Prospects and requirements for the neutron radiography method on DNS-IV neutron source

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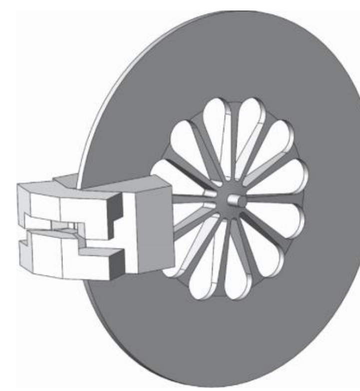
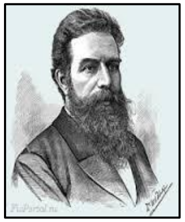
FLNP

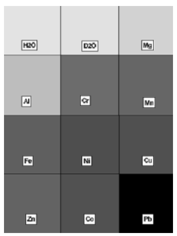


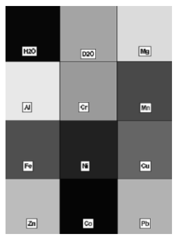
The neutron radiography and tomography advantages

A Nondestructive probe of large rare valuable objects

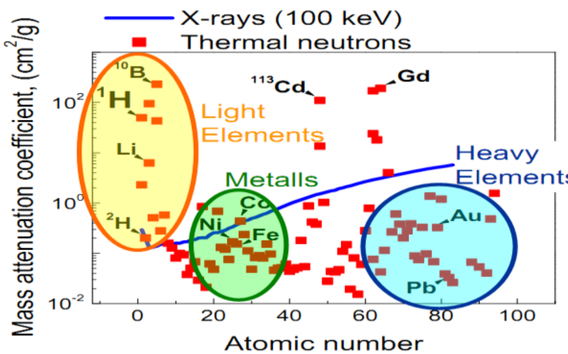


X-ray radiography (imaging)





