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:: Paul Scherrer Institut

Neutron field spectrometry at high energy neutron facility with extended range Bonner Sphere Spectrometer system

19th Sep. 2018, DENIM2018 at PSI

SINQ upgrade

The ***beam flux*** at a sample position

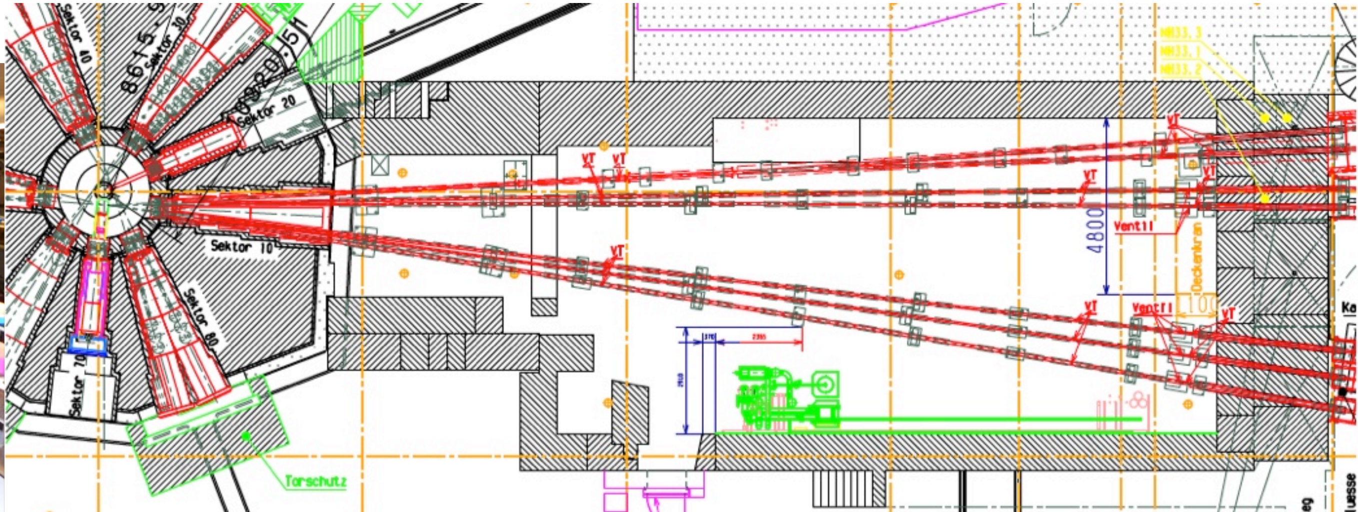
The ***background*** at a sample position

by Factor > 2

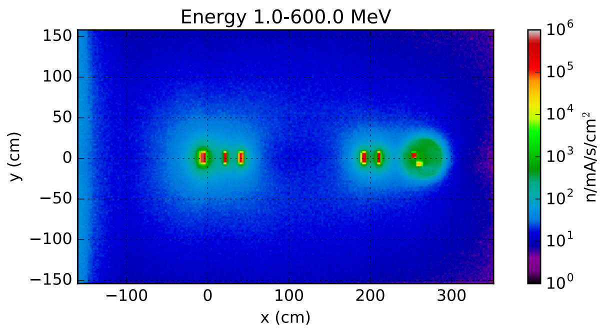
- **Borated water tanks around guide bundles in neutron guide bunker (sector10)**
- **New concrete material and lamella structure for shielding**

➢ **Our own system** to measure a neutron spectrum

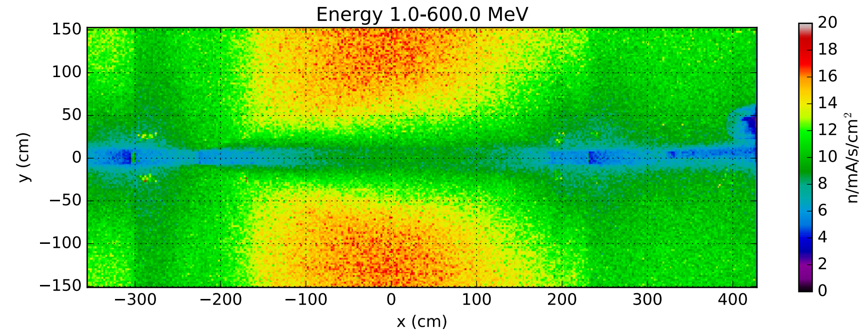
- over wide energy range with simple system is necessary.



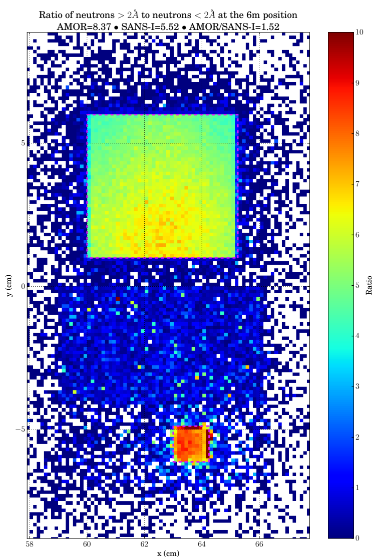
Background Reduction and Shielding Concept



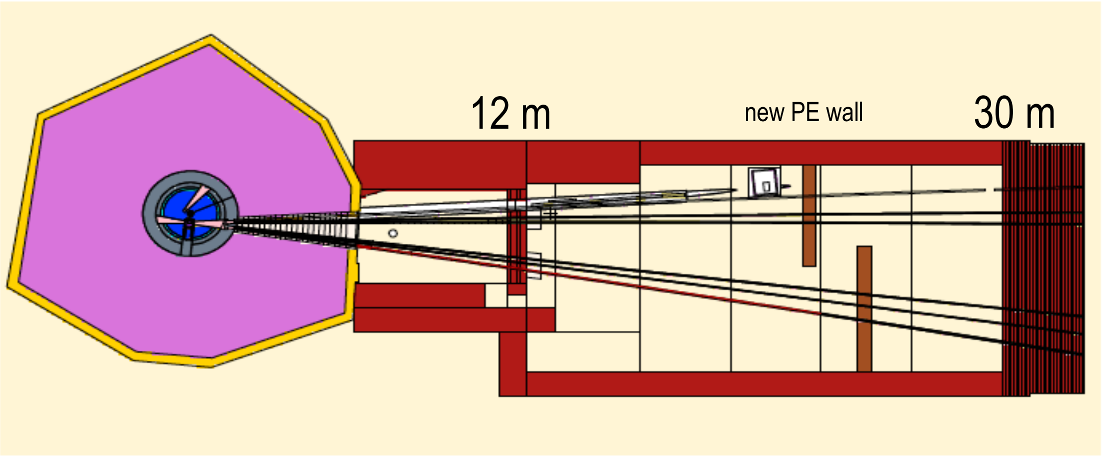
Neutronic Background at 12 m distance from the cold source

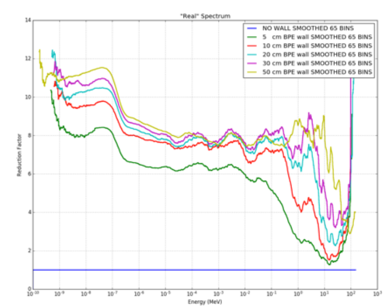


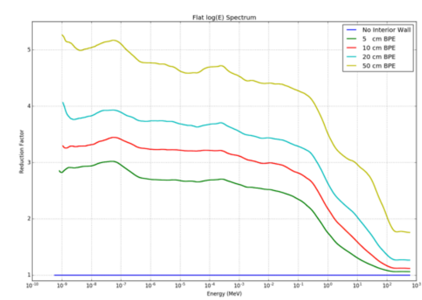
Neutronic Background at 30 m distance from the cold source



AMOR guide system transports 1.5 better signal to noice ratio as the SANS guide







50 cm borated PE wall reduces the background by a factor 5-6

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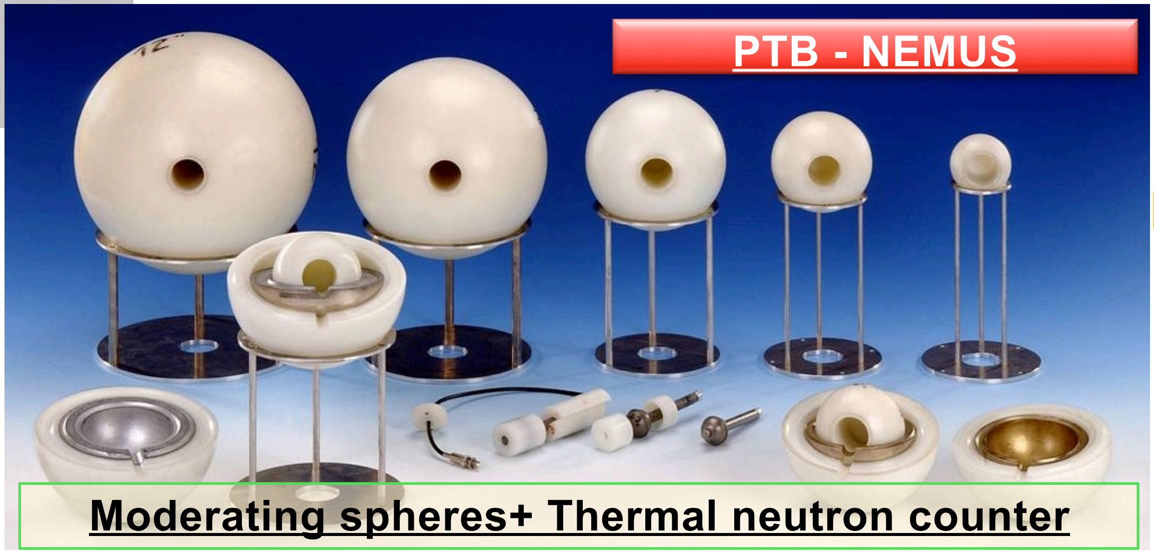
Bonner Sphere Spectrometer (BSS)

Neutron spectrum in a broad energy range with coarse energy resolution
: **12 order of magnitude (1 meV – 20 MeV)** → possible extension ~ **100GeV**



Moderating spheres+ Thermal neutron counter

Measurement: count rate suite

$$N_i = \int R_i(E)\phi(E)dE$$

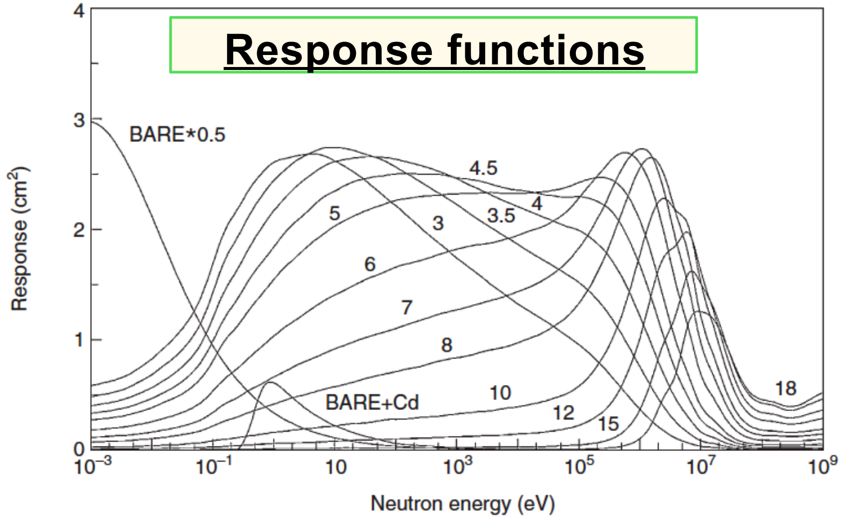
$$(i = 3, 3.5,,,, 12)$$

N_i [n/s] : Count rate

R_i [cm^2] : Response func.

ϕ [$n/s/cm^2$] : Spectrum

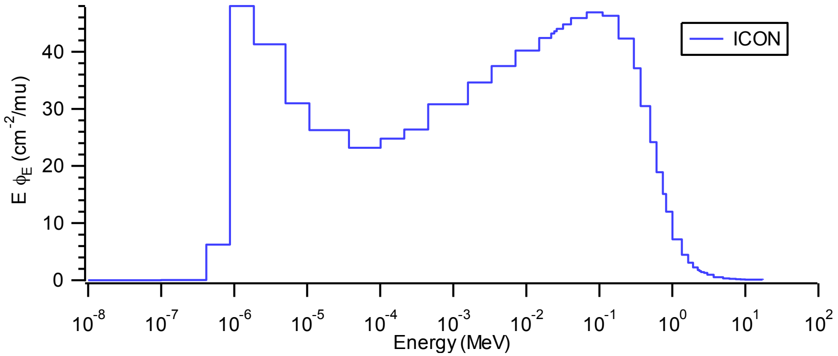
Response functions



B. Wiegel, A.V.Alevra, NIMA 476 (2002) p.36

Unfolding a spectrum using a guess spectrum

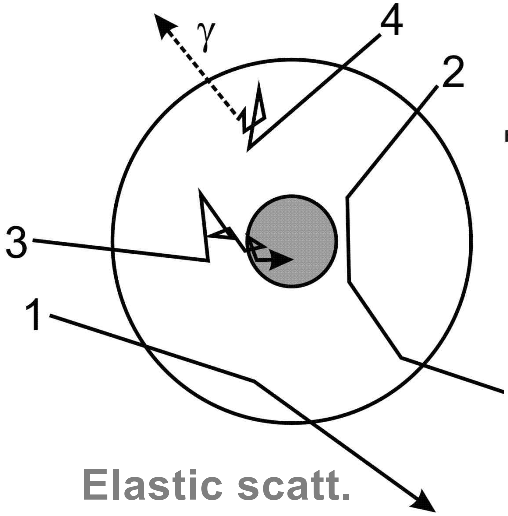
- **Maximum Entropy Method**
- **Bayesian Parameter Estimation method**



Energy extension of BSS system (PTB-NEMUS)

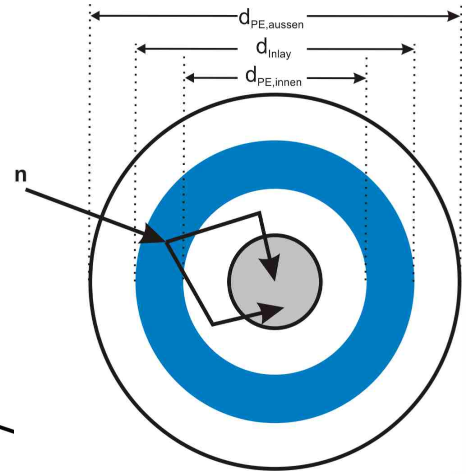
Extension of energy range up to 100 GeV

Polyethylene(PE) < 20 MeV



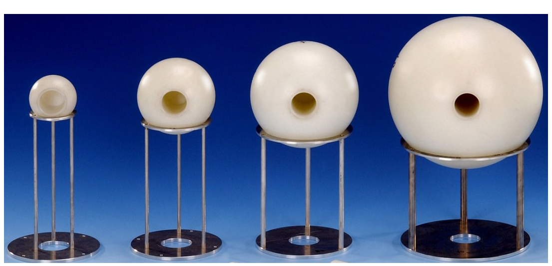
Elastic scatt.

