The Neutron Time-of-Flight facility GELINA at IRMM

J. Heyse

EC – JRC – IRMM

Standards for Nuclear Safety, Security and Standards (SN3S)

jan.heyse@ec.europa.eu

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Overview

- IRMM
- GELINA
- Neutron cross section measurements at GELINA

Overview

European Commission

- **IRMM**
  - **EC – JRC**
  - **Nuclear Data**
- **GELINA**
- **Neutron cross section measurements at GELINA**

European Commission (EC)

European Commission

The European Commission

AGR … RELEX ENER ENV … COMM **JRC** TRADE …

A research based,
policy support Institution

Scientific support of the
decision-taking process in the EU

Joint Research Centre (JRC)

European Commission

7 Institutes in 5 Member States ≅ 2700 staff

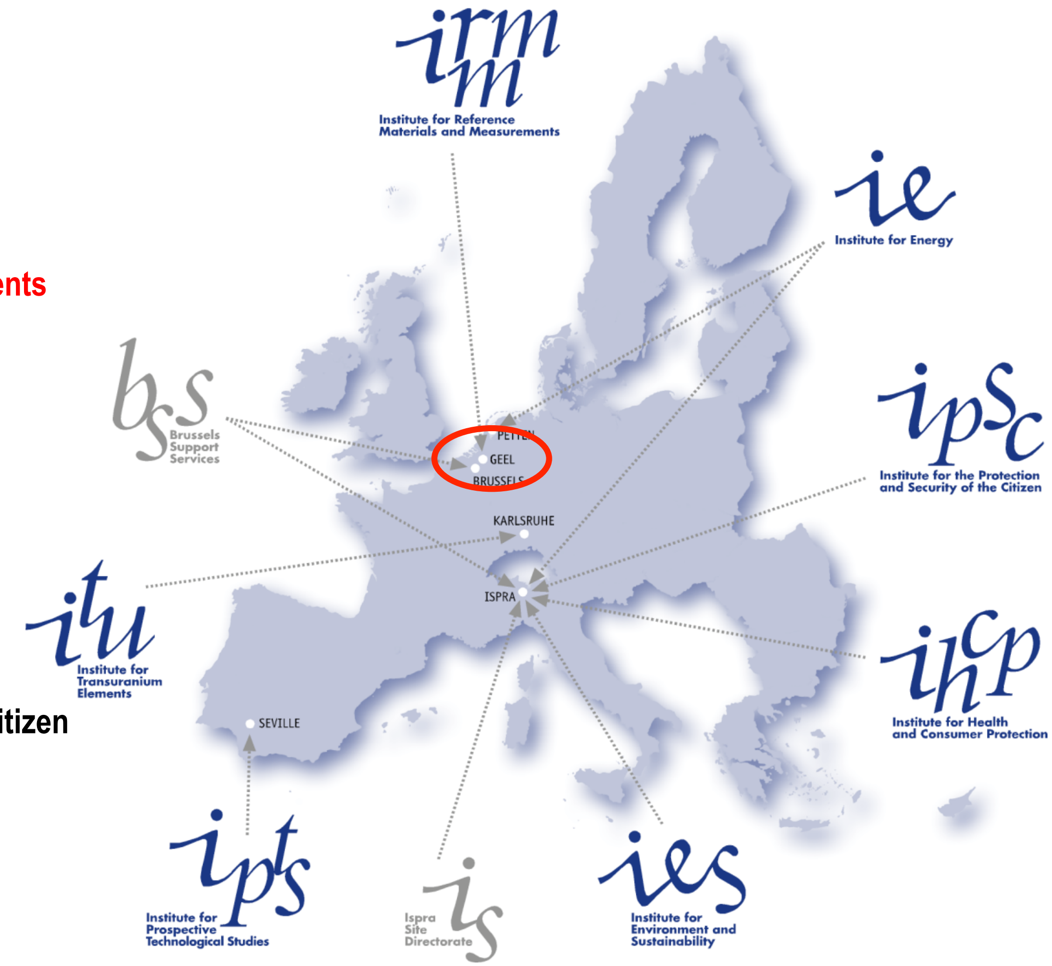
IE - Petten The Netherlands
-Institute for Energy

IRMM - Geel Belgium
- Institute for Reference Materials and Measurements

ITU - Karlsruhe Germany
- Institute for Transuranium Elements

IPSC - IHCP - IES - Ispra Italy
- Institute for the Protection and Security of the Citizen
- Institute for Health and Consumer Protection
- Institute for Environment and Sustainability

IPTS - Seville Spain
- Institute for Prospective Technological Studies



Institute for Reference Materials and Measurements (IRMM)

European Commission

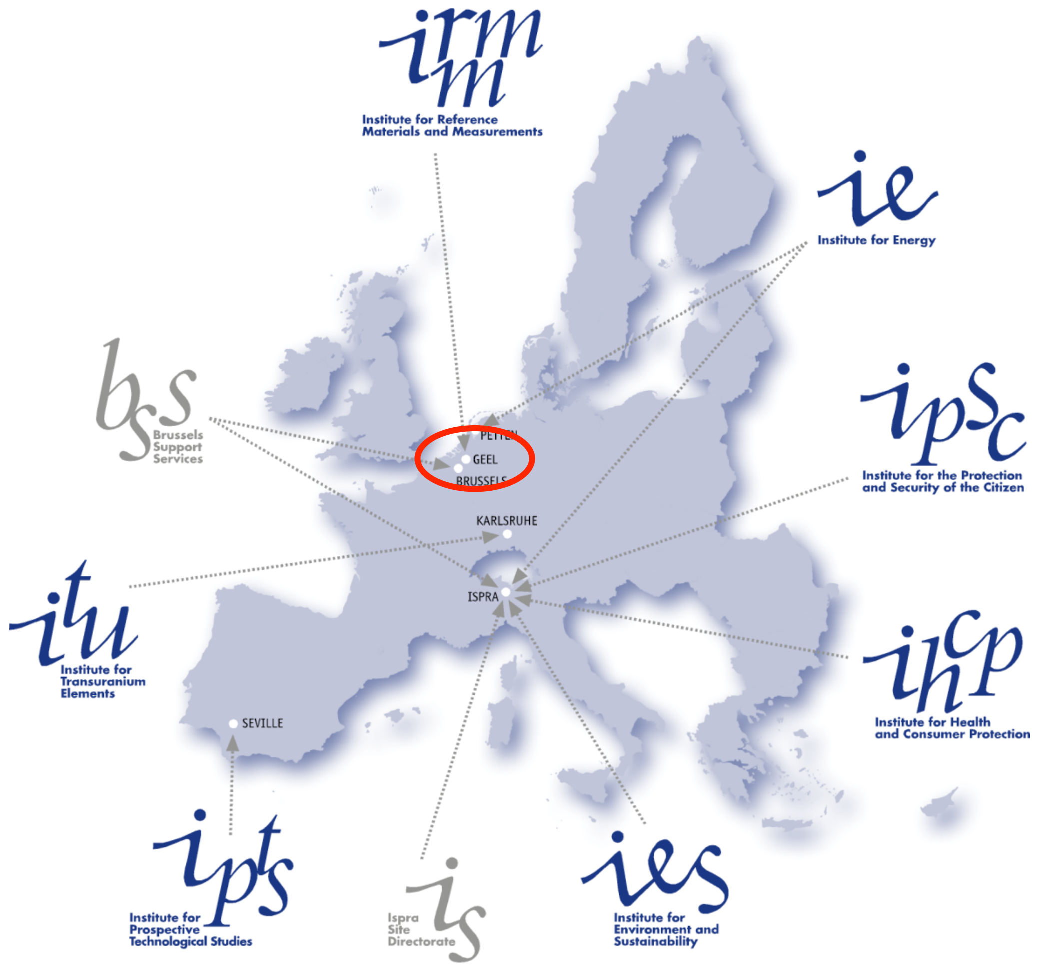
Mission:

to promote a **common and reliable European measurement system** and to provide science-based advice for EU policies

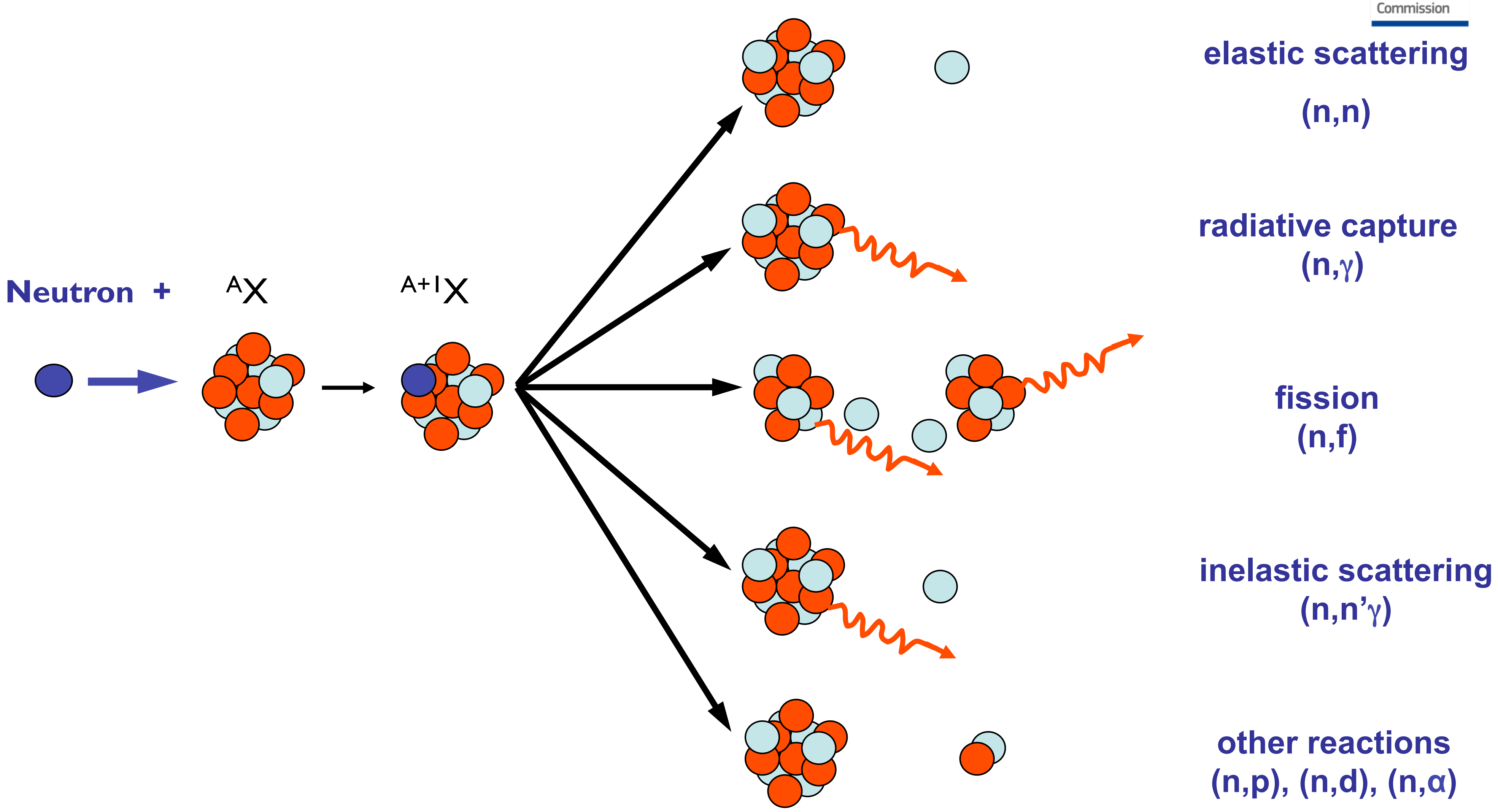
Four research units:

- Standards for Innovation and Sustainable Development
- Knowledge Transfer and Standards for Security
- Food Bioscience Standards
- Standards for Nuclear Safety, Security and Safeguards (SN3S)

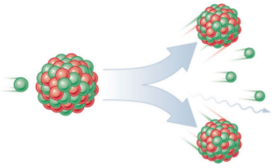
→ **Nuclear Data**



Neutron induced reactions



Reactor calculations



MEASUREMENT

- Boltzmann equation: neutron balance

$$\frac{1}{v}\frac{\partial f}{\partial t} + \Omega \cdot \nabla f + f \sum_i N_i \sigma_{T,i} = S + \int f(E',\Omega') \Sigma_s (E' \to E, \Omega' \to \Omega) dE' d\Omega'$$

$$S = \sum_i N_i \int f(E') \overline{\nu}_i (E') \sigma_{F,i} (E') \chi_{P,i} (E', E) dE' + S'$$