X-ray neutrons

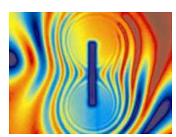


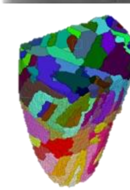
X-ray neutrons

E.Lehmann and et al, Journal of Instrumentation 6(01):C01050

- Nuclear interactions

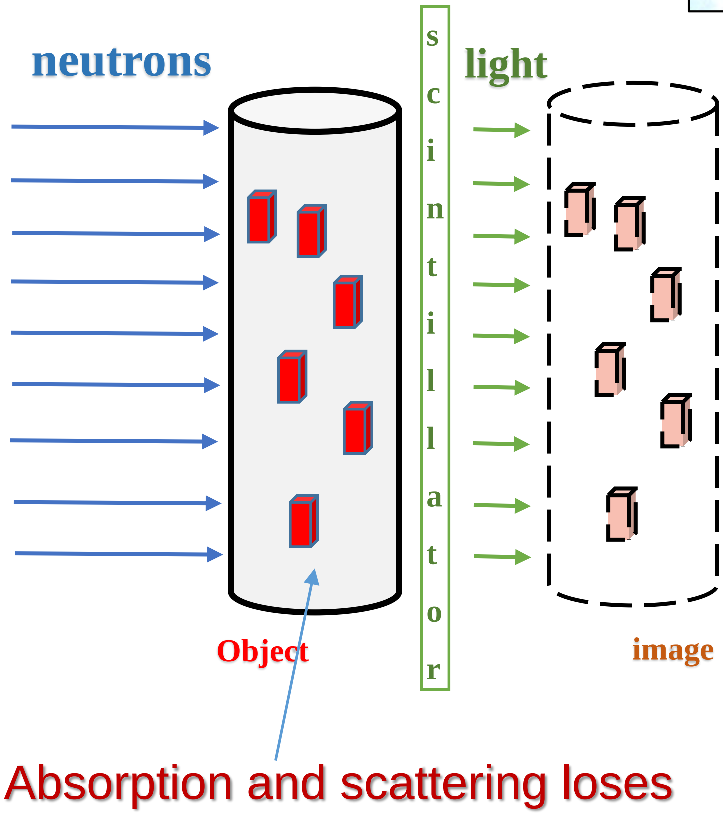
- Magnetic interactions

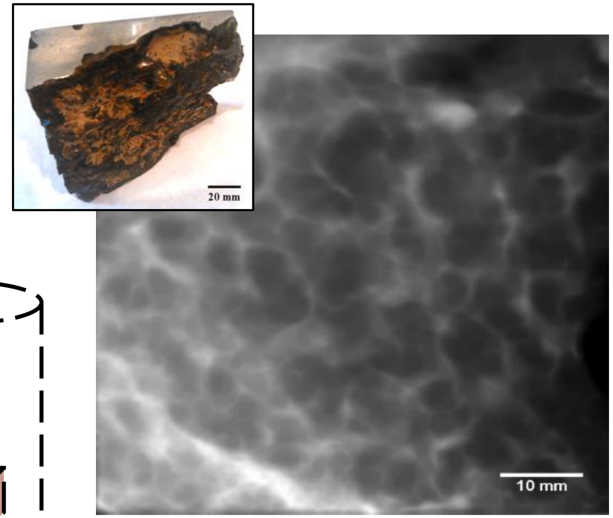




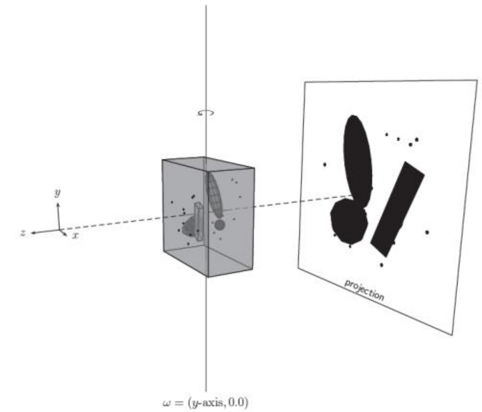
- High penetration

The neutron radiography and tomography methods

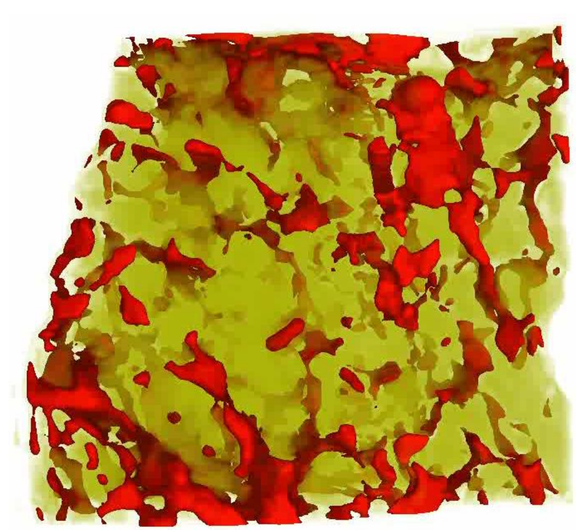




Neutron image



Neutron tomography

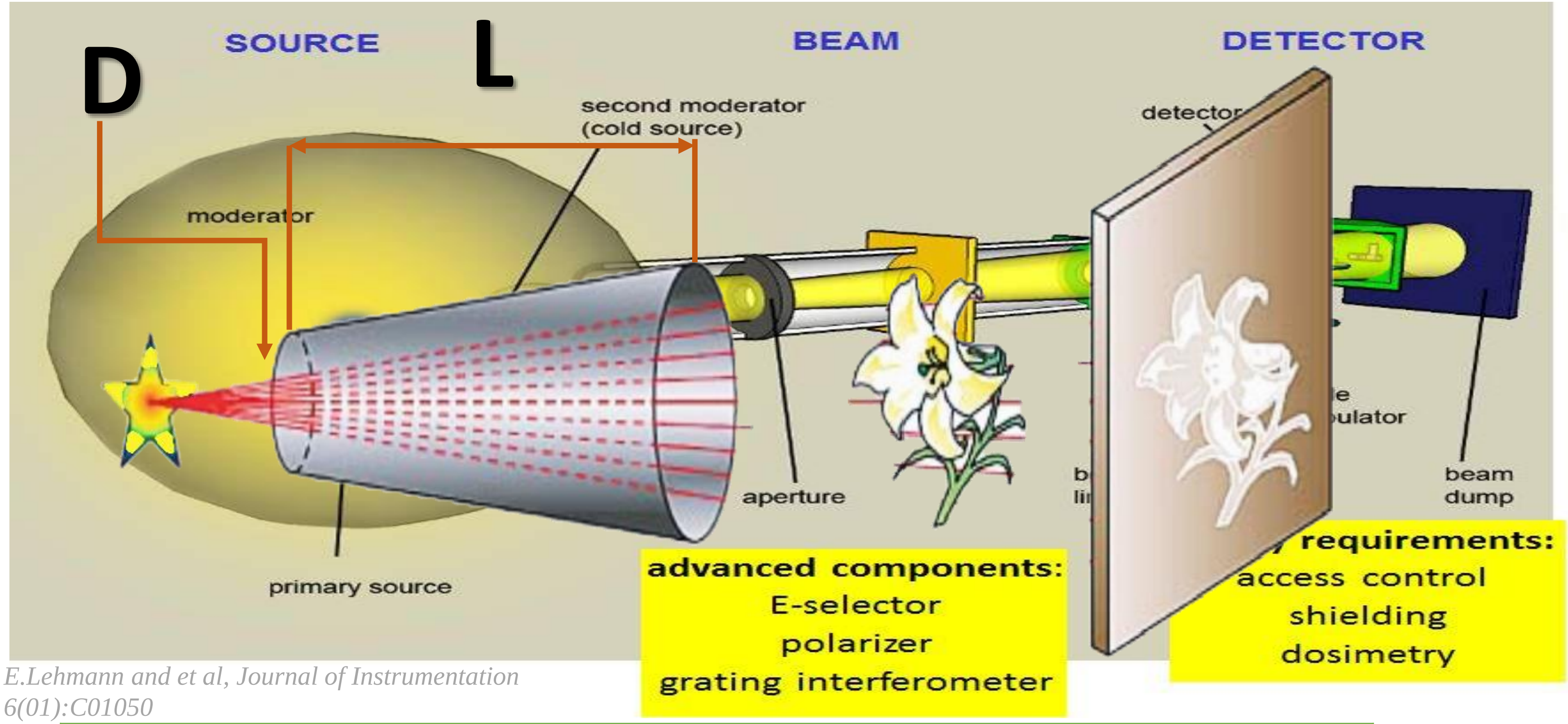


3D model from neutron tomography

Status of Neutron Imaging – Activities in a Worldwide

Country	Center	Station	Source
Australia	ANSTO	DINGO	OPAL reactor
Germany	TU Munich	ANTARES	FRM-2 reactor
Germany	TU Munich	NECTAR	FRM-2 reactor
Germany	HZB	CONRAD	BER-2 reactor
Hungary	KFKI	NORMA	WWS-M reactor
Hungary	KFKI	NRAD	WWS-M reactor
Japan	Kyoto Univ	NI	MTR reactor
Japan	JAEA	NI	JRR-3M reactor
Japan	JAEA	RADEN	J-SNS
Korea	KAERI	NI	HANARO
Russia	JINR	NRT	IBR-2 reactor
Switzerland	PSI	NEUTRA	SINQ
Switzerland	PSI	ICON	SINQ
UK	RAL	IMAT	ISIS
USA	NIST	BT-2	NBSR reactor
USA	NIST	NG-6	NBSR reactor
USA	ORNL	CG-1D	HFIR reactor
South Africa	NECSA	SANRAD	SAFA RI reactor

