Tomography with fission neutrons and Co-60

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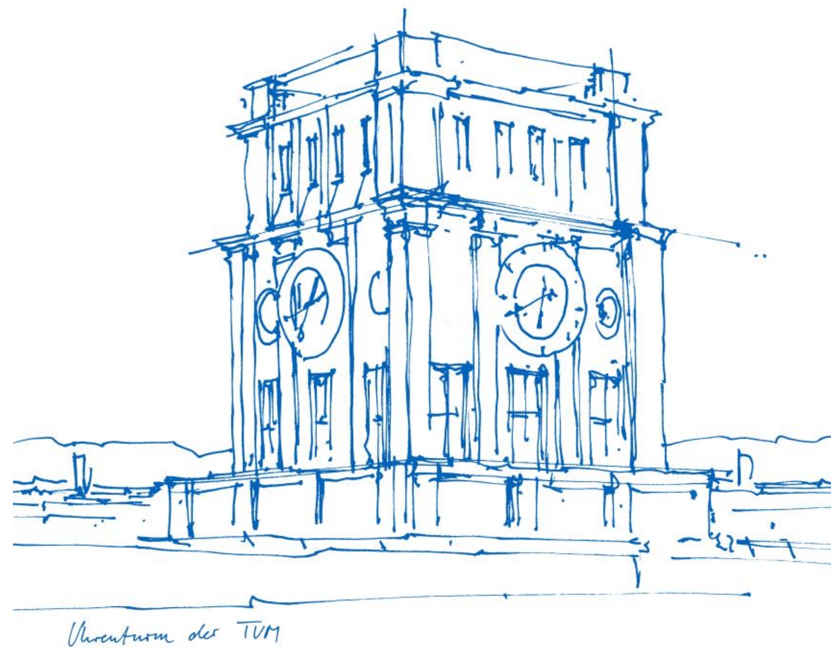


Content

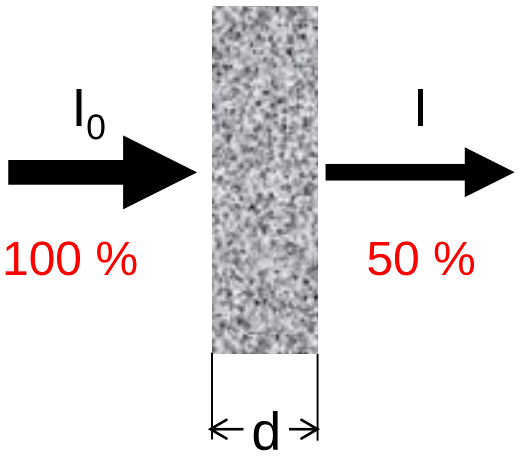
- Motivation
- The NECTAR facility
- ITS
- Examples

Motivation

Why using

- different types of sources (neutrons, X-rays, γ-rays etc.)?
- different energies of these sources?

➢ The term **transmission**



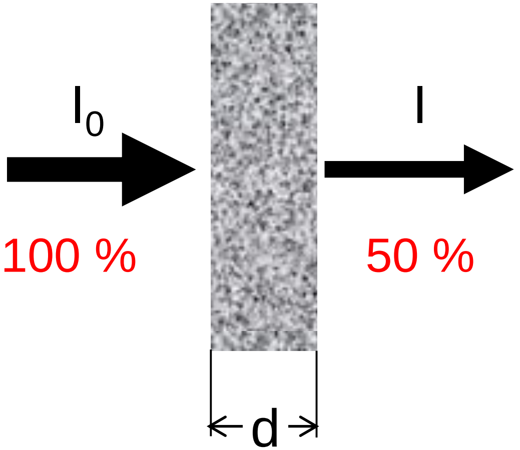
Motivation

$$I = I_0 \cdot exp(-\mu \cdot d)$$ (Beer–Lambert law)

$$I = I_0 \cdot exp\left(-\left(\frac{\mu}{\rho}\right) \cdot \rho \cdot d\right)$$

with

I_0	primary intensity
I	attenuated intensity
d	thickness of sample
μ	linear attenuation coefficient
(μ/ρ)	mass attenuation coefficient
ρ	density



Motivation

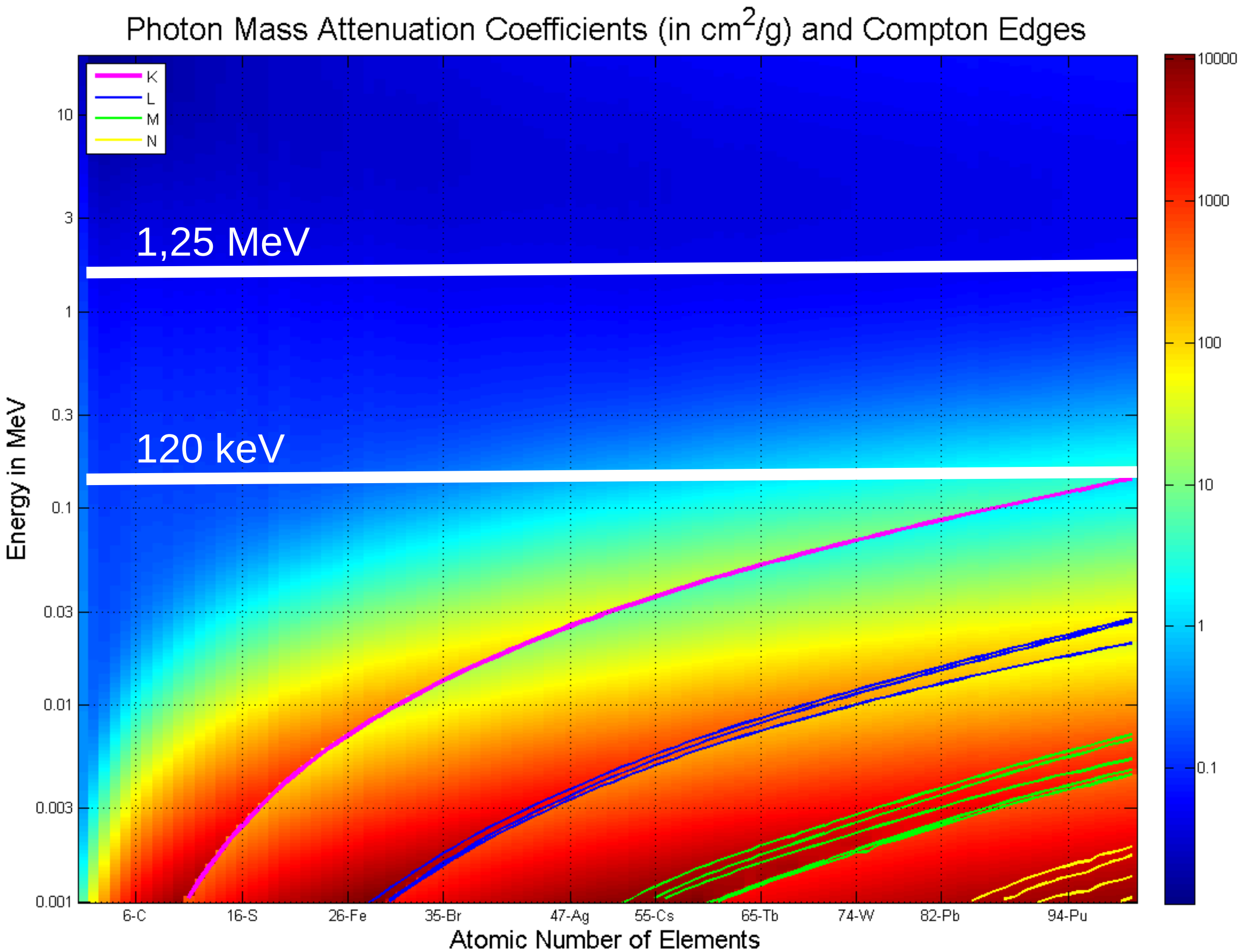
Why using

- the mass absorption instead of the linear attenuation coefficient?

Often preferred in praxis (when using γ-rays) as it is

- nearly constant for γ-rays for important range of energies
- approximately the same for many elements
- accounts for different densities of materials

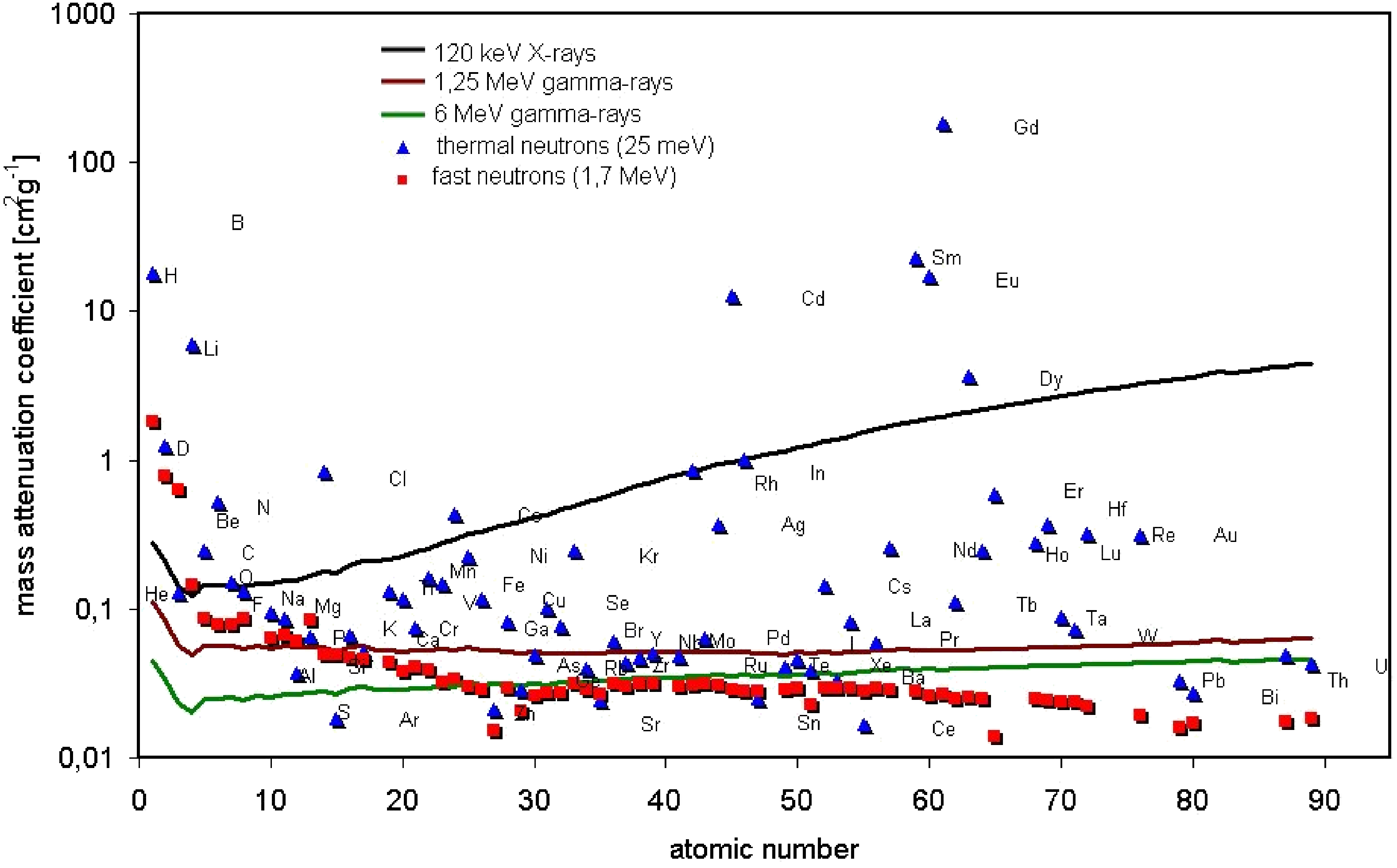
Motivation



Mass attenuation coefficient values shown for all elements with atomic number Z smaller than 100 collected for photons with energies from 1 keV to 20 MeV. The discontinuities in the values are due to absorption edges which were also shown.

https://en.wikipedia.org/wiki/Mass_attenuation_coefficient#/media/File:Photon_Mass_Attenuation_Coefficients.png

Motivation

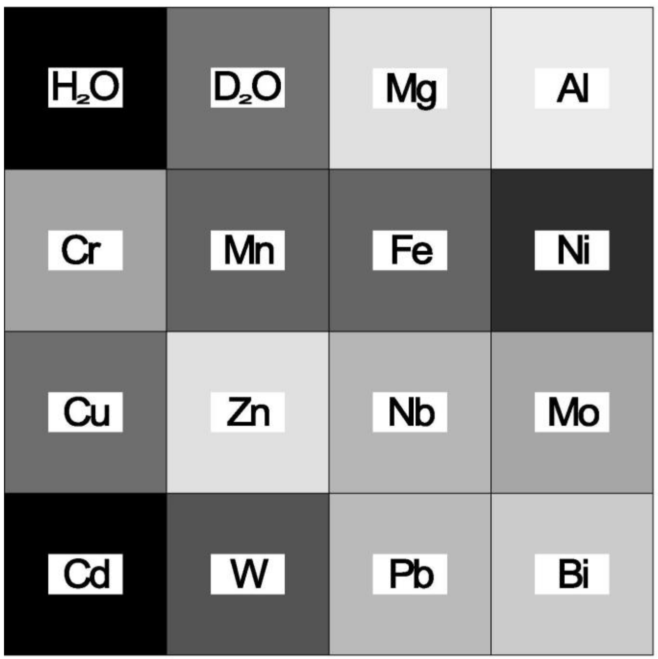

120 keV X-rays
1,25 MeV gamma-rays
6 MeV gamma-rays
thermal neutrons (25 meV)
fast neutrons (1,7 MeV)
mass attenuation coefficient [cm²g⁻¹]
atomic number
1000
100
10
1
0,1
0,01
0
10
20
30
40
50
60
70
80
90
H
D
He
Li
Be
B
C
N
O
F
Na
Mg
Al
S
Cl
Ar
K
Ca
Cr
Mn
Fe
Ni
Cu
Ga
As
Se
Br
Kr
Sr
Y
Zr
Mo
Rh
Pd
Ag
Cd
In
Ru
Sn
Te
I
Xe
Cs
Ba
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Hf
Lu
Ta
W
Re
Au
Pb
Bi
Th
U

Motivation

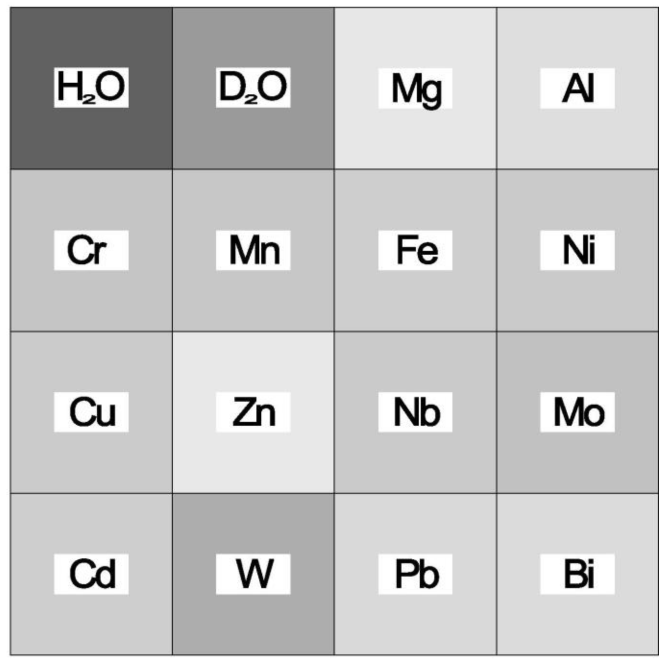
Thickness of materials: 1 cm

Neutrons

thermal neutrons (E = 25 meV)



fast (fission) neutrons (E = 1.7 MeV)

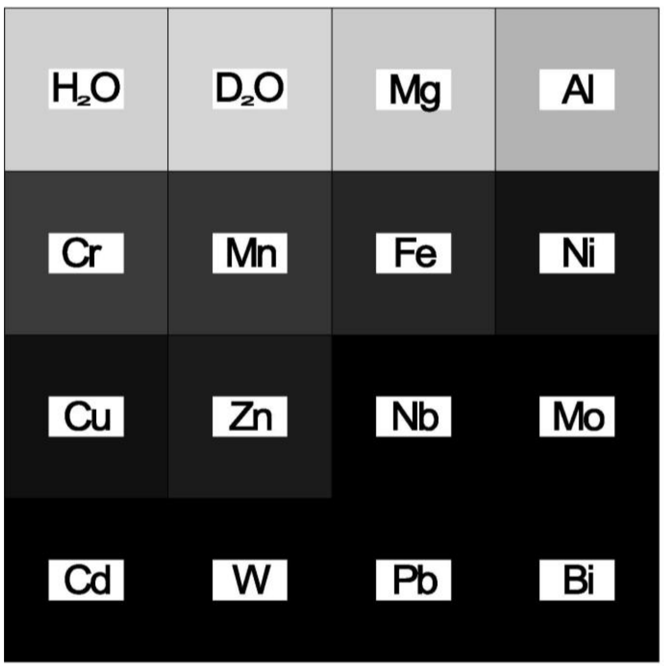


Motivation

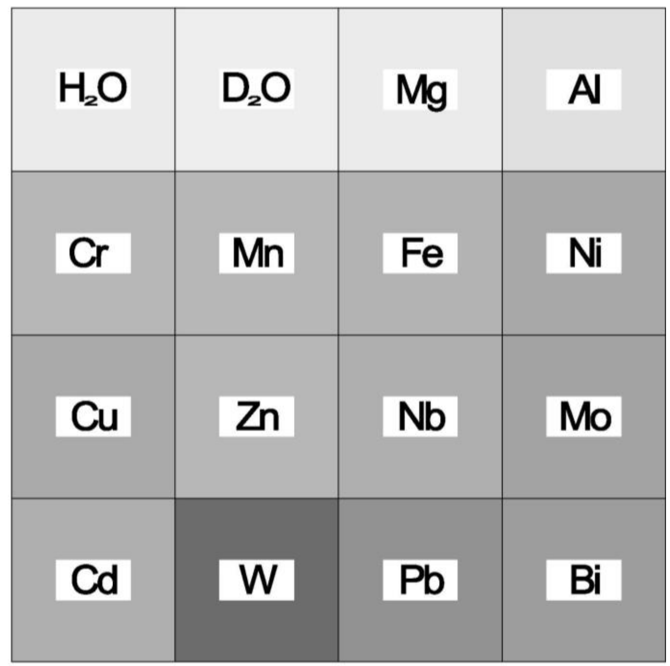
Thickness of materials: 1 cm

X-rays and gamma-rays

X-rays (E = 120 keV)



gamma-rays (E = 1.25 MeV)