- Bateman equation: nuclide inventories

$$\frac{dN_i}{dt} = -\lambda_i N_i - N_i \int \sigma_{a,i} f dE d\Omega + \sum_{j \neq i} \lambda_i p_{j \to i} + \int \sigma_{a,i \to j} f dE d\Omega$$

Fission neutron spectrum

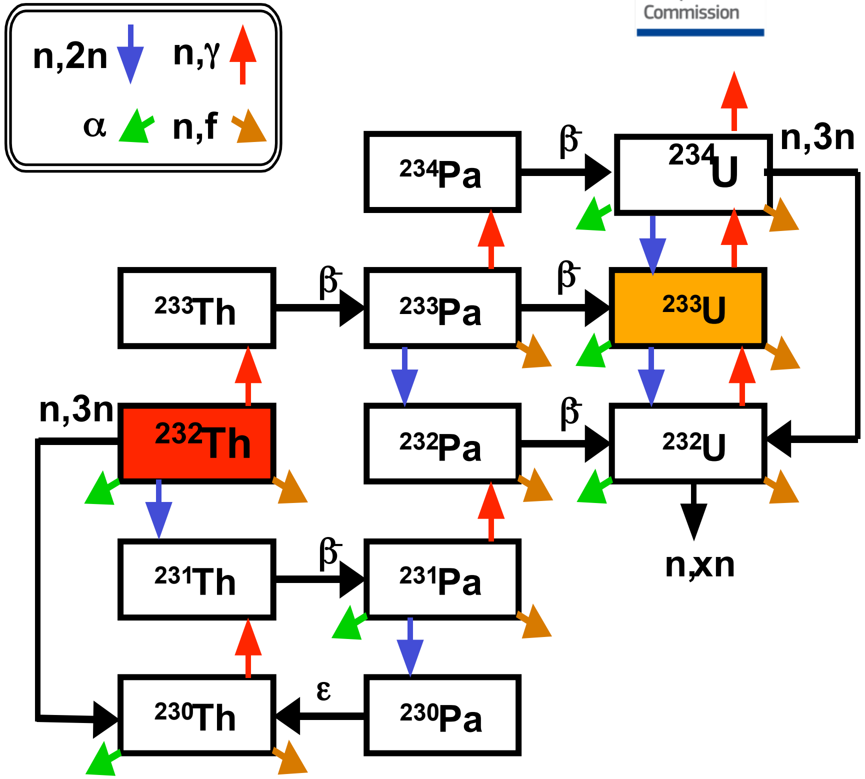
Neutrons / fission

Neutron cross sections

Nuclear data for reactor technology

European Commission

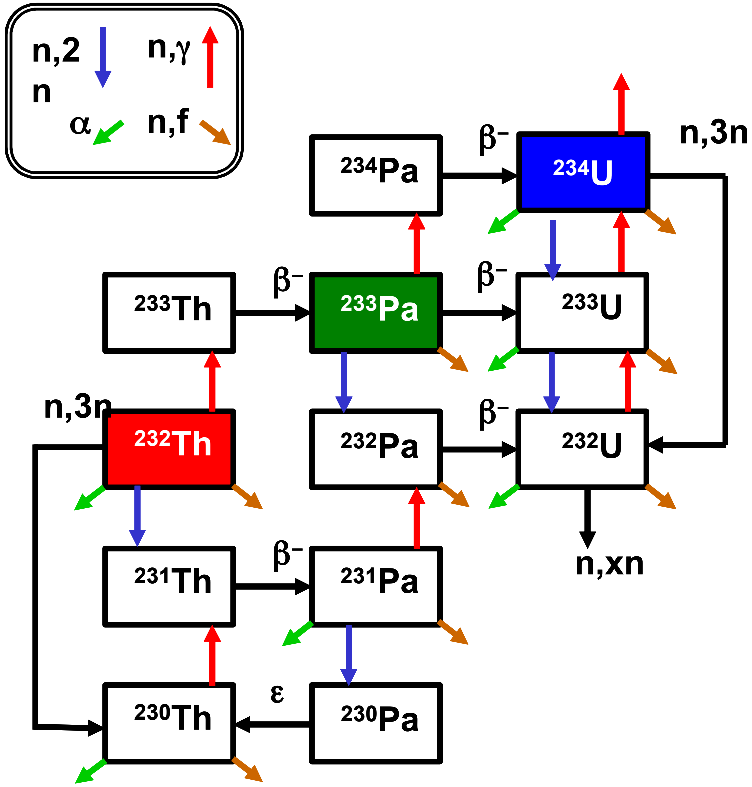
e.g. Th-U cycle



- **Nuclear Fuel**
  U, Pu, Th, … (n,f), (n,γ), ν
- **Fission Products**
  ^{103}Rh, ^{135}Xe, ^{135}Cs, ^{149}Sm,… (n,γ)
- **Neutron absorbers**
  Cd, Hf, (n,γ)
- **Structural Materials**
  Fe, Cr, Ni, Zr, … (n,n), (n,n' γ)

\+ **Standard cross sections**

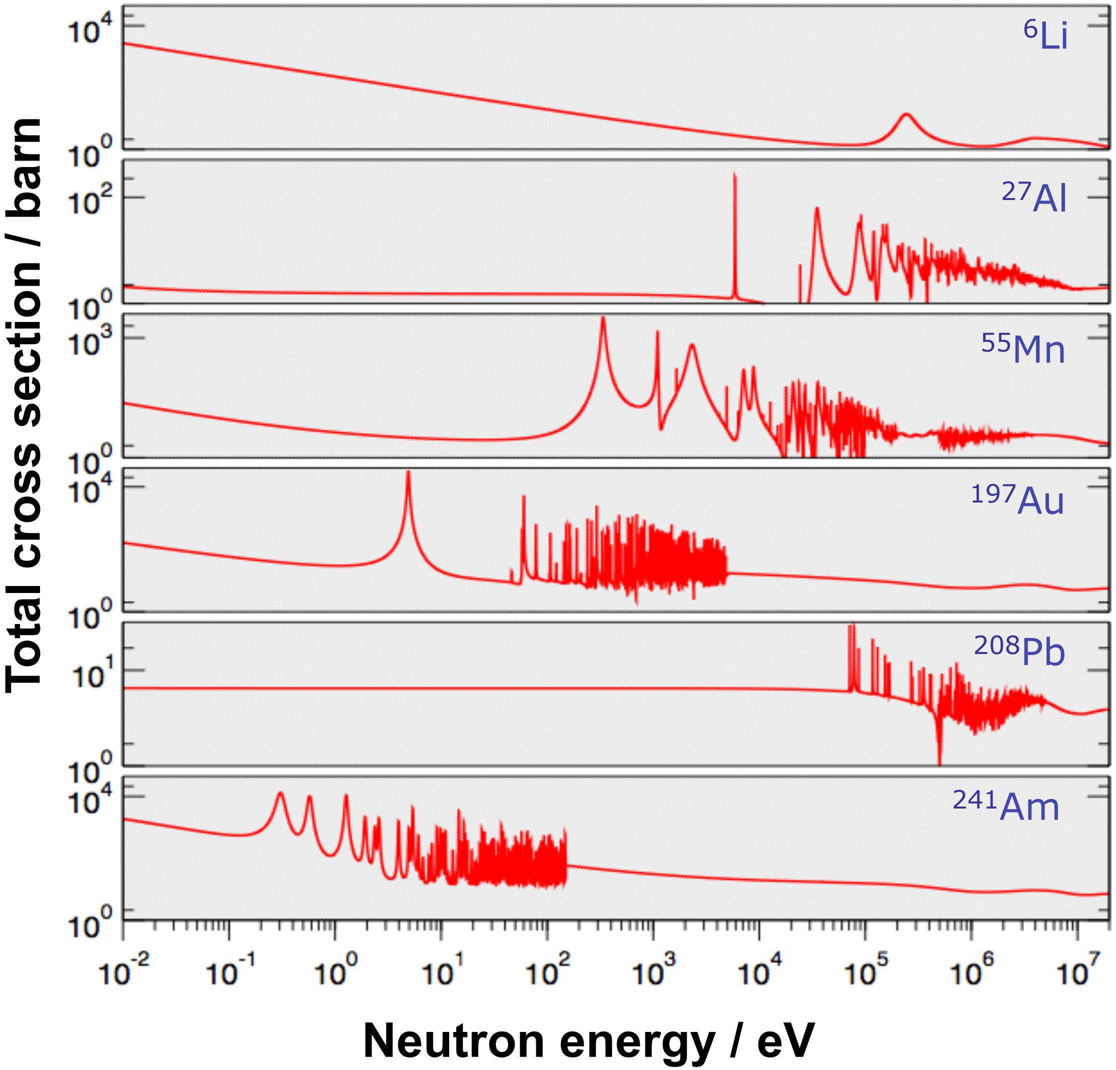
Thorium – Uranium fuel cycle



Nuclide	Reaction	Accuracy (%)
^{232}Th	total	3
	(n,γ)	1-2
^{233}Pa	(n,f)	20
^{234}U	(n,f)	3
^{236}U	(n,f)	5

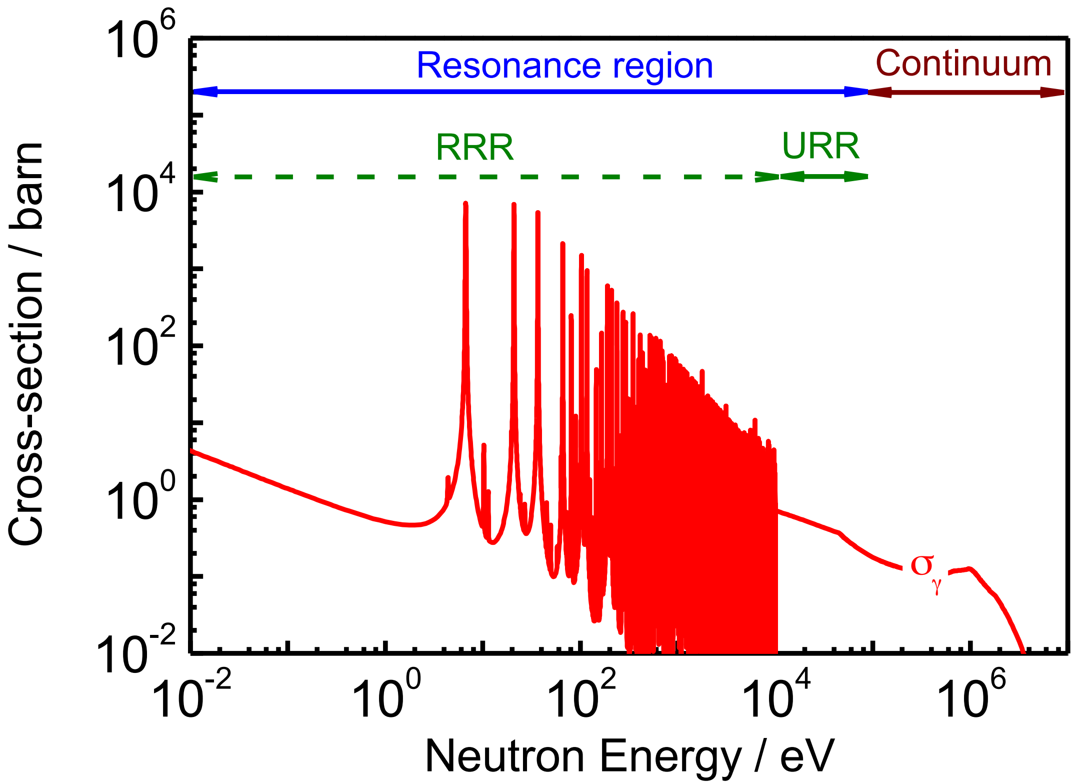
- 2 % uncertainty on σ_γ for ^{232}Th(n,γ) ⇒ 1% uncertainty on ^{233}U production rate
- 10 % uncertainty on σ_γ for ^{232}Th(n,γ) ⇒ 30% uncertainty on proton current to operate ADS with a $k_{eff} \approx 0.97$

