FaNGAS
Fast Neutron induced Gamma-ray Spectrometry

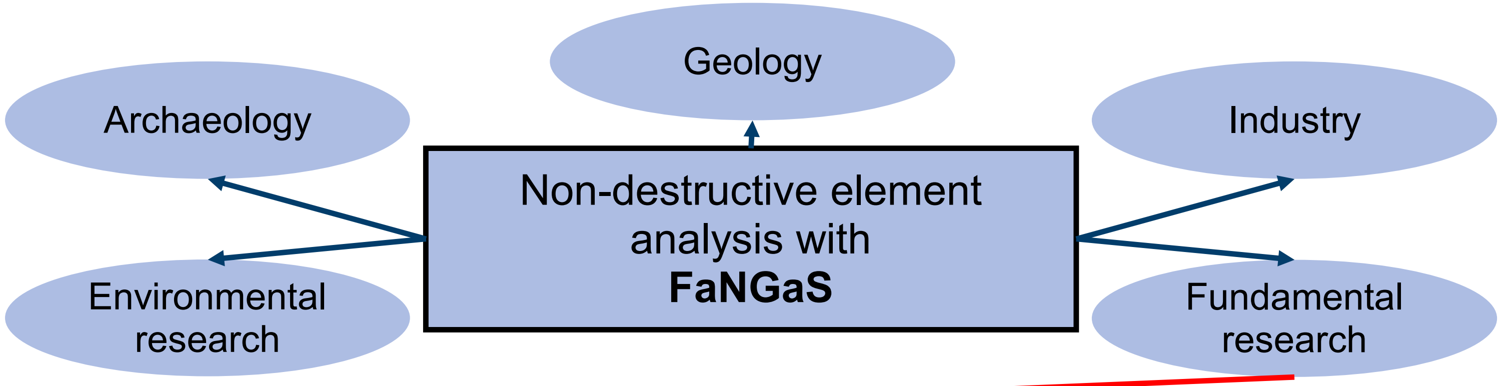
28.02.2023 I ERIC MAUERHOFER

THE FANGAS PROJECT

Aims & scopes

- TANDEM collaboration (2011): PGAA as tool for improving nuclear reaction data of actinides with focus on nuclear waste
- Developed at IEK-6 at Forschungszentrum Jülich GmbH, installed at Strahlrohr SR10 of FRM-II reactor in Garching in 2014
- Since 2016 instrument of JCNS
- Non-destructive elemental analysis by use of prompt γ-radiation: **(n,n’)**, (n,p), (n,α)

Evaluated and **reliable** nuclear data of (n,n’γ) reactions lacks/ "**Demidov Atlas**„ (1978) has to be validated!