Motivation

Thickness of materials: 1 cm

Fission neutrons and gamma-rays

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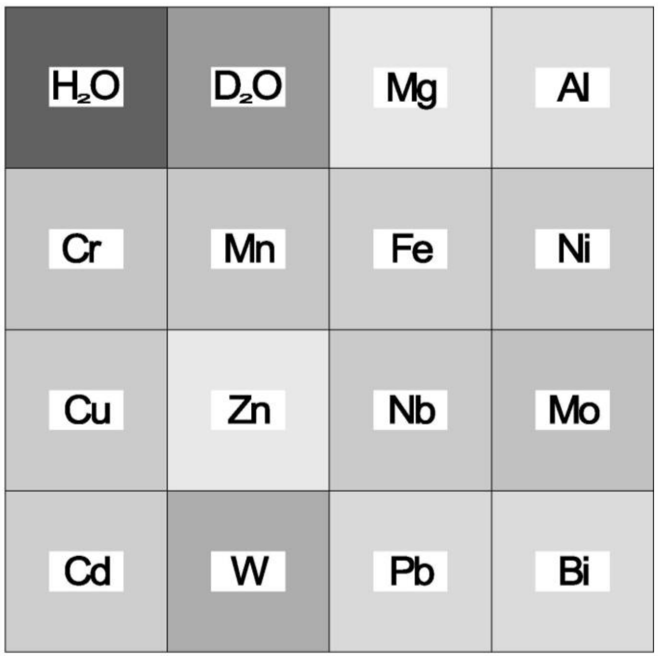

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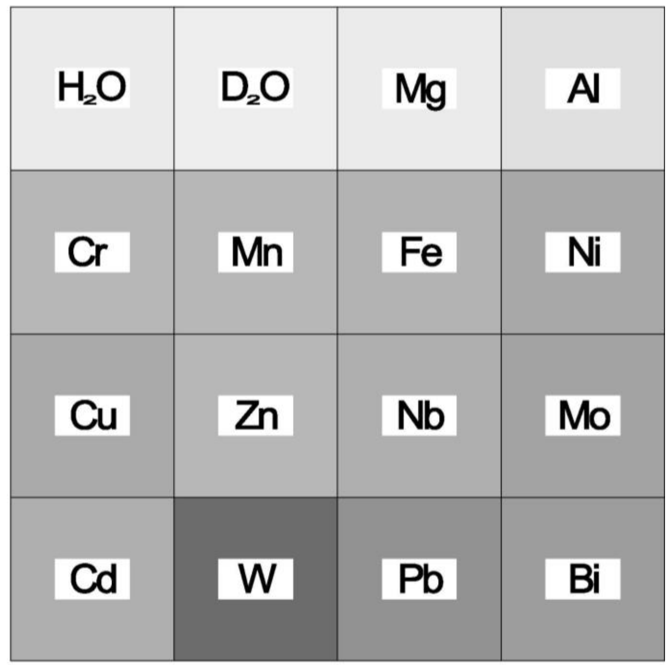


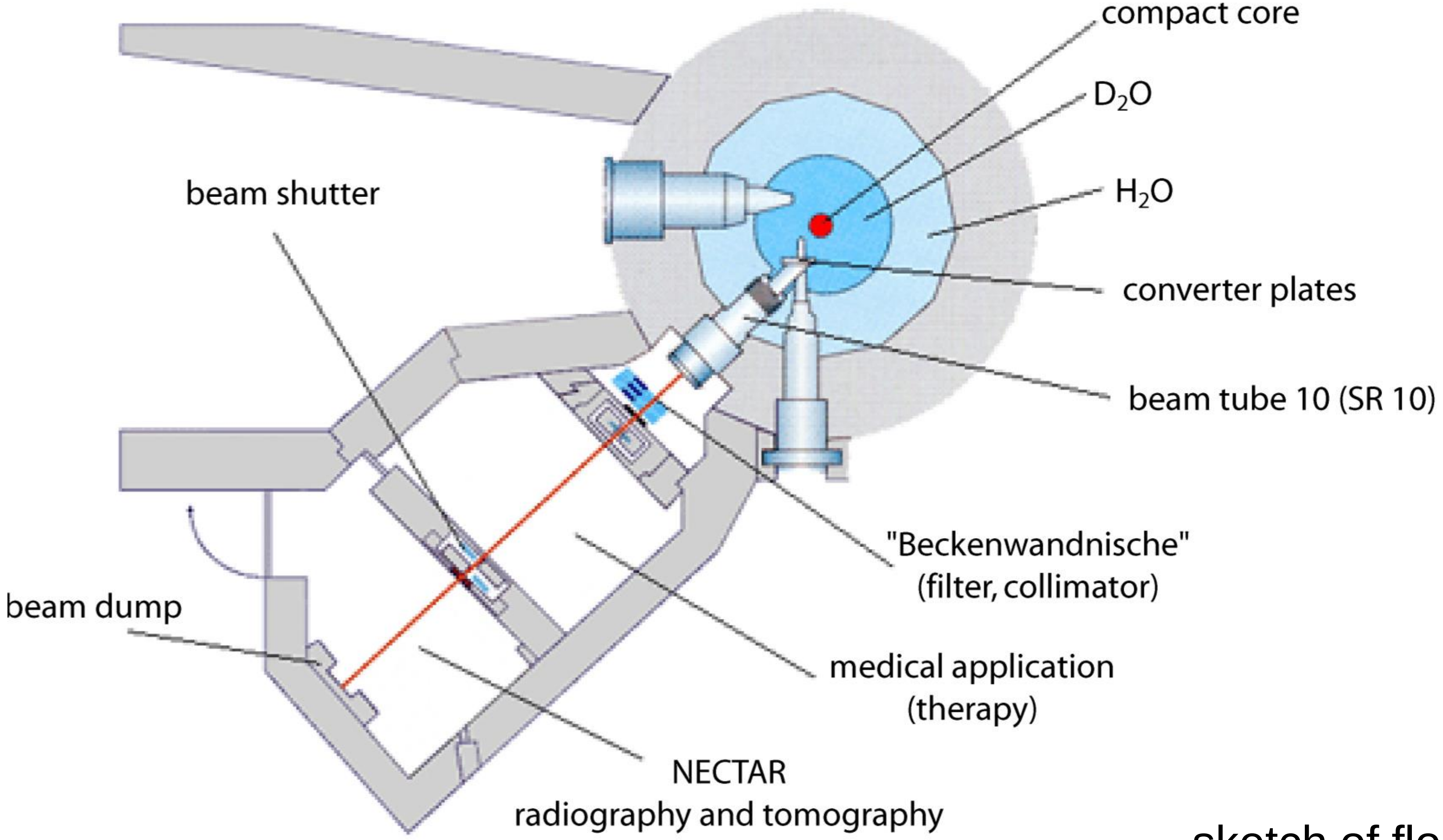
The NECTAR facility

NECTAR: **NE**utron **C**omputerized **T**omography **A**nd **R**adiography

Facility offering fission neutrons for investigations.

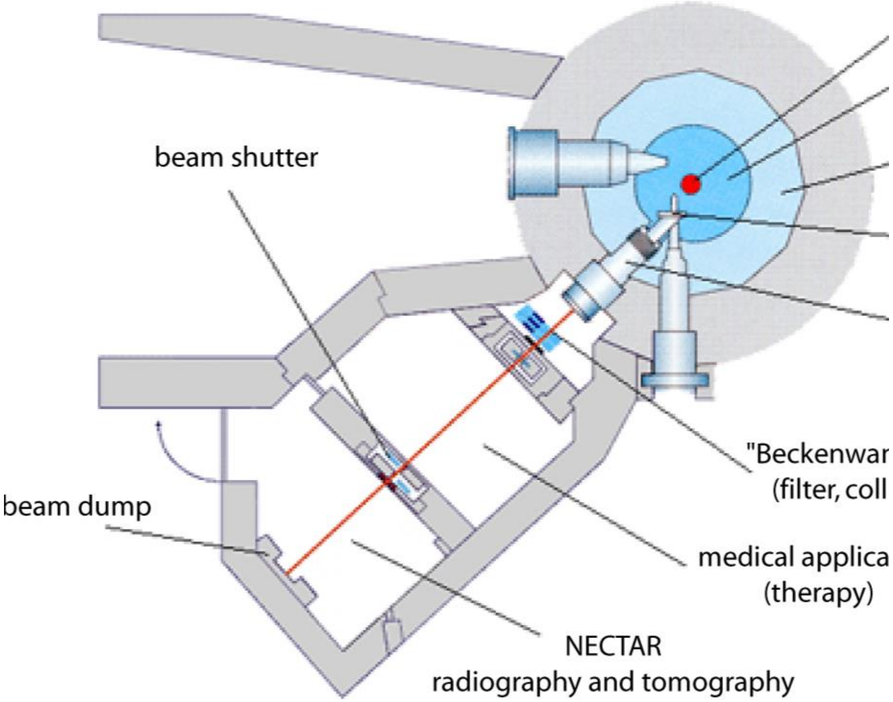
In the near future also offering thermal neutrons, too!

The NECTAR facility



sketch of floorplan

The NECTAR facility



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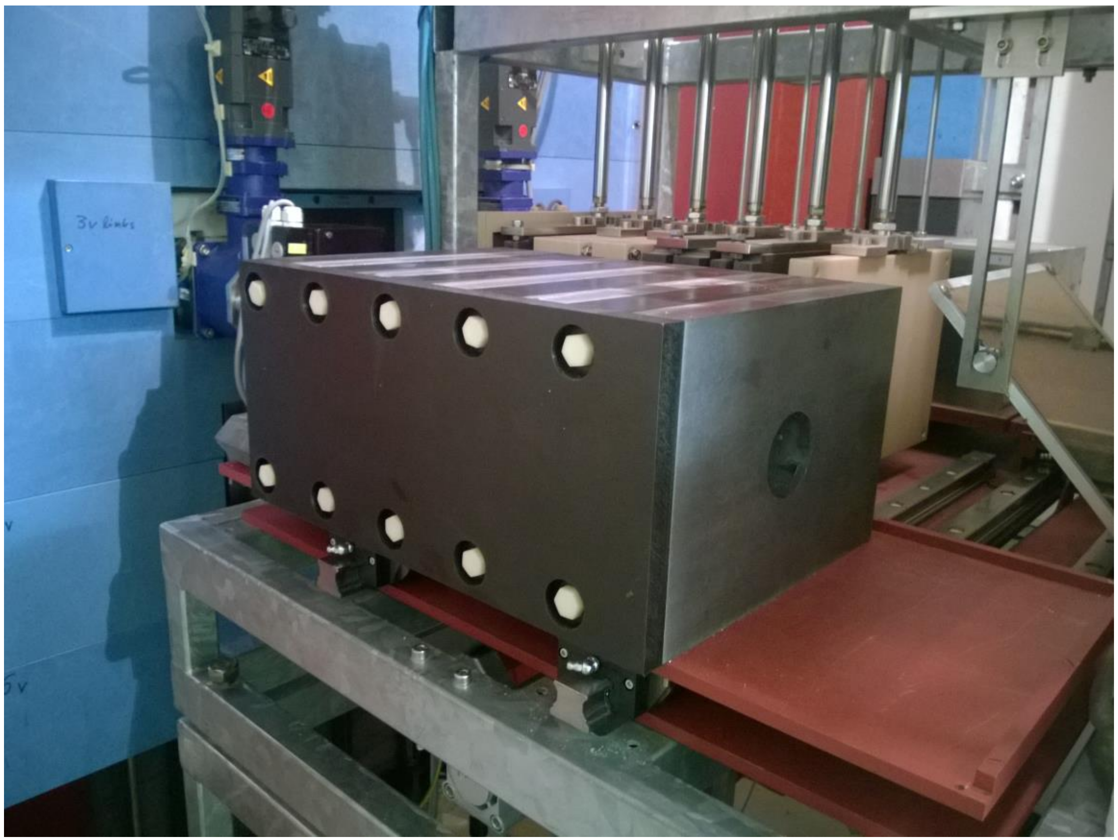

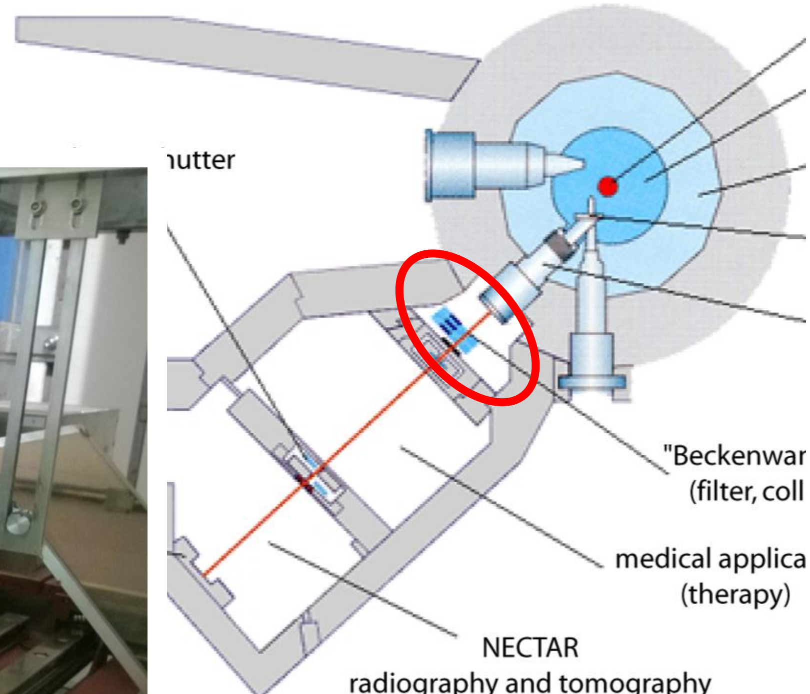

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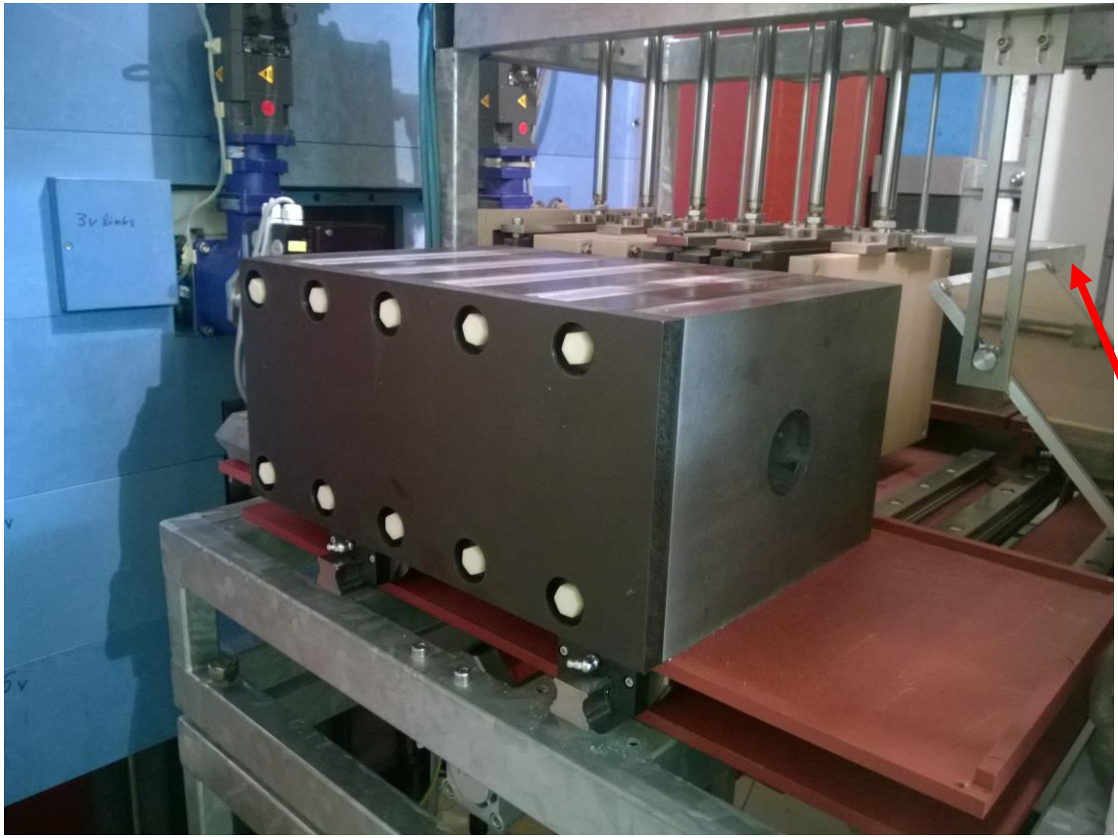
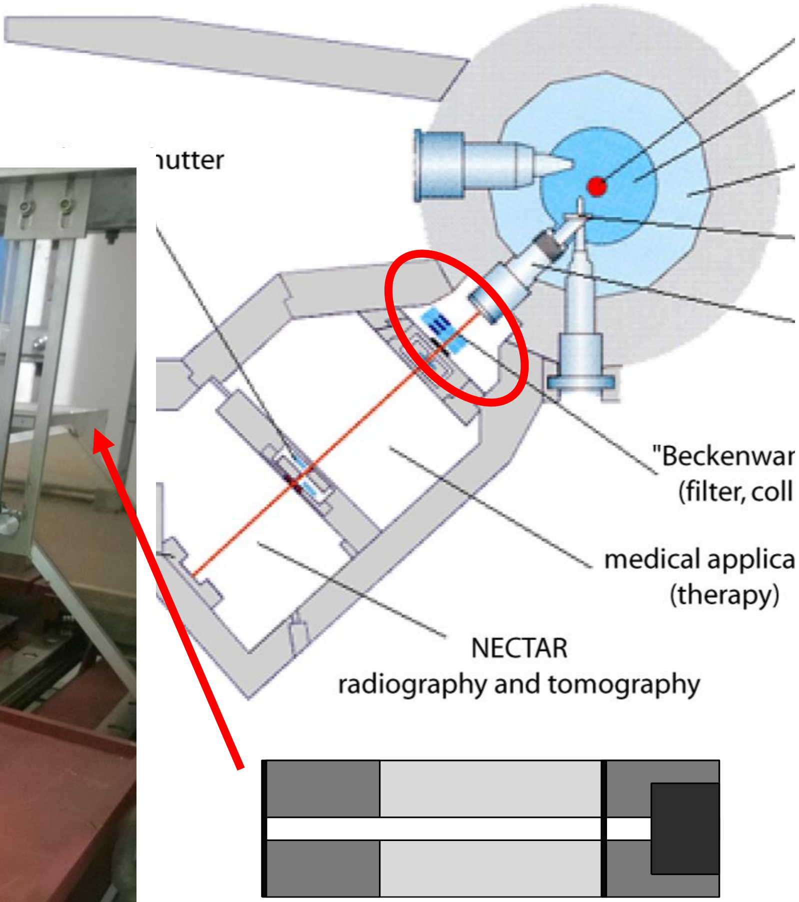
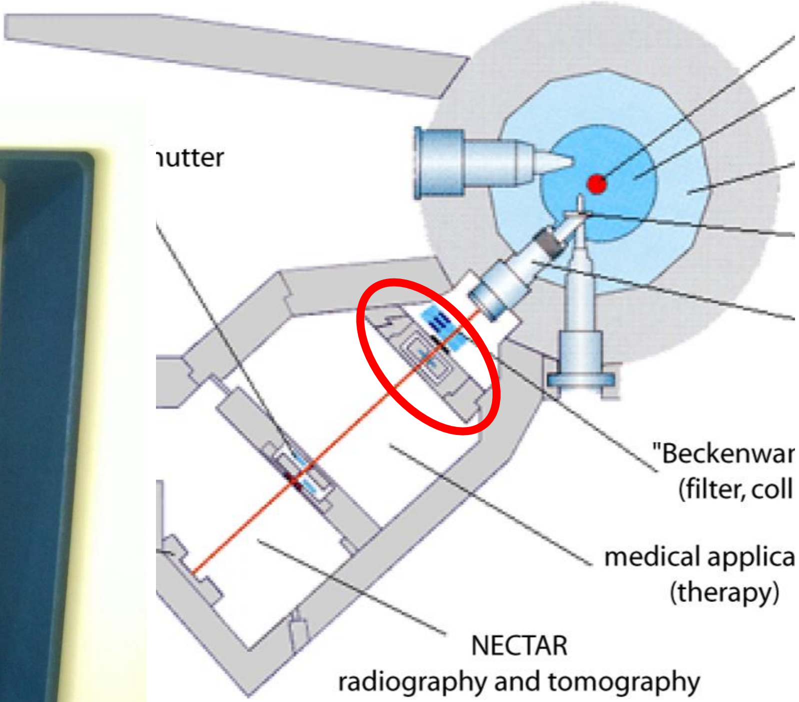