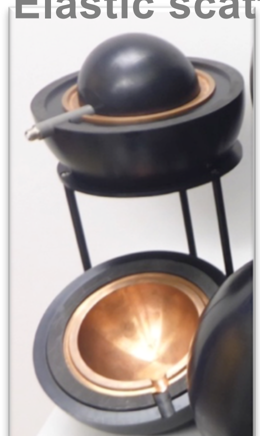
Metal inlay > 20MeV

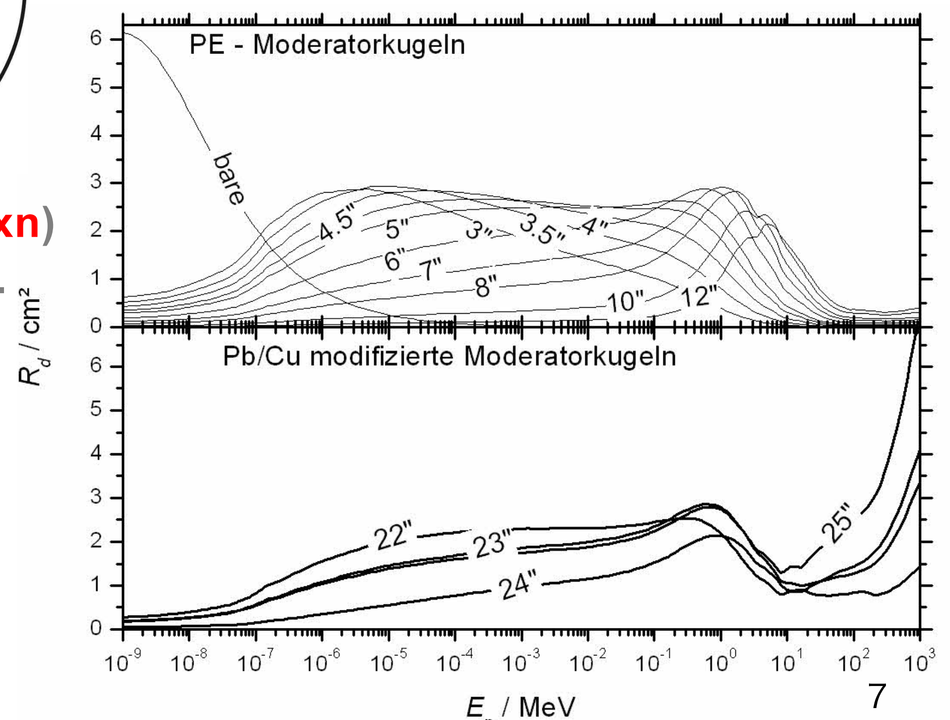


(n,2n), (n,3n), (n,xn) & Elastic scatt.

Index (i)	$d_{PE,inside}$	Material	d_{Inlay}	$d_{PE,outside}$
22”	3”	**Pb**	5”	7”
23”	4”	**Cu**	5”	7”
24”	4”	**Pb**	5”	7”
25”	4”	**Pb**	6”	8”







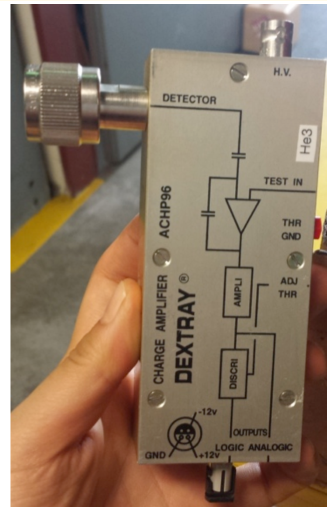
PSI in-house BBS system, Fine tuning

Moderating spheres

- PE x 10 spheres
- Extension (Cu) x 1
- Extension (Pb) x 4

☑Machining PE & Cu
☑Casting Pb (n-CT, BE)
☑Calibration at PTB
☑Detailed characterization for fine-tuning of response functions (PE, Cu, Pb)

^{3}He proportional counter + pre-Amp



- ø3.2cm, 2.3 bar /0.02bar
- 10kcps @4% loss
- Angle dependencies < ±60º (otherwise => 50%)

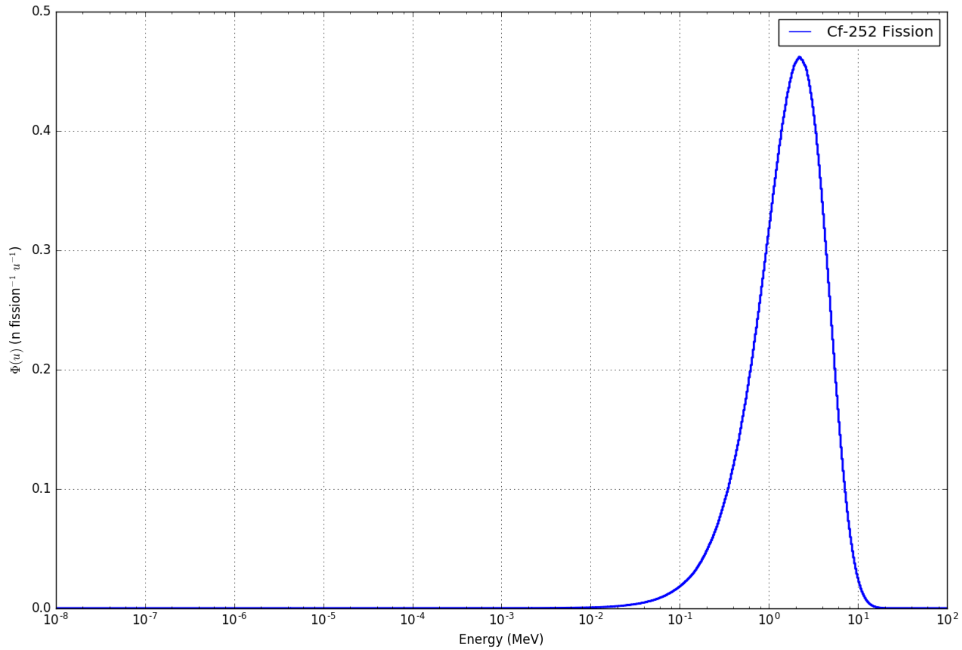
☑Characterization
☑Low efficiency counter
☑Refinement (better S/N, dead time correction, etc)
☑Calibration stations (neutronic and electronics)

Mobile DAQ rack + PC

- Mobile
- TOF option

Internal
: NUM / GFA/ LOG, NIAG
External
: SINE2020 program

Exercise using Cf-252 at calibration laboratories (PSI, PTB)



Source

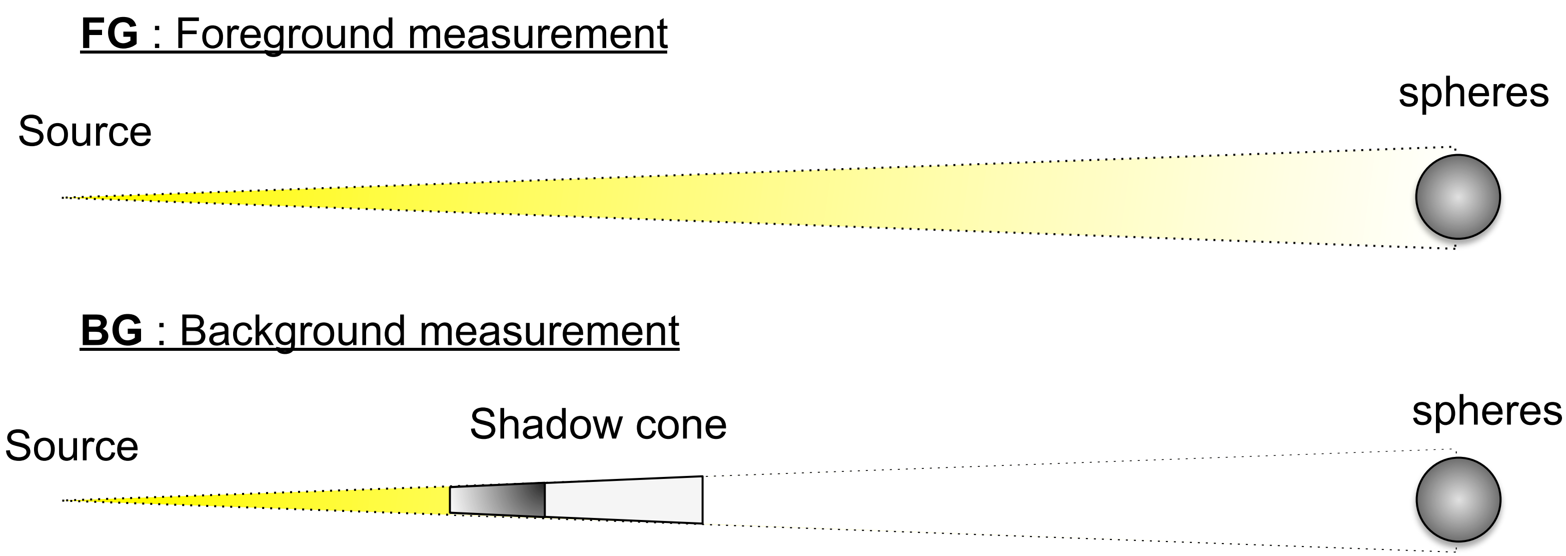
- **Cf-252**

Measurements

1. **PSI (FG)**
2. **PTB (FG – BG)**

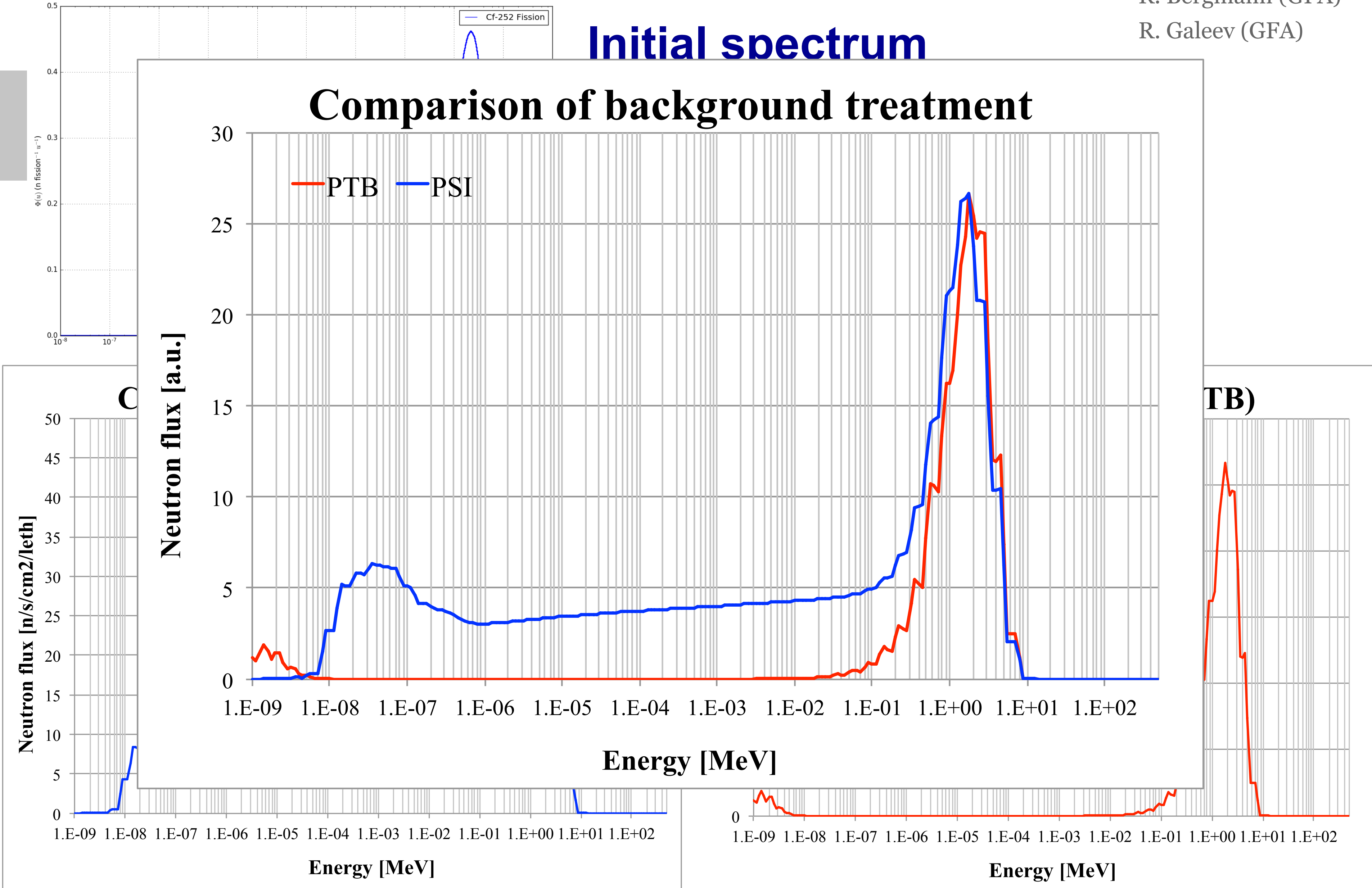
Unfolding codes

1. **MAXED(UMG)**



Unfolding Cf-252 spectra using MAXED, UMG

R. Bergmann (GFA)
R. Galeev (GFA)



Characterization of Pb spheres using Neutron tomography

NEUTRA, SINQ

6-4'' sphere

Index (i)	$d_{PE,inside}$	Material	d_{Inlay}	$d_{PE,outside}$
22"	3"	Pb	5"	7"
24"	4"	Pb	5"	7"
25"	4"	Pb	6"	8"

Aanlysis

- Positions and volume of Void or interstices
- Density homogenity

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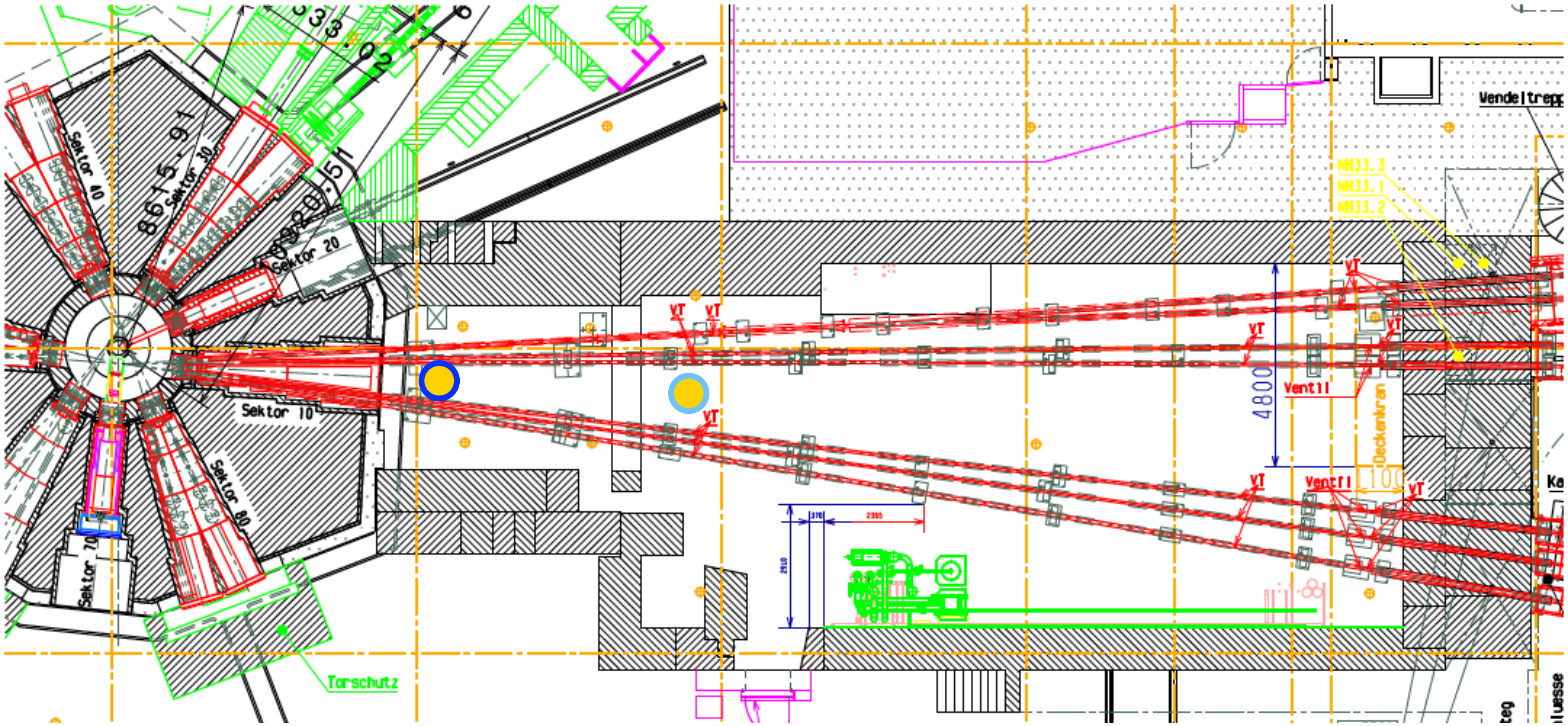
Measurement location and setups