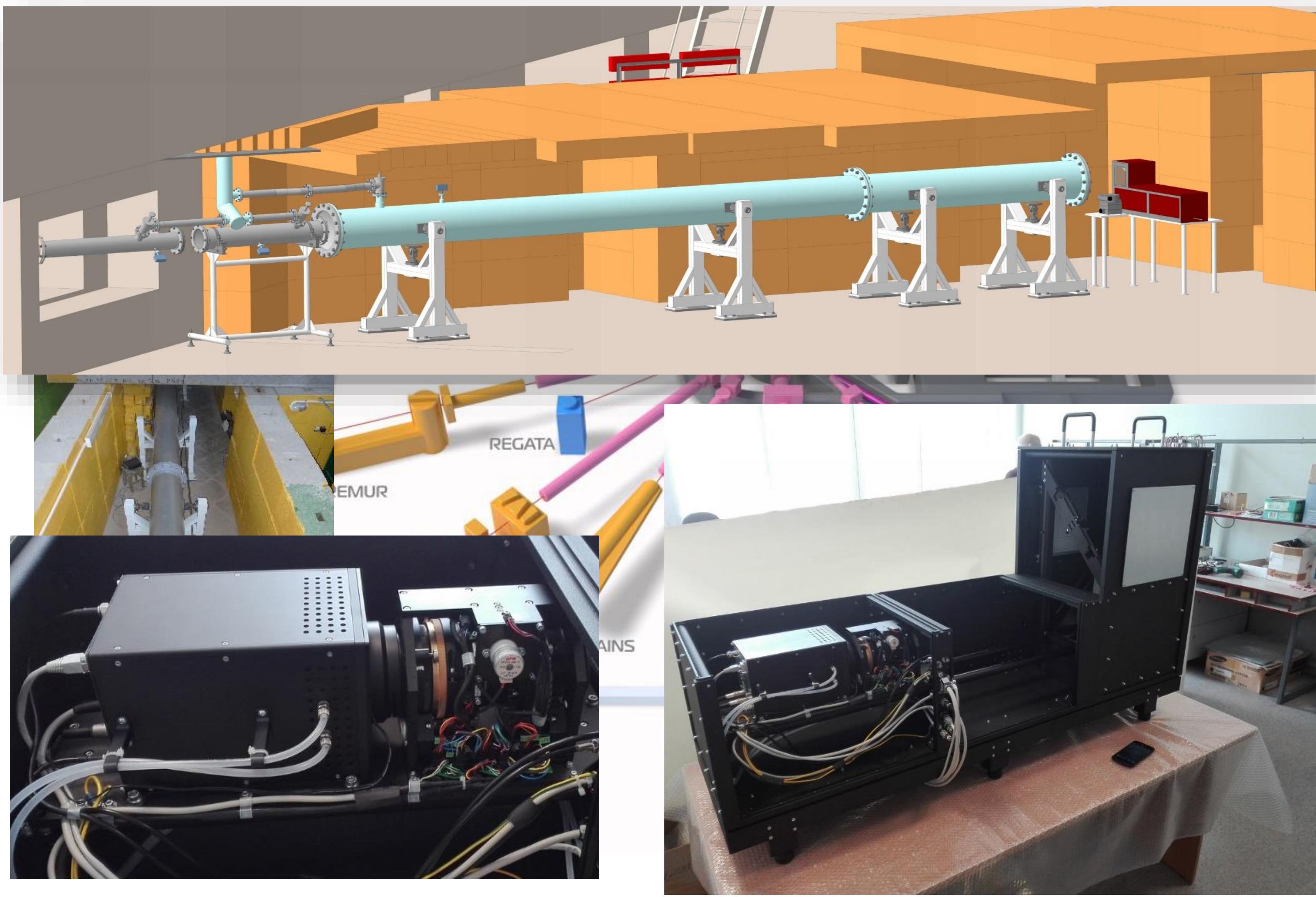
The traditional scheme of neutron imaging stations



E.Lehmann and et al, Journal of Instrumentation 6(01):C01050

Facility	Source	INTENSITY	L/D
CONRAD	BER-2 reactor	2.4×10^7 n/cm^{2}s	330
ICON	SINQ	1.3×10^7 n/cm^{2}s	343
ANTARES	FRM-2 reactor	4×10^8 n/cm^{2}s	200
IMAT	ISIS	3.8×10^7 n/cm^{2}s	245
NRT	IBR-2 reactor	5.5×10^6 n/cm^{2}s	198

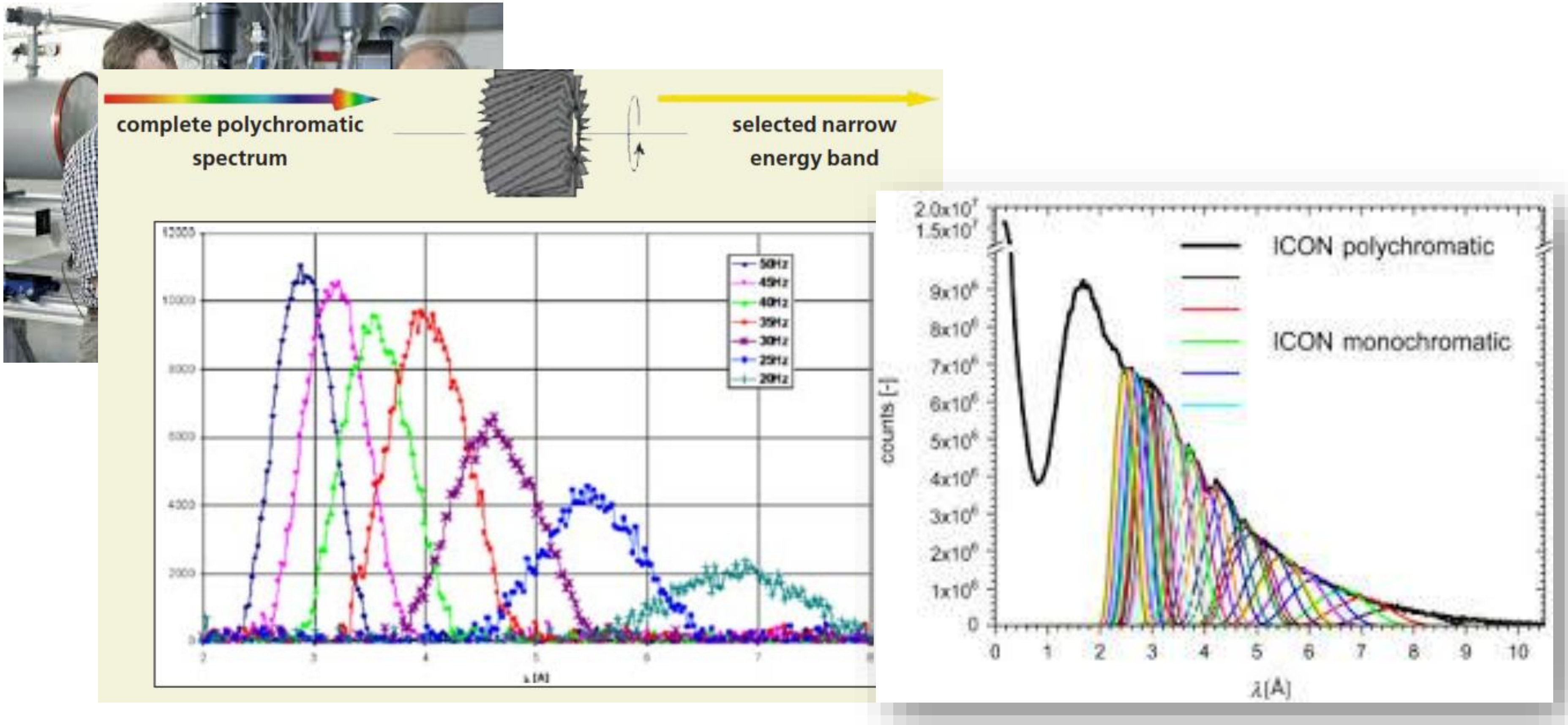
Neutron radiography and tomography station on IBR-2