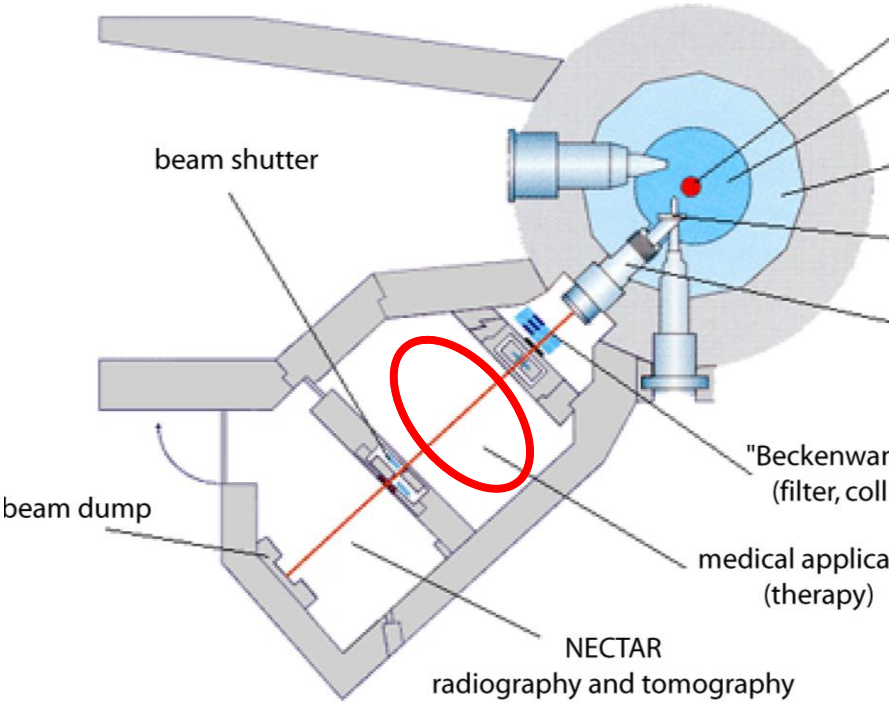


Kollimator
(Cd, Fe, bPE, Cd, Fe, Pb)

The NECTAR facility

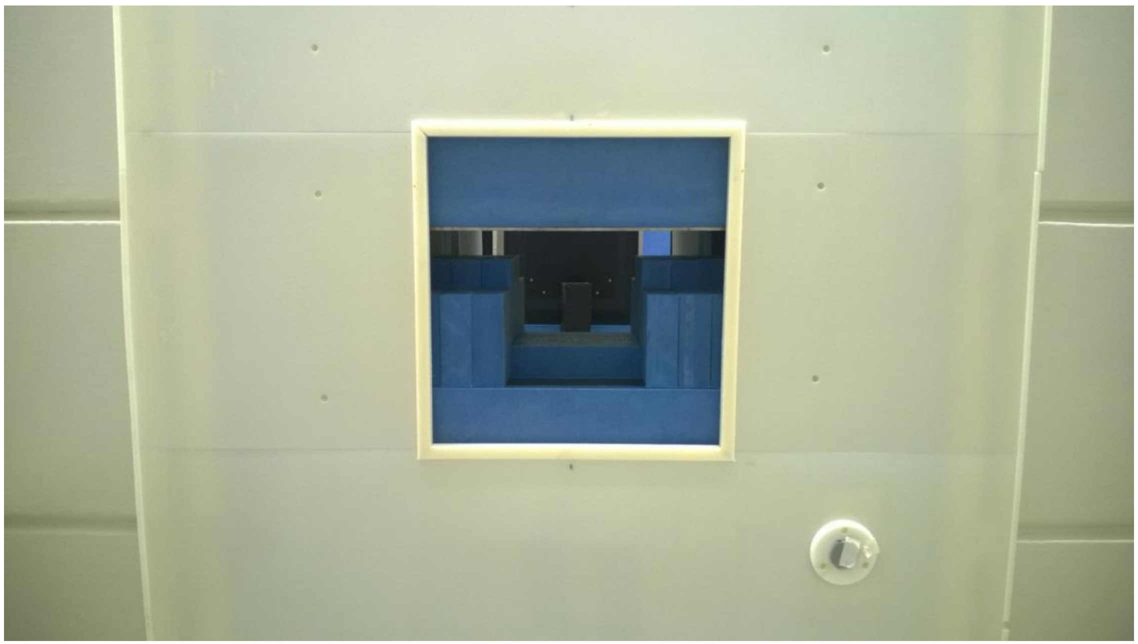


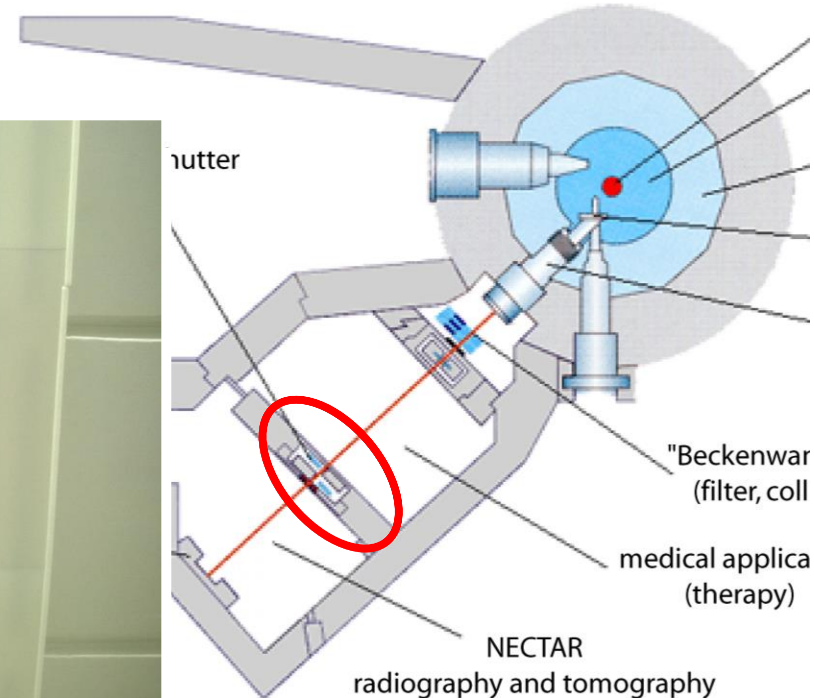
The NECTAR facility



Medical application

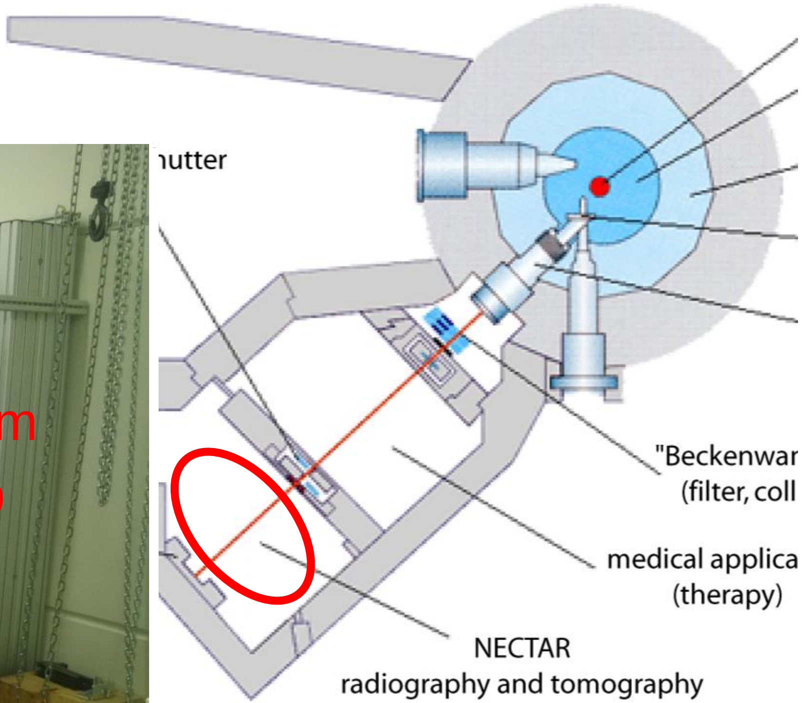
The NECTAR facility





Zwischenwand

The NECTAR facility



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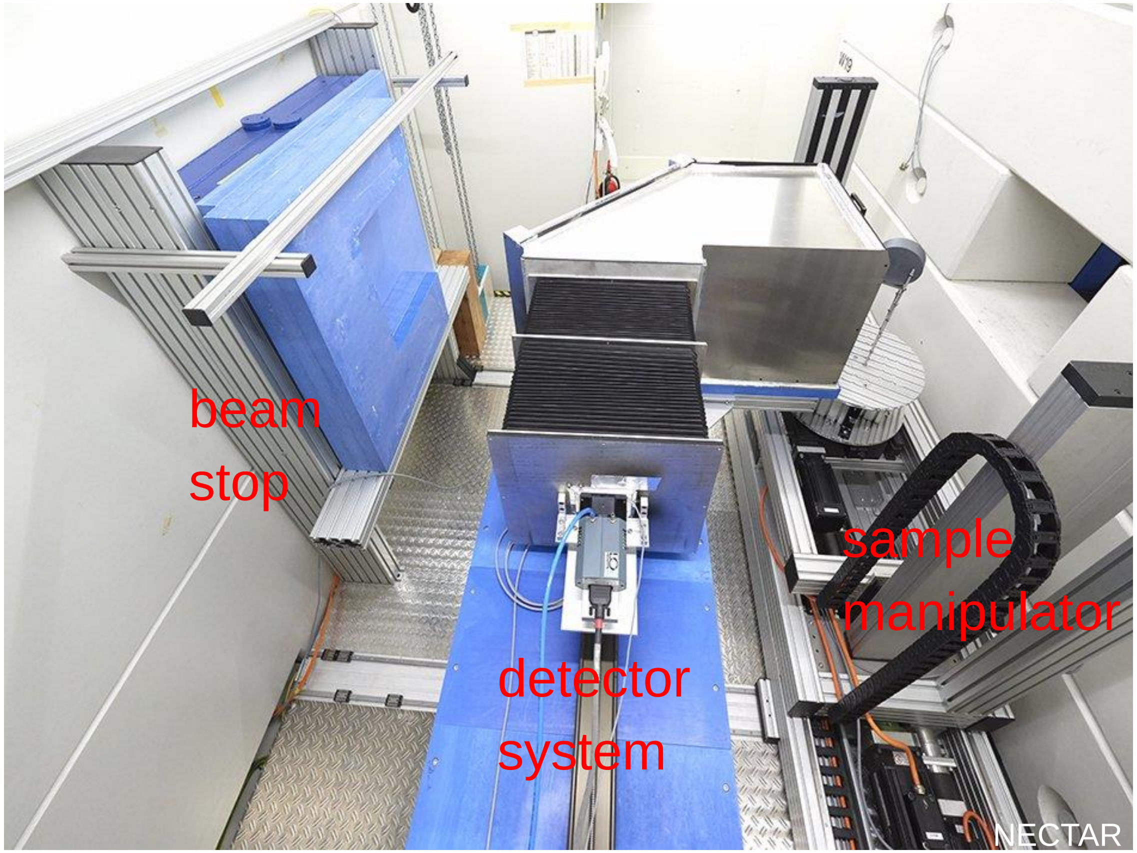

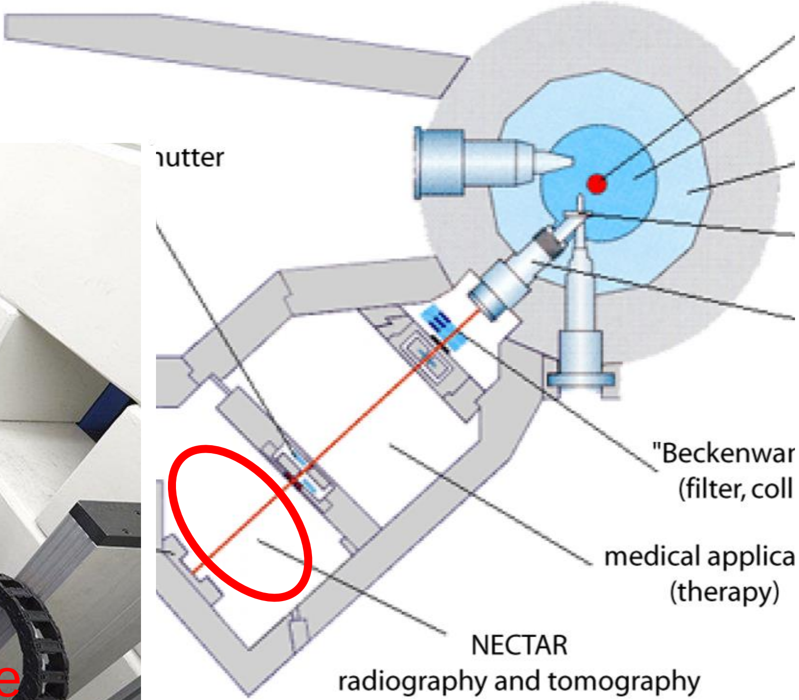

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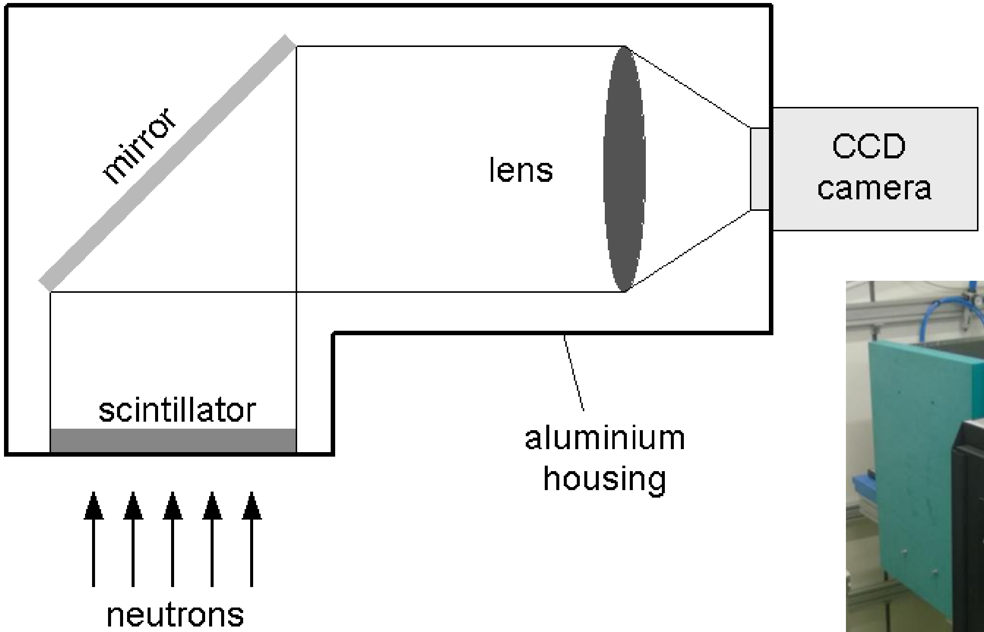
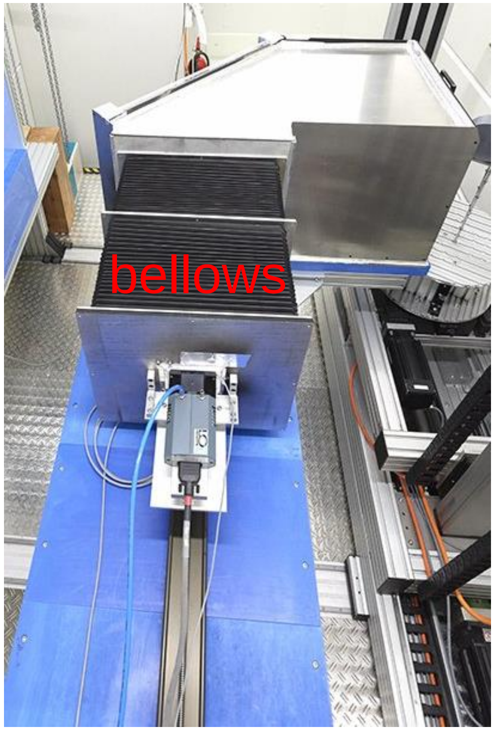