Cross section



Resonances appear at energies, which are specific for each nuclide

Neutron Induced Reactions



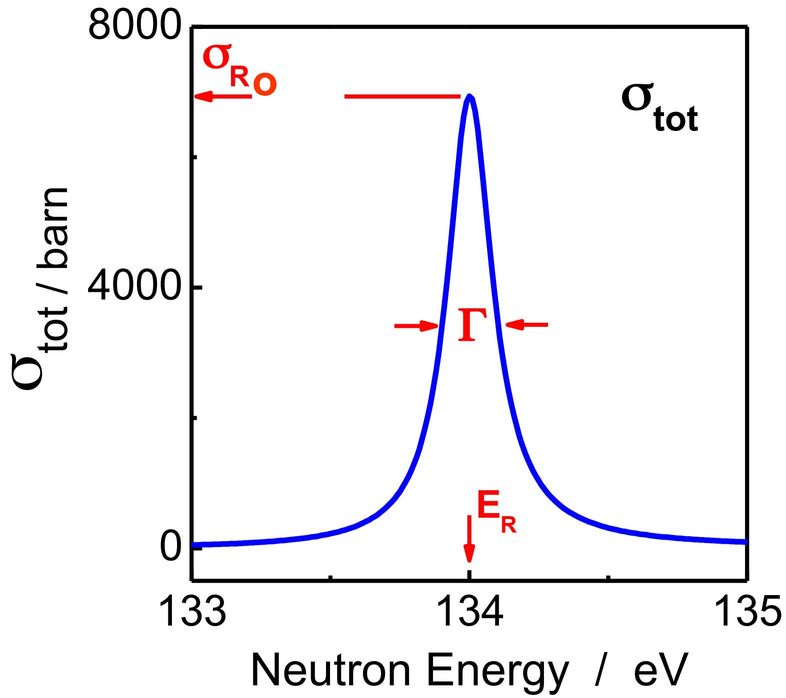
- **Resonance Region : D > Γ**
  - **Resolved Resonance Region**
    Δ_R < D
  - **Unresolved Resonance Region**
    Δ_R > D
- **Continuum : D < Γ**
  (fast, high energy)

Γ : level width

D : level distance

Δ_R : **resolution**

Resonance structure



- **Cross sections as a function of E_n reveals a resonant structure**
- **Breit-Wigner shape :**

$$\sigma_{tot} \sim \frac{1}{(E_n - E_R)^2 + (\Gamma/2)^2}$$

E_R	**resonance energy**
Γ	**total width**
Γ_n, Γ_γ	**partial widths**

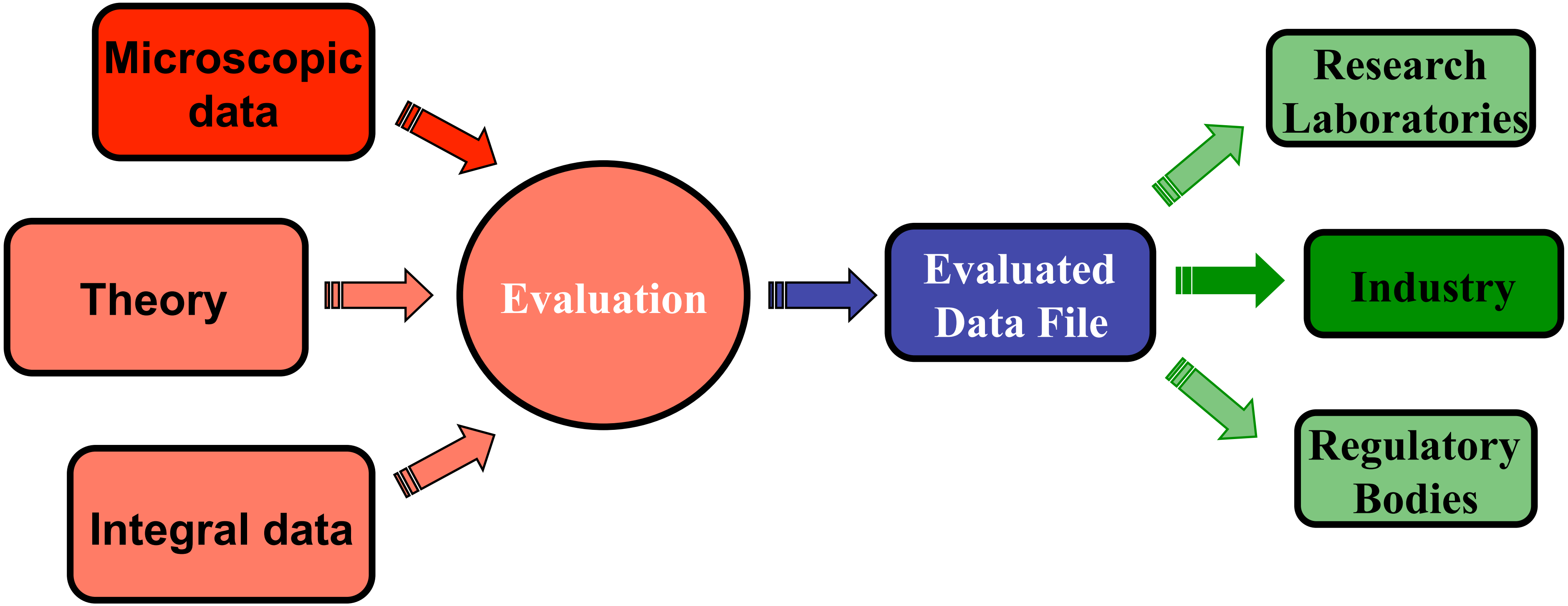
$\Gamma = \Gamma_n + \Gamma_\gamma + \ldots$

$(E_r, J^\pi, \Gamma_n, \Gamma_\gamma, \ldots)_j$ can not be predicted by theory

Determination of RP requires a combination of complimentary experimental data

$\Rightarrow$ TOF-facility GELINA

Cross sections result of evaluation process



Benchmark measurements

Overview

- IRMM
- GELINA
  - Neutron production
  - Time of flight facility
- Neutron cross section measurements at GELINA

JRC – IRMM : neutron facilities

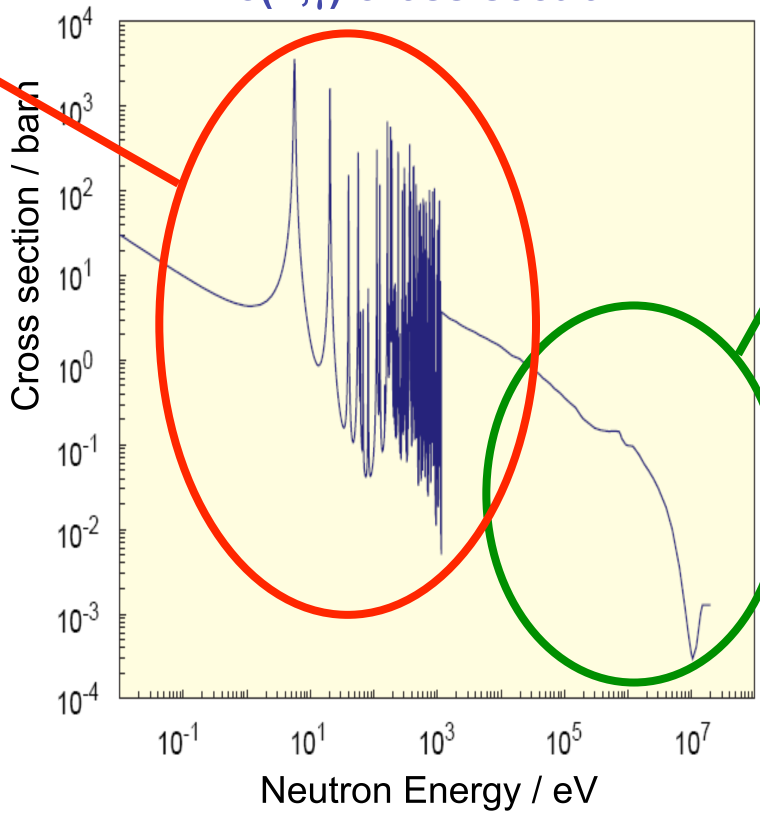
European Commission

GELINA

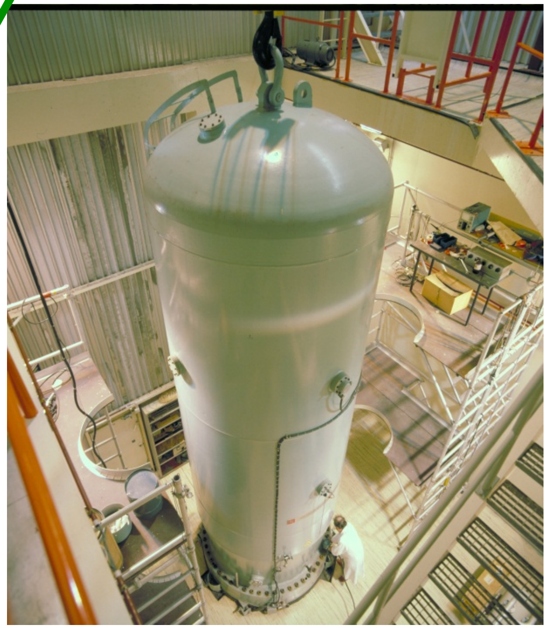
White neutron source
+
Time-of-flight (TOF)

~ 3.4 10^{13} n/s
(integrated)

^{99}Tc(n,γ) cross section



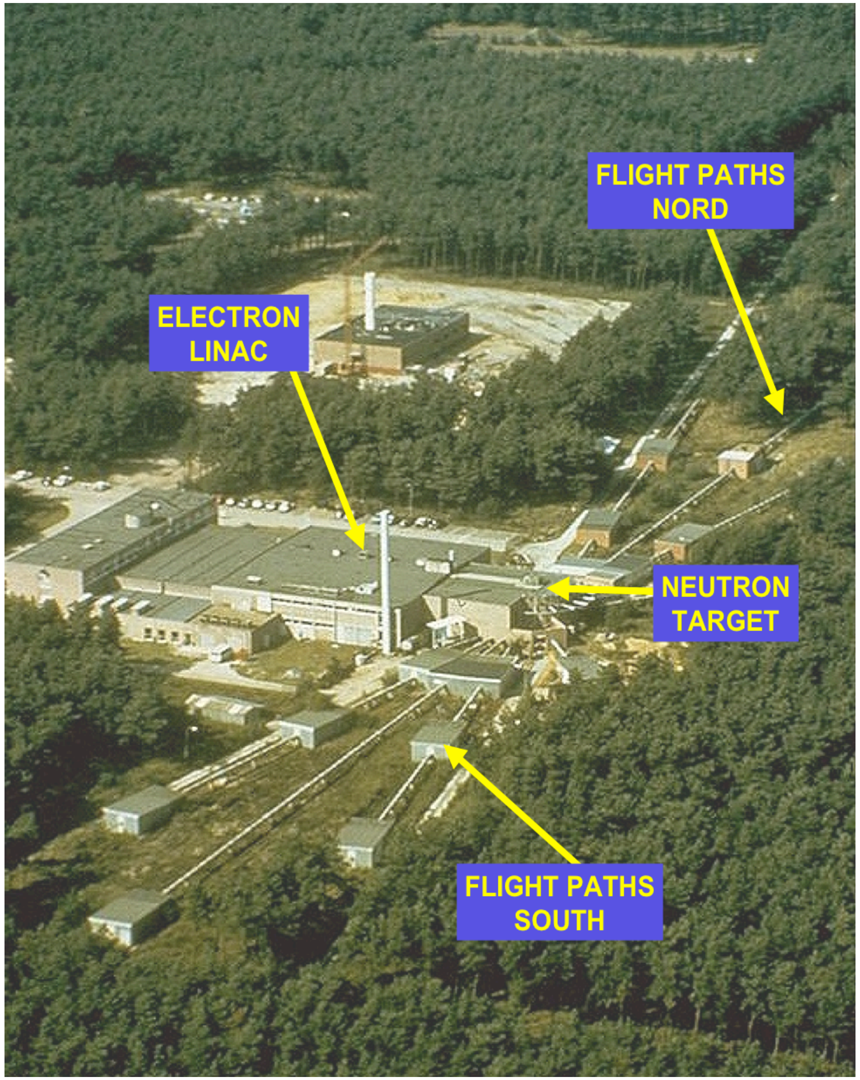
Van de Graaff



Mono-energetic neutrons
(cp,n) reactions

~ 10^6 n/s/cm^2
(10 cm from target)

TOF - Facility GELINA



- **Pulsed white neutron source**

  ($10\ meV < E_n < 20\ MeV$)