	1st bunker	2nd bunker
Distance from the CS	7.4 m	12.5 m
Heigh [m]	1.53 m	1.25 m
Proton beam current	20 μA	200 μA
Exposure time	600 sec	60 sec

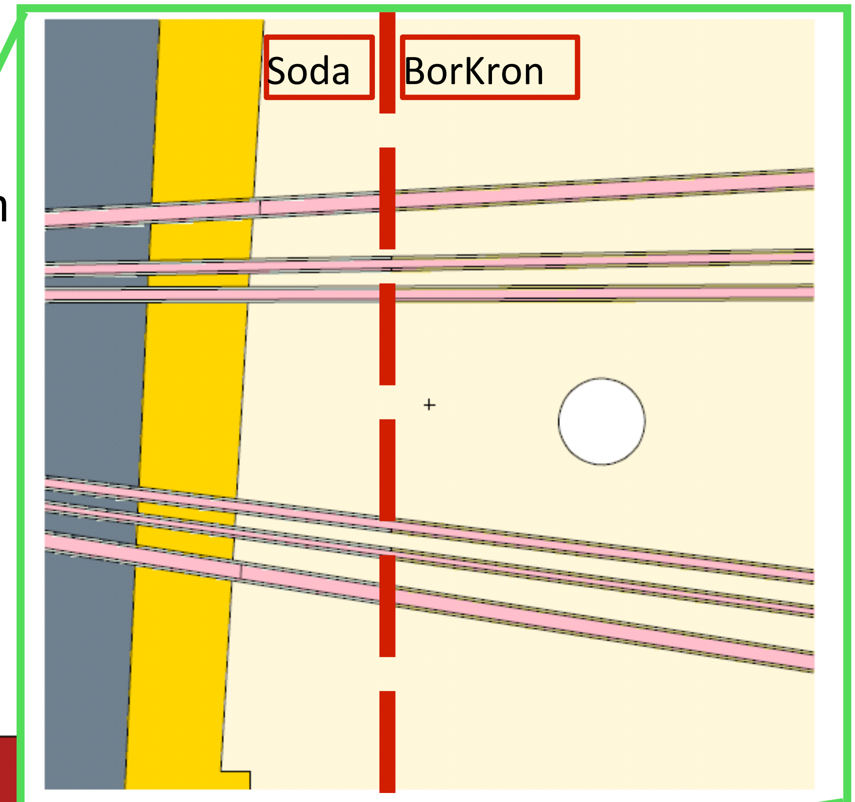
![PSI logo]

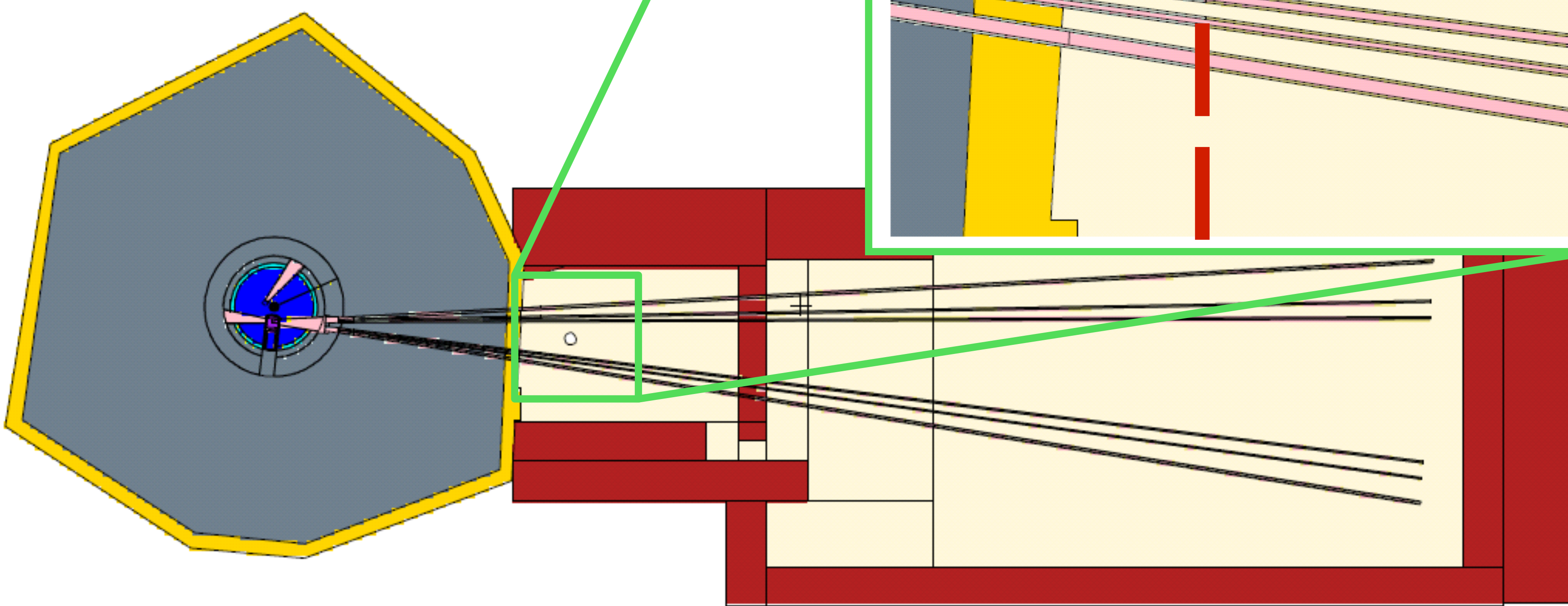
Simulation (by MCNP, R. Bergmann (GFA))

Guide bunker 1st room

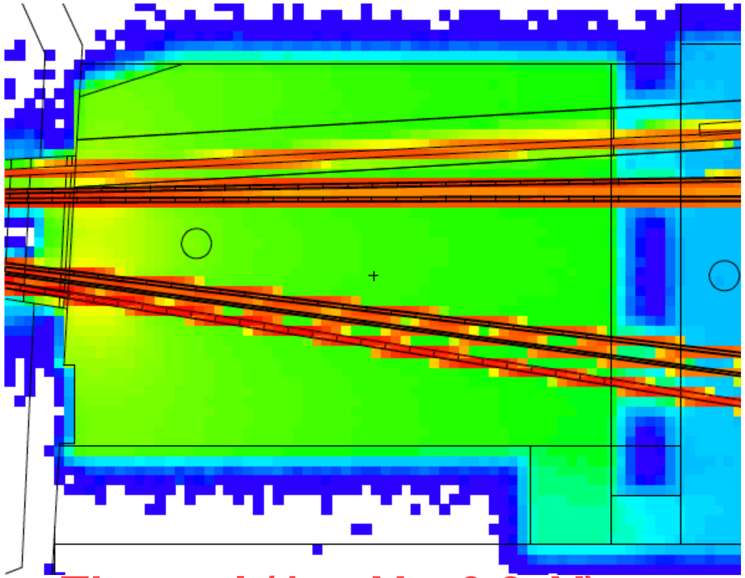
- Distance from CS : 7.4 m
  Distance from the monolith wall: 1.4m
- Shielding material : Steel t4.6m

	1st bunker
Proton beam current	20 μA
Exposure time	600 sec

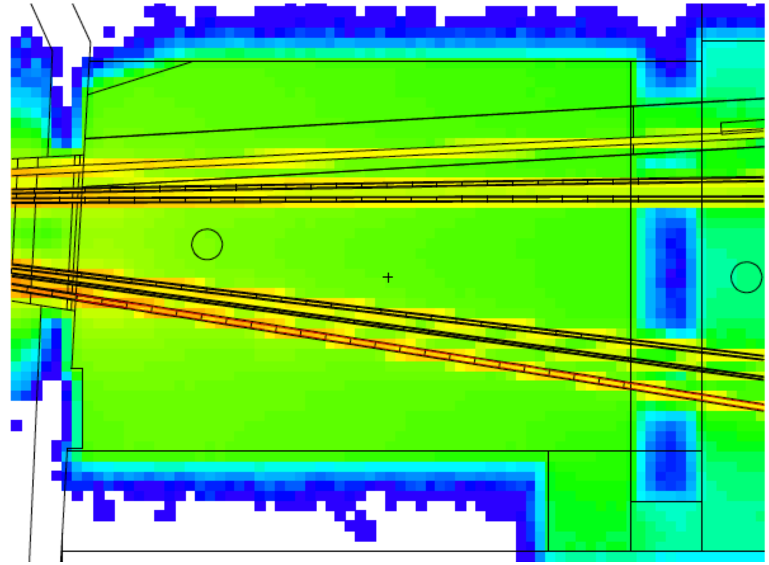




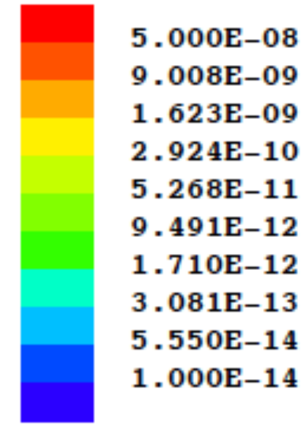
Spatial distribution (by MCNP, R. Bergmann)

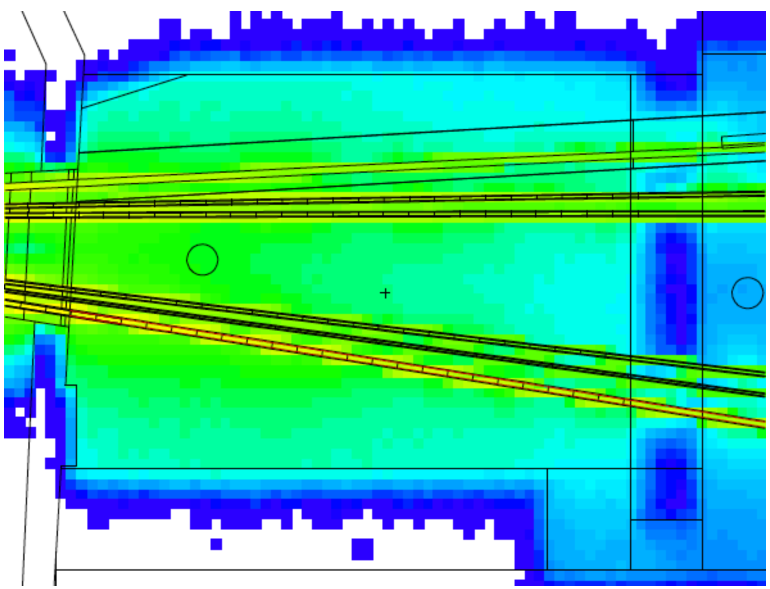


Thermal (1meV – 0.3eV)

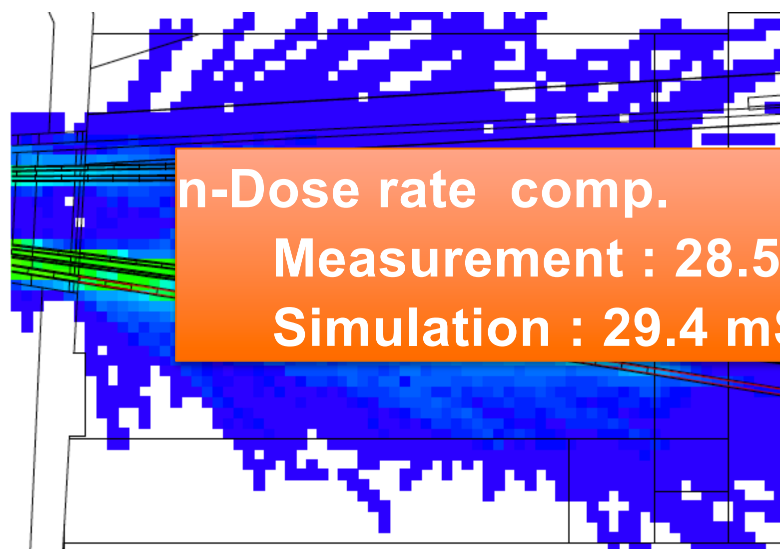


epi-thermal (0.3eV – 0.1 MeV)





Fast (0.1 MeV - 20 MeV)



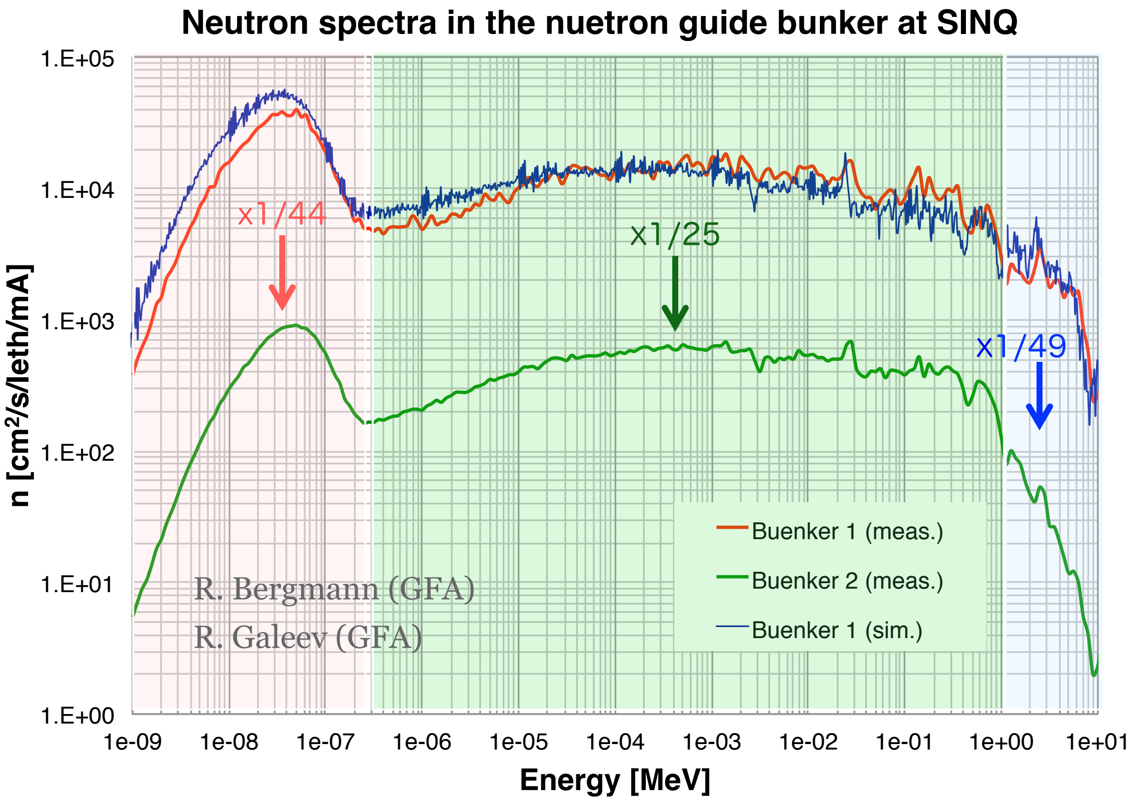
Fast (20 MeV – 600 MeV)