light tight detector box



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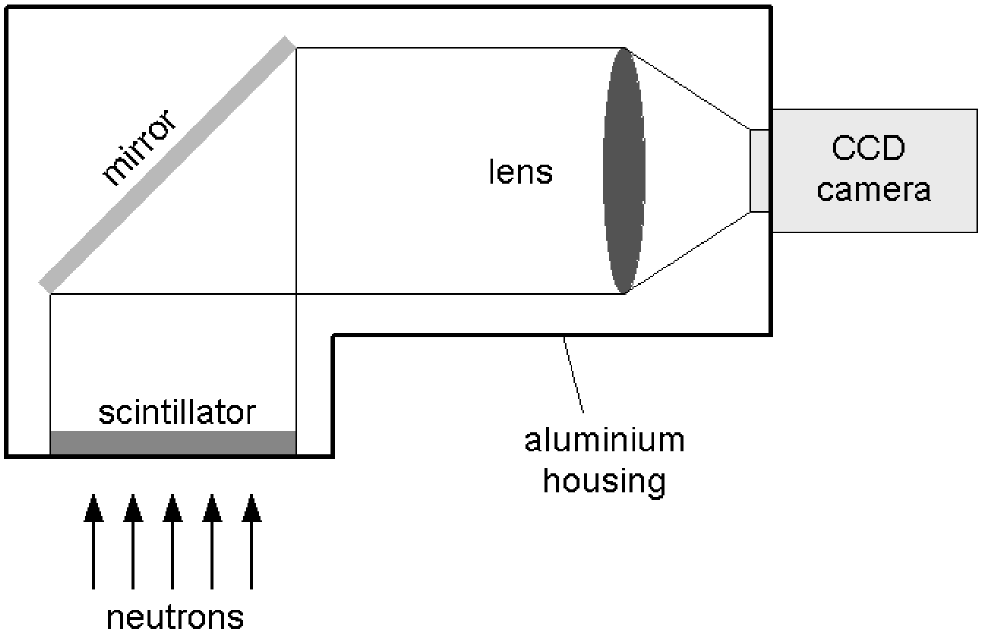
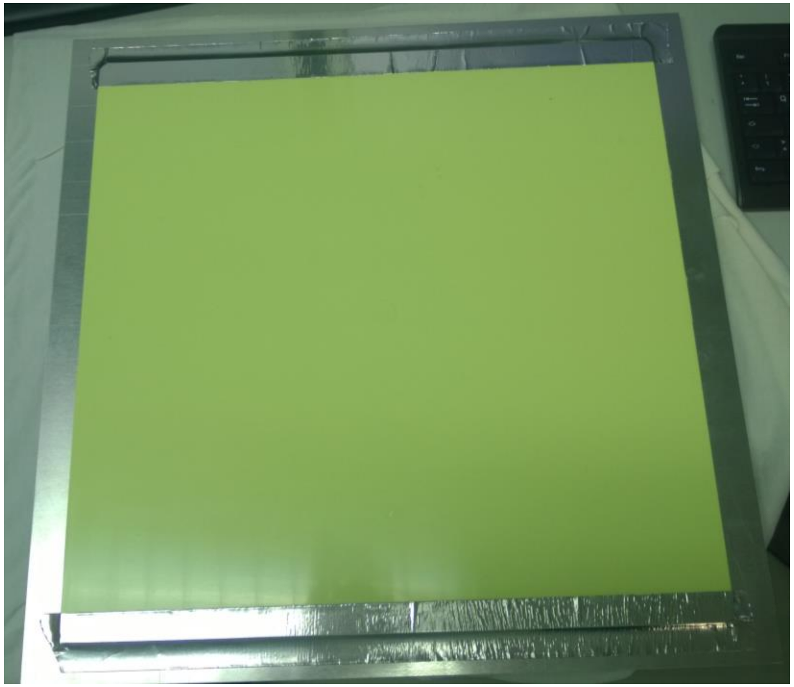


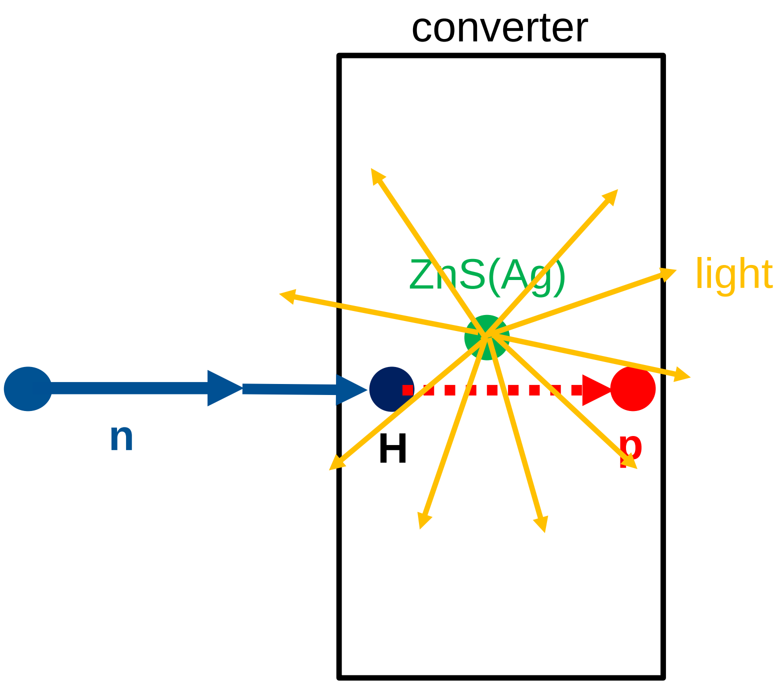


converter/scintillator:

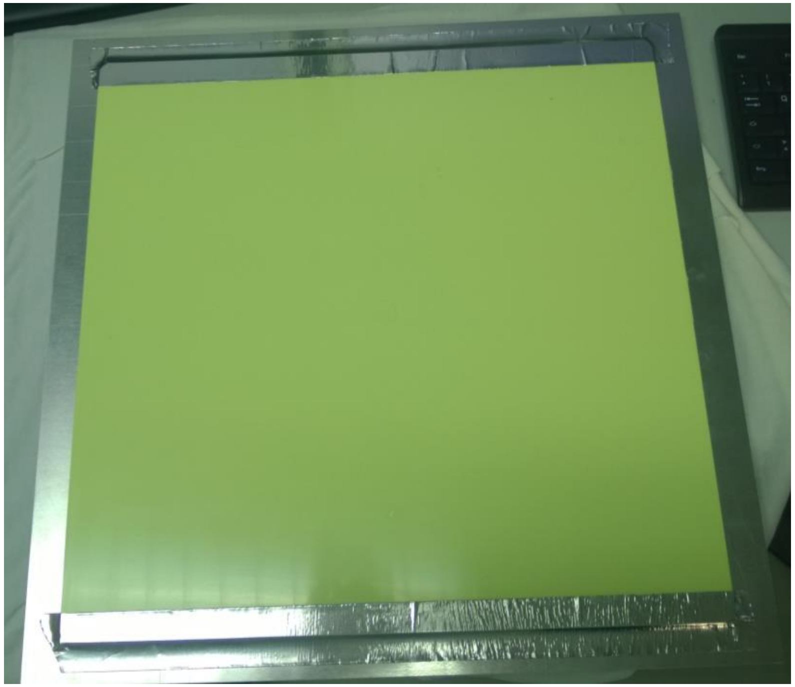
converts neutrons into visible light.

(e.g. ZnS(Ag) in PP)

The NECTAR facility



Sketch of conversion process



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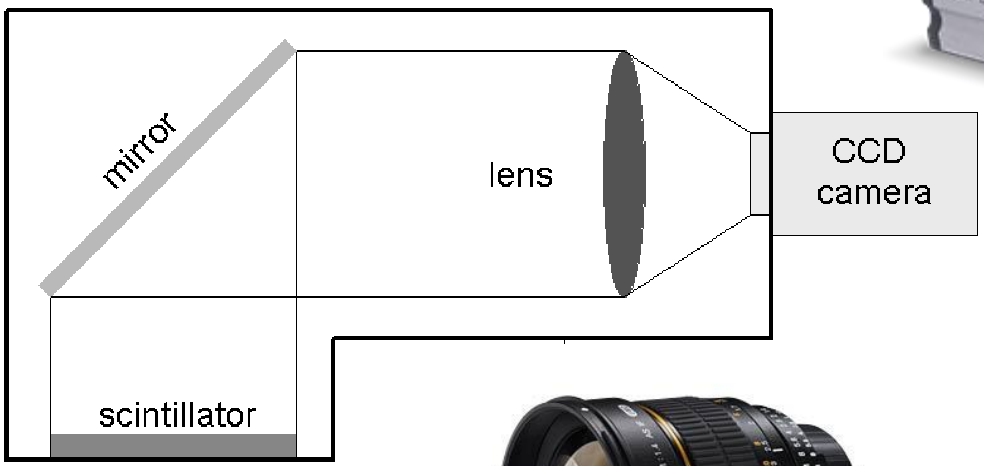
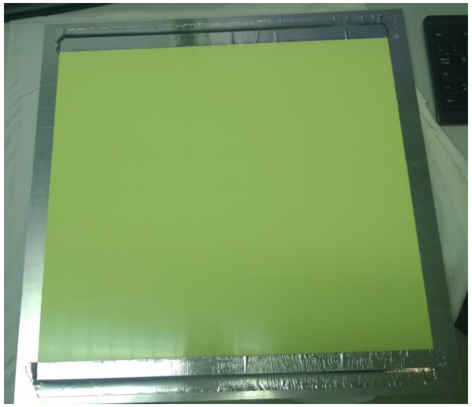




@ NECTAR

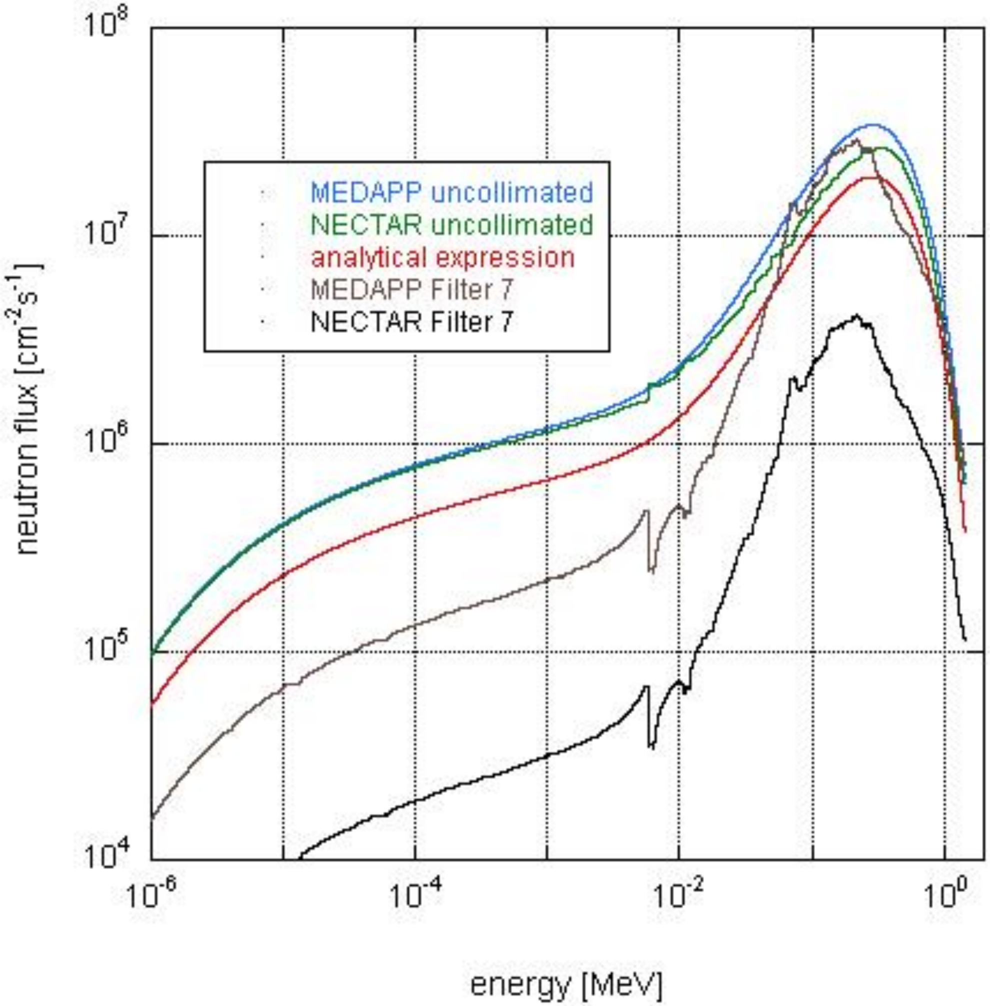
CCD-cameras:

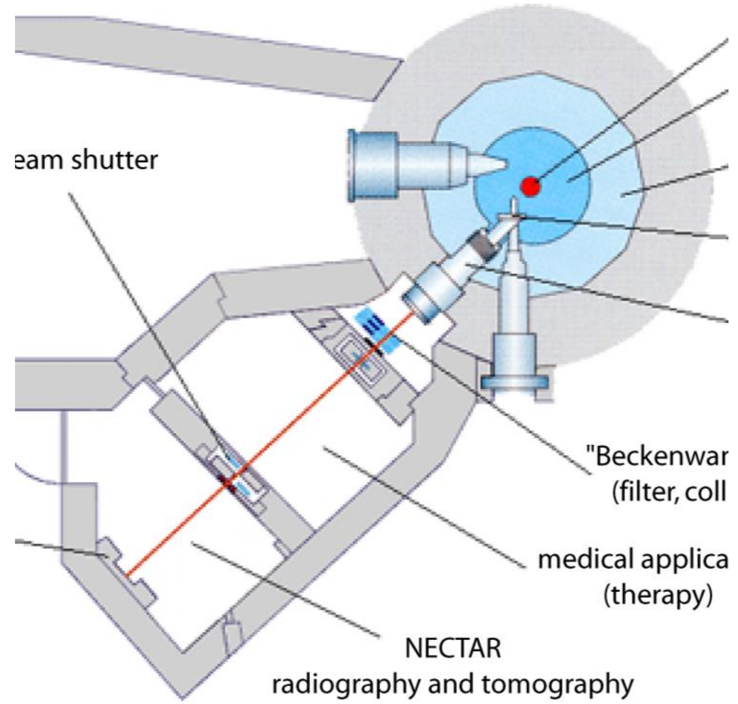
- ANDOR DV434-BU (1024 x 1024)
- pco.1200 (1280 x 1024)
- ANDOR DV934 iKon-M (2048 x 2048)

Lenses:

- 50 mm
- 58 mm
- 85 mm
- 100 mm (planned)

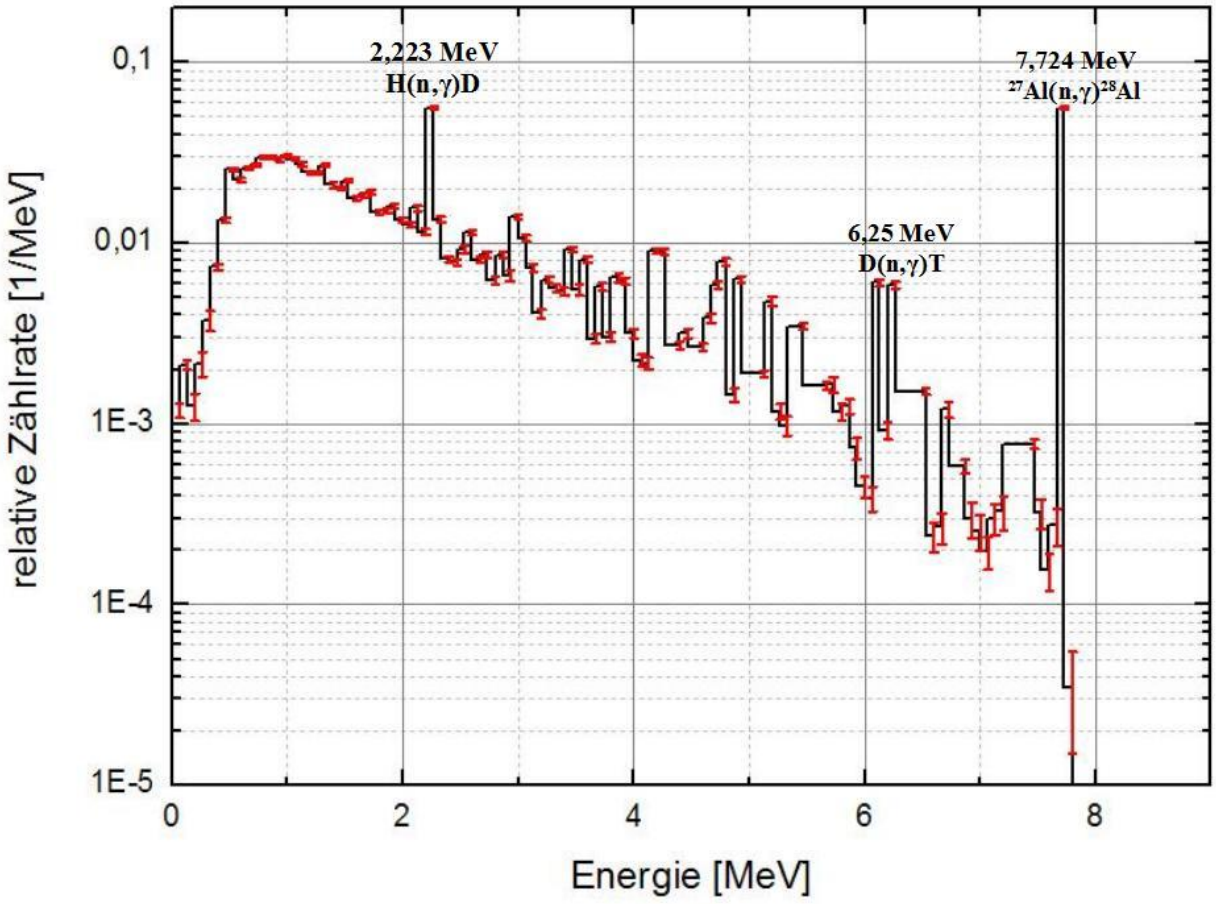
The NECTAR facility

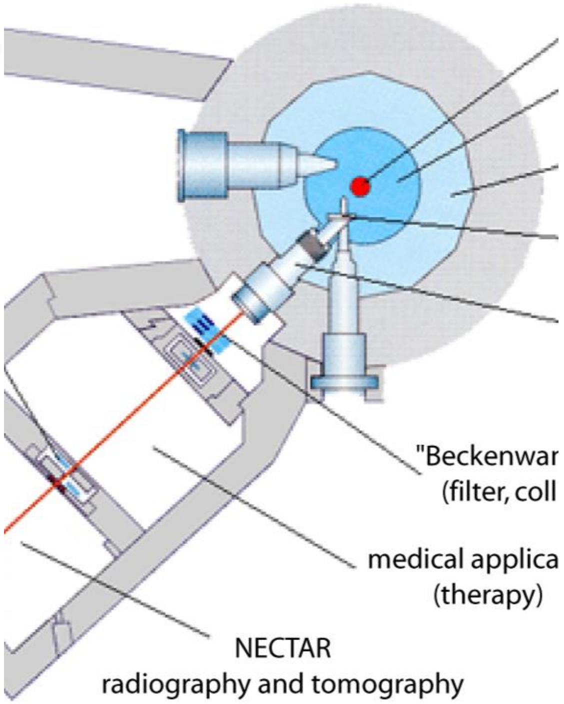




Calculated neutron spectra for both, the non-collimated and the collimated mode. For the sake of clarity resonances due to resonances in the attenuation cross sections of the different materials are filtered out.