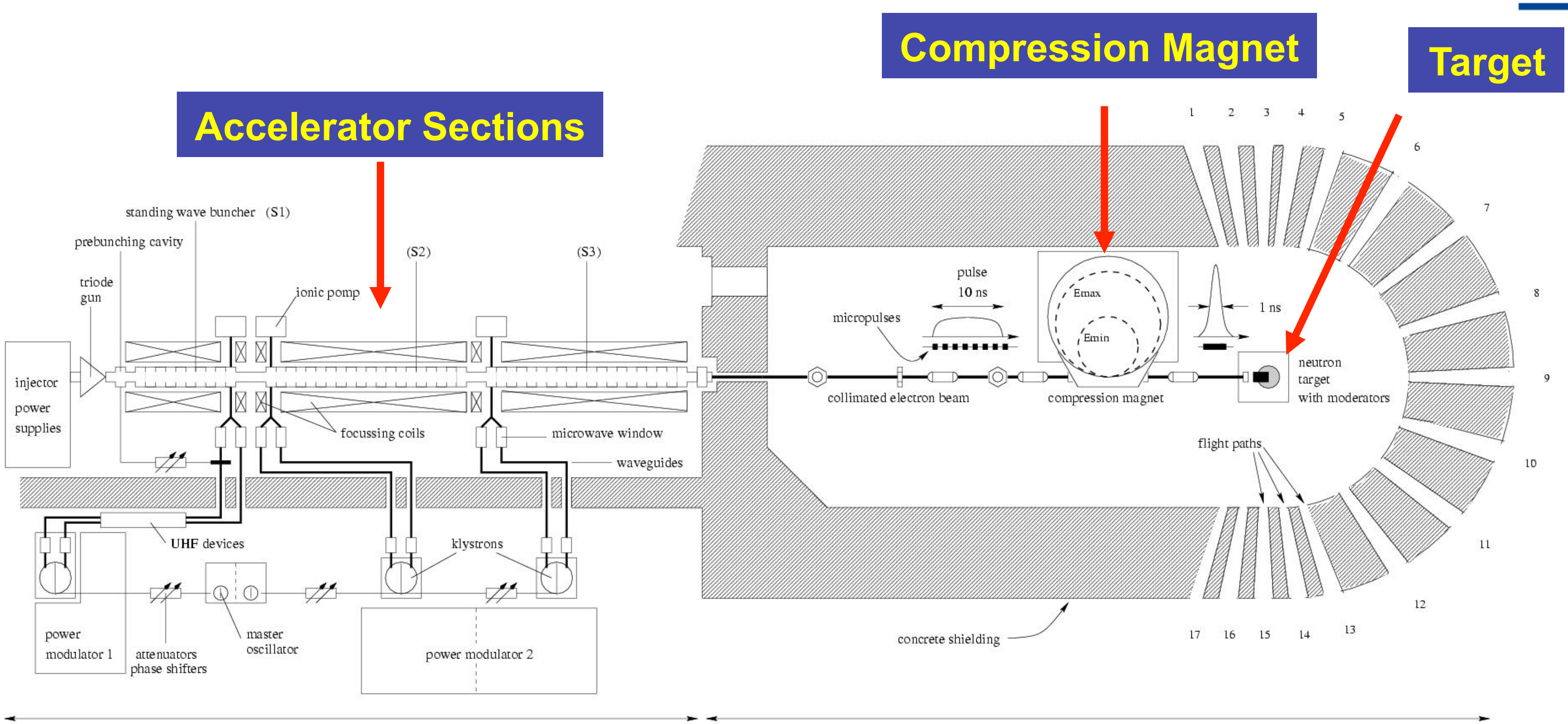
- **Neutron energy : time-of-flight (TOF)**

- **Multi-user facility: 12 flight paths**

  (10 m - 400 m)

- **Measurement stations with special equipment to perform:**
  - **Total cross section measurements**
  - **Partial cross section measurements**

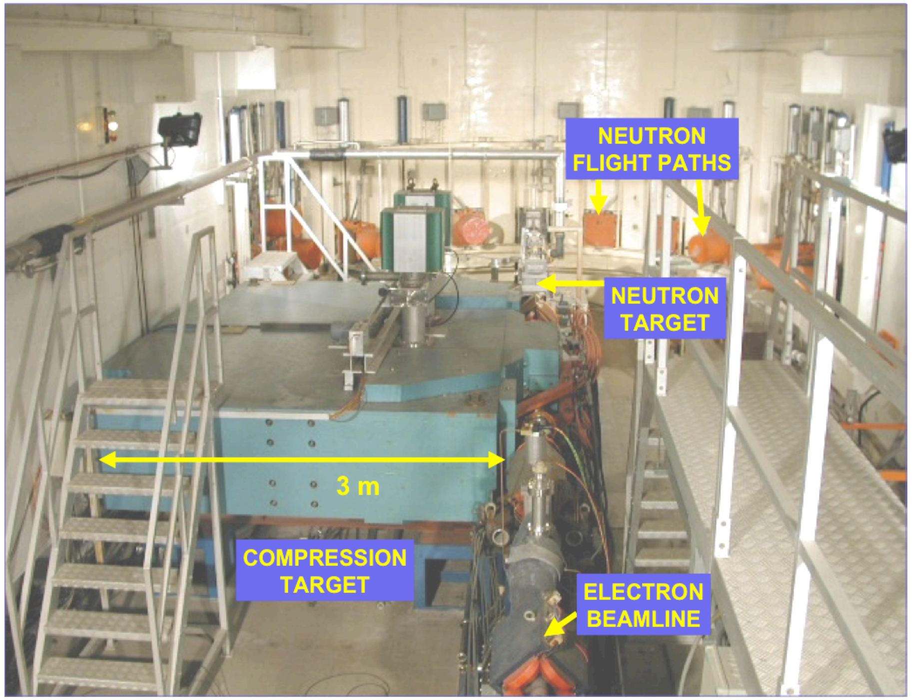
Accelerator

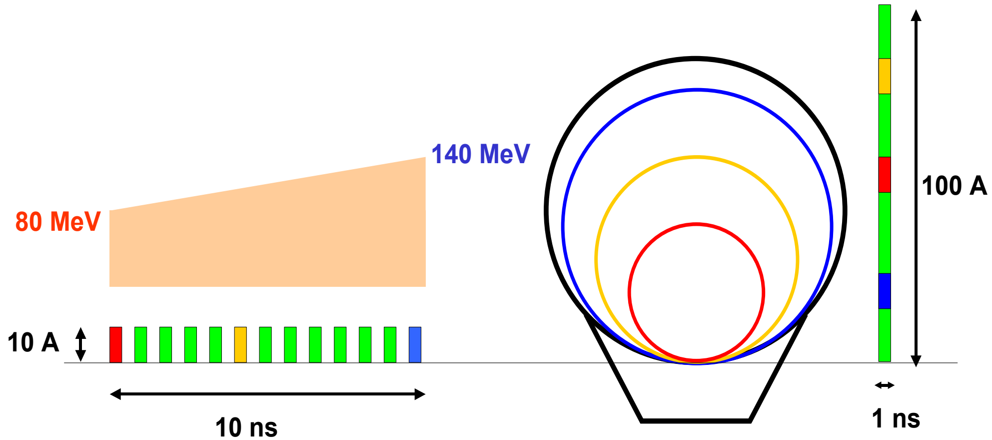


Normal Operating Parameters

Average Current	: 75 μA	Frequency	: 800 Hz
Average Electron Energy	: 100 MeV	Pulse Width	: 1 ns
Mean Power	: 7.5 kW	Neutron Flux	: 3.4 x 10^{13} n/s