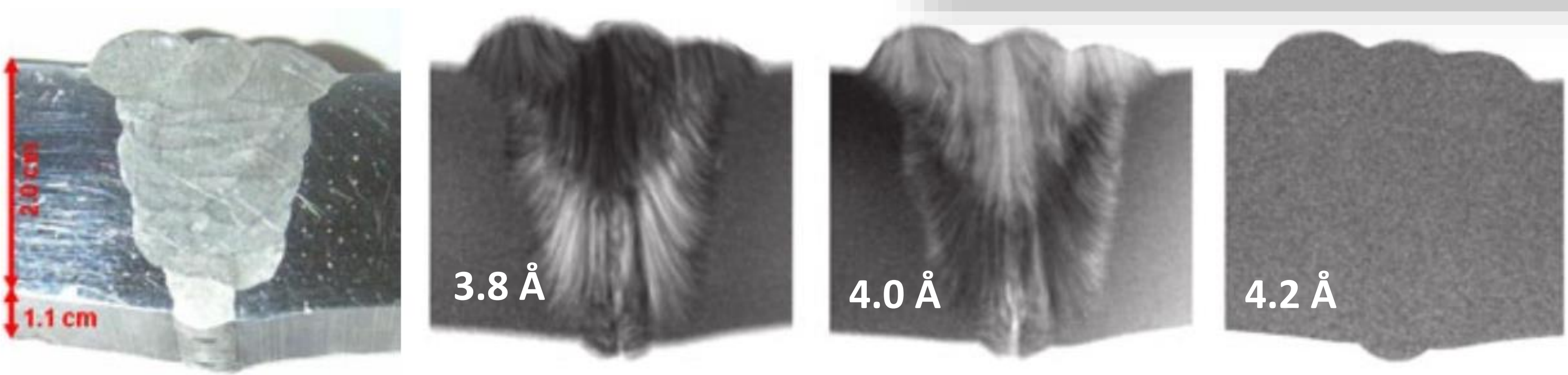


The classical scheme of neutron imaging stations: Requirements

1. Neutron radiography (10^4 - 10^5) ⇨ Flux-Cold
2. Neutron tomography (360 x 10^4 - 10^5) ⇨ Flux-Cold
3. Energy dispersive neutron radiography (10^6 - 10^7) ⇨ Flux-SP.Range
4. Neutron microscope (10^7 - 10^9) – high L/D ratio ⇨ Flux
5. Phase contrast (neutron interferometer) (10^7 - 10^9) ⇨ Flux
6. Polarized neutrons (10^6 - 10^7) ⇨ Flux
7. **Multimodal facilities (neutron and X-rays; imaging and diffraction; imaging and activation analysis)**

The energy dispersive neutron radiography





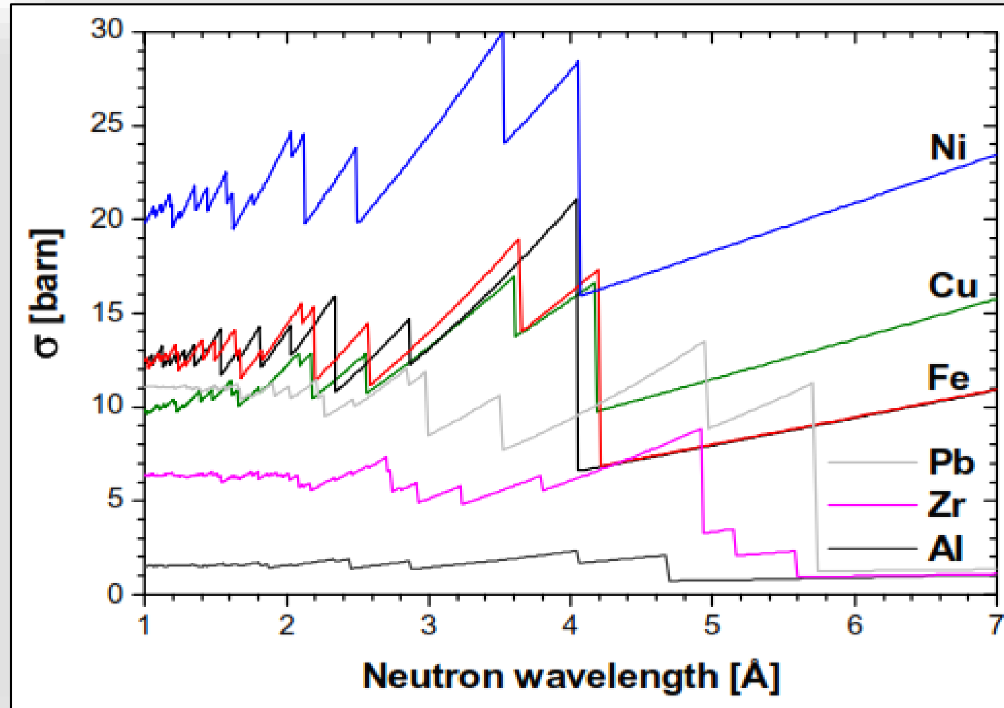
N.Kardjilov et al, International Journal of Materials Research, 103, 151-154

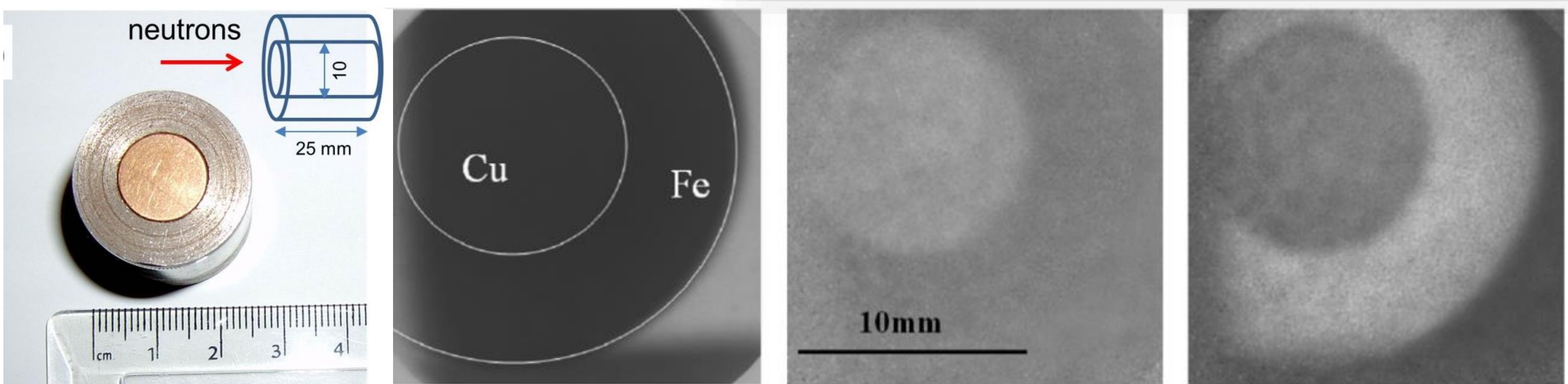
The energy dispersive neutron radiography