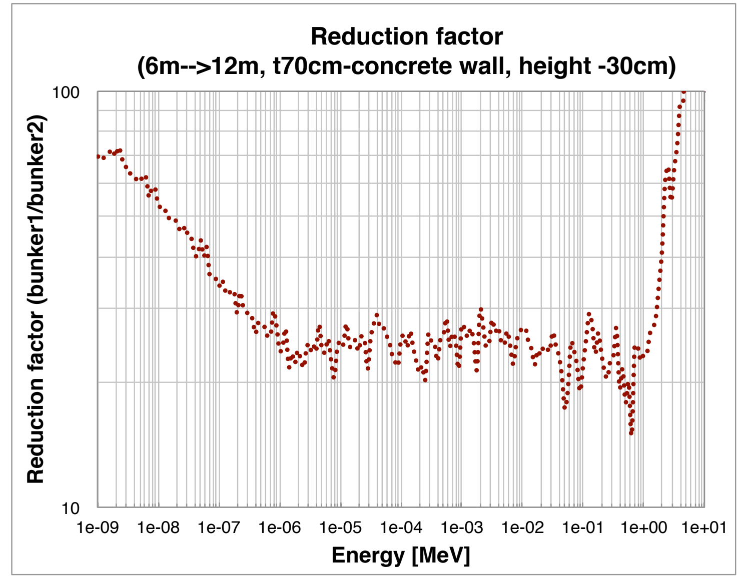
n-Dose rate comp.

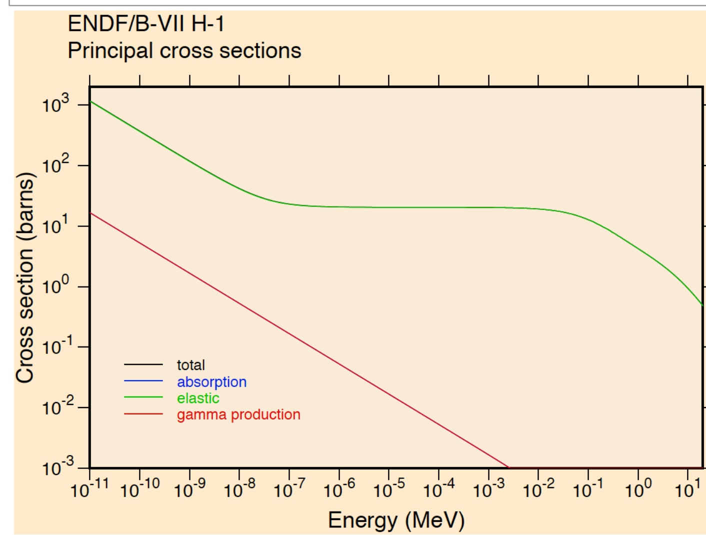
Measurement : 28.5 mSv/h/mA

Simulation : 29.4 mSv/h/mA

Unfolded spectra





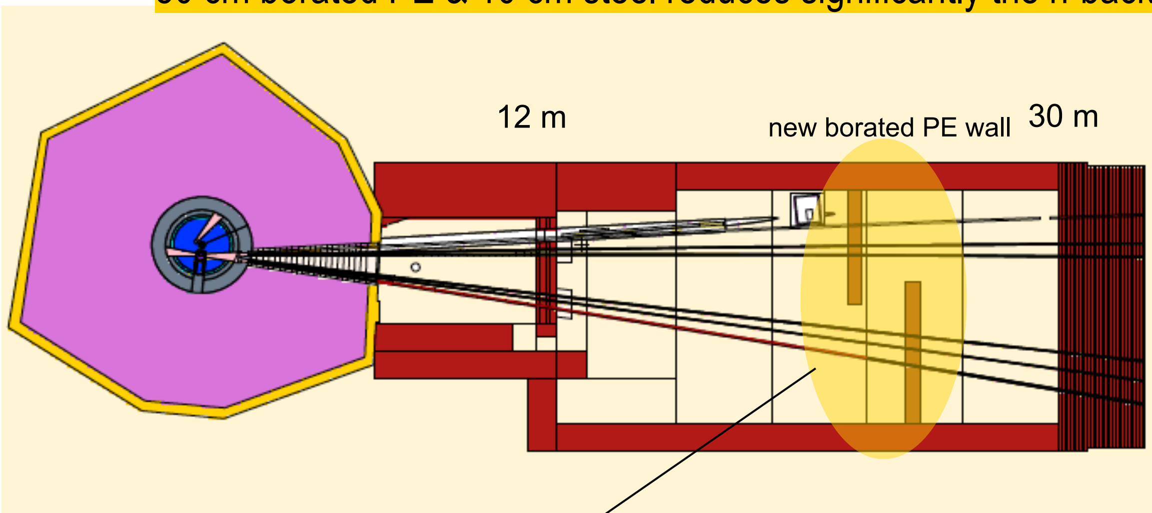


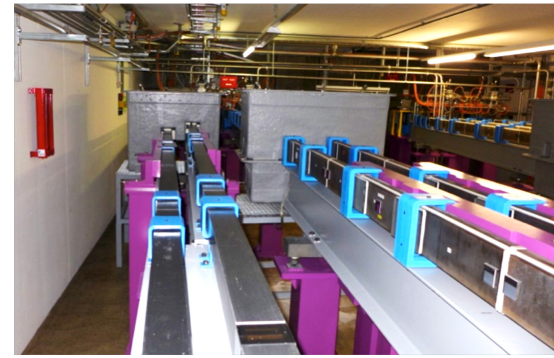
→ epi-/ Thermal neutrons are dominant.
→ Above 10 MeV, not many neutrons exist.
→ Distance (5m), concrete wall (t70cm), height difference (-30m) reduced the background by factor of 25-50.

→ The validation of PSI- BSS system is planned at a know field.
→ The unfolding accuracy is improving.

Simulation study of new shielding in bunker

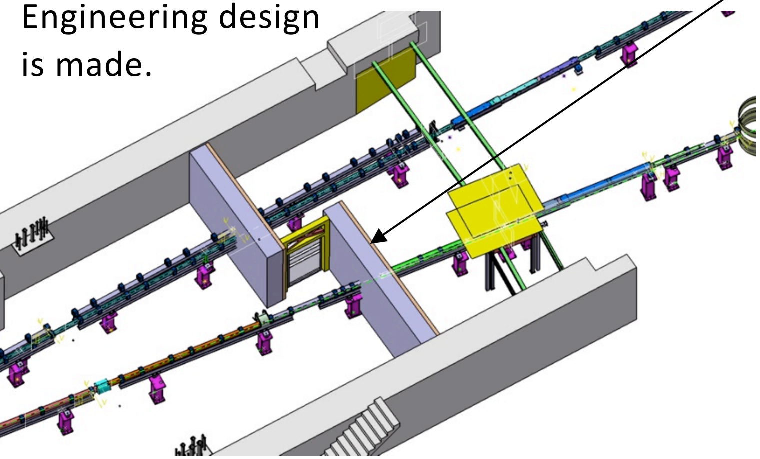
50 cm borated PE & 10 cm steel reduces significantly the n-background (5-6 times)

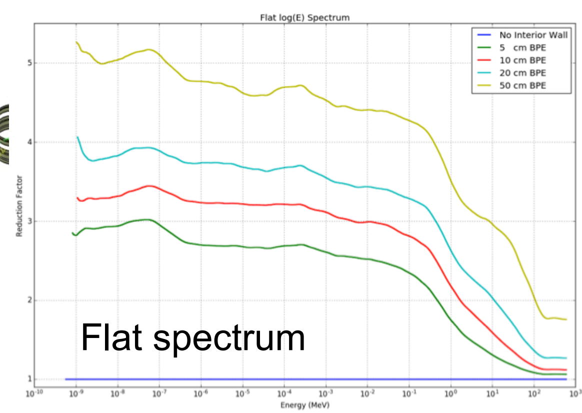


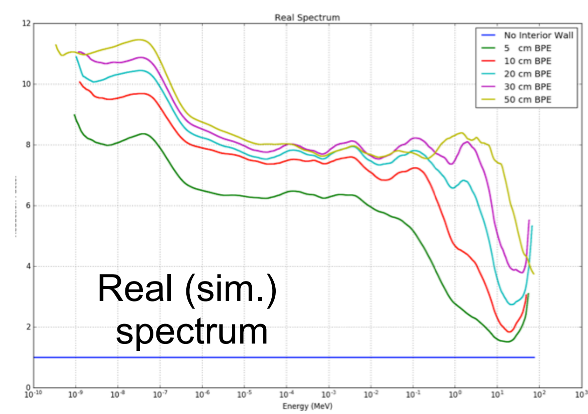


Borated-water tanks in bunker

Engineering design is made.







→ 50 cm borated PE wall reduces the background by a factor 5-6

→ Validation by measurement strongly supports simulation study.

Contents

1. Development of Bonner Sphere Spectrometry (BSS) system at PSI
2. Measurement at the neutron guide bunker in SINQ
3. **Measurement at AKR-reactor in TU-Dresden**
4. Application to “in-Bean” measurement
5. Investigation of new shielding materials

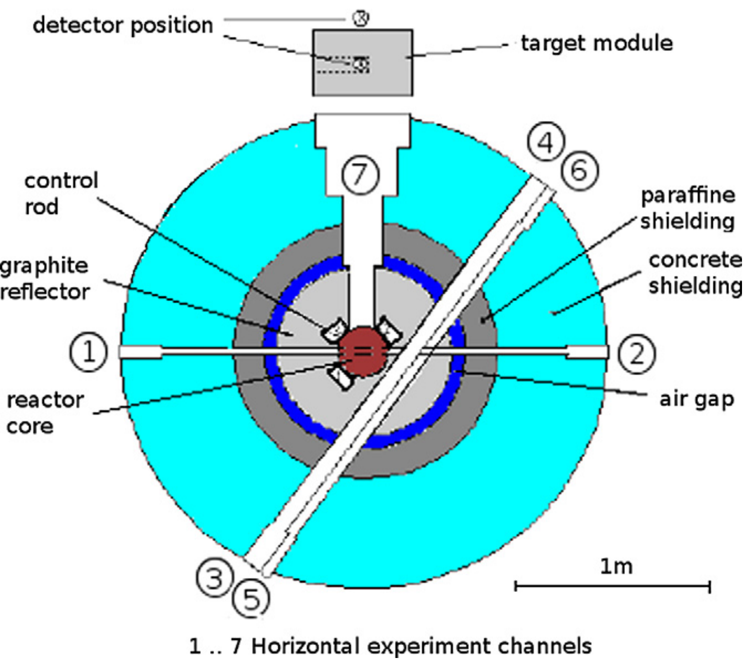
The training and research reactor AKR-2, TU Dresden

Neutron source

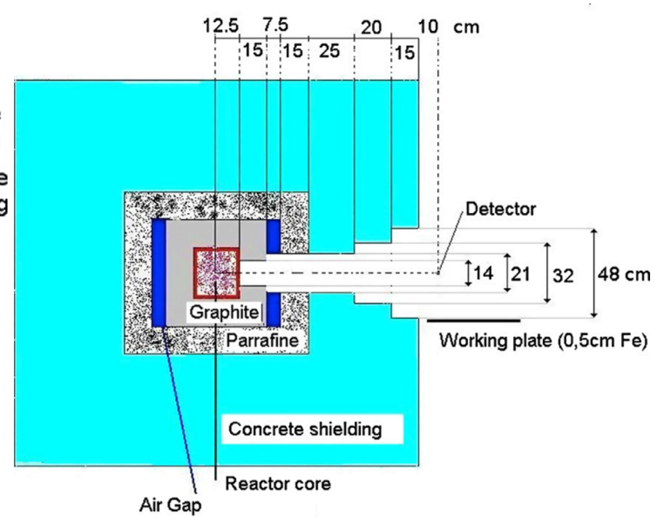
– AKR-2 of the TU Dresden, Educational reactor:

The thermal, homogeneous, solid material moderated zero power reactor with maximum continuous power of 2 Watt.

Ref : https://tu-dresden.de/ing/maschinenwesen/iet/wket/ausbildungskernreaktor-akr-2/profil



Horizontal cross section of AKR-2 reactor, distances in cm



Vertical cross section

Reactor Core

– A homogeneous mixture of 20% enriched Uranium oxide and PE.

– Diameter : ø25cm

– Height : 27cm

– Flux : 2.7×10^7 n/s/cm^2

Reflector

– Graphite, t15cm

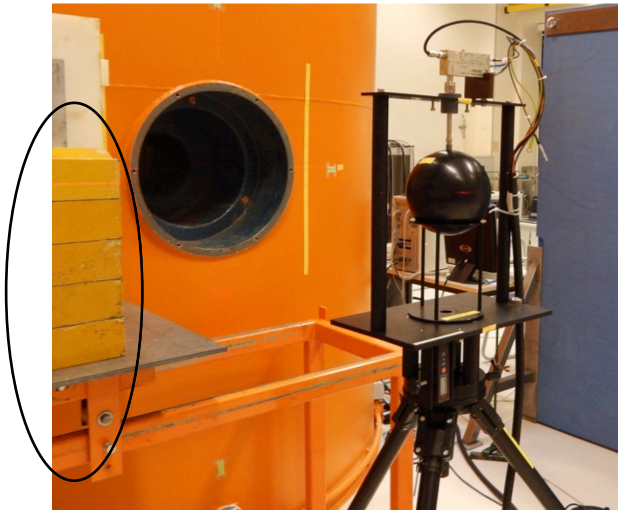
Biological shielding

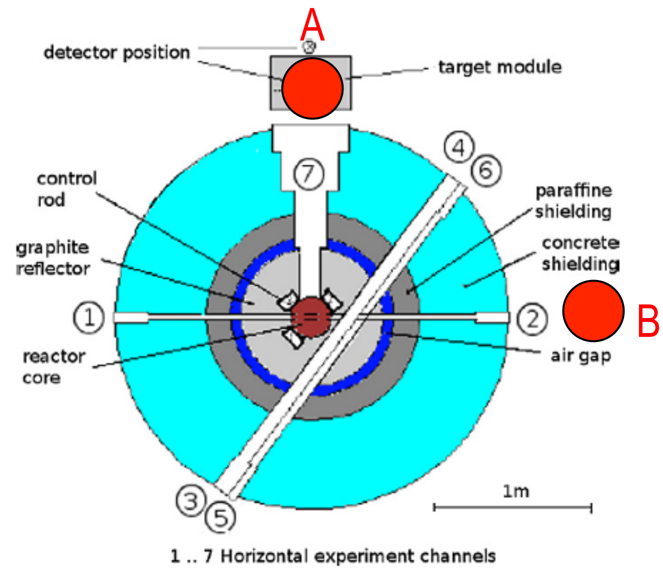
– Paraffin, t15cm

– Heavy concrete, t60cm

By Michal Košťal, et al.