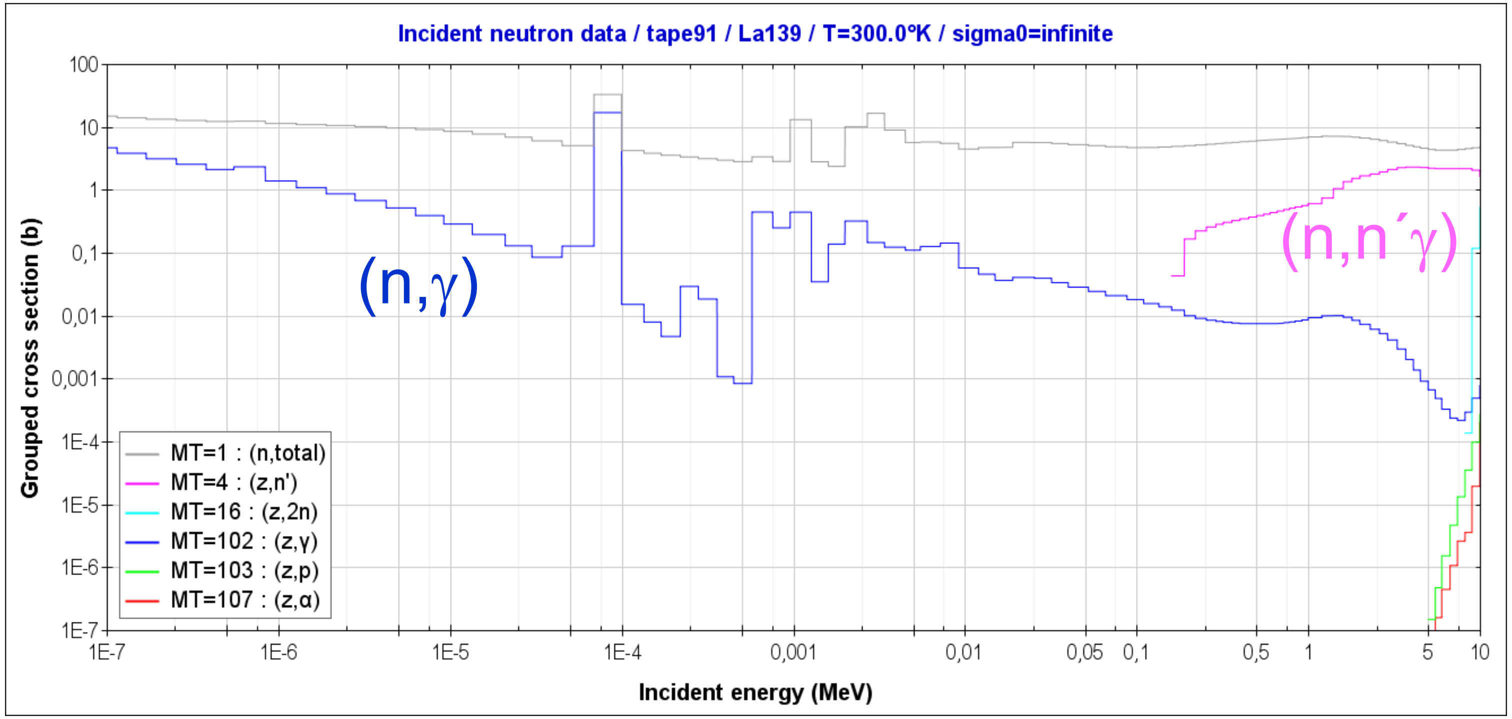


Final aim: Comprehensible **(n,n’γ) cross section catalogue** with state of the art equipment

BASICS

PGNAA & PGAINS: Thermal vs. fast neutrons

ENDF/B-VIII.0 reaction data processed with the NJOY code for La-139

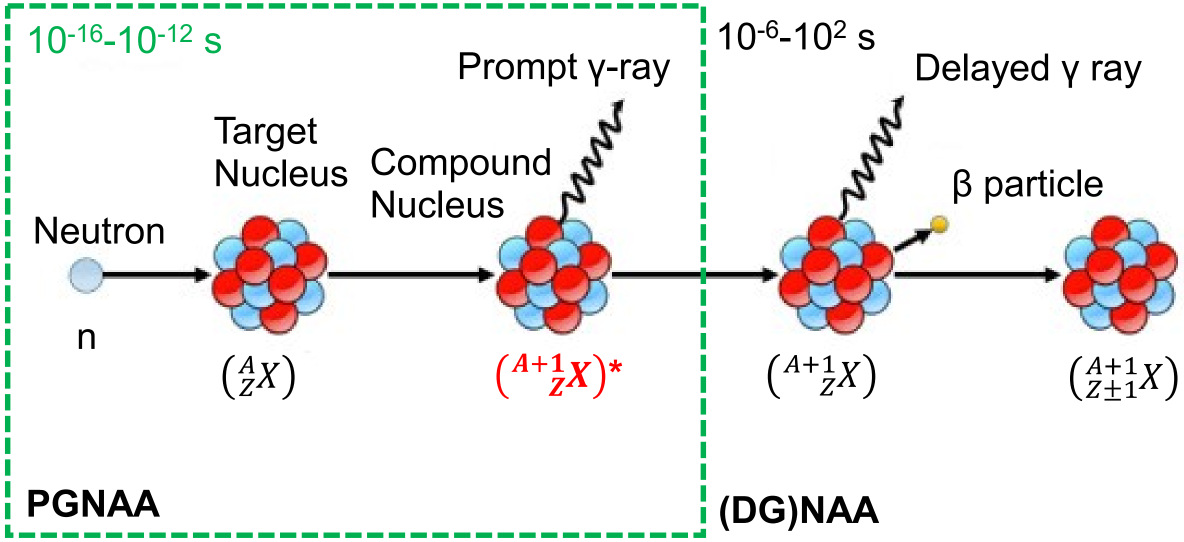


Radiative capture dominates at low energies, but **inelastic scattering** is the **dominant energy loss mechanism in the high energy region around a few MeV!**