The NECTAR facility





Gamma spectrum at the MEDAPP station for 1 cm B_4C and 3.5 cm lead

The NECTAR facility

Fission neutron spectrum

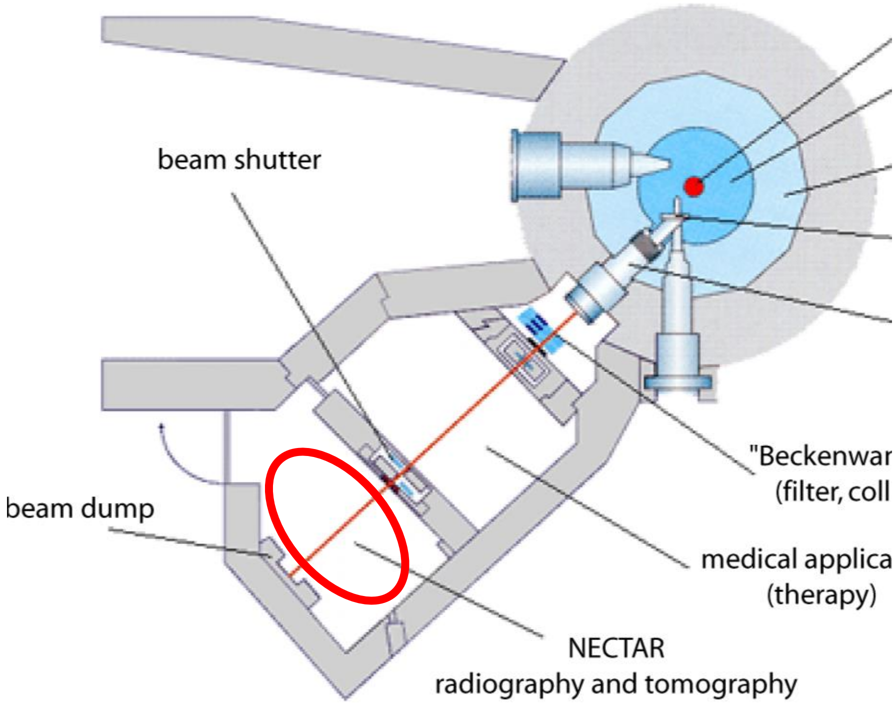
- E_{mean}= 1.8 MeV
- Φ_{min} = 8.7E+05 $cm^{-2}s^{-1}$
- Φ_{max} = 4.7E+07 $cm^{-2}s^{-1}$
- $(L/D)_{max}$ ~ 233

Sample space (max)

- 80 cm x 80 cm x 80 cm
- ~ 800 kg

Detection system

- Converter and CCD-camera
- FOV ~ 30 cm x 30 cm



The ITS facility

ITS: **I**ntegrated **T**omography **S**ystem

The ITS facility

Source

- type: radioactive nuclide
- source: ^{60}Co
- activity: 1.7E+13 Bq
- half-life: 5.27 a

collimator

- fan-beam geometry
- height: 2 cm
- opening angle: 30°

Shielding container

- material: depleted uranium
- weight: ca. 300 kg

The ITS facility

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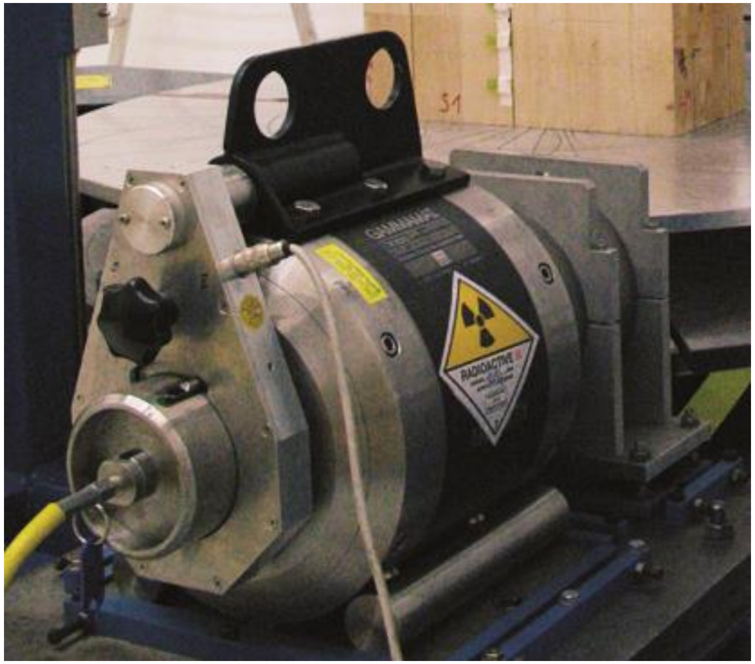

The ITS facility

Detection system

type: photon counting system

components:

- collimator
- 30 plastic scintillators
- 30 photomultipliers
- counting electronics

The ITS facility

Detection system

type: photon counting system

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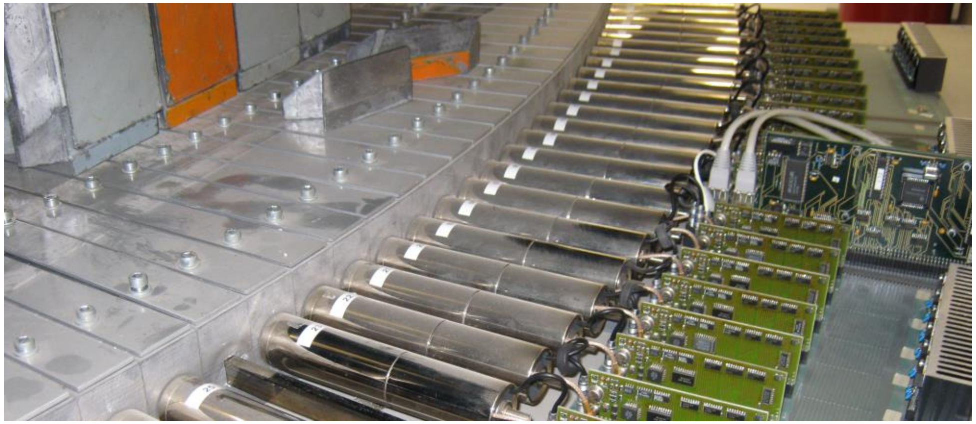
- counting electronics

collimator

height: 0 cm - 1 cm

width/channel: 2 mm (fixed)

arranged on a 30° arc



The ITS facility

Detection system

type: photon counting system

components:

- collimator
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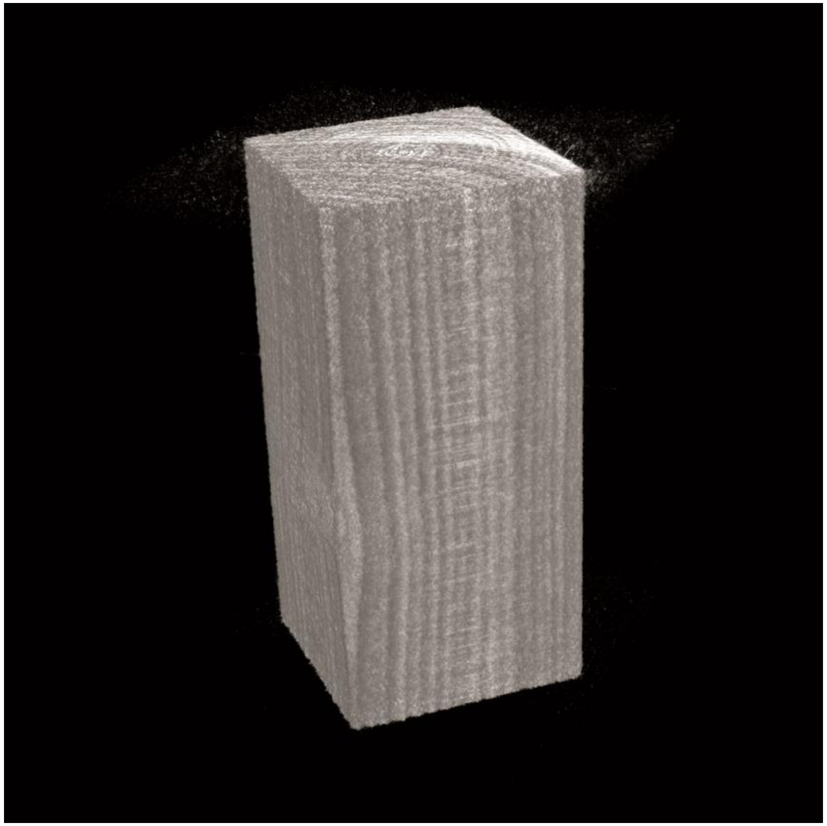
The ITS facility

@RCM mainly used for non-destructive characterization of radioactive waste packages

Examples @NECTAR and @ITS

Examples (research on wood)

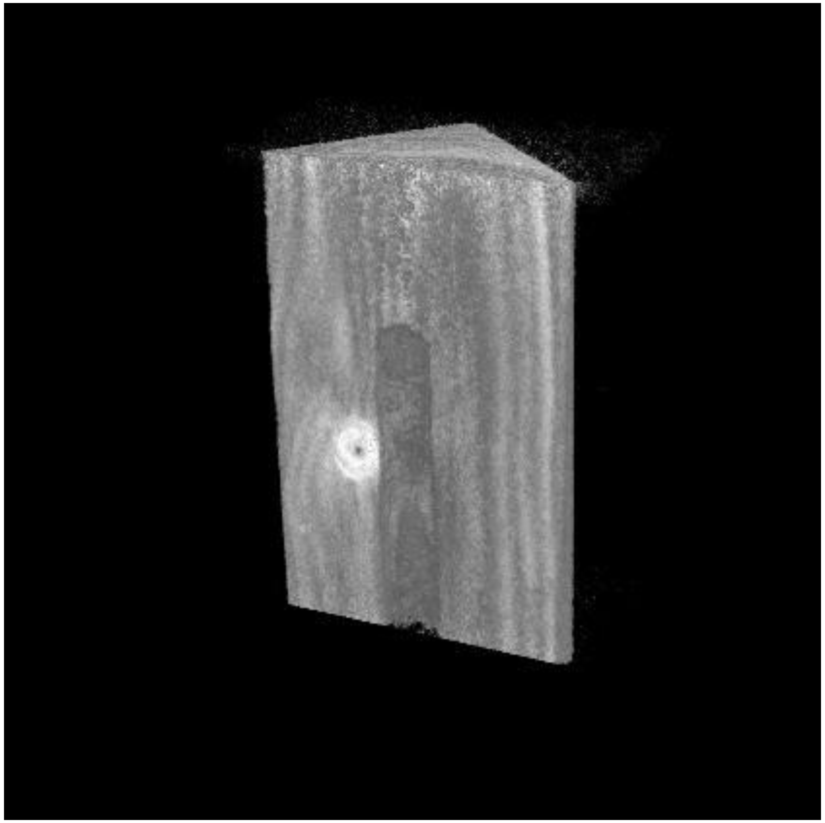
squared timber

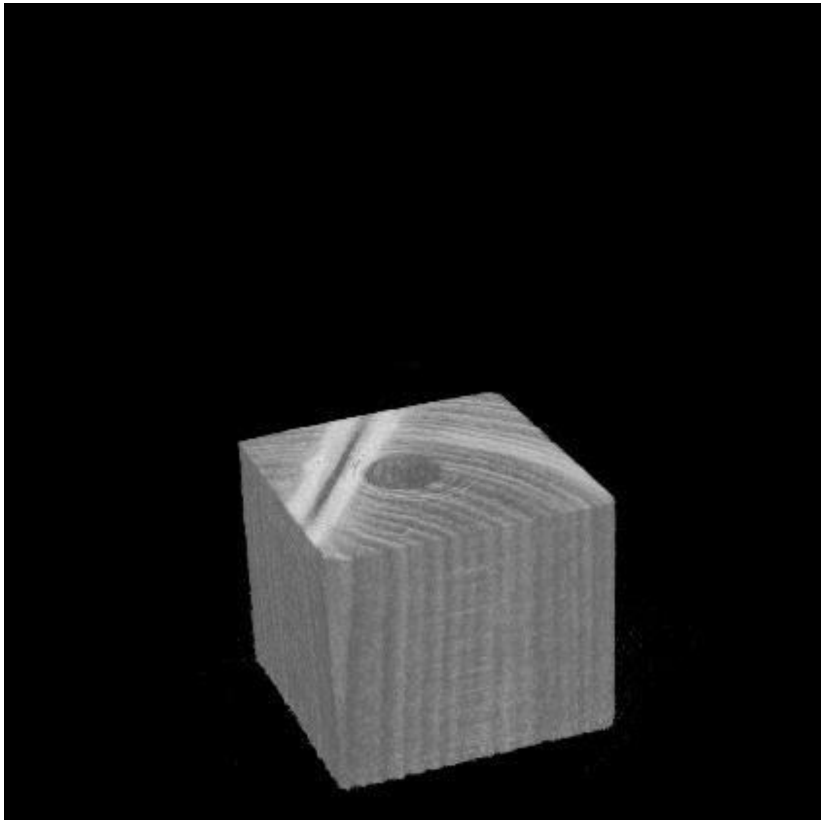


3D-tomography @NECTAR

Examples (research on wood)

squared timber

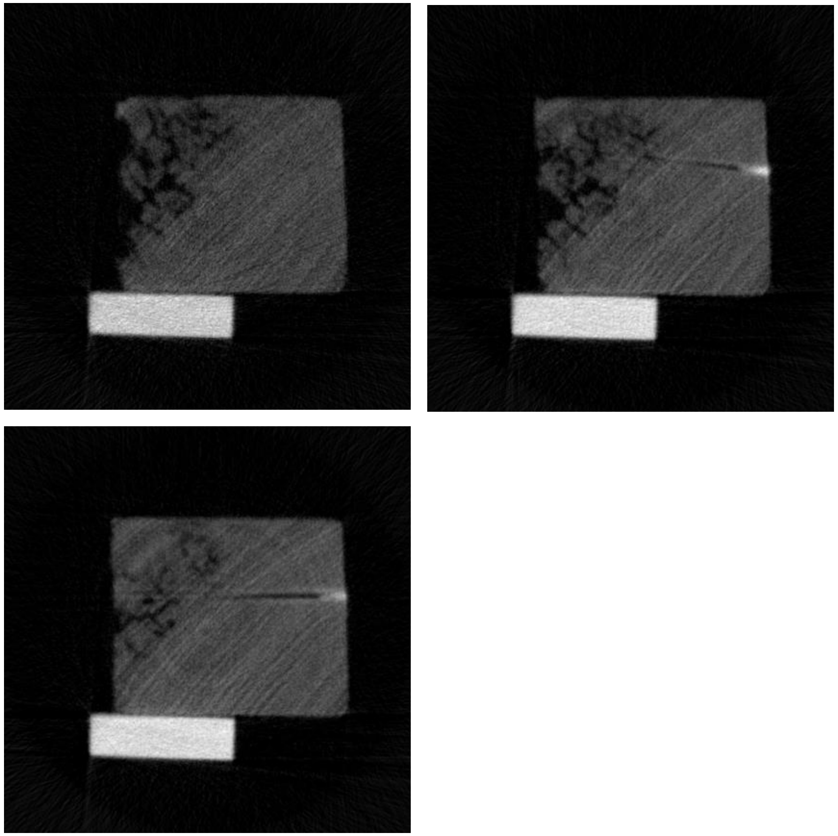




3D-tomography @NECTAR

Examples (research on wood)

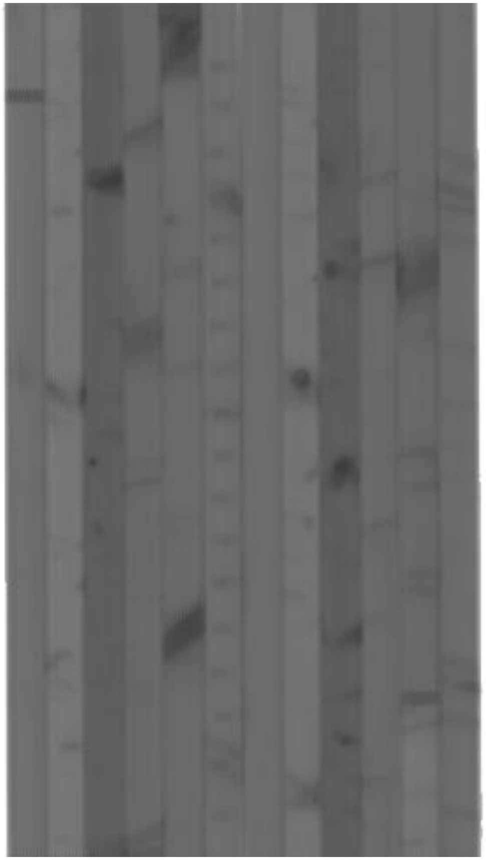
influence of absorbers



2D-tomography @NECTAR

Examples (research on wood)

glued laminated wood – investigation of the glue layers



Dimension:
1000 mm x 492 mm x 235 mm

radiography @ITS

Examples (research on wood)