Field Test with BSS system



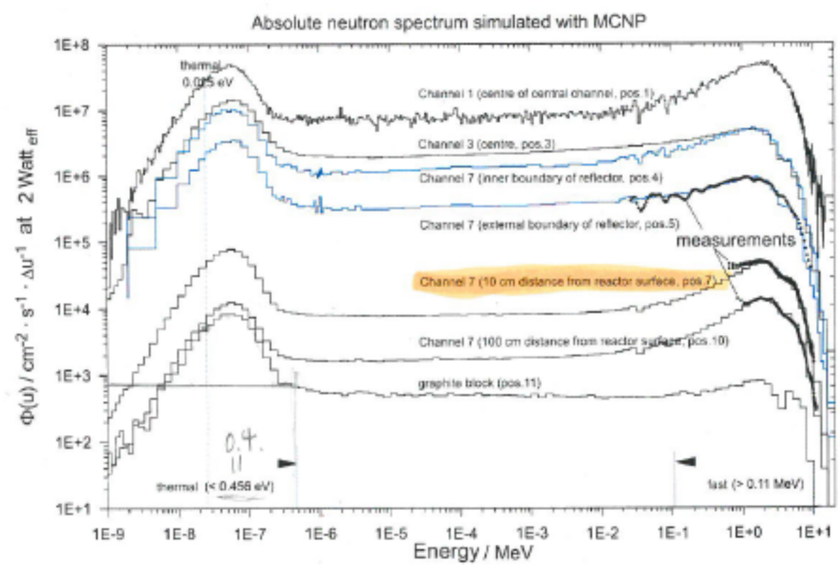


- detailed MCNP model exists
- at position A the fast neutron spectrum was measured by another group (proton recoil method)

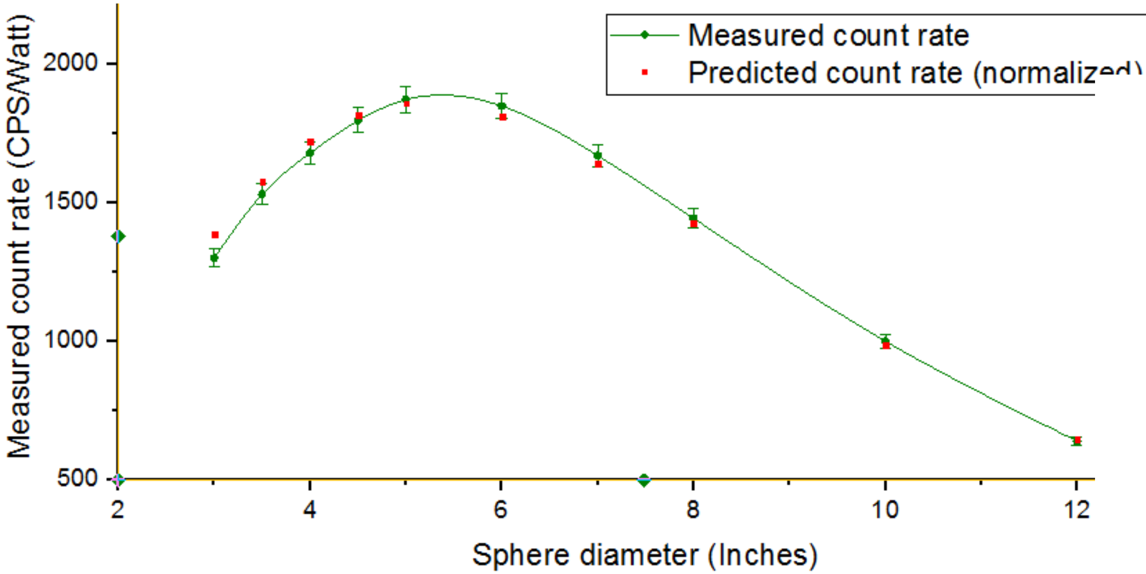
Field test was in April 2018

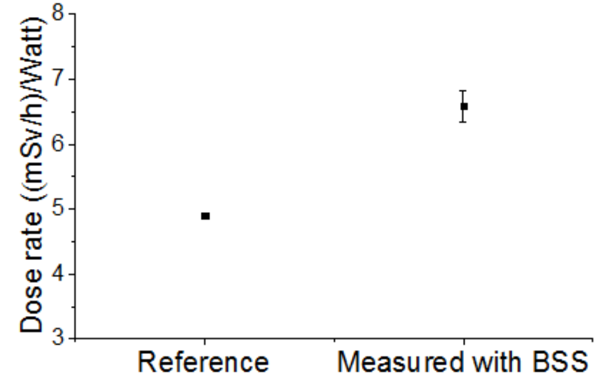
(1) Verification of the known n-spectrum

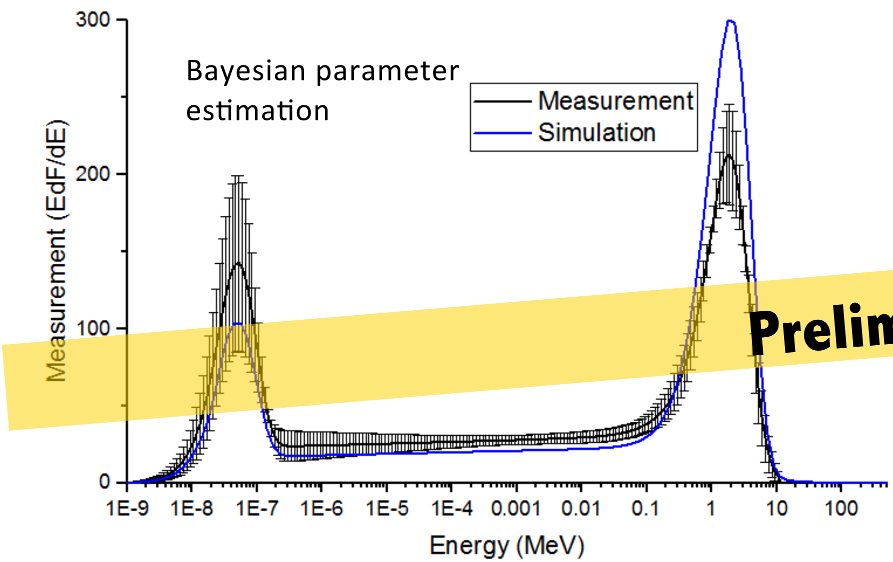
(2) Measurement an un-known n-spectrum (Pos. B)

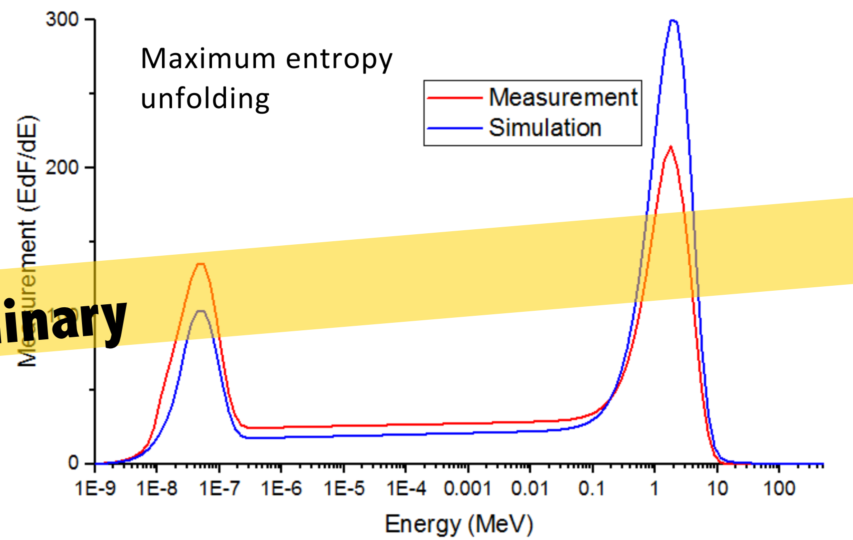


Measurements at AKR-2 reactor. Preliminary Results



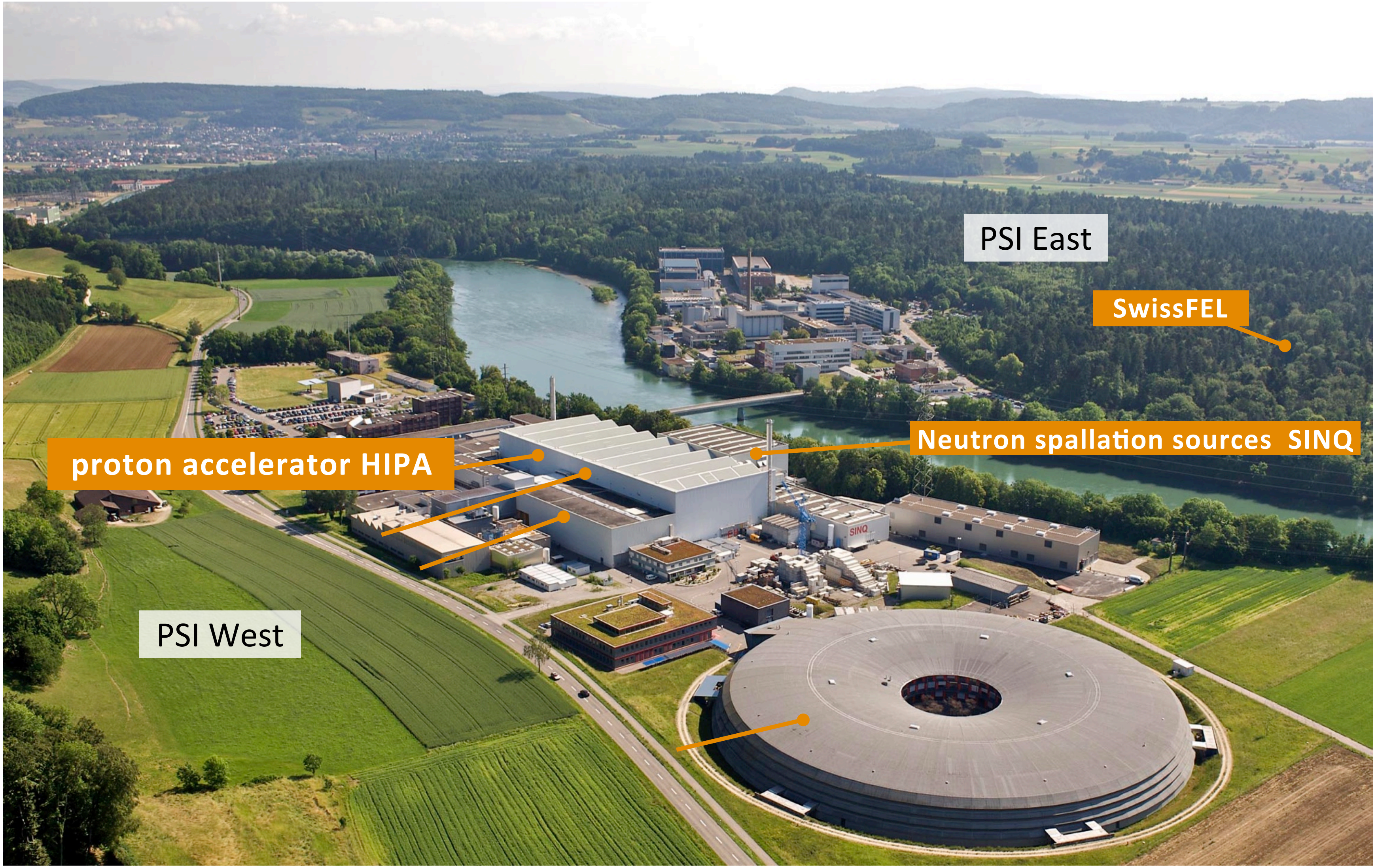




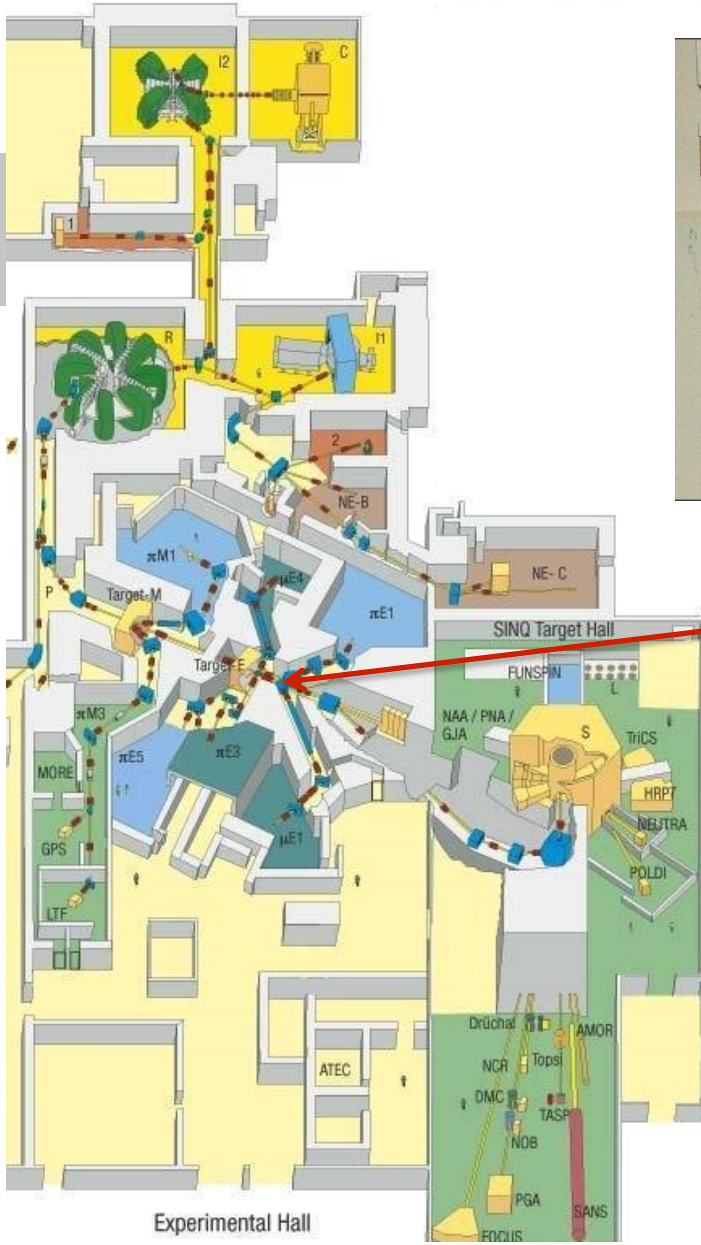


Paul Scherrer Institute (PSI)

← Zurzach Germany ↑ Aarau/Bern ↓ Zürich →



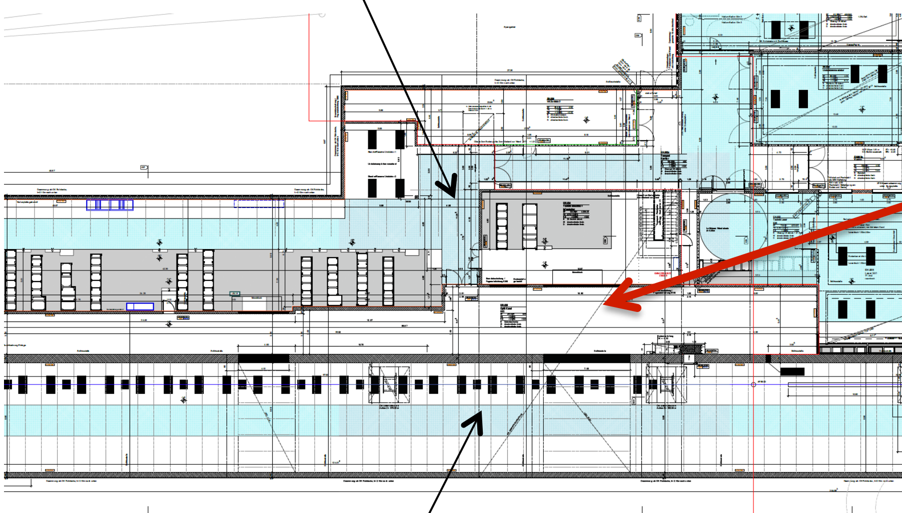
PSI: Layout High-Intense-Proton Accelerator



SwissFEL measurements

- Measurements in OPTICS hutch
- Position z585
- Measurements behind 90cm of concrete shielding

Optics room



Accelerator tunnel

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Contents

Extension for “In-beam” measurement

1. High intensity beam

➔ The flux is ~ 10^2 to 10^3 times higher than “background” field.