BASICS

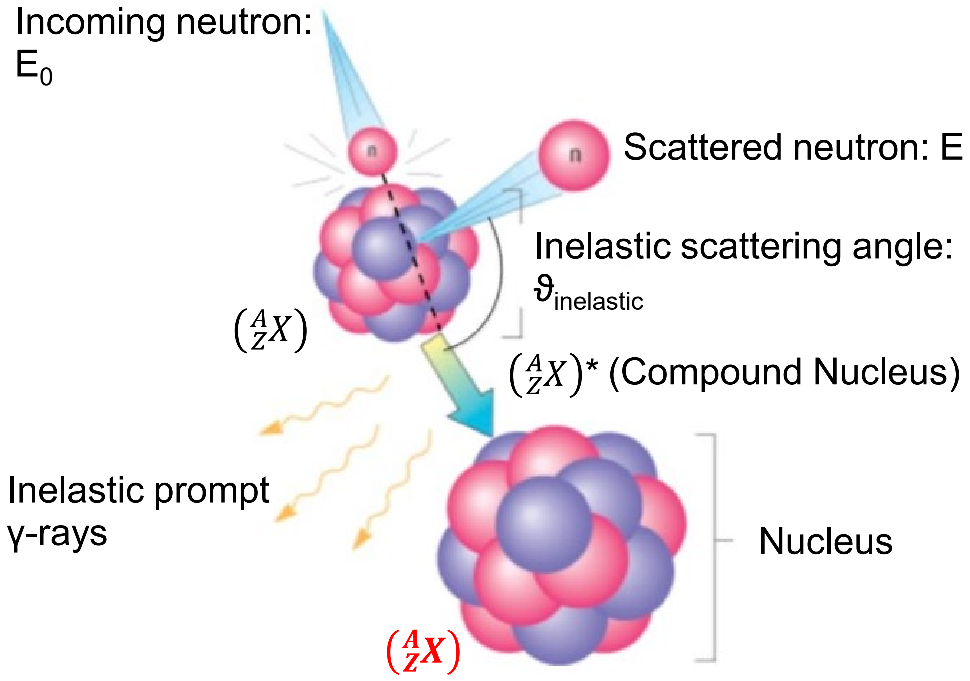
PGNAA & PGAINS: Thermal vs. fast neutrons

PGNAA: **P**rompt **G**amma **N**eutron **A**ctivation **A**nalysis



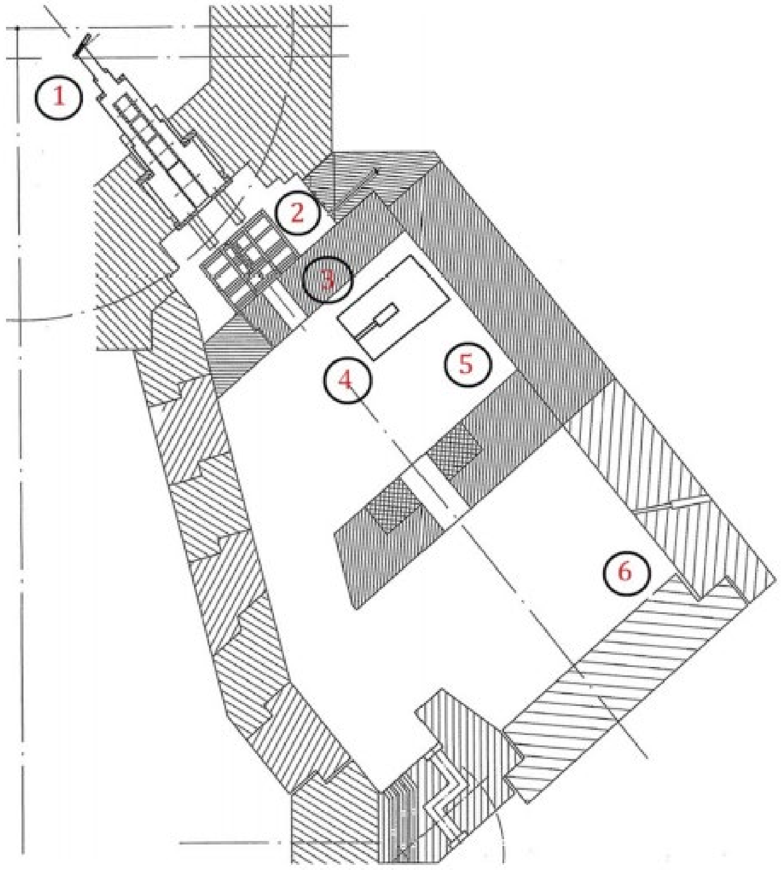
[1]Shahabinejad et al., PROG NUCL ENERGY (2020, modified)