Pulse neutron source

time-of-flight
wavelengths separation

Bragg edge method





W.Kockelmann et al, Journal of Imaging, 4, 47

The energy dispersive neutron imaging stations: Requirements

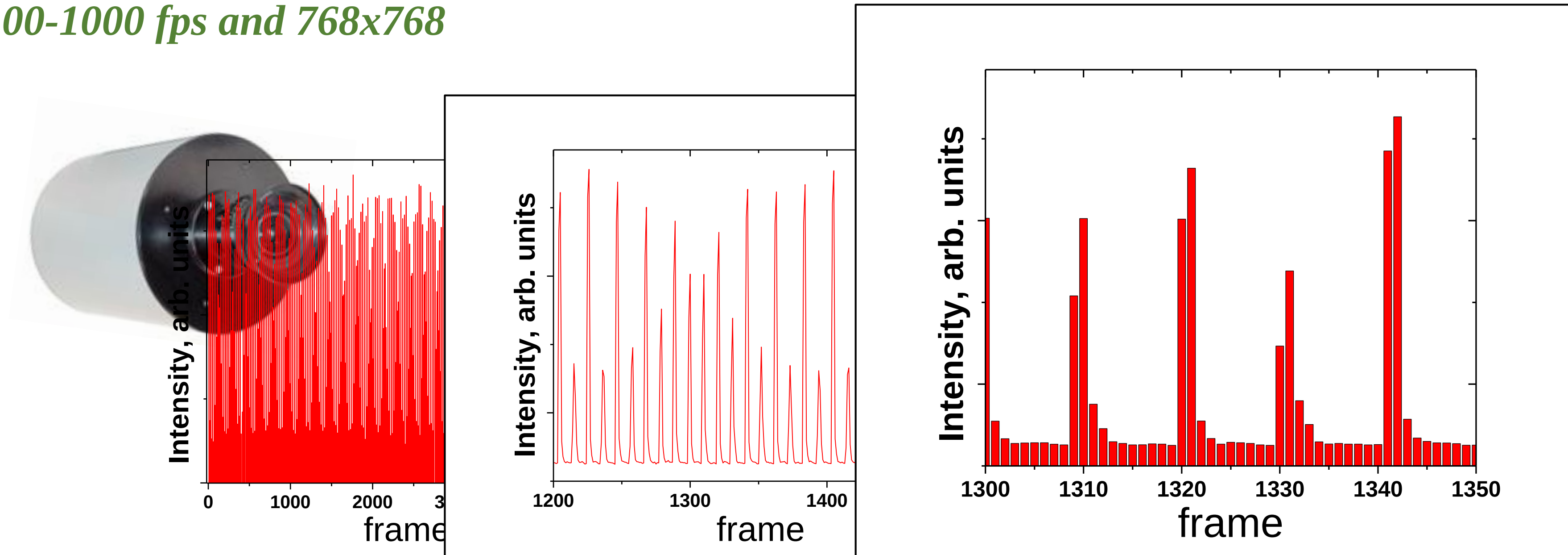
The spectral range Δλ

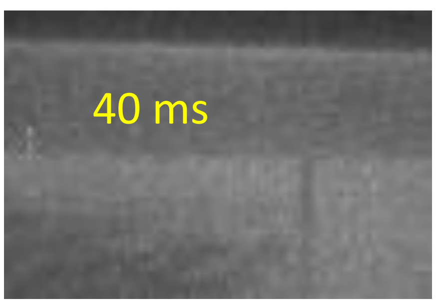
Facility	Source	ν, Hz	Source <Flux>	Facility Flux	L, м	Δλ, Å
NRT	IBR-2	5	$0.08 \cdot 10^{14}$	$5.5 \cdot 10^{6}$	10 (20)	7.8
RADEN	J-PARK	25	$0.1 \cdot 10^{14}$	5.8×10^{7}	10 (18)	6.9
IMAT	ISIS	10	$0.007 \cdot 10^{14}$	3.8×10^{7}	14 (56)	6
VENUS	SNS	60	$0.1 \cdot 10^{14}$	$\sim 10^{8}$	15 (20)	2.4
ODIN	ESS	14	$3 \cdot 10^{14}$	$\sim 10^{9}$	10 (64)	4.6 (14 Hz)

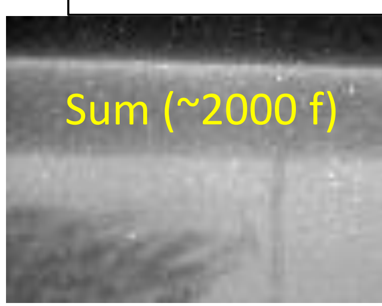
«Accordingly, a number of instrumentation projects at pulsed neutron sources are on the way, namely ***RADEN at JPARC*** *[Kiyanagi et al. (2011)], which has meanwhile entered commissioning,* ***IMAT at ISIS*** *[Kockelmann et al. (2015)] which is in the final stage of construction,* ***VENUS at SNS*** *which reportedly has received funding for construction, but also an imaging instrument project at the pulsed reactor source* ***IBR-2*** *[Lukin et al. (2015)].»*

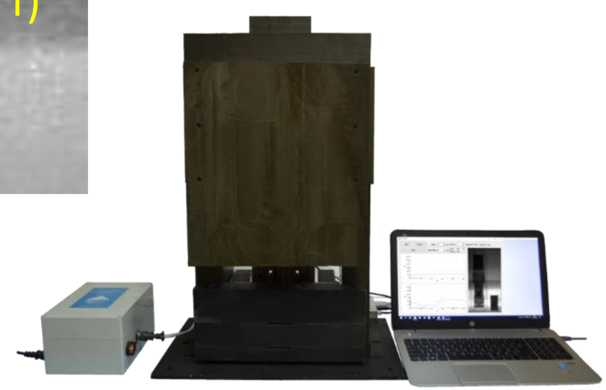
The energy dispersive neutron radiography on IBR-2 reactor