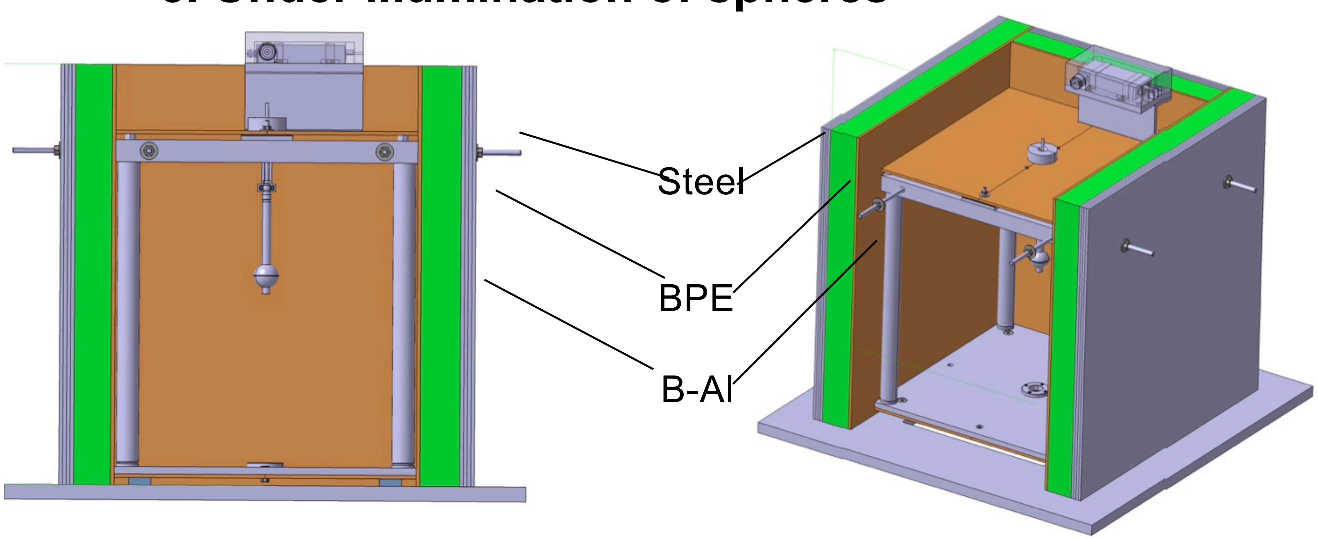
→ Low-efficiency detector (10^{-2})

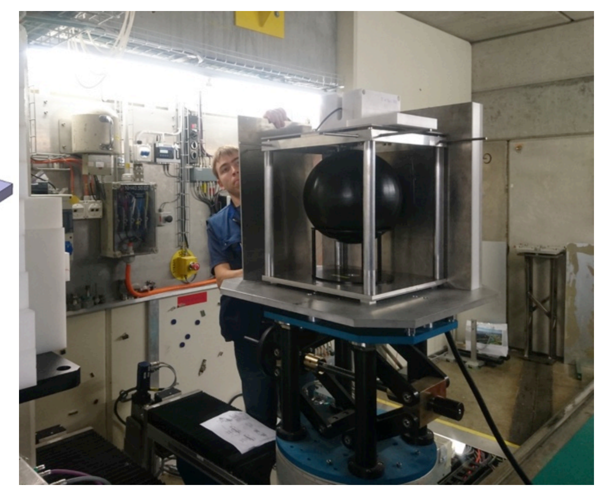
2. Discriminate the “back ground” neutrons from the beam

➔ The shielding box which has a lamella structure is under development.

→The optimum design will be investigated.

3. Under illumination of spheres



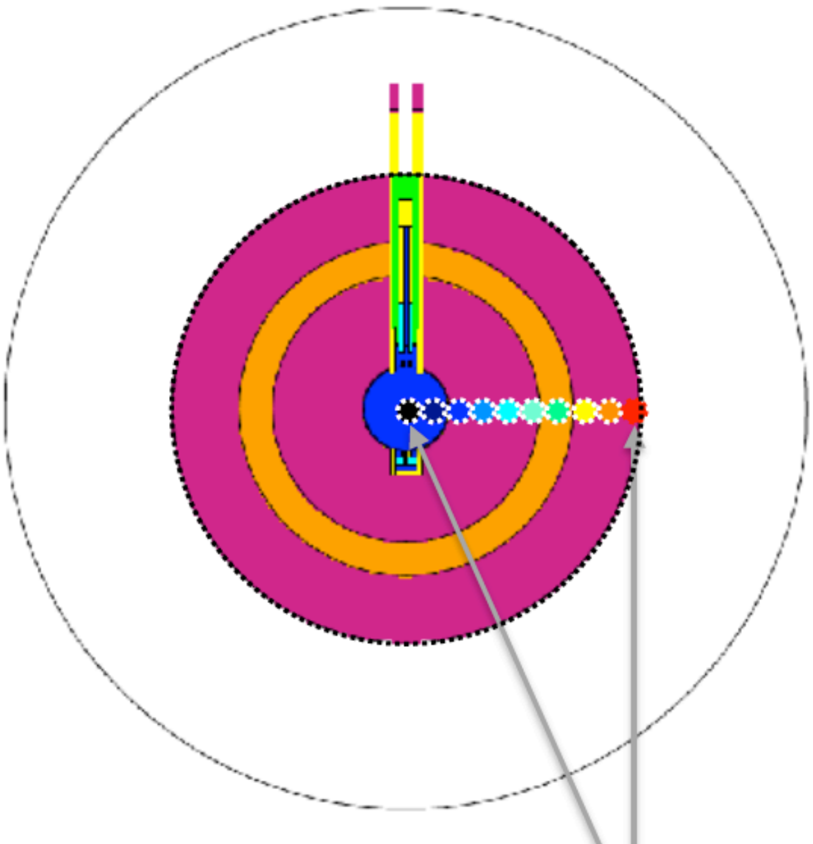


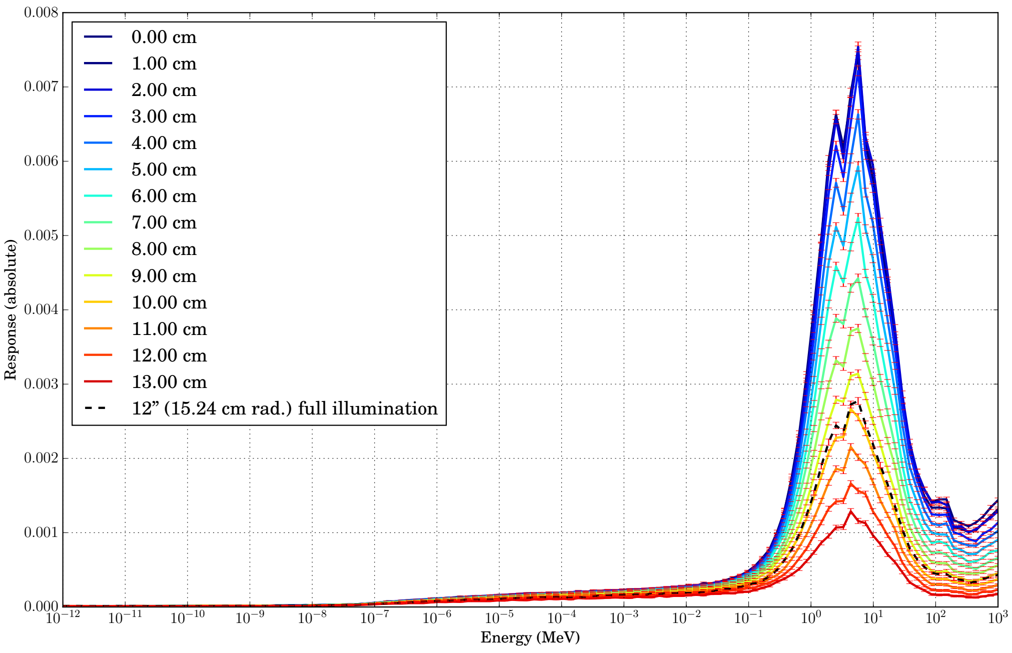
Modification of response functions

Sphere is **under/inhomogeneously illuminated**
→ Response function should be modified

- **MCNP calculation**

Ø5cm beam, 12”(PE) sphere





→ In-beam measurement needs
- Beam size on the sphere
- Beam position on the sphere

R. Bergmann (GFA)

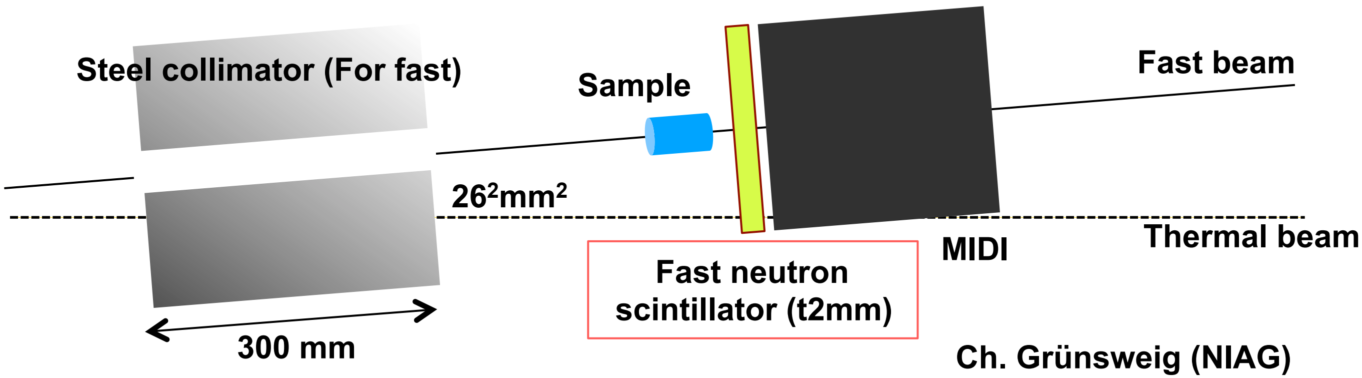
Application for Material Studies

- ☑ Modified response functions (method)
- ❒ Beam size on the sphere
- ❒ Beam position on the sphere

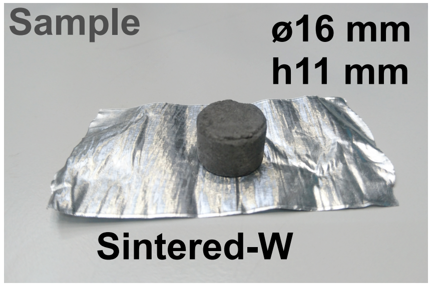
Fast neutron imaging

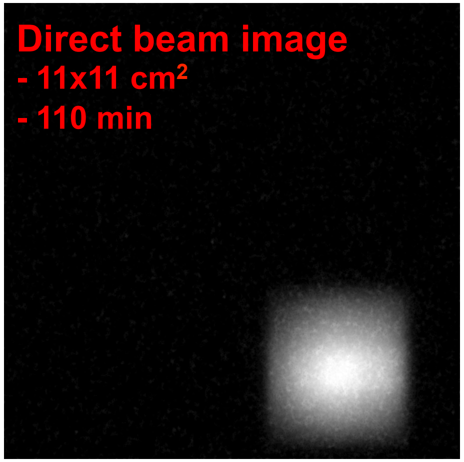
- Fast neutron scintillator (>0.8MeV)
- MIDI imaging box

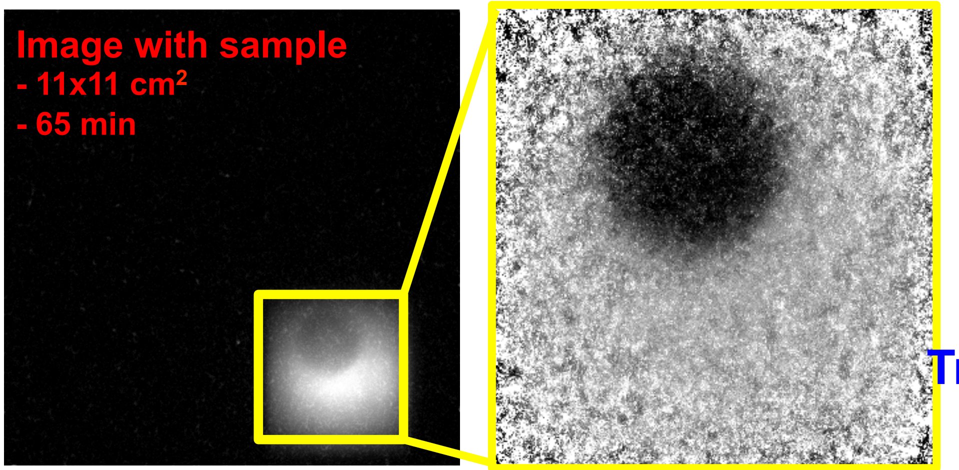
Fast neutron imaging setup at BOA



Ch. Grünsweig (NIAG)