PGAINS: **P**rompt **G**amma **A**nalysis based on **I**nelastic **N**eutron **S**cattering



[2]Chen, PhD thesis (2015, modified)

FANGAS INSTRUMENT



Mauerhofer et al., 2021

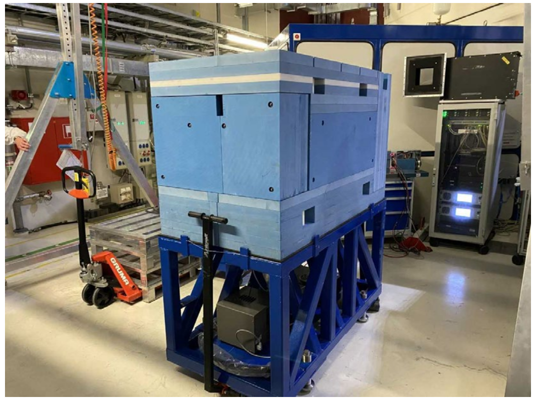
FRM-II (Forschungs-Neutronenquelle Heinz-Maier-Leibnitz) reactor:

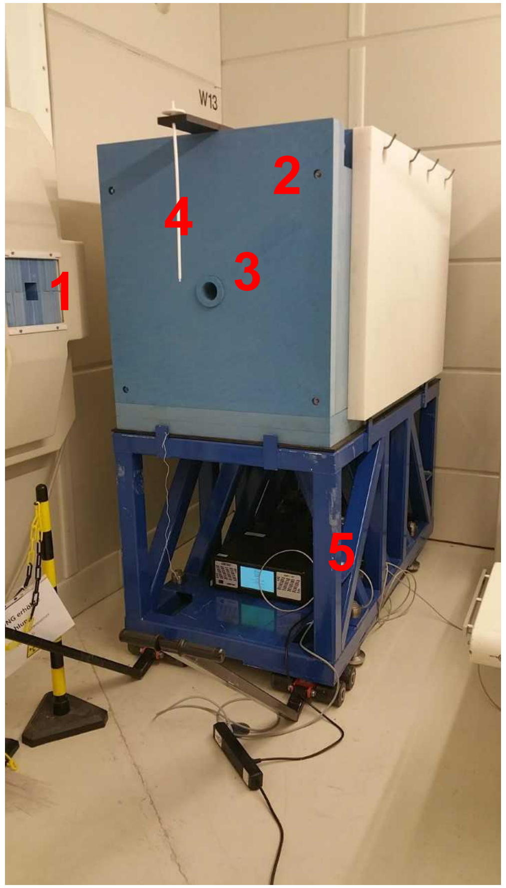
- Swimming pool type
- Extraction channel: **SR10** (Strahlrohr 10)

1. Convertor plate containing 498 g of enriched uranium (93% ^{235}U)
2. Bench filters bunker (FaNGaS collimator)
3. Multi-leaf-collimator of MEDAPP facility
4. FaNGaS spectrometer (measuring position)
5. MEDAPP facility bunker
6. NECTAR facility bunker (radiography)

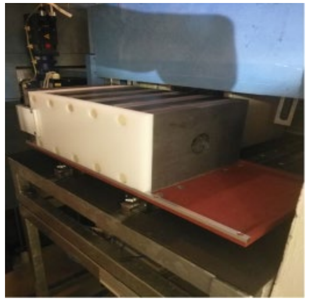
FANGAS INSTRUMENT