Compression magnet





$$B\rho = \frac{p}{q}; \quad E \cong pc; \quad q = e$$

$$\Rightarrow \quad \rho = \frac{1}{B}\frac{E}{qc}$$

$$\Rightarrow \quad B = \frac{2\pi}{qc^2}\frac{\Delta E}{\Delta\tau}$$

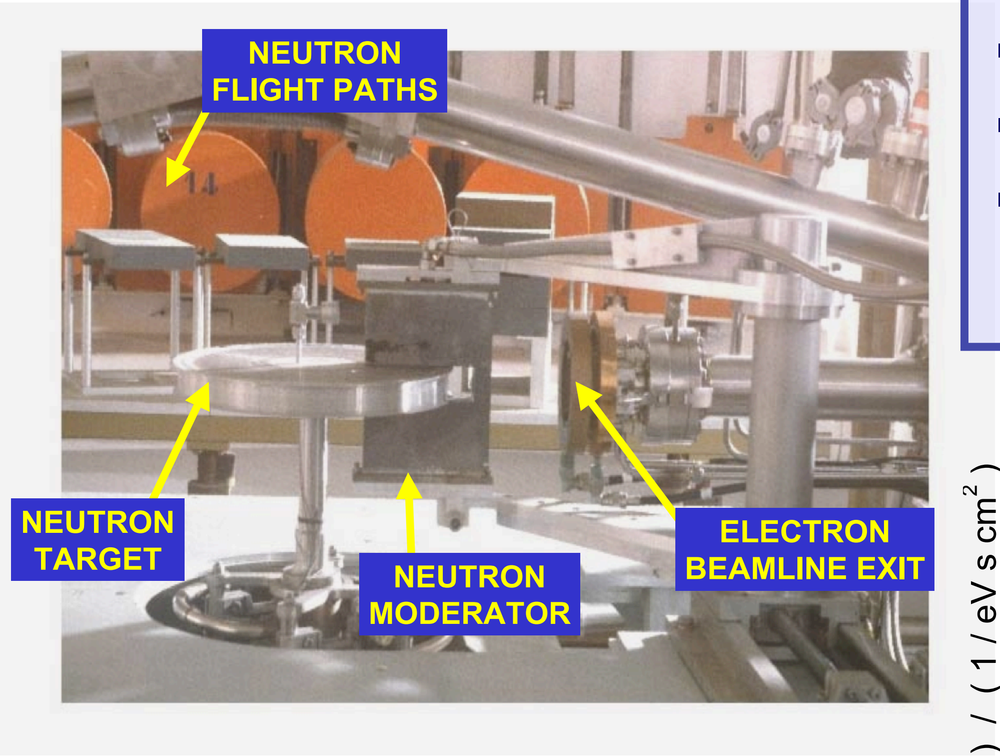
ΔE = 60 MeV
$\Delta\tau$ = 10 ns

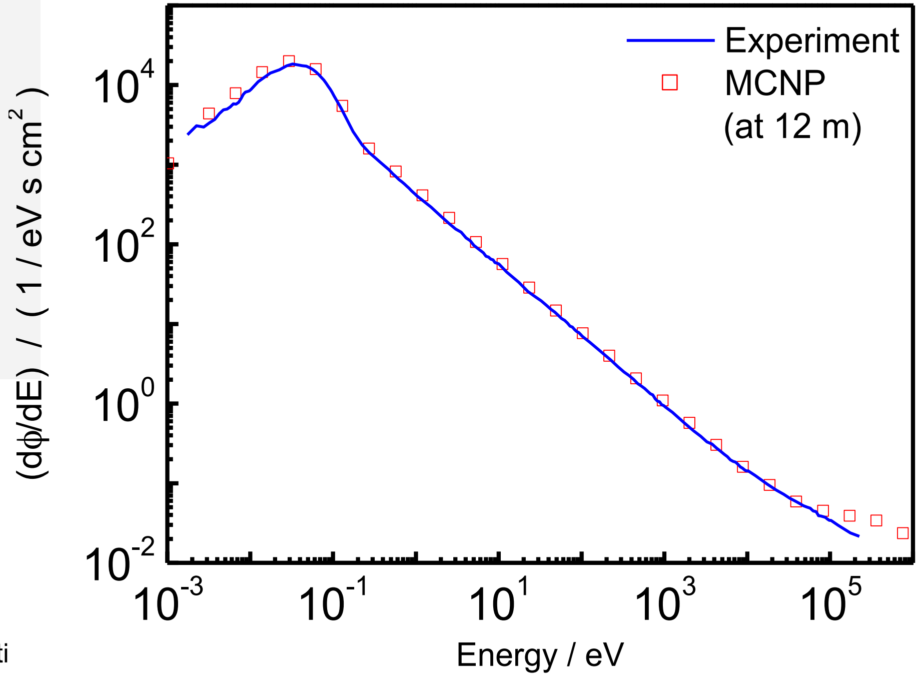
➔ compressed pulse length ~ 1 ns

Neutron production

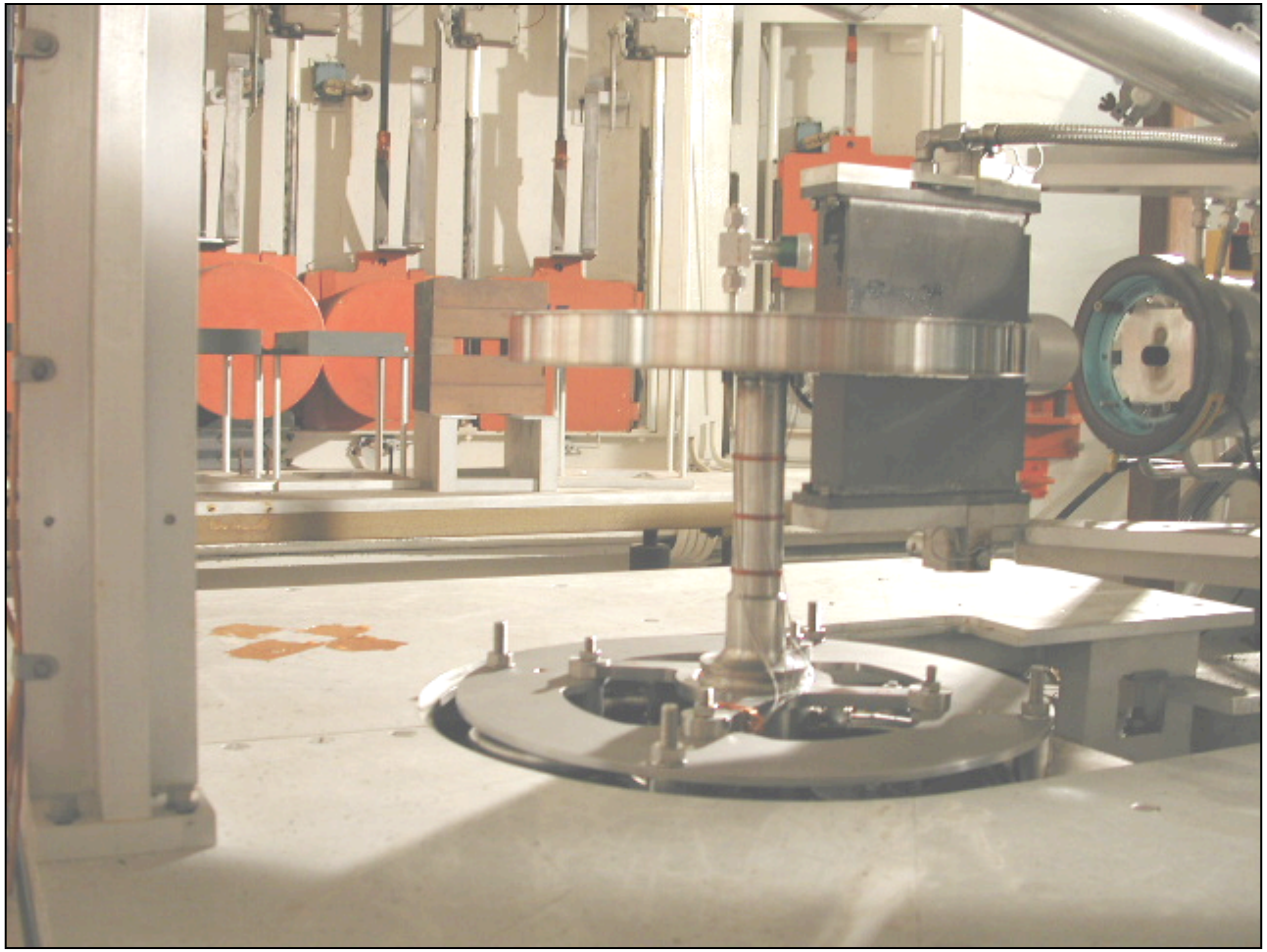
European Commission

- e^- accelerated to $E_{e-,max}$ ≈ 140 MeV
- Bremsstrahlung in U-target
- (γ , n) , (γ , f) in U-target
- Low energy neutrons by moderation (water moderator in Be-canning)



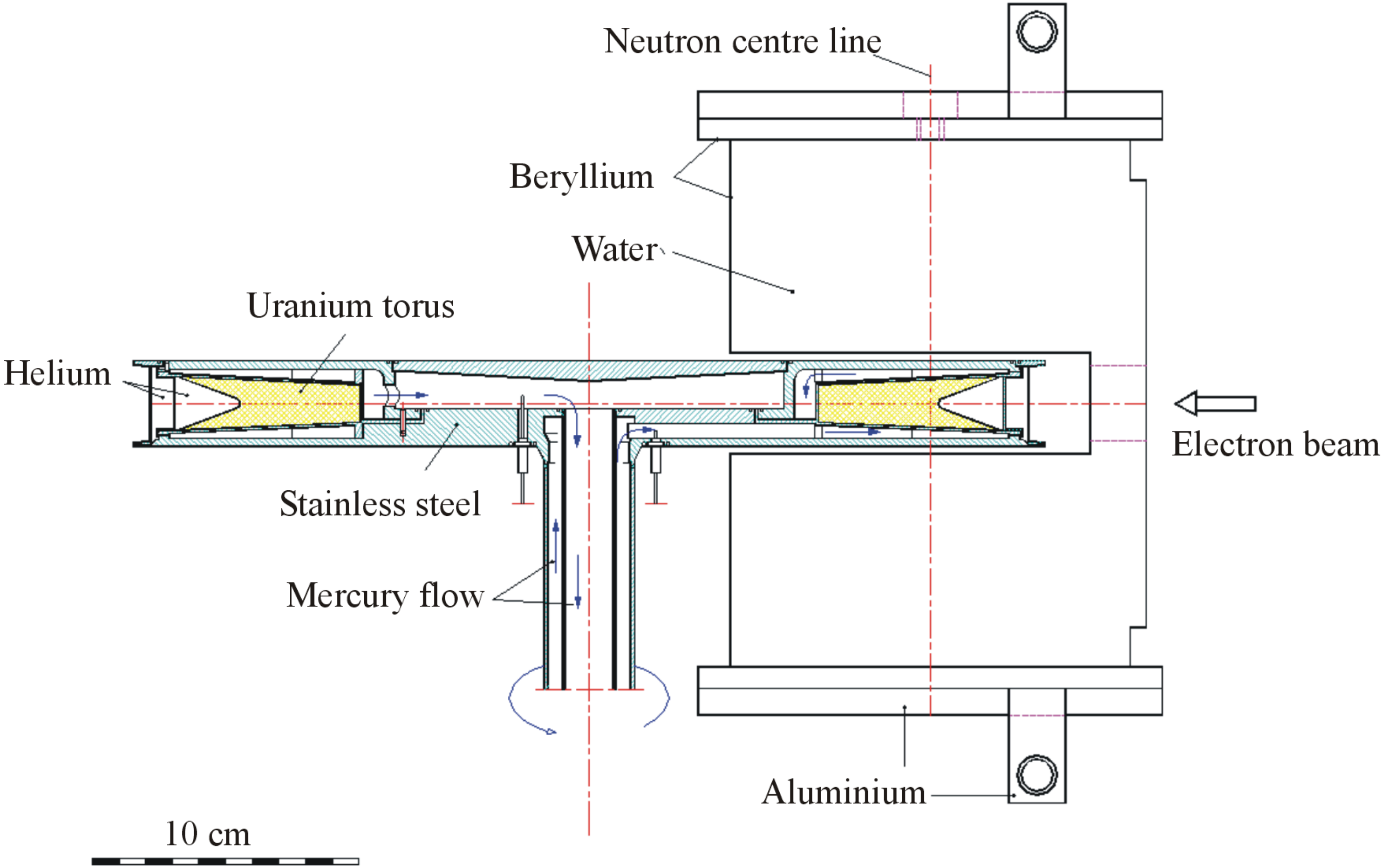


Neutron target



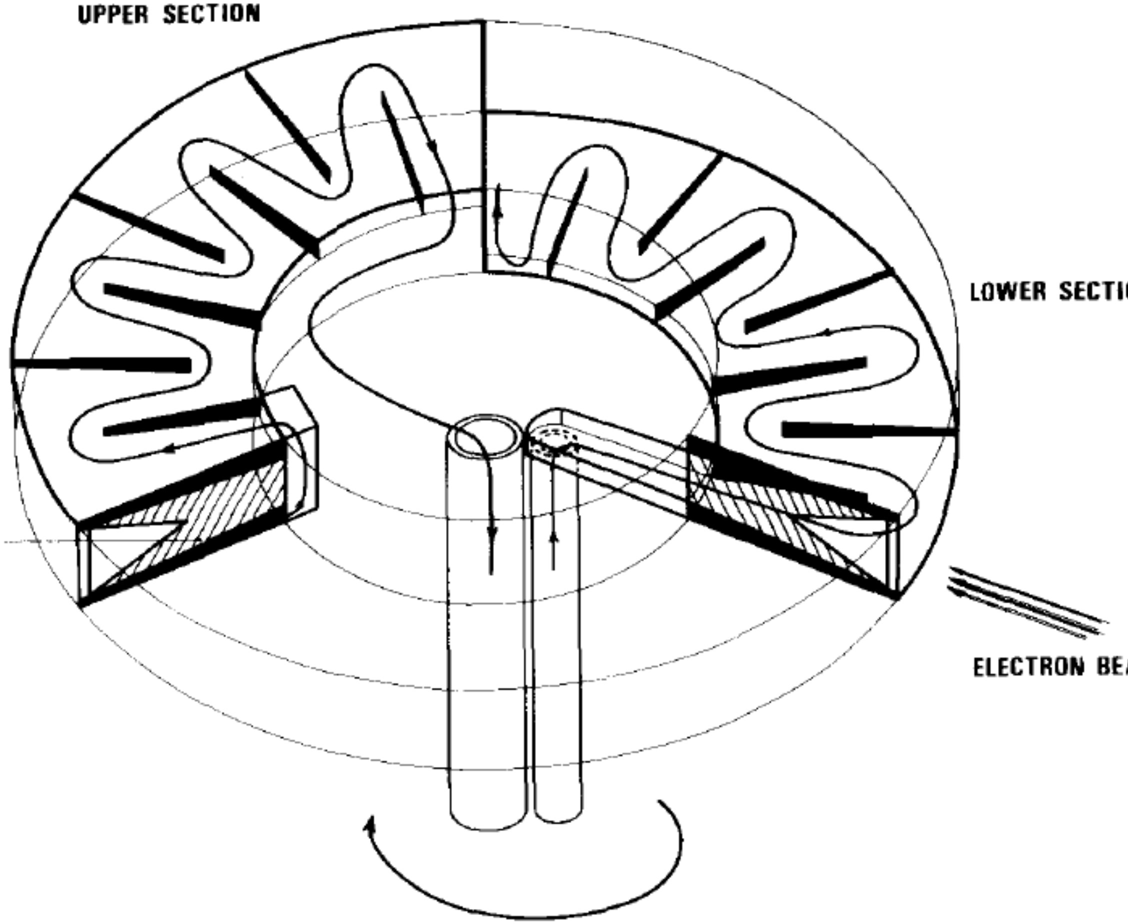
- Depleted uranium
  - high (e,γ) yield
  - high (γ,n) yield
- 10-wt% Mo
- Up to 10 kW
- Mercury cooled
  - low moderation
- Rotating
  - 10 kW/cm^3
- Canned in SS
- Remote handling