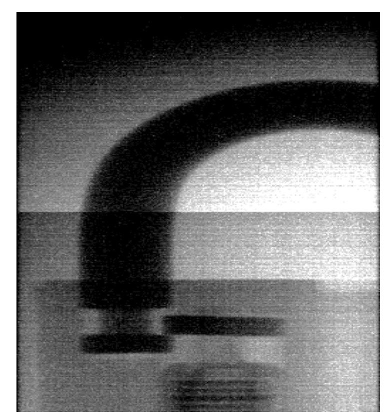
Fast camera Videoscan-415
100-1000 fps and 768x768





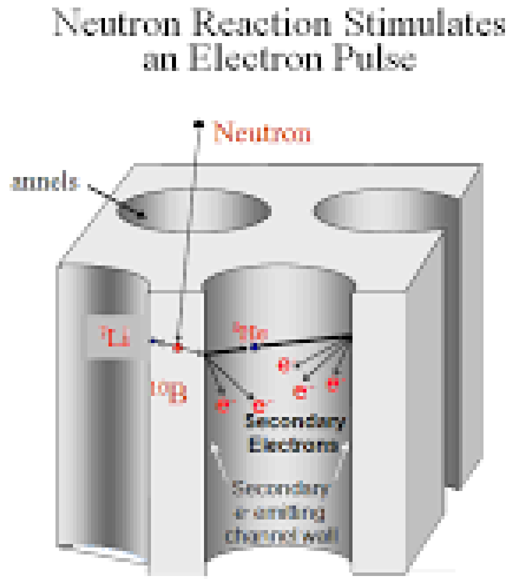


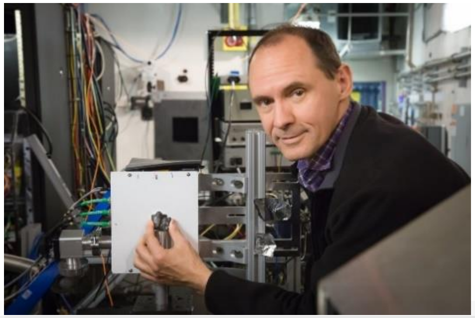


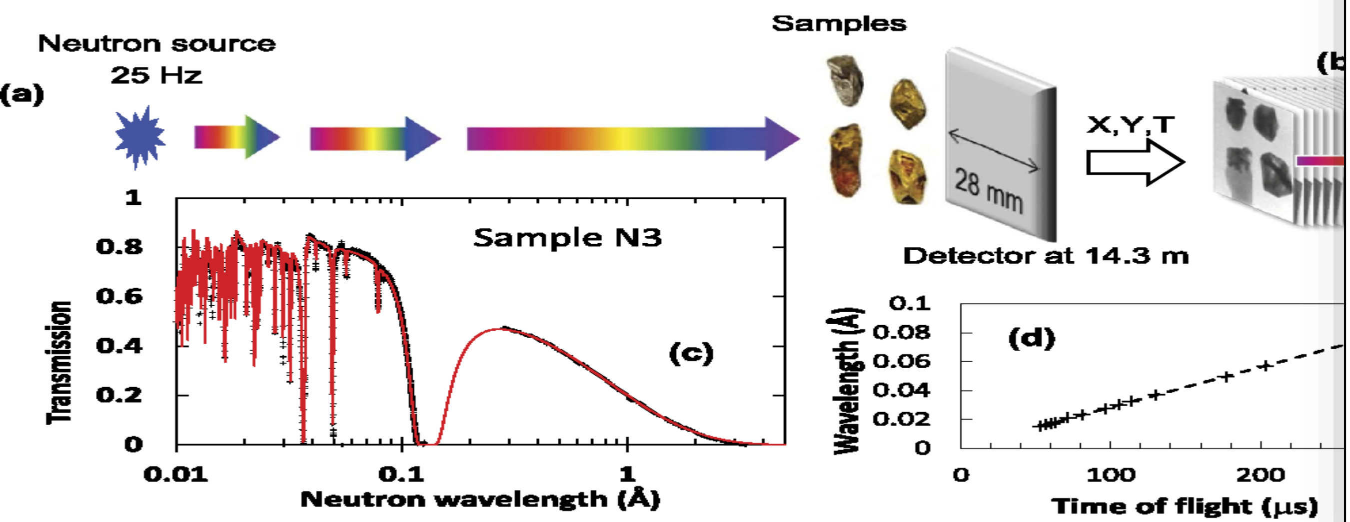


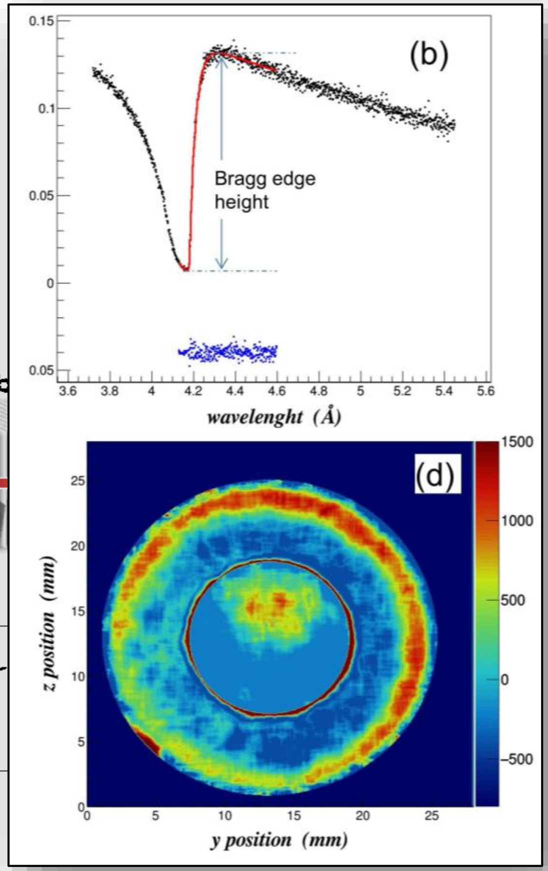
The energy dispersive neutron radiography: requirements