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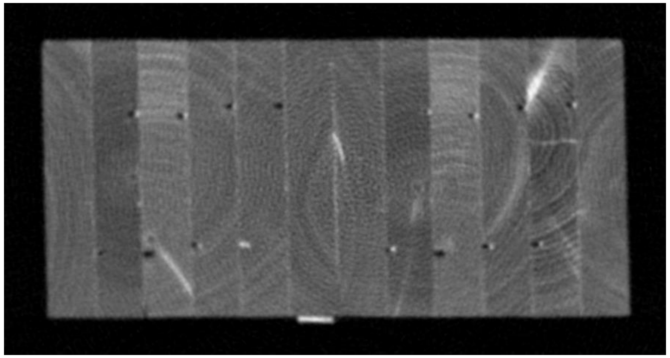

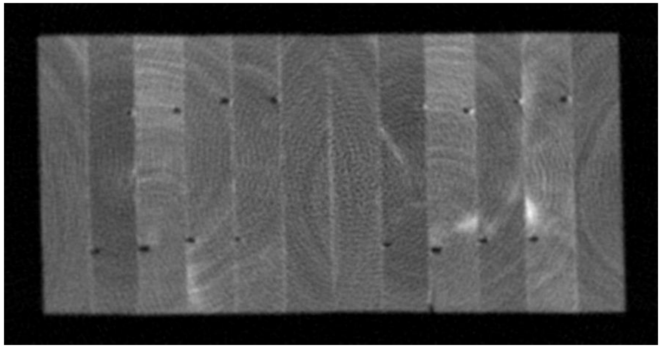

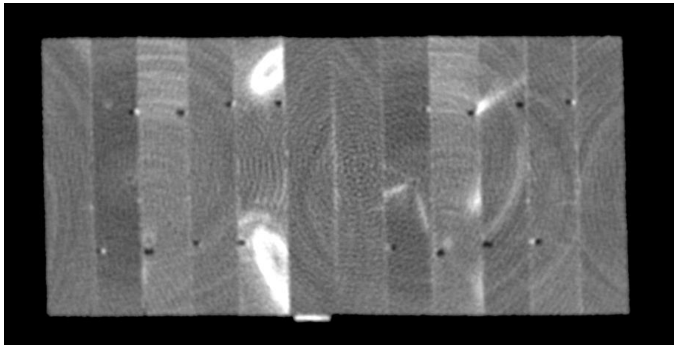

no information on glue layers

2D-tomography @ITS

Examples (research on wood)

glued laminated wood – investigation of the glue layers

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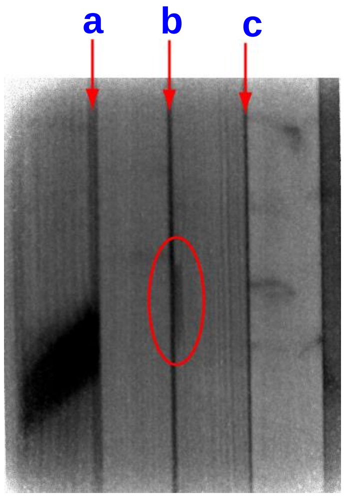
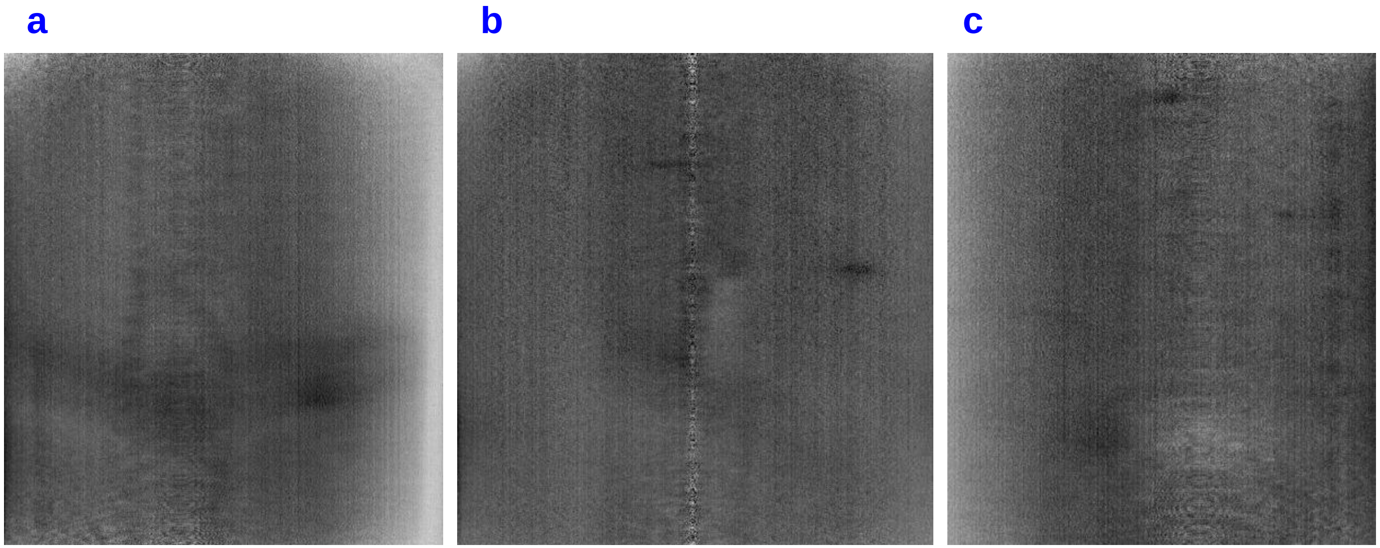


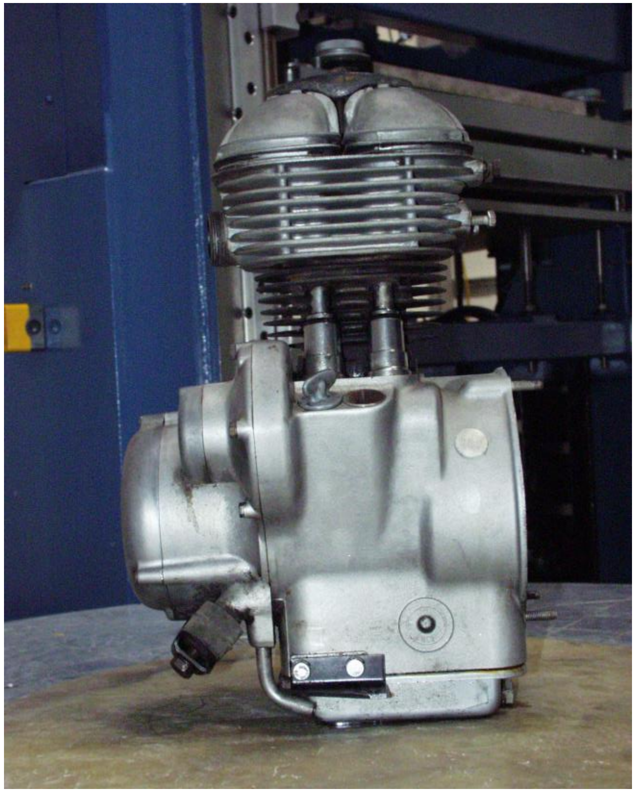


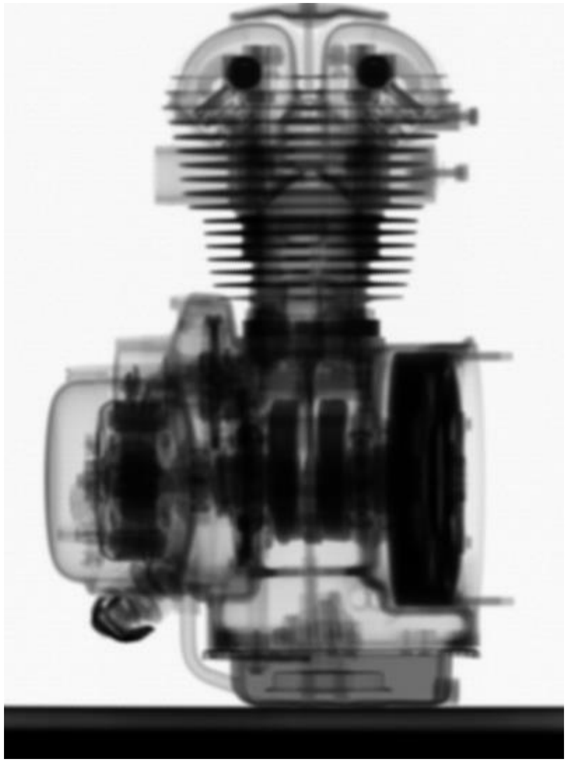
information on glue layers available!

radiography and 3D-tomography @NECTAR

Examples (technical objects)

Motor of an old motorbike





radiography @ITS

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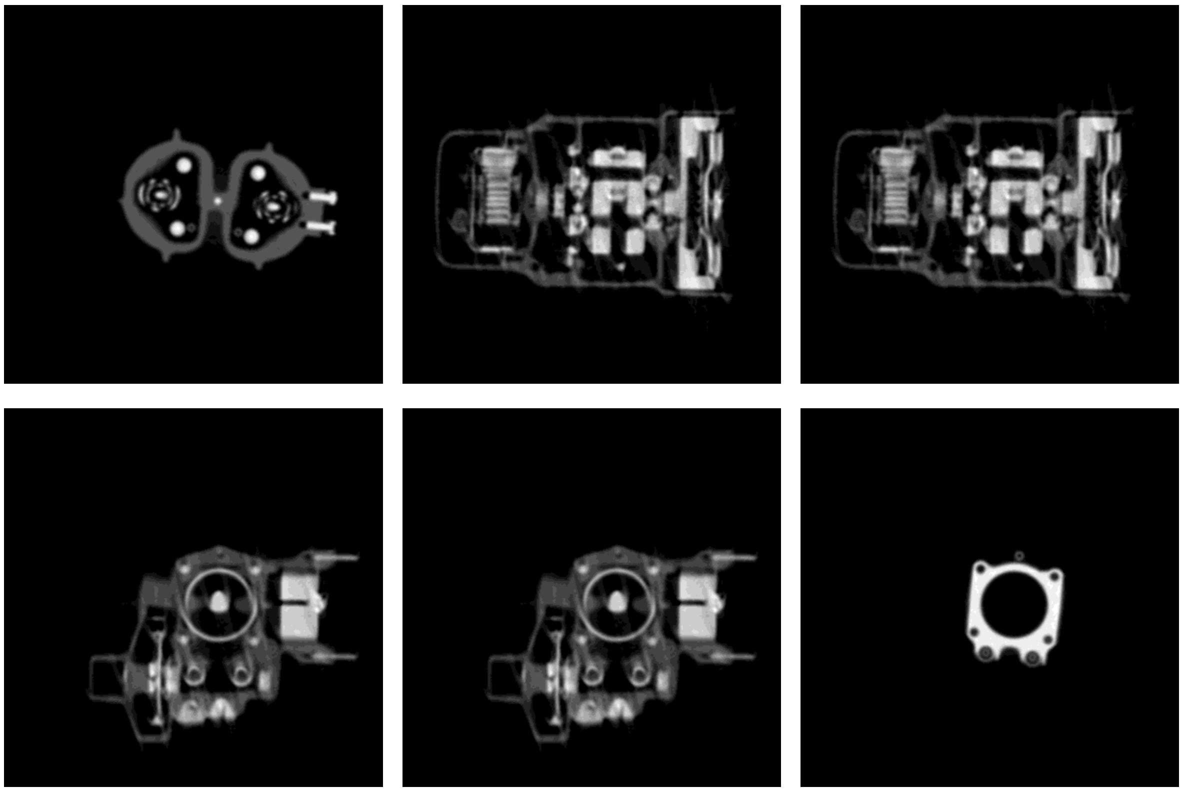

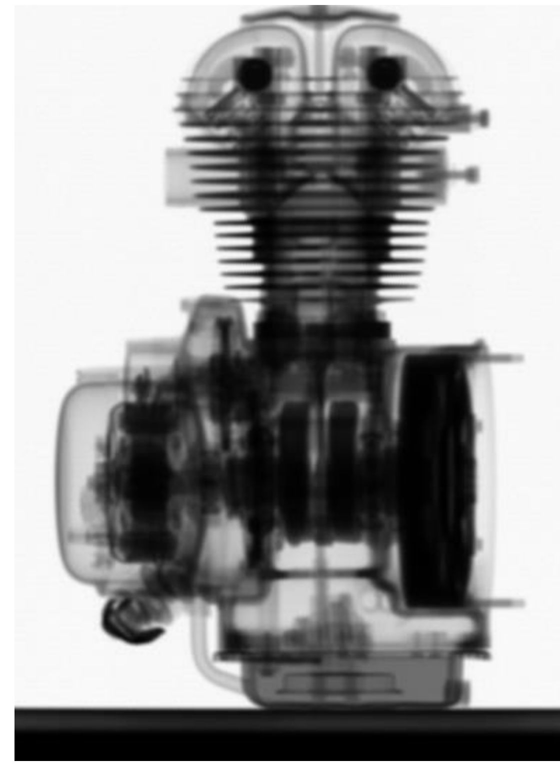

2D-tomography and radiography @ITS

Examples (technical objects)

gear box of a modern car

radiography @ITS

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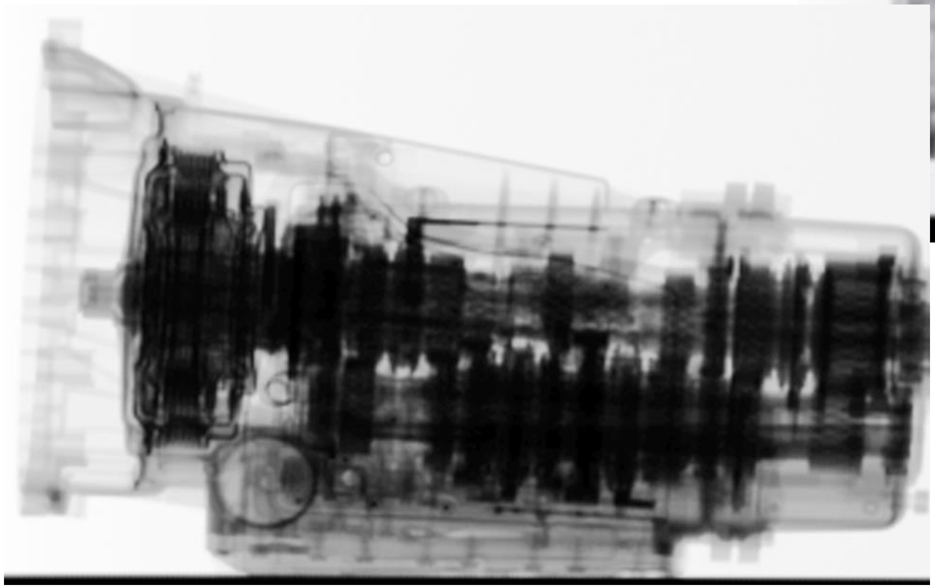

variation of greyscale

radiography @ITS

Examples (technical objects)

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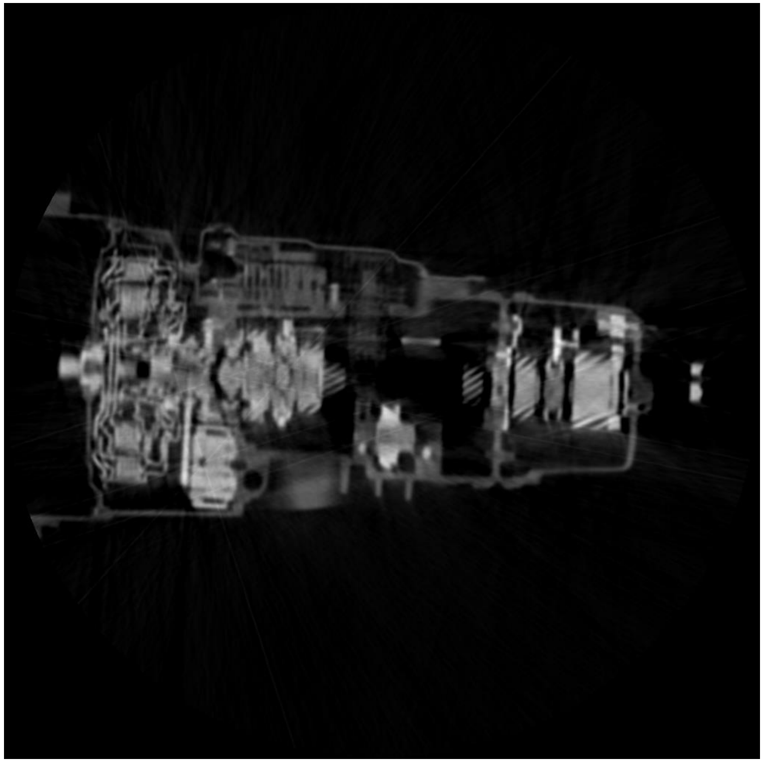