Neutron target

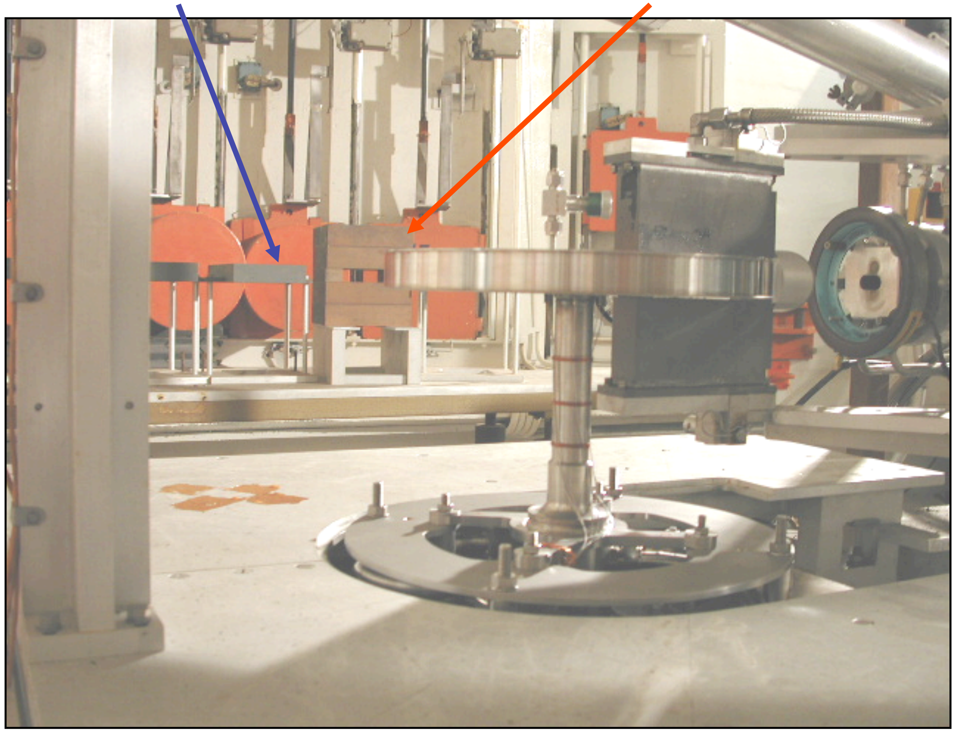


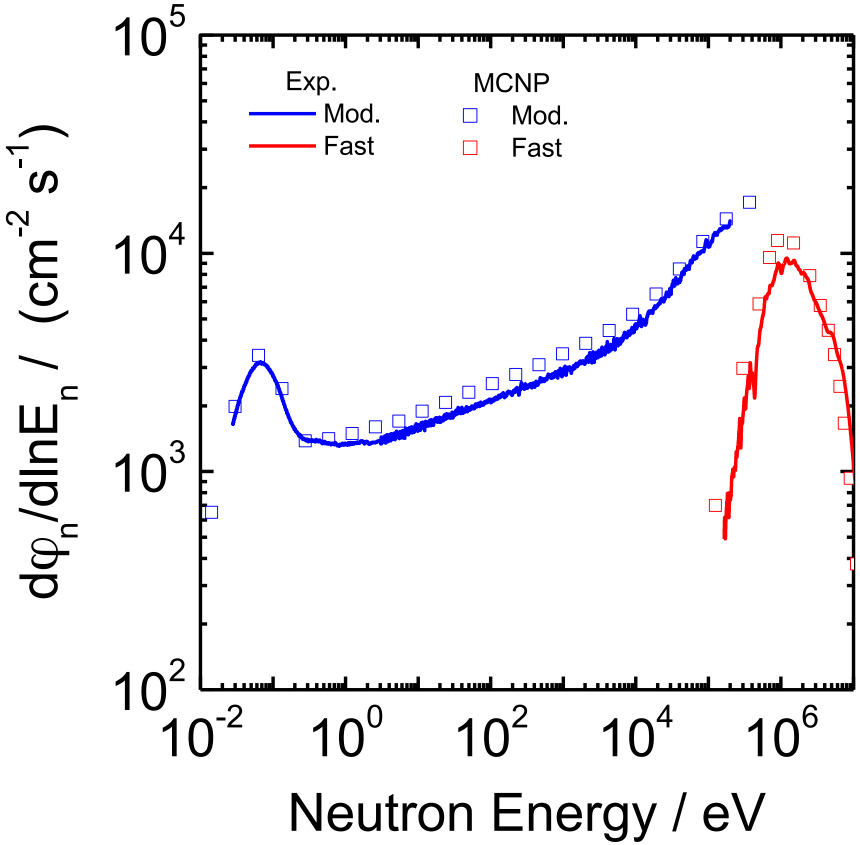
Neutron target

European Commission

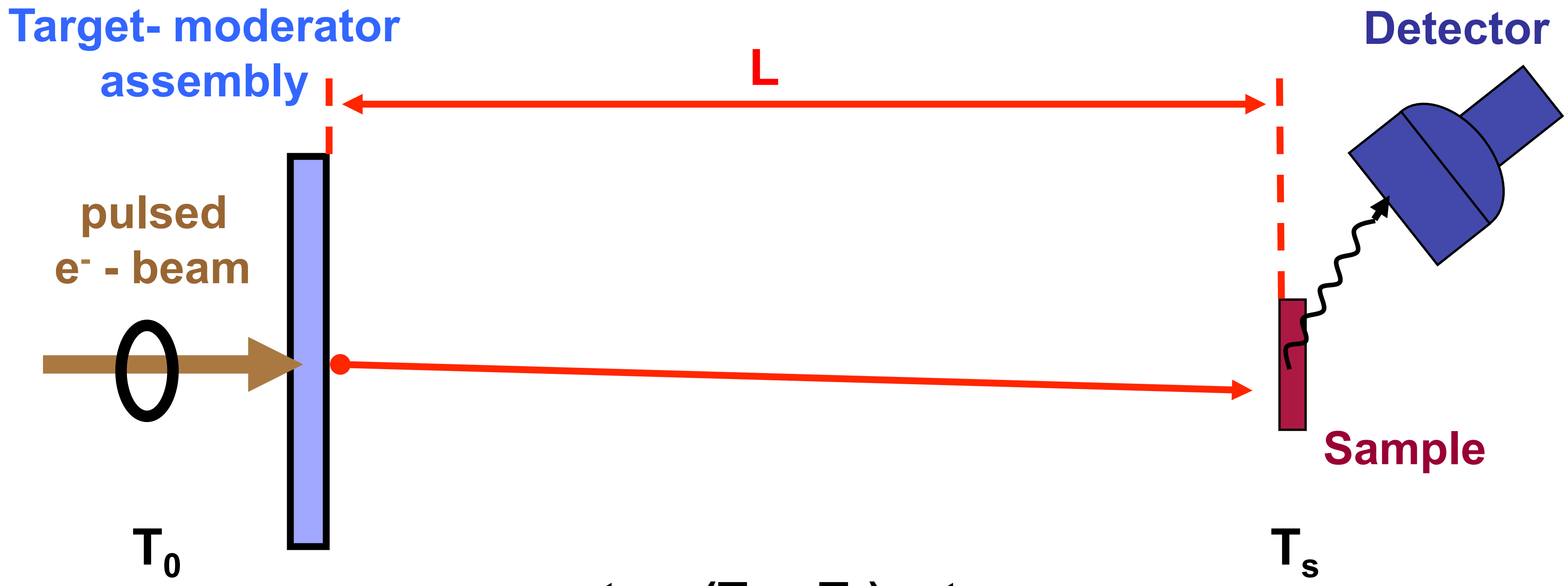


Neutron spectra





Time – of – flight (TOF) technique

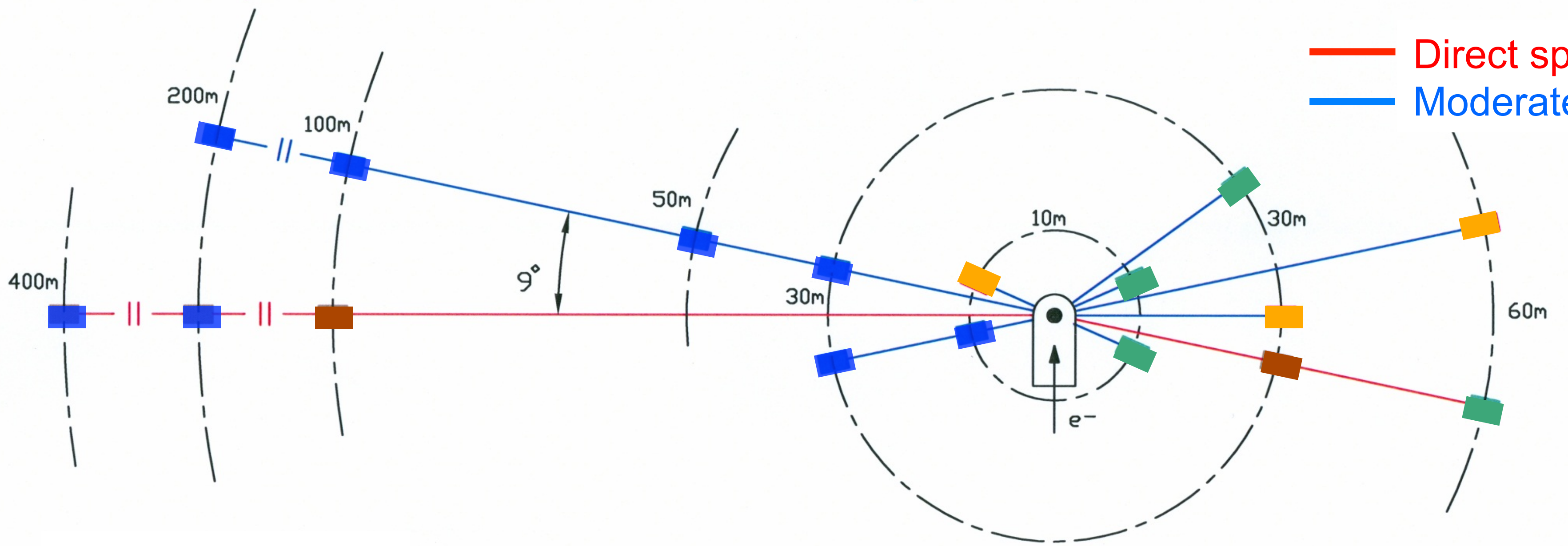


$$t_m = (T_s - T_0) + t_0$$

$$v = \frac{L}{t_m}$$

$$E = mc^2\left(\frac{1}{\sqrt{1-(v/c)^2}} - 1\right)$$

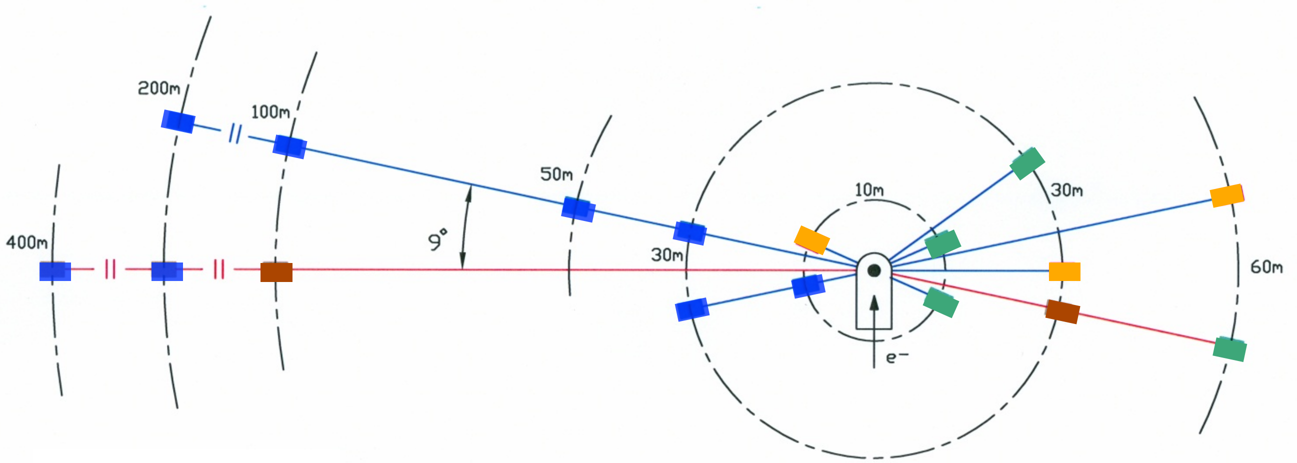
Measurement stations



Direct spectrum
Moderated spectrum

(orange)	**(n,γ)**	**NIM A, 577, 626 (2007)**
(blue)	**(n,tot)**	**NP A 773, 173 (2006)**
(green)	**(n,f) and (n,cp)**	**NSE 156, 211 (2007)**
(brown)	**(n,n'γ)**	**NP A 786, 1 (2007)**

TOF - measurements



- (n,γ) — NIM A, 577, 626 (2007)
- (n,tot) — NP A 773, 173 (2006)
- (n,f) and (n,cp) — NSE 156, 211 (2007)
- (n,n'γ) — NP A 786, 1 (2007)

- **Velocity from TOF**

$$v = \frac{L}{t_m}$$

- **Neutron flux** ⇒ L ↘

$$\varphi(L) \propto \frac{1}{L^2}$$

- **Resolution** ⇒ L ↗

$$\frac{\Delta E}{E} \cong 2\frac{\Delta v}{v} = 2\sqrt{\frac{\Delta t_m^{\ 2}}{t_m^{\ 2}} + \frac{\Delta L^2}{L^2}}$$