Tremsin et al, Strain 2016, 52, 548–558



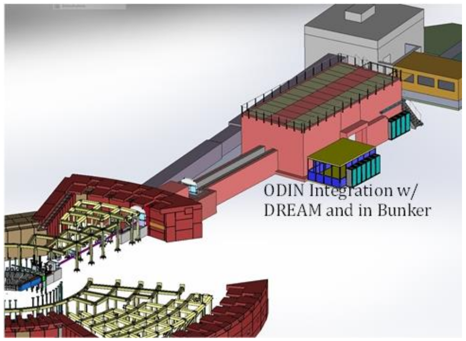


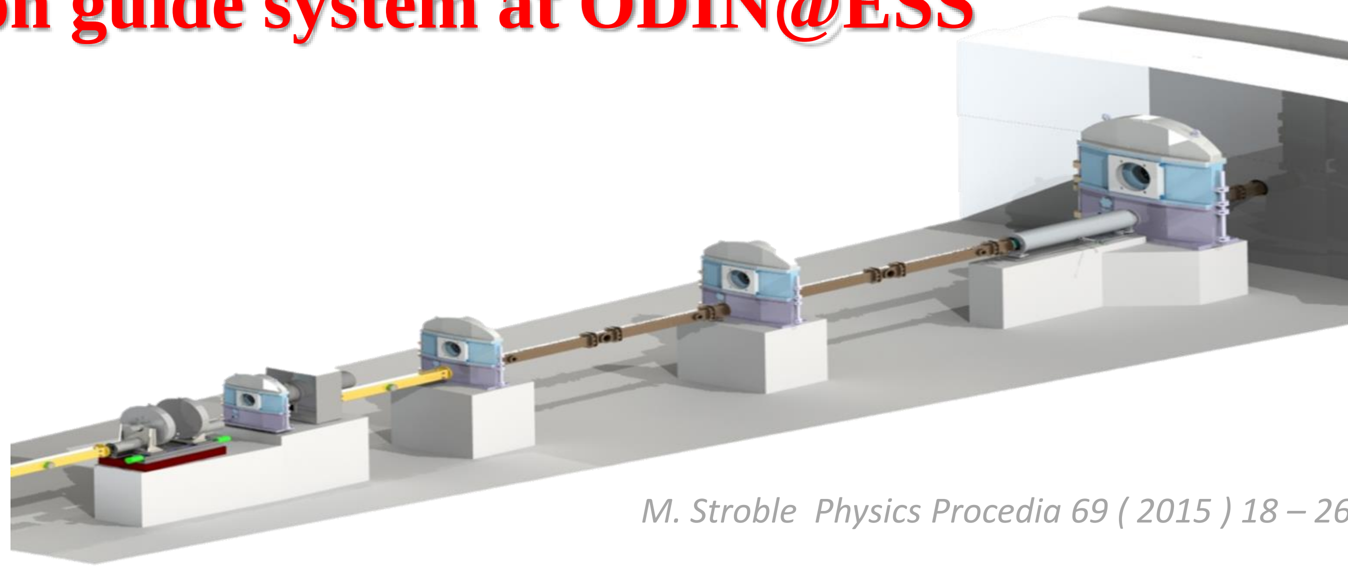




Tremsin et al, Scientific Reports, 7, 40759

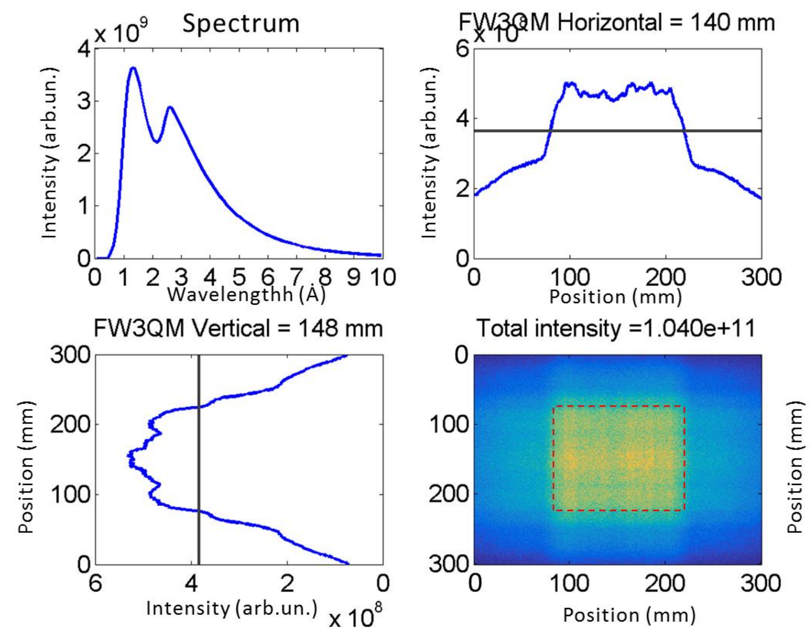
The energy dispersive neutron radiography: neutron guide system at ODIN@ESS





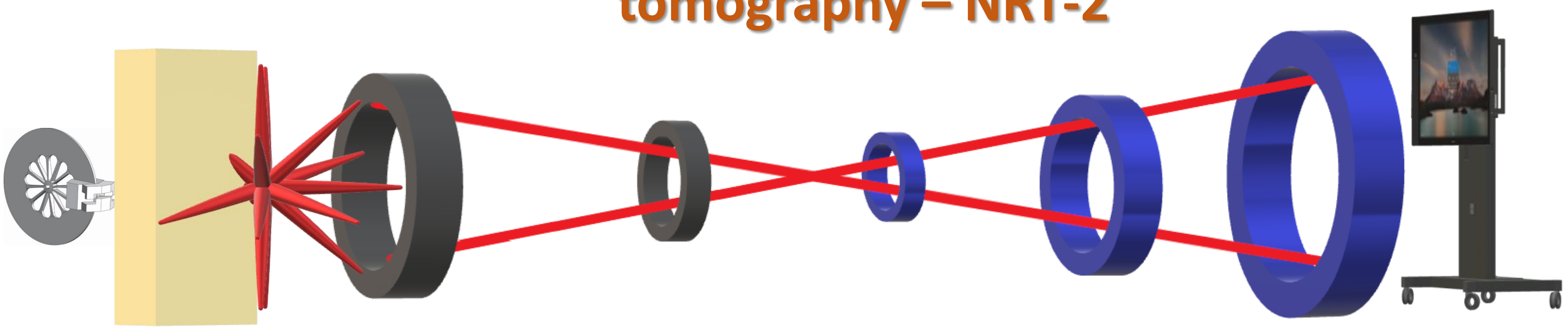
M. Stroble Physics Procedia 69 (2015) 18 – 26

Parameter	
L/D	400…2000
L	50(guide)+14 m
Flux	~10^9 n/cm^2/s
Spectral resolution ($\Delta\lambda/\lambda$)	0.5% - 10 %
Spatial resolution (L/D=2000)	10 µm
FOV	200x200 mm^2
Neutron bandwidth (14 Hz) (7 Hz)	~4.6 Å ~9 Å