Transmission: ~60%

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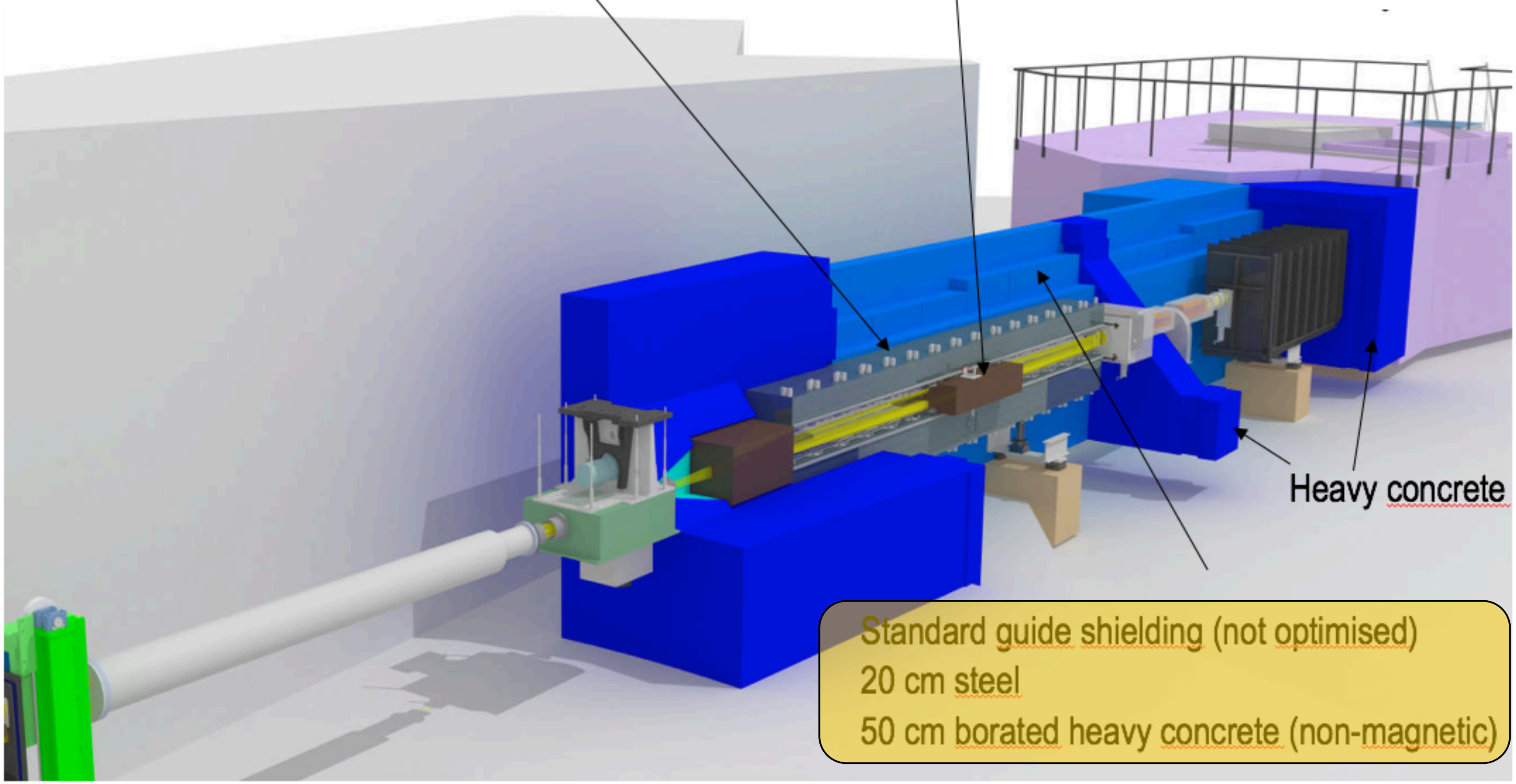
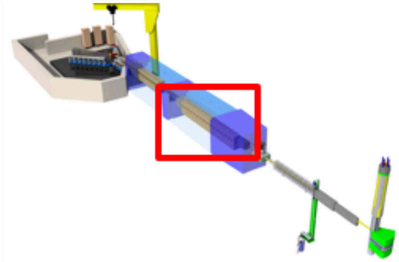
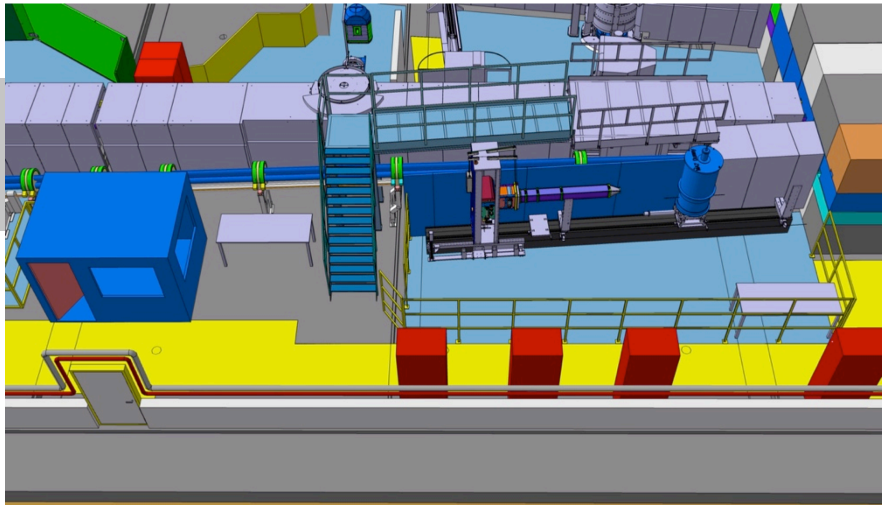
Needs at PSI/ESS - ESTIA

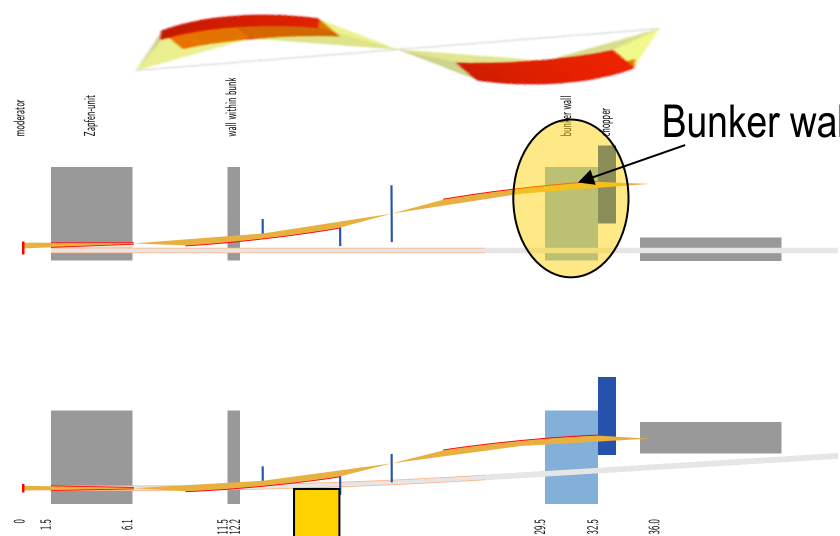




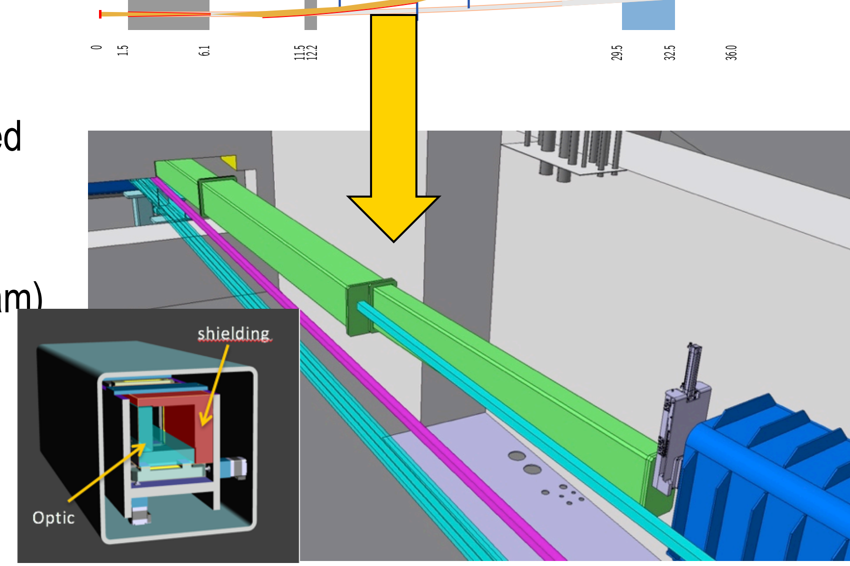
Needs at PSI/SINQ – Upgrade AMOR



Upgraded AMOR – SELENE Type guide

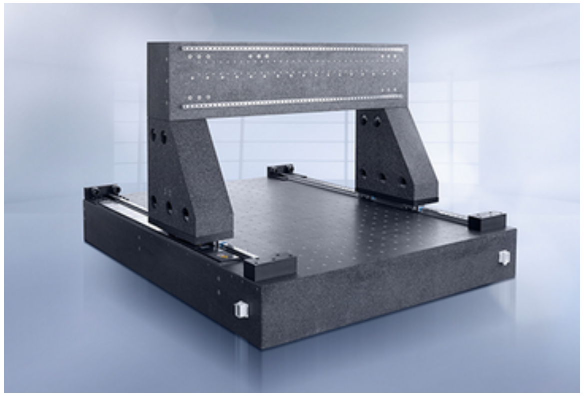


- inside vacuum housing 32 shielding blocks are positioned
- must be high precision and non-magnetic (polarized beam)
- shielding through neutron guide bunker must be very compact because of space limitation (performance), use of non-magnetic heavy concrete is foreseen



Vaccum Housing of Selene guide system

New high-precision Shielding Material – Mineral Cast



Epustone

Epument

Mineral cast is used as the base of high-precision machines

Epustone has the mechanical properties of granite – interesting for our ESTIA project

Epument has good shielding properties like concrete – high hydrogen content – SINQ Upgrade (AMOR)
Optimisation: add a thermal neutron absorber (B4C) in the composition.

First test series (14 compositions) in the BOA neutron field were done (activation, attenuation for diff. E)

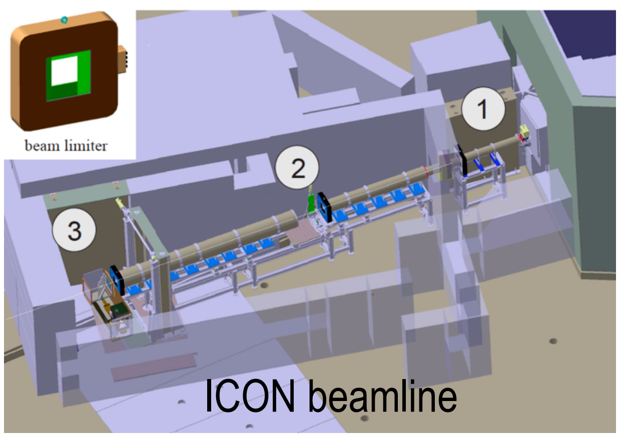
Partner: RAMPF Machine Systems GmbH & Co. KG

High dencity concrete

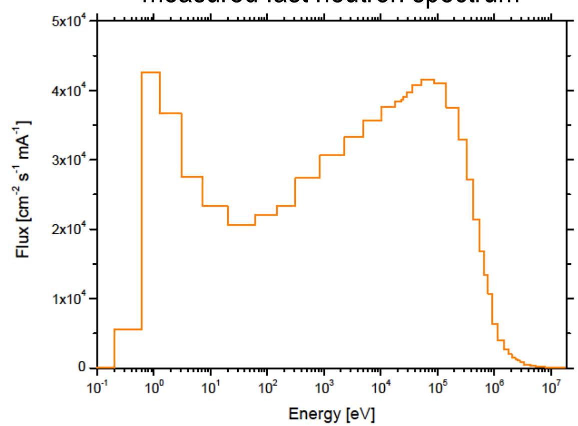
Requirement

- non-magnetic material -> polarized beamlines
- high content of boron
- high dencity material for compact shielding (> 5 g/cm3)

Characterisation on BOA and ICON Beamline at SINQ (both beamlines have fast neutrons)



measured fast neutron spectrum



Partner: SACAC AG Switzerland

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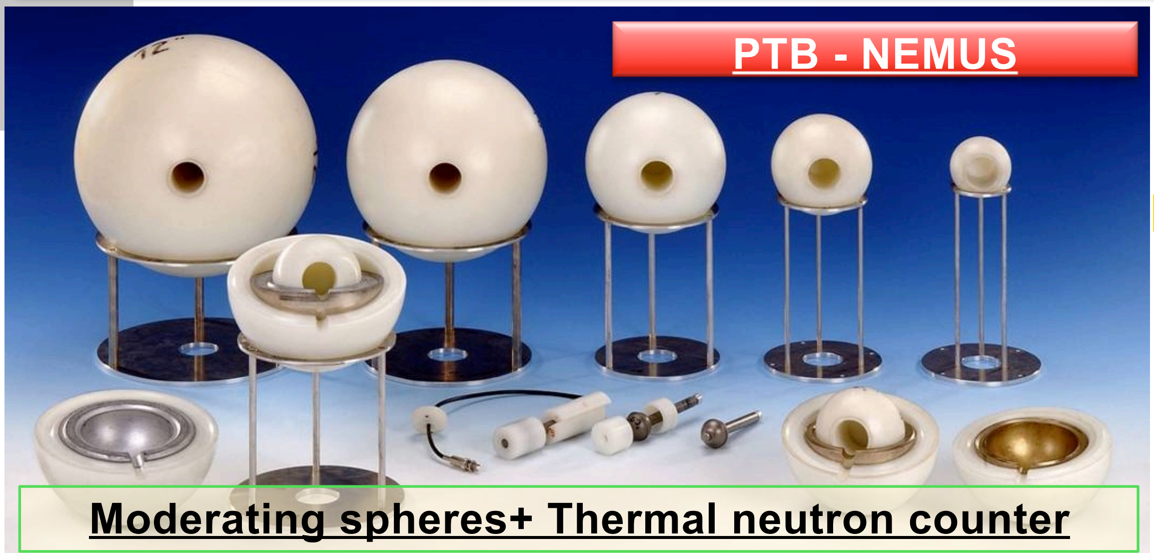
Mineral Cast Samples

- 20 different mineral cast samples were investigated.
- Epument 130 and Epument 145 are comparible to concrete
- Epustone 161 is specially made as a replacement for granite
- Epument is usually without Boron (test samples have 1 and 3 % B4C)
- EFA (ash) is a problem because C-60 is included

Sample Nr.	Mineral cast (base material)	Modification
1	EPUMENT 130	no (reference sample)
2	EPUMENT 130	1 % wt B_4C
3	EPUMENT 130	3 % wt B_4C
4	EPUMENT 130	without superplasticizer (flue-ash)
5	EPUMENT 130	without superplasticizer (flue-ash),1 % wt B_4C
6	EPUMENT 130	without superplasticizer (flue-ash), 3 % wt B_4C
7	EPUMENT 161L	no (reference sample)
8	EPUMENT 161L	1 % wt B_4C
9	EPUMENT 161L	3 % wt B_4C
10	EPUMENT 161L	1 % wt B_4C (Sand reduced by 1 %wt)
11	EPUMENT 161L	3 % wt B_4C (Sand reduced by 1 %wt)
12	EPUMENT 145	without basalt, without superplasticizer (flue-ash)
13	EPUMENT 145	without superplasticizer (flue-ash), 1 % wt B_4C, without basalt
14	EPUMENT 145	without superplasticizer (flue-ash), 3 % wt B_4C , without basalt

Bonner Sphere Spectrometer (BSS)

Neutron spectrum in a broad energy range with coarse energy resolution
: **12 order of magnitude (1 meV – 20 MeV)** → possible extension ~ **100GeV**



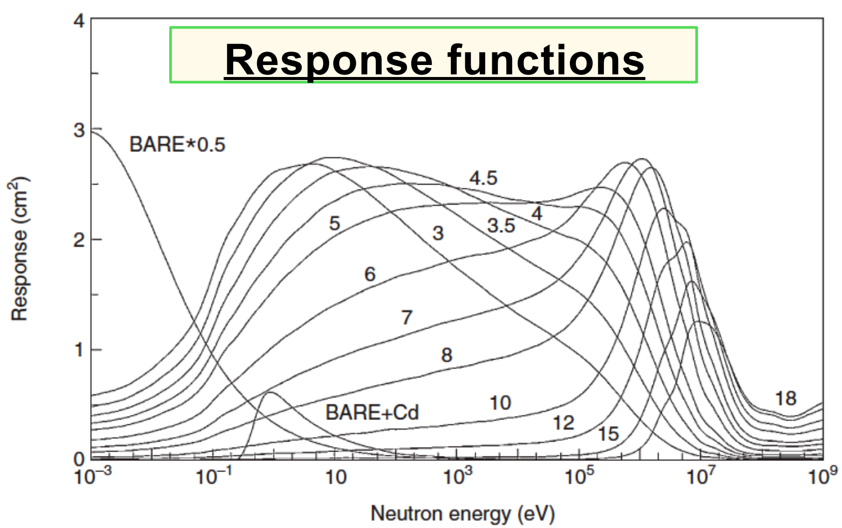
Measurement: count rate suite

$$N_i = \int R_i(E)\phi(E)dE \quad (i = 3, 3.5,,,, 12)$$

N_i [n/s] : Count rate

R_i [cm^2] : Response func.