Response of TOF-spectrometer

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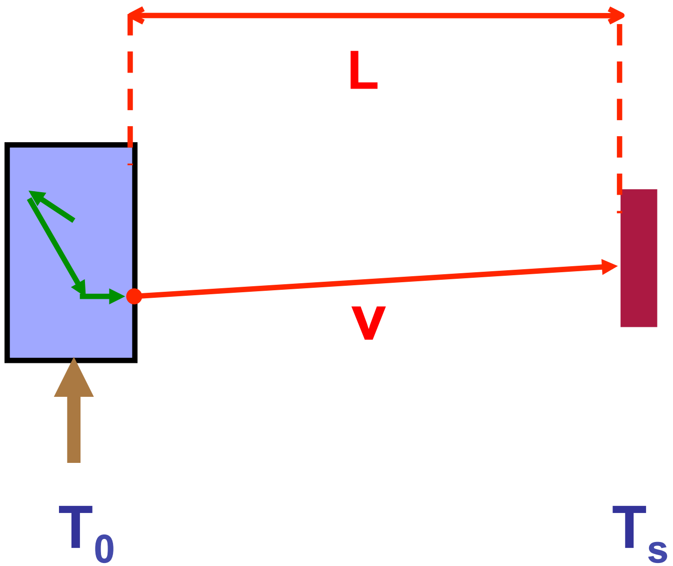
$$v = \frac{L}{t} \quad \Rightarrow \quad E = m c^2(\gamma - 1)$$

$$\frac{\Delta v}{v} = \sqrt{\frac{\Delta t^2}{t^2} + \frac{\Delta L^2}{L^2}} \quad \Rightarrow \quad \frac{\Delta E}{E} = (\gamma + 1)\gamma \frac{\Delta v}{v}$$



- ΔL (~ 1 mm)
- Δt
  - Initial burst width ΔT_0
  - Time jitter detector & electronics ΔT_s
  - Neutron transport in target - moderator Δt_t
  - Neutron transport in detector Δt_d

$$t = t_m - (t_t + t_d)$$

Neutron transport in the target

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$$\Delta t_t$$

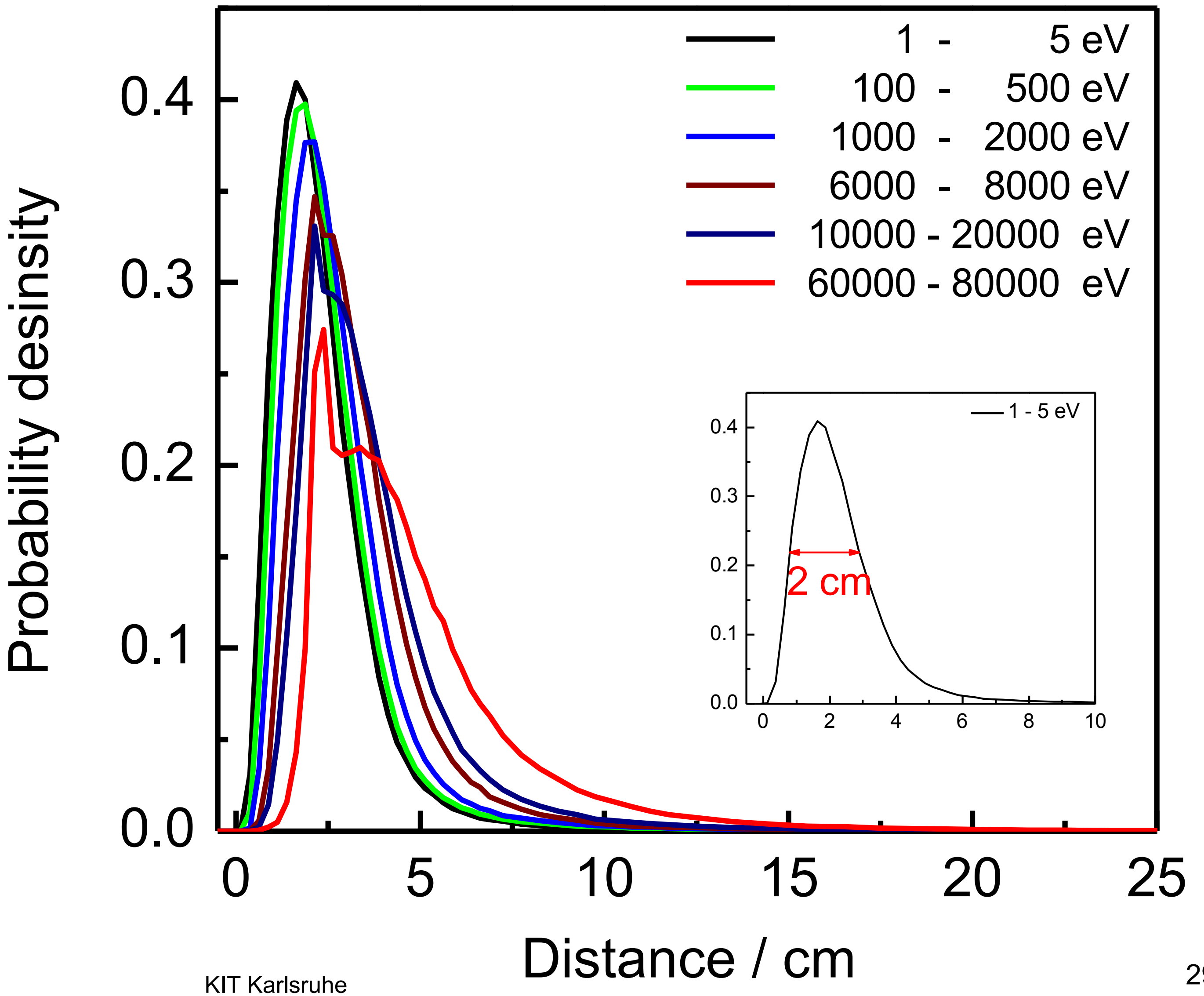
$$\Downarrow$$

$$L_t = v\, t_t$$

$$P(t_t, E_n) = P'(L_t(t_t), E_n)\left|\frac{dL_t}{dt_t}\right|$$

$$\Downarrow$$

$$\Delta L_t$$

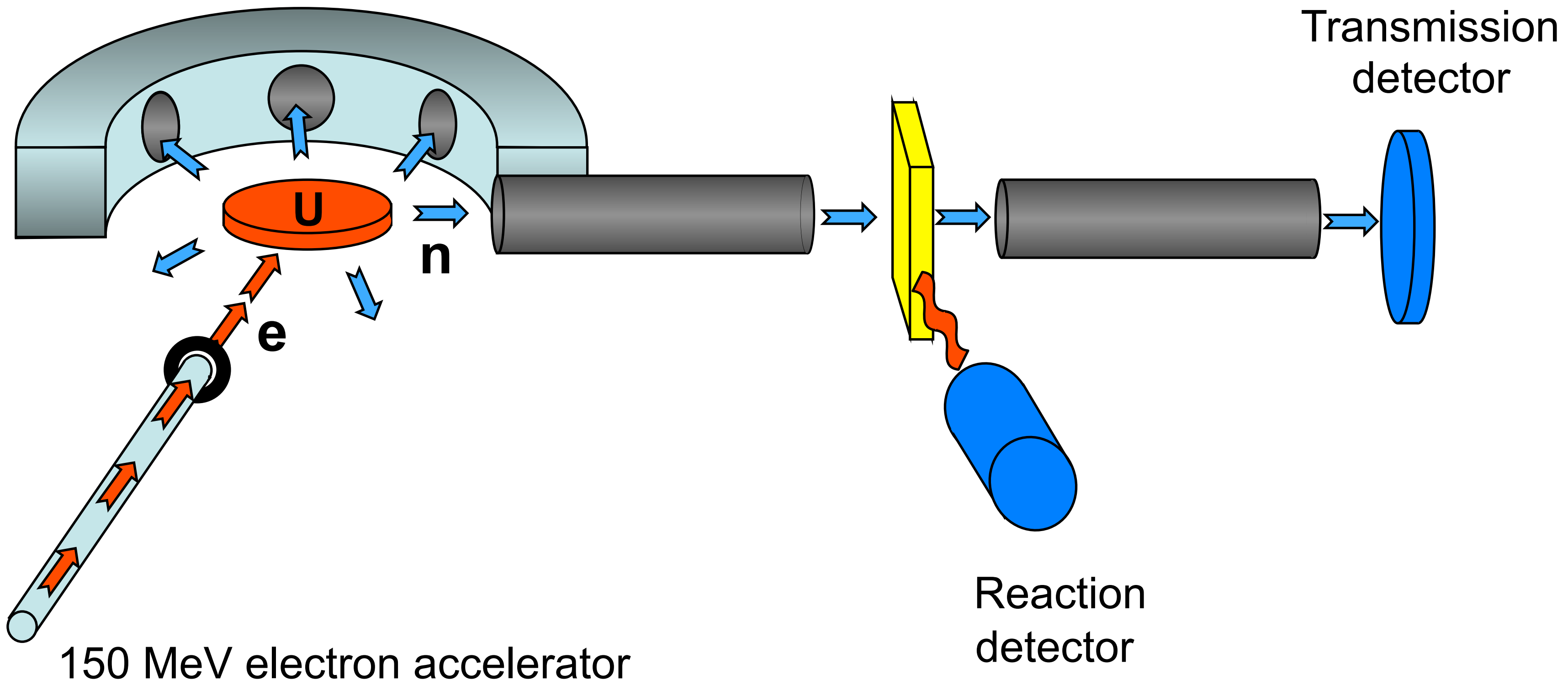


Overview

European Commission

- IRMM
- GELINA
- **Neutron cross section measurements at GELINA**

Types of TOF - experiments



Cross section measurements

Transmission

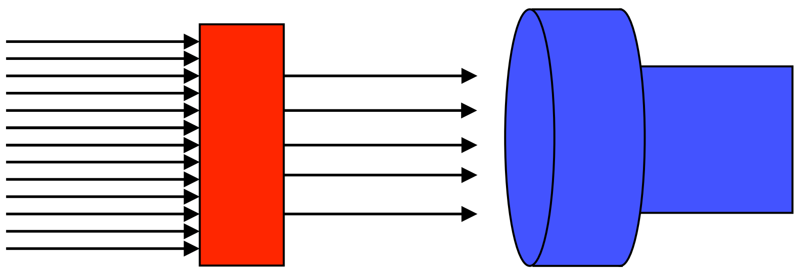
$$T_{exp} = \frac{C_{in}}{C_{out}}$$

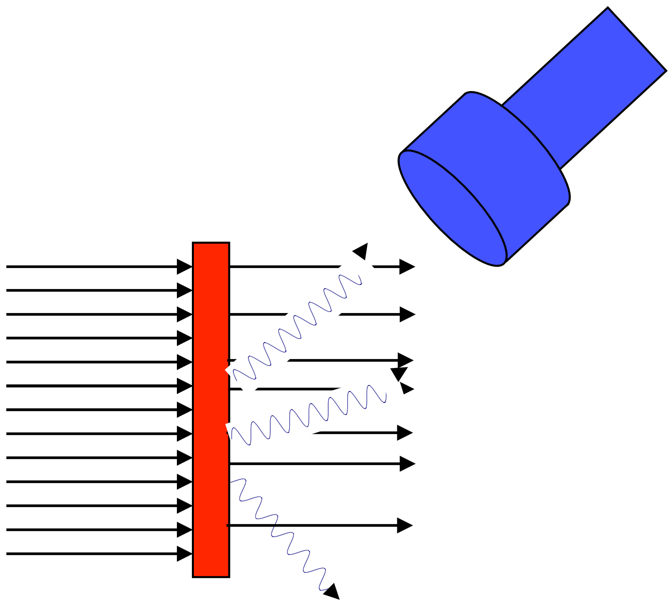
$$T \cong e^{-n\sigma_{tot}}$$

Reaction: (n,r)