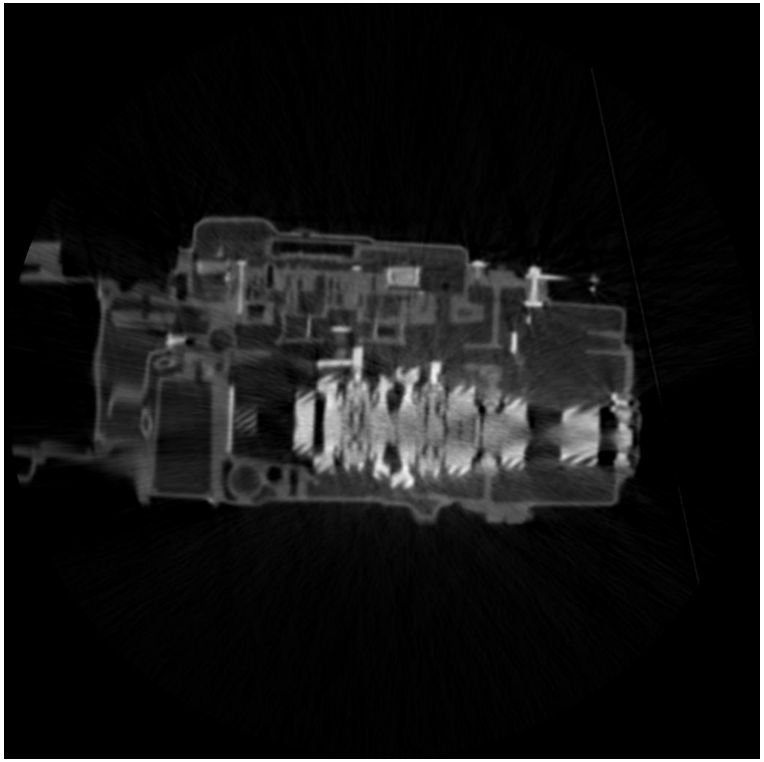

2D-tomography @ITS

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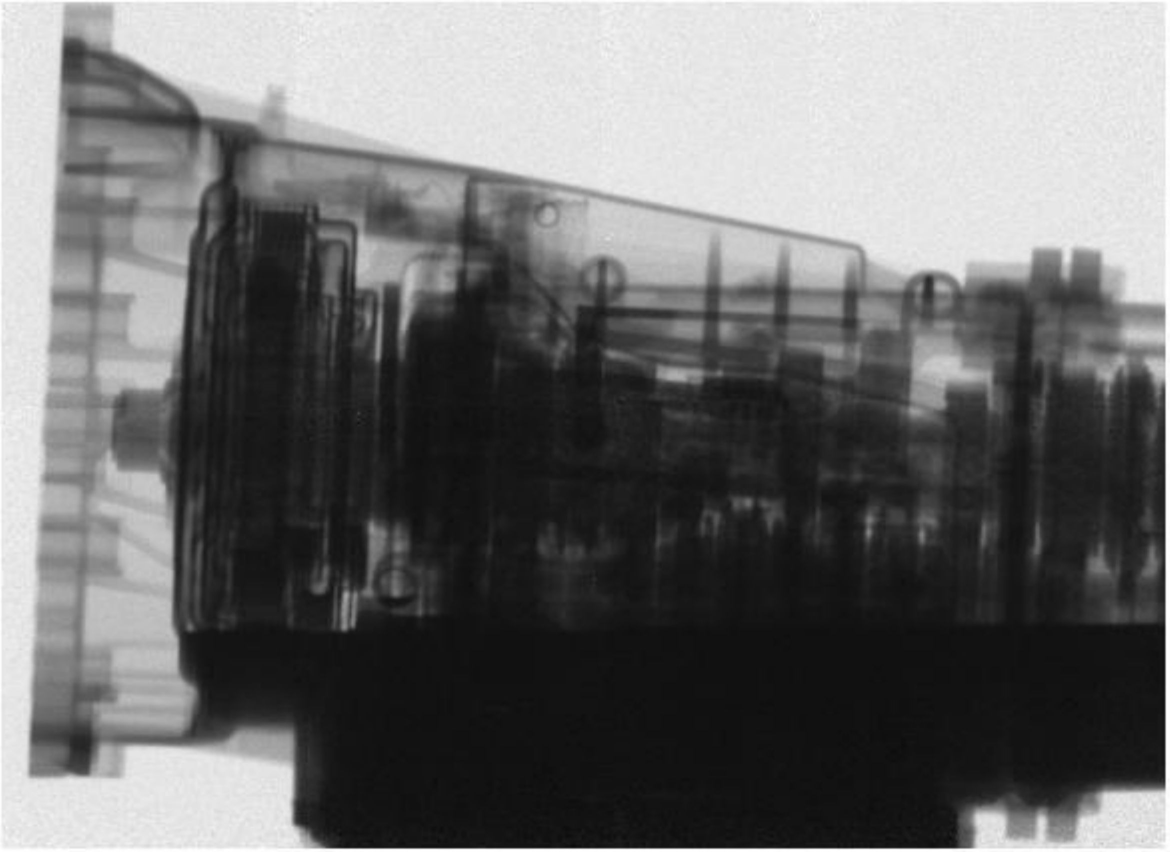
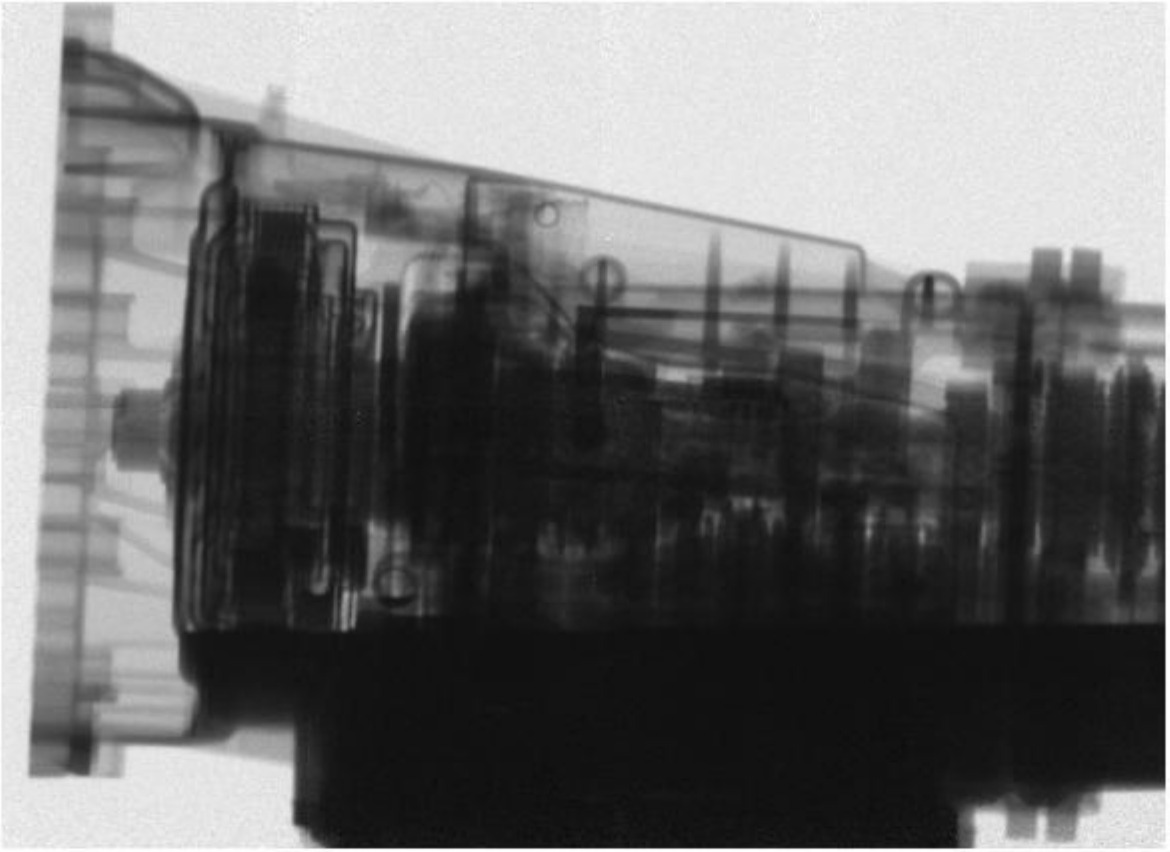
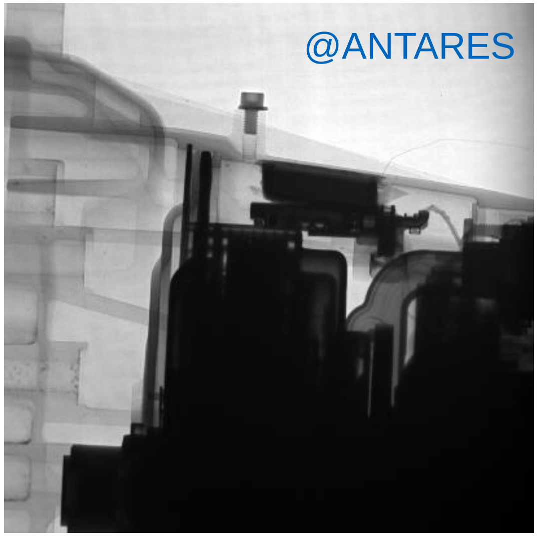


radiography @NECTAR

Examples (technical objects)

gear box of a modern car

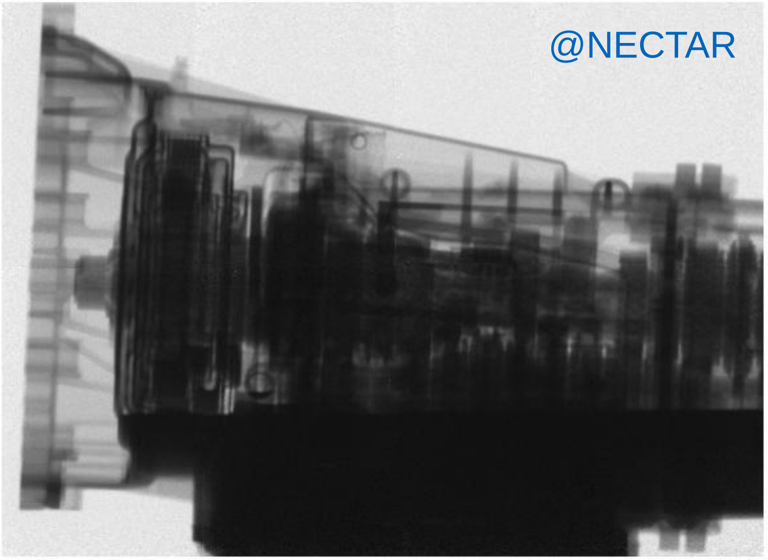


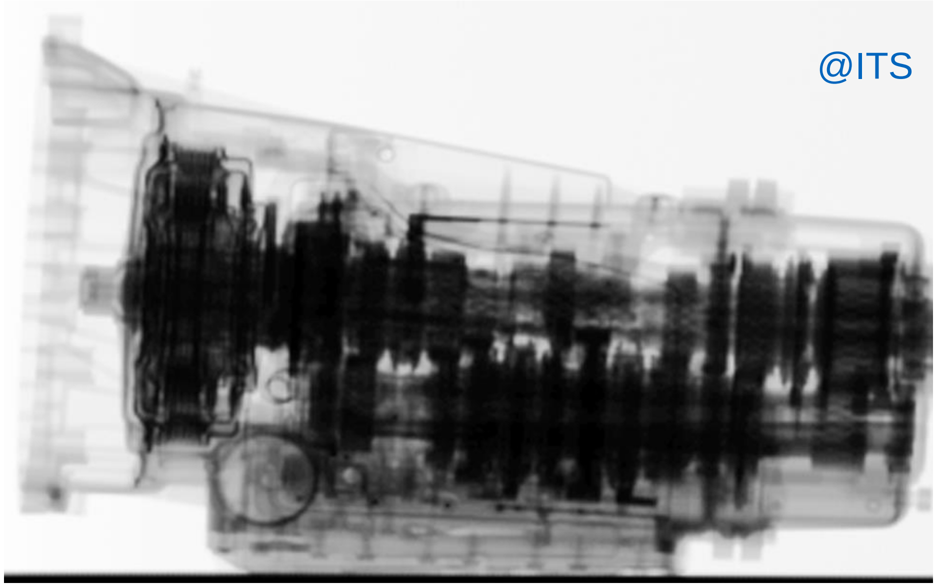


radiography @NECTAR

Examples (technical objects)

gear box of a modern car



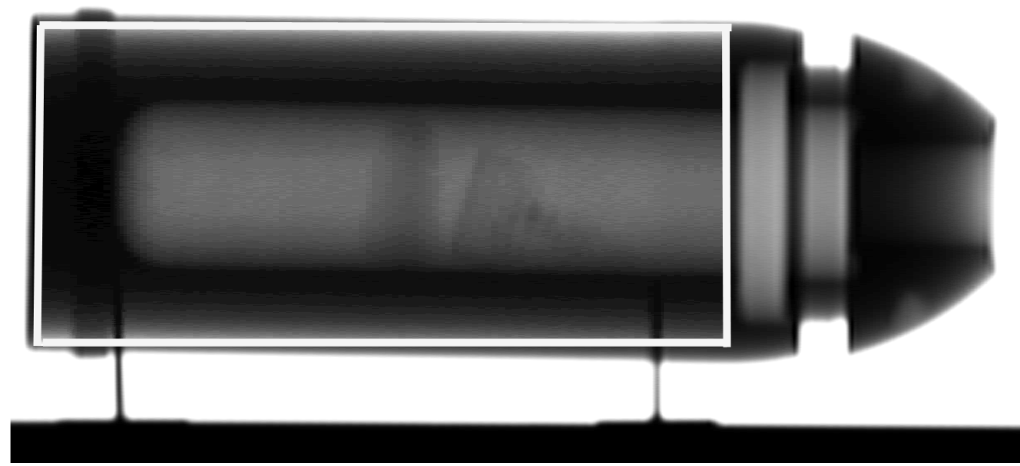


comparison

radiography @NECTAR and @ITS

Examples (technical objects)

artillery shell



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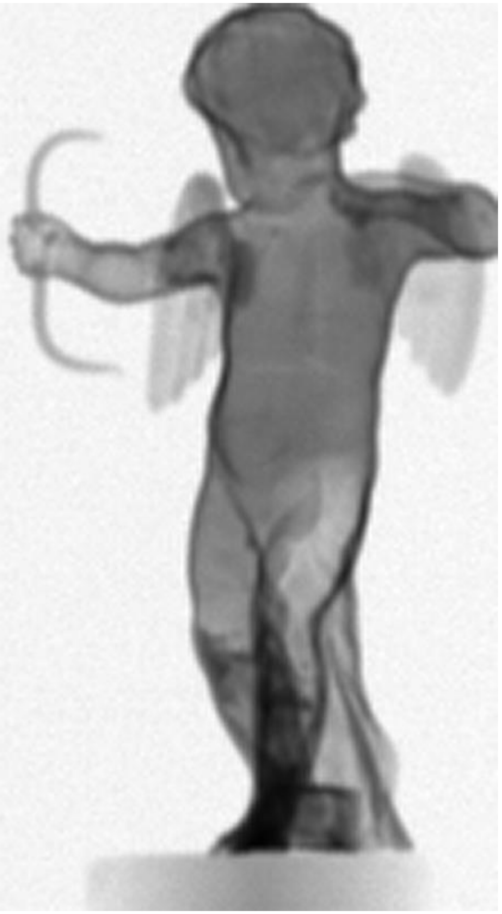
Examples (art history)

statue



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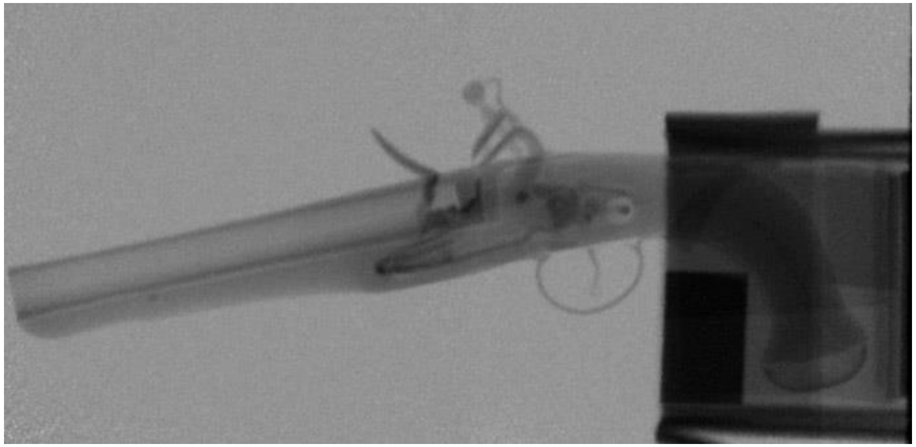
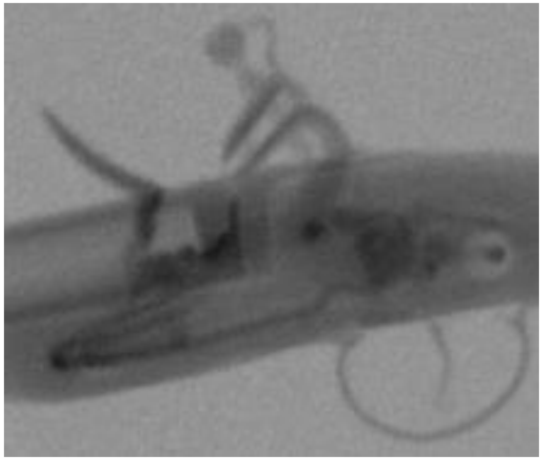
Examples (art history)

duelling pistol, statue





magnificated

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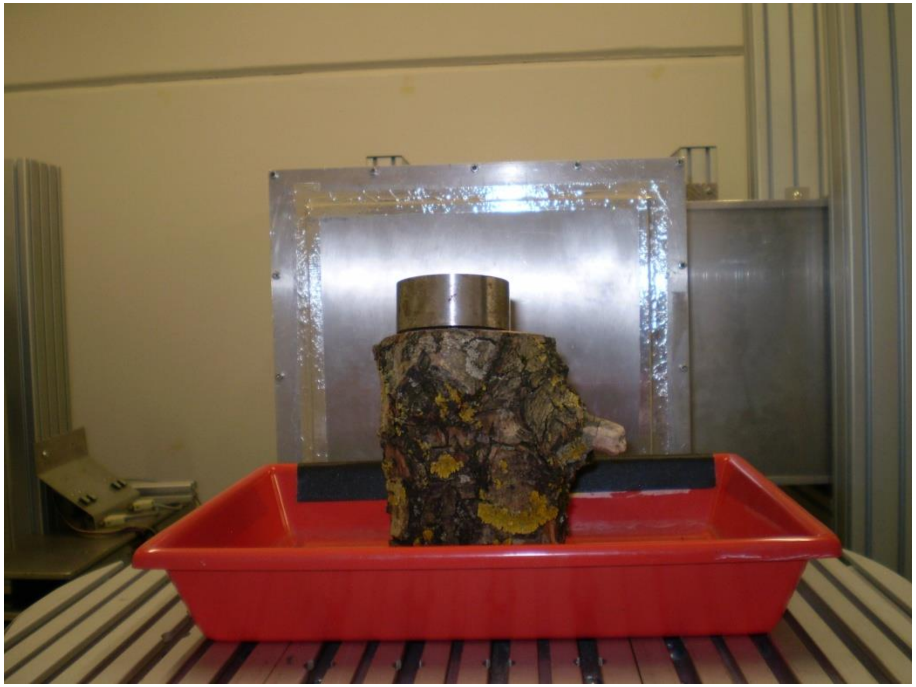
Examples („real“ time measurements)

water uptake of a trunk



iron cylinder to avoid floating
of trunk when water is added

Sample: trunc (Ø about 12 cm)

