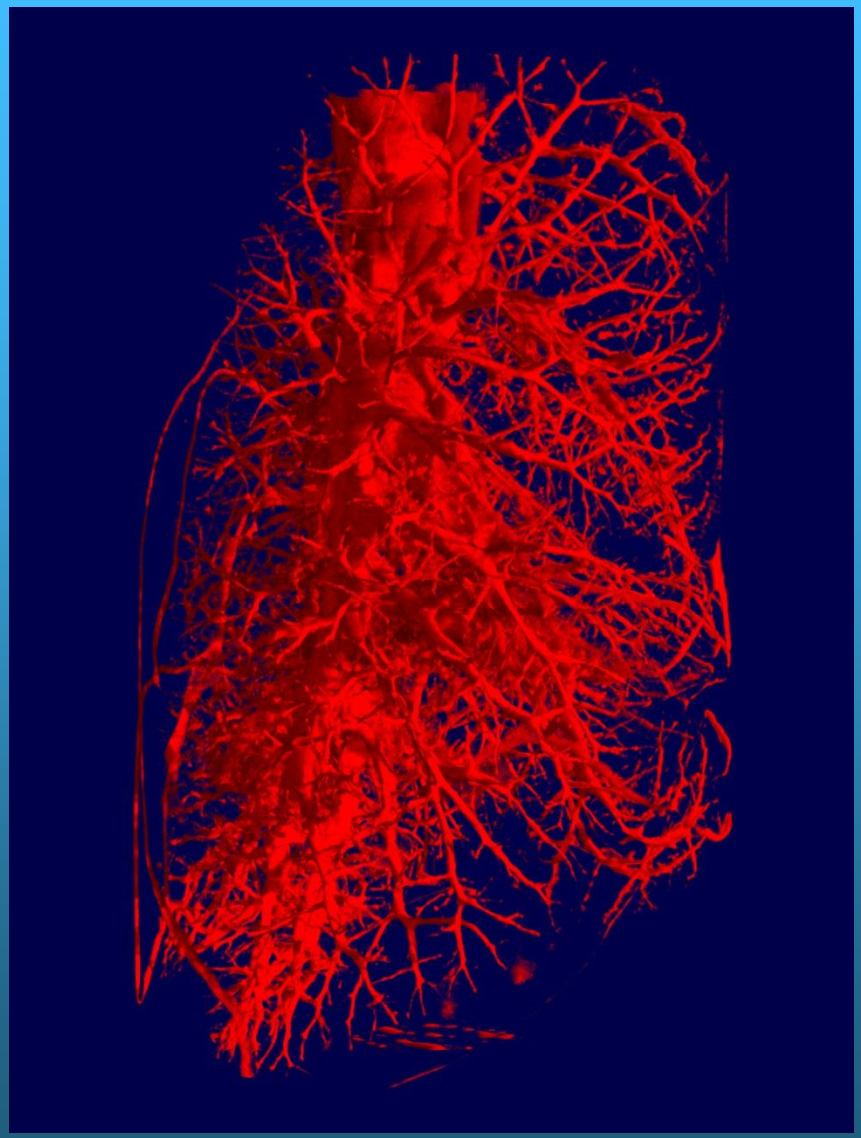


Neutrons

Example: Mini-Transistor-Radio

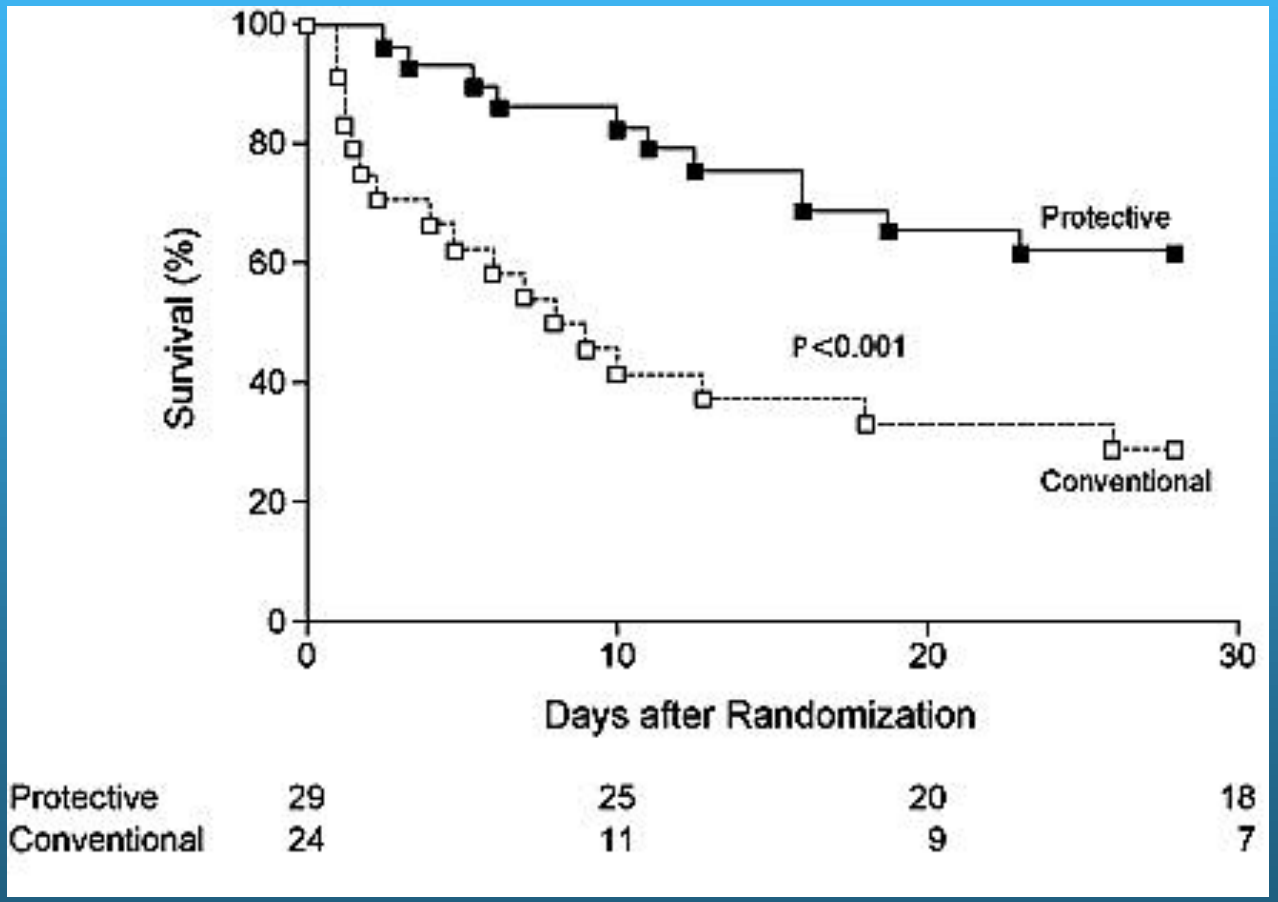
Lehmann et al, PSI

Tomography of a rat lung



Schillinger (FRM II), Metzge (MW –TUM), Runck, Stahl (Uni-Klinik Freiburg)

Artifical ventilation: survival rate



Marcello B.P. Amato, The New England Journal of Medicine, 338, 6, 347-54, 1998


Thank you for listening !