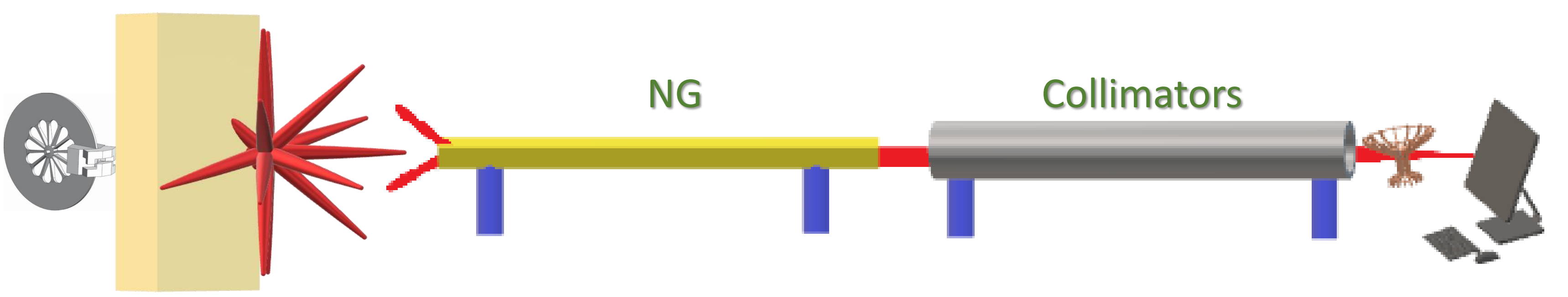


Prospects and requirements for the neutron radiography method on DNS-IV neutron source

1. Traditional or classical facility for neutron radiography and tomography – NRT-2

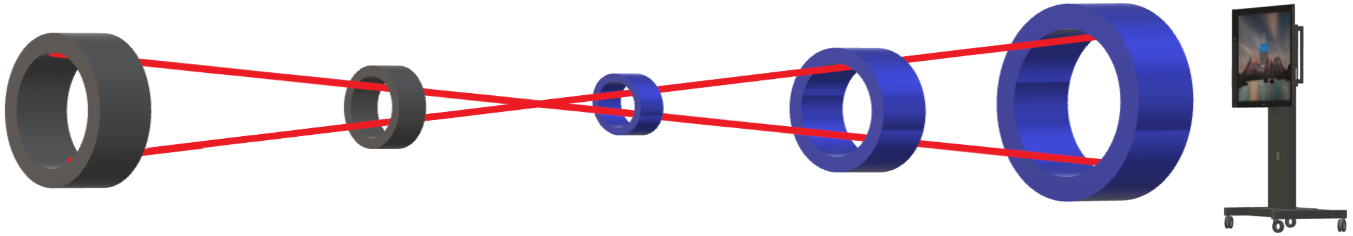


2. Energy dispersive neutron radiography station - EDNR



Prospects and requirements for the neutron radiography method on DNS-IV neutron source

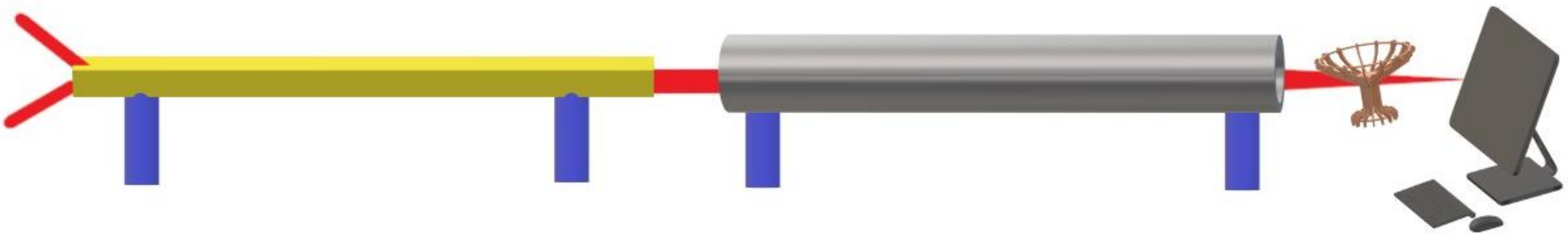
Requirements for neutron source



1. High flux at the sample position
2. High *L/D* parameter: long L and small *D*. We ask *L* to ~20 m
3. Low fast neutron background. We ask the tangential channel
4. Broad spectral range $\Delta\lambda$, repetition rate of source ν=10 Hz
5. Cold neutron spectra (moderator *T*=30 K)

Prospects and requirements for the neutron radiography method on DNS-IV neutron source

Requirements for neutron source



1. High flux at the sample position. Short exposition time

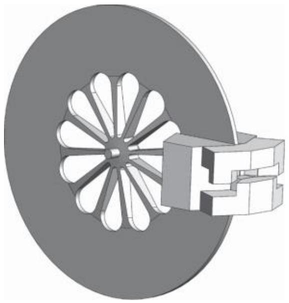
2. High *L/D* parameter: 15 m of NG and 30 m of Collimators

3. Neutron Guide. Uniform beam. M=2 and M=3. The radial channel.

4. Broad spectral range $\Delta\lambda$, repetition rate of source ν=10 Hz.

5. Cold neutron spectra (moderator *T*=30 K +60 K)

Prospects and requirements for the neutron radiography method on DNS-IV neutron source



Requirements for neutron source

1. Time-average flux density: (0.5 – **1.5**)·10^{14} → **Φ_0 = 1.5·10^{14} n/cm²/s**
2. Half-width of neutrons: (20 - **200**) μs → **Δt_0 = 200 μs**
3. Pulse repetition rate: (**10** - 30) Hz → **ν = 10 Hz**
4. Moderators: **cold (~90 K) + very cold (~30 K)**

Facility	Source	ν, Hz	<Flux>	Flux	L, м	Δλ, A
NRT	IBR-2	5	0.08·10^{14}	5.5·10^6	10 (20)	7.8 (exp)
RADEN	J-SNS	25	0.1·10^{14}	5.8x10^7	10 (18)	6.9
IMAT	ISIS	10	0.007·10^{14}	3.8x10^7	14 (56)	6
VENUS	SNS	60	0.1·10^{14}	1·10^8	15 (20)	2.4
ODIN	ESS	14	3·10^{14}	~10^9	10 (64)	4.6 A (14 Hz)
NRT-M EDNR	DNS-IV	10	1.5·10^{14}	~10^9	~40 ~45	~6-7

Thank you for your attention