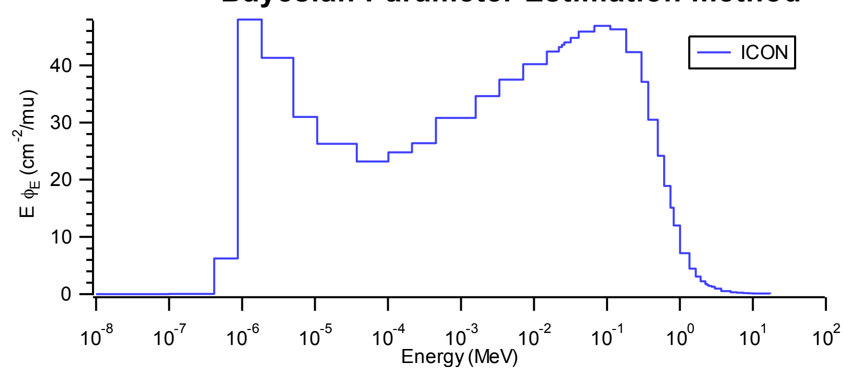
ϕ [n/s/cm^2] : Spectrum



B. Wiegel, A.V.Alevra, NIMA 476 (2002) p.36

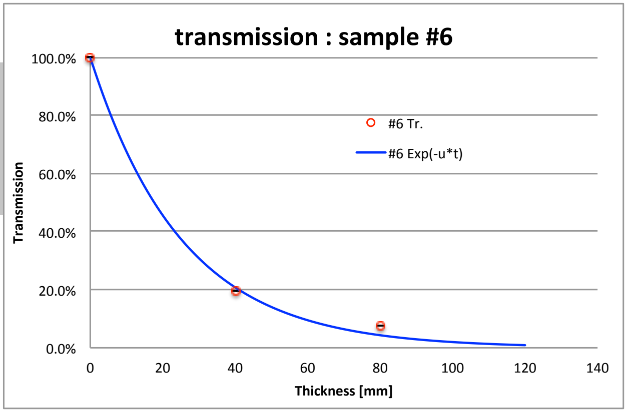
Unfolding a spectrum using a guess spectrum

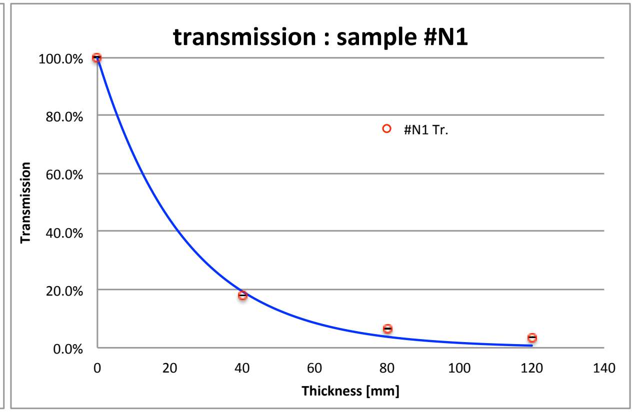
- **Maximum Entropy Method**
- **Bayesian Parameter Estimation method**

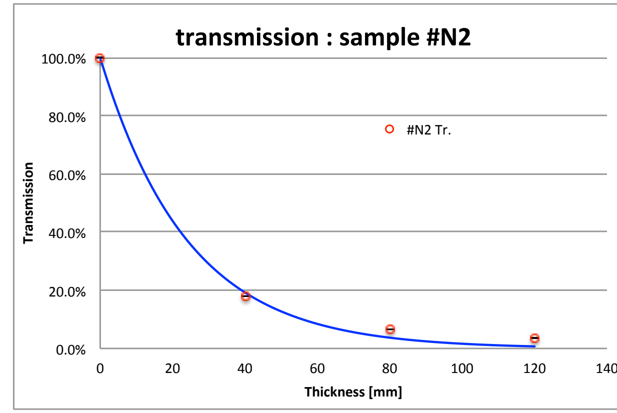


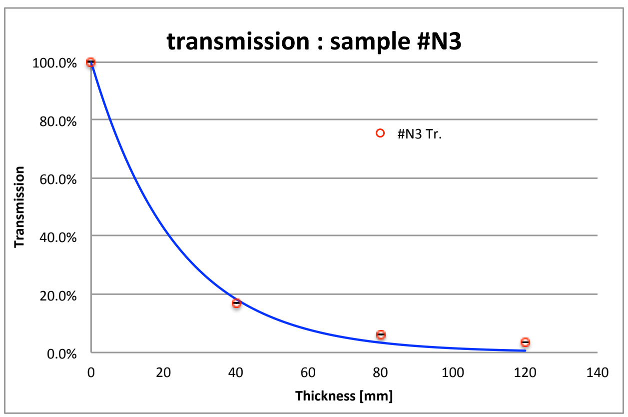
4. 3.5", transmission of 5 samples (Epi-thermal)

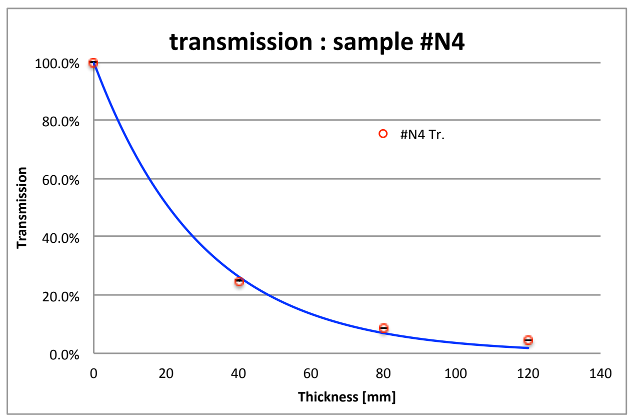
3.5" – has broad sensitivity in epithermal, the peak is at 10keV











sample	linear attenuation coefficiency [mm^{-1}]
no.6	0.0393
N1	0.0409
N2	0.0412
N3	0.0423
N4	0.0333

Best sample is N3

5. 12”, transmission of 5 samples (Fast neutrons)

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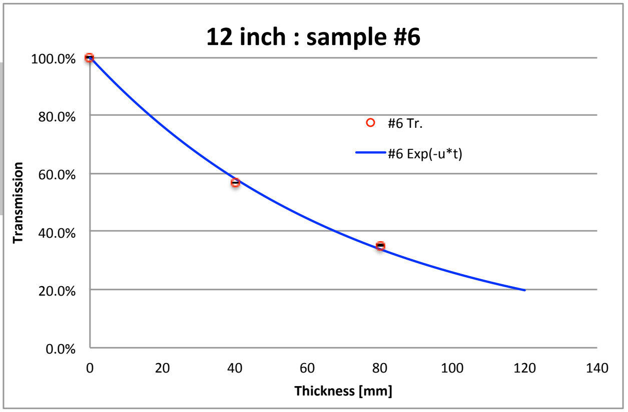
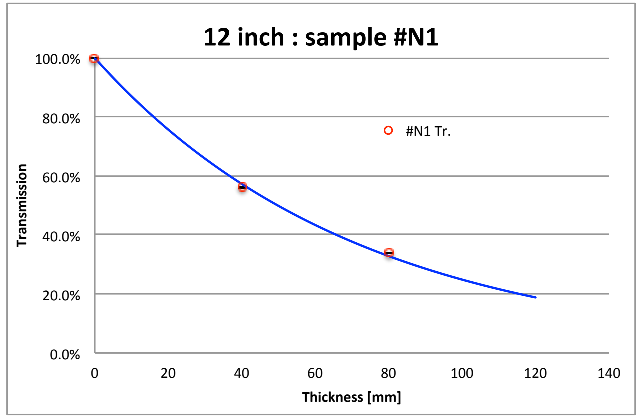
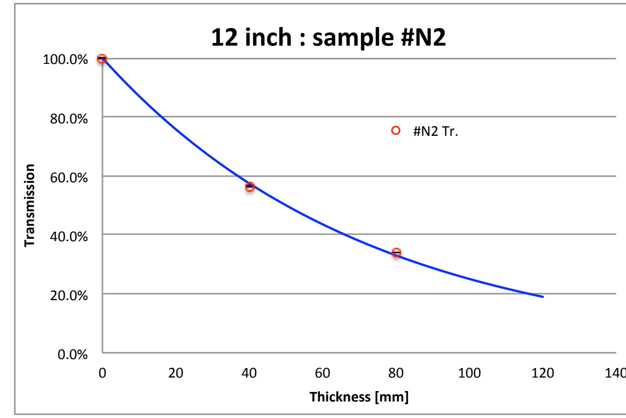
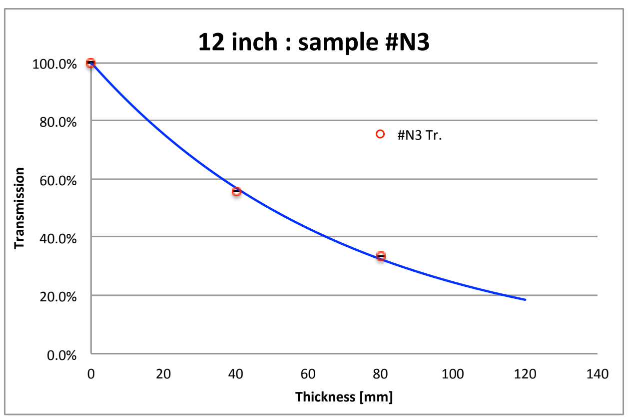
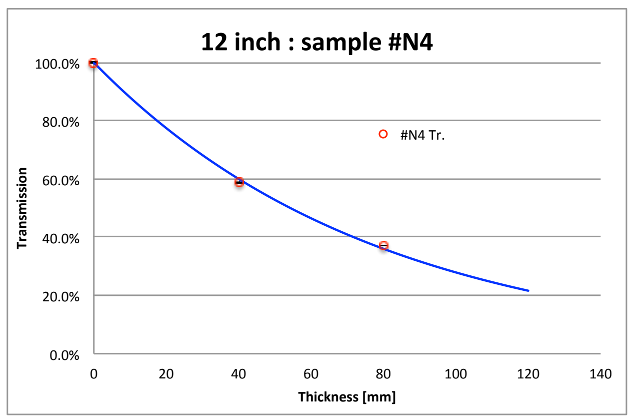
12” – sensitivity peak is at <u>4 MeV</u>







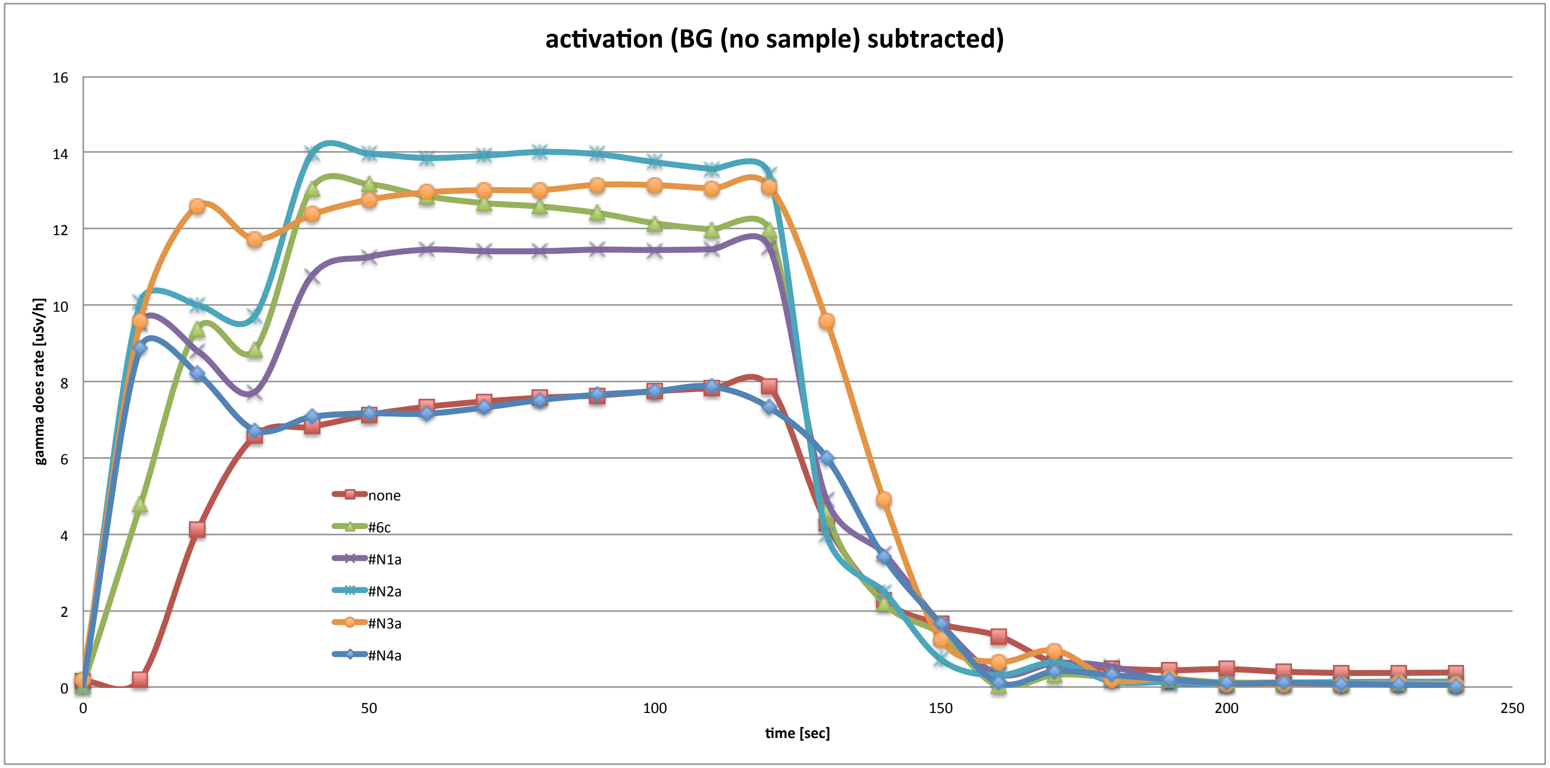




sample	linear attenuation coefficiency [mm^{-1}]
no.6	0.0135
N1	0.0139
N2	0.0138
N3	0.0141
N4	0.0128

Best sample is N3

6. Activation with thermal neutrons



Conclusion:

N1, N2, and N3 have the same activation level as #6. N4 has a lower activation level, but shielding performance is low.

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