Parameter

Φ = $5.4\cdot10^5$ $cm^{-2}s^{-1}$

L/D = 233 ± 16

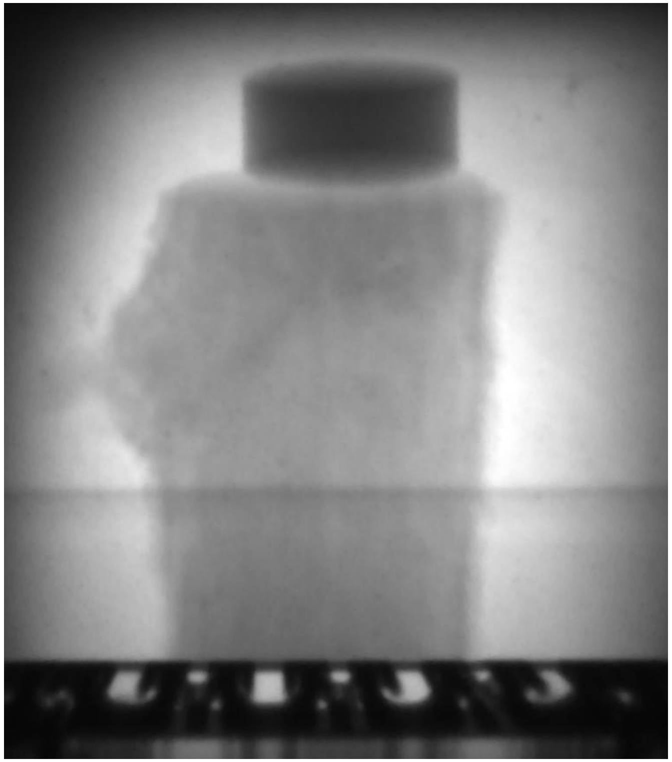
Δt = 62.2 s

t_{total} = 2000 min

V_{water} = 250 ml

Examples („real“ time measurements)

water uptake of a trunk



Reference image

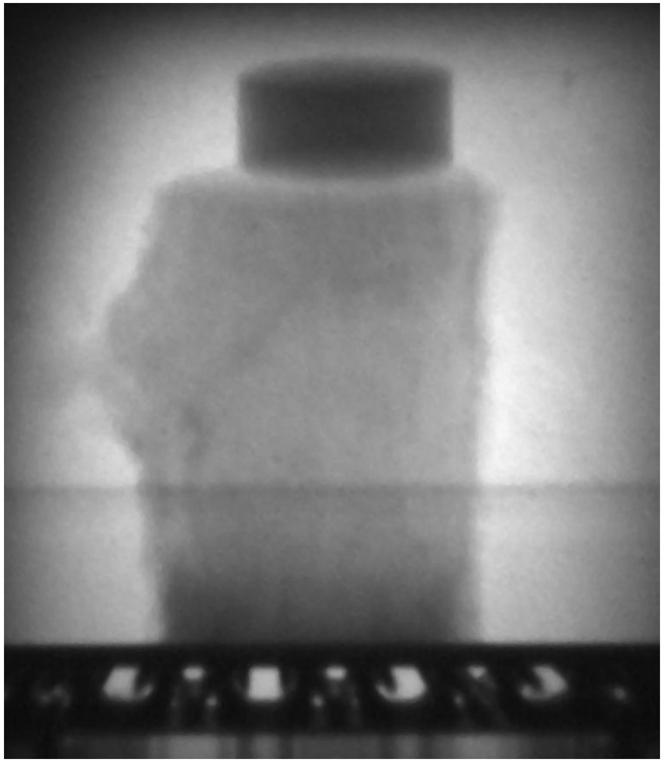
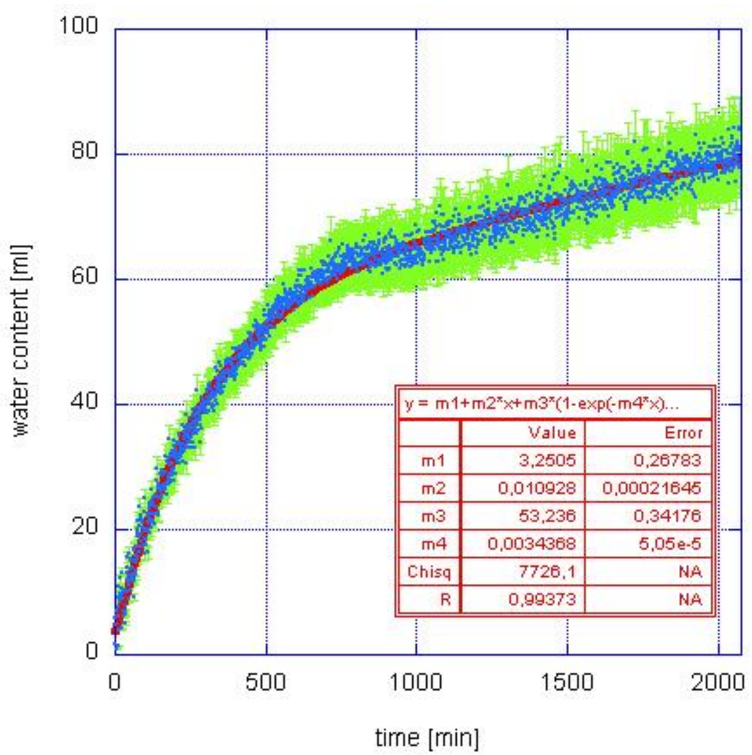


Image after 1000 min

Examples („real“ time measurements)

water uptake of a trunk

Quantitative evaluation:



$$V = 3.3 + 1.1 \cdot 10^{-2} \cdot t + 53.2 \cdot \left(1 - \exp\left(-3.4 \cdot 10^{-3} \cdot t\right)\right)$$

Within the first 2000 min, there are two mechanisms:

t < 750 min: soaring within the bark
⇨ <u>exponential rise</u>

750 min < t < 2000 min:
water uptake in the inner part of the trunk becomes dominant
⇨ <u>linear function</u>

Examples (NDT of radwaste)

200-L waste packages

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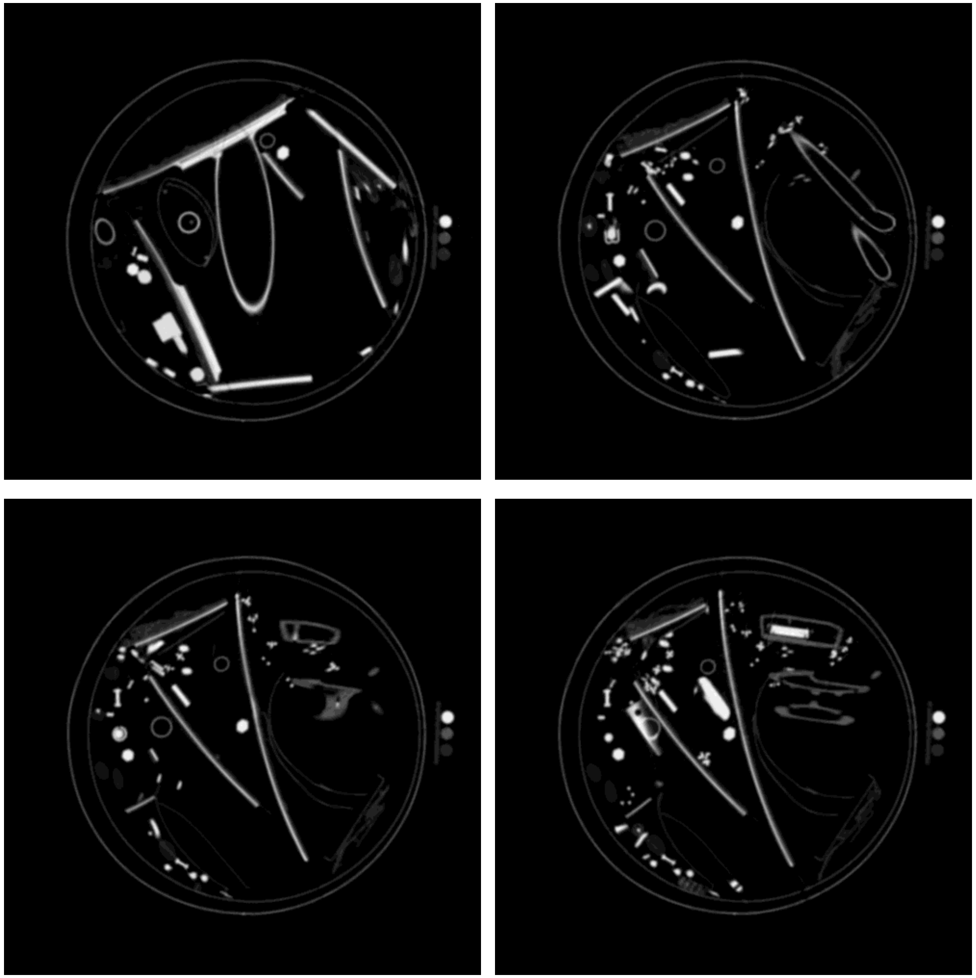
200-L waste packages

radiography @ITS

Examples (NDT of radwaste)

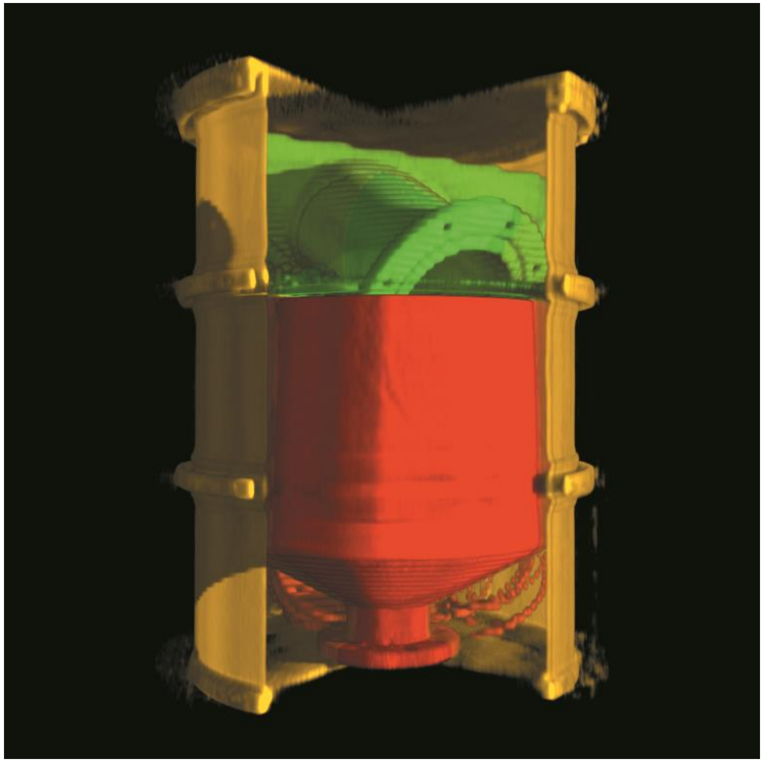
200-L waste packages



2D-tomography @ITS

Examples (NDT of radwaste)

200-L waste packages



3D-tomography @ITS

Examples (NDT of radwaste)

200-L waste packages – feasibility test @NECTAR

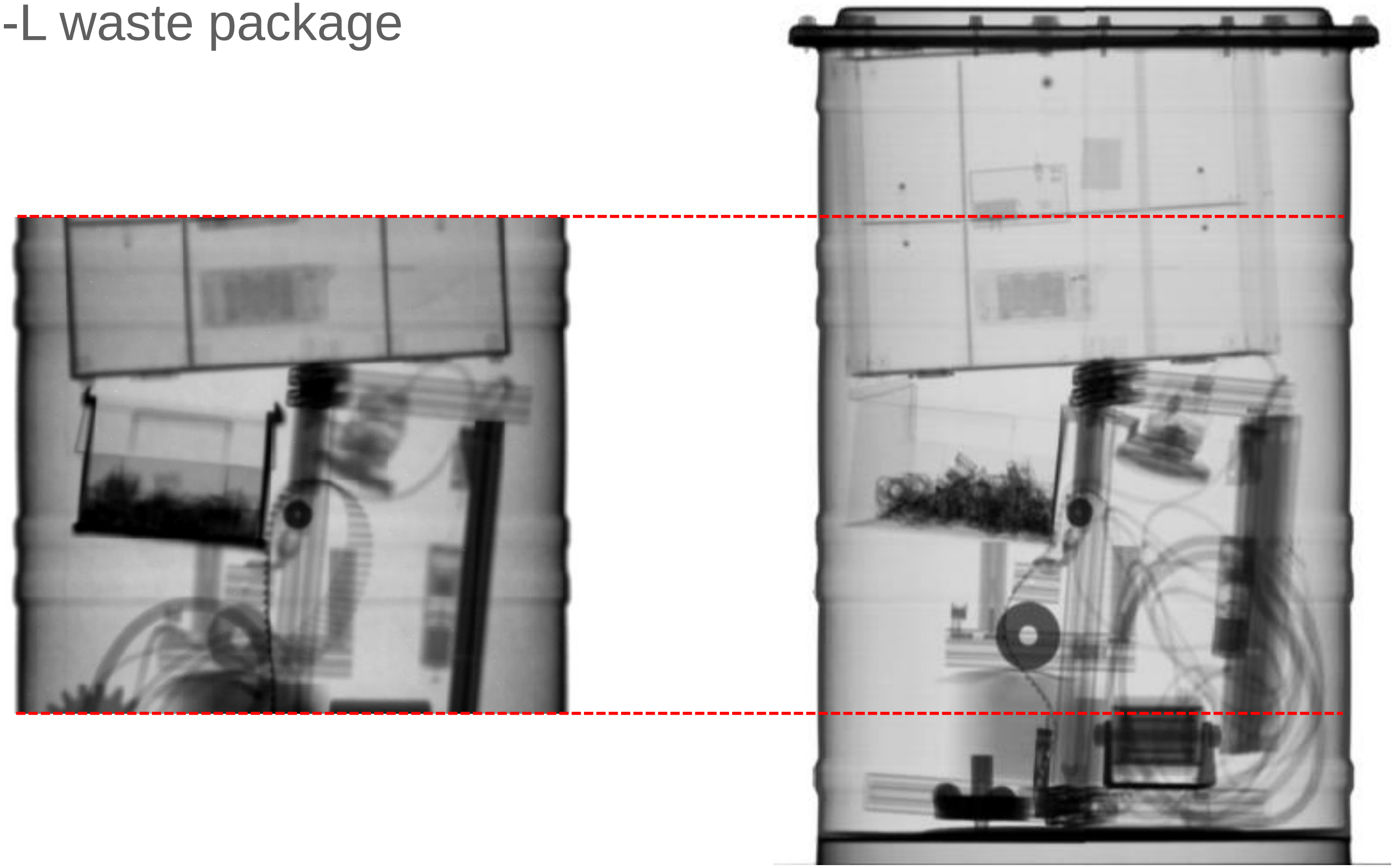
Examples (NDT of radwaste)

200-L waste packages – feasibility test @NECTAR

preparation of
mock-up drum

Examples (NDT of radwaste)

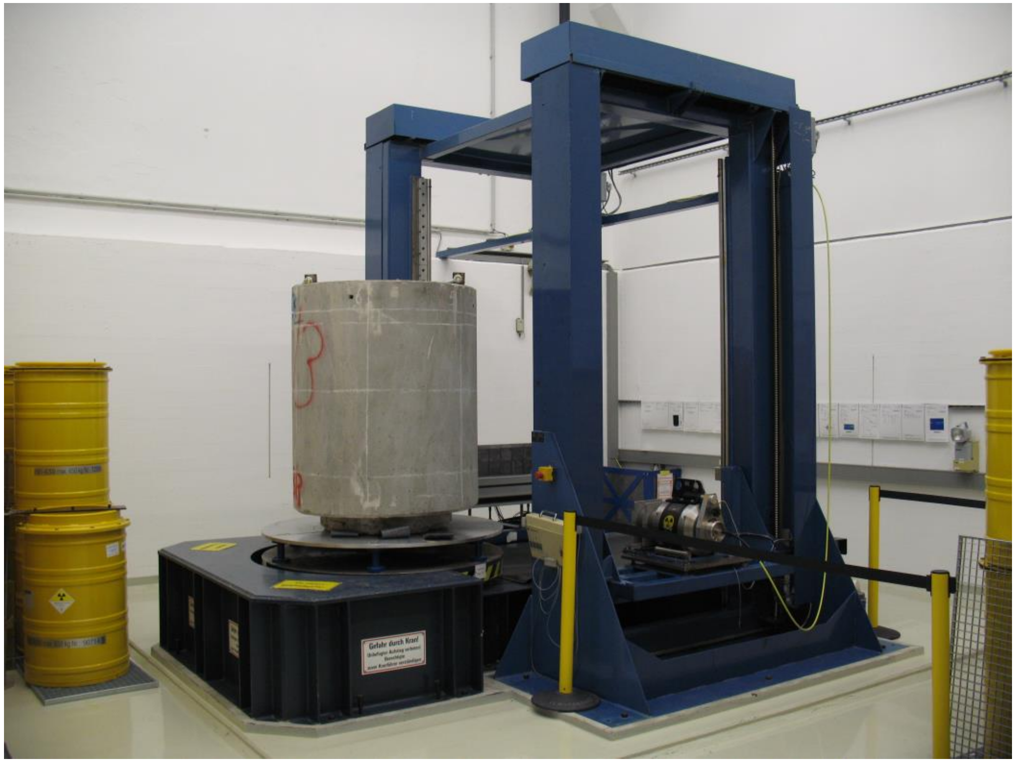
200-L waste package



radigraphy @NECTAR and @ITS

Examples (NDT of radwaste)

NBA („Normalbetonabschirmung“)



radiography @NECTAR

How to get beam time at NECTAR

- get into contact with me (thomas.buecherl@tum.de) or
  Malgorzata Makowska (Malgorzata.Makowska@frm2.tum.de)
- discuss feasibility of planned measurement
- submit a proposal (see http://mlz-garching.de/user-office)
- if accepted, contact me for arranging beam time