$$C_r \approx \varepsilon_r \, \Omega \, P_r \, Y_r \, A_r \, \varphi$$

Y_r reaction yield
fraction of neutron beam creating (n,r)
related to σ_r





Transmission : principle

$$T = \frac{C_{in}}{C_{out}} \propto e^{-n\,\sigma_{tot}}$$

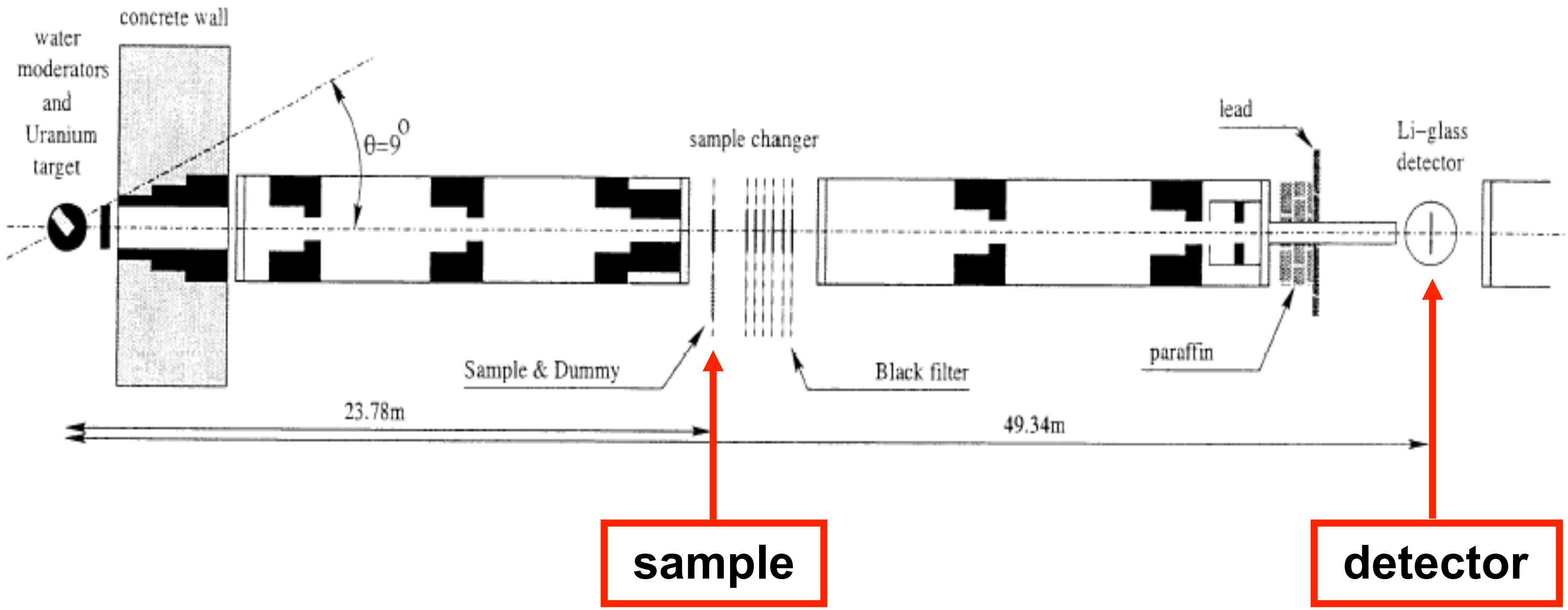
(1) All detected neutrons passed through the sample

(2) Neutrons scattered in the target do not reach detector

(3) Sample perpendicular to parallel neutron beam

⇒ **Good transmission geometry (collimation)**

⇒ **Homogeneous target (no spatial distribution of n)**



Transmission: experimental set-up (50 m)

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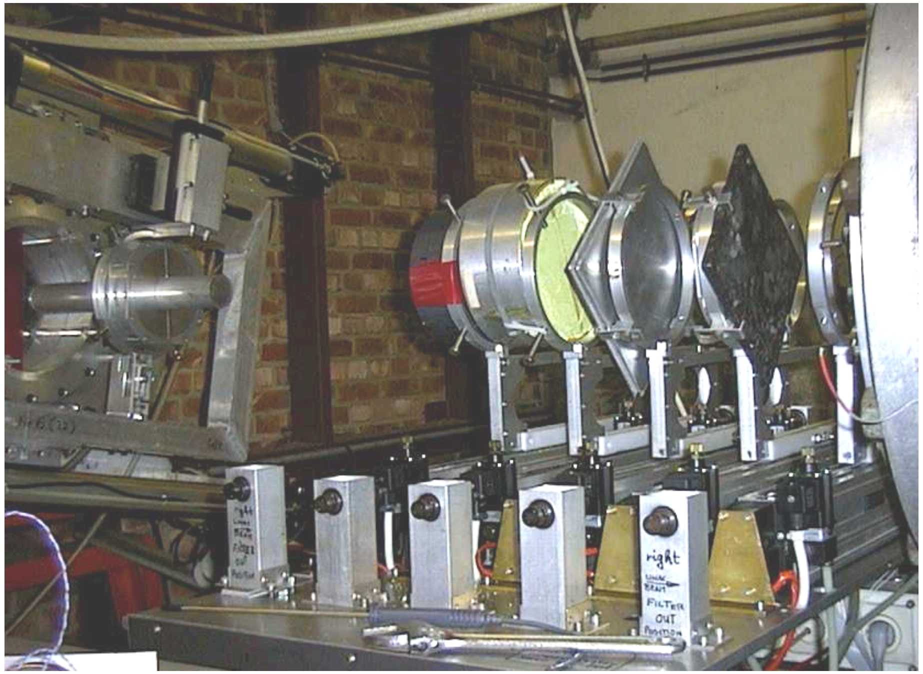
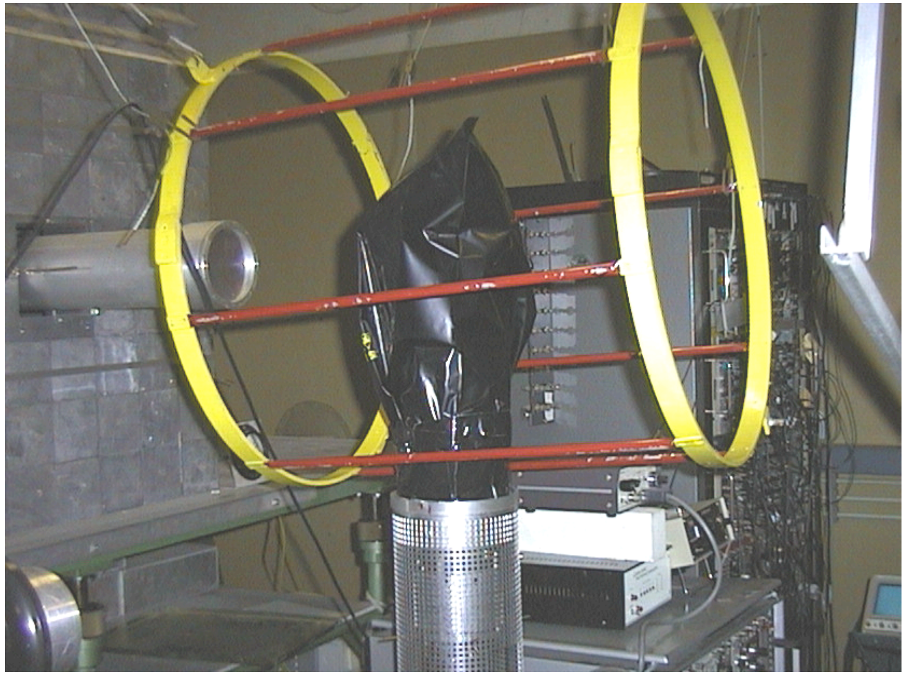
Sample & Background Filters
at 25 m



Neutron detector
at 50 m



Detector stations at GELINA

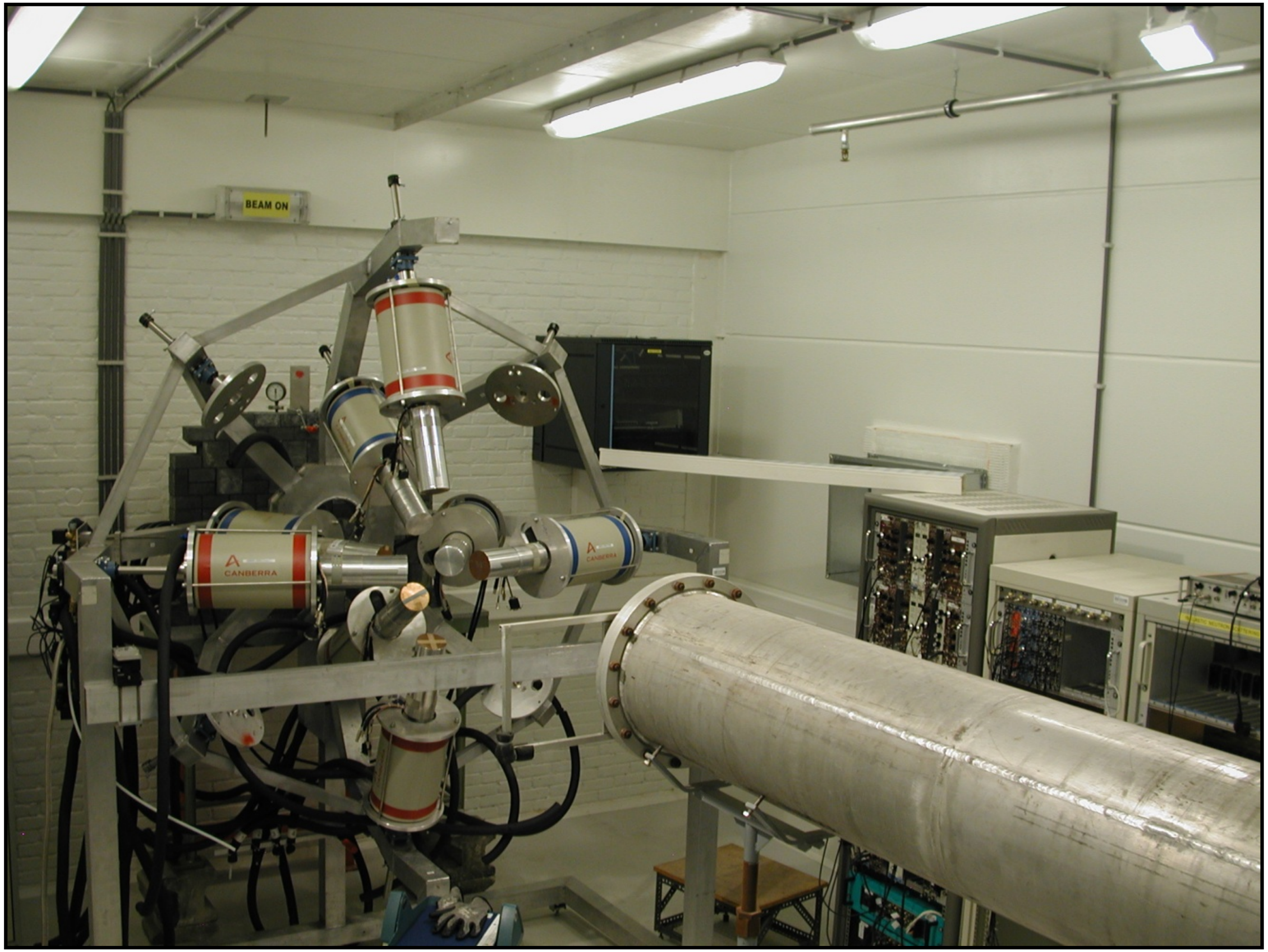
Moderated	:	at 30 m, 50 m, (100 m, 200 m)
Fast	:	at 400 m

Detectors

Low energy	:	$^{6}Li(n,t)\alpha$	Li-glass
High energy	:	H(n,n)H	Plastic scintillator

Kopecky and Brusegan, Nucl. Phys. A 773 (2006) 173
Borella et al., Phys. Rev. C 76 (2007) 014605

(n,n') reaction: experimental setup (200m)



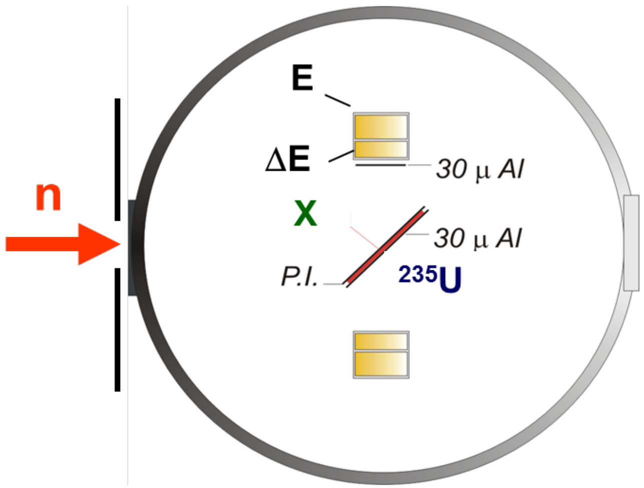
Measurement setups

Transmission

- Li-glass detectors
- Plastic scintillators
- NE213 scintillators
- Cryostat and over for Doppler measurements

Reaction

- Frisch-gridded ionisation chambers, SBD for (n,f), (n,α), (n,p)
- HPGe detectors: (n,n'), (n,γ)
- C_6D_6 scintillators: (n,γ)



Applications

- **Safety assessment of existing reactor systems**
  - **dependence of nuclear reactor parameters on nuclear data under different (extreme) operating conditions**
  - **extension and optimization of the fuel cycle**
- **Future reactor systems (GEN IV – ADS)**
  - **e.g. support to licensing of MYRRHA**
  - **LLFP and MA**
- **Cross section standards**
  - **$^{10}B(n,\alpha)$**
- **Non destructive material analyis**
  - **NRCA and NRTA**
  - **e.g. post Fukushima safeguards support**

Thanks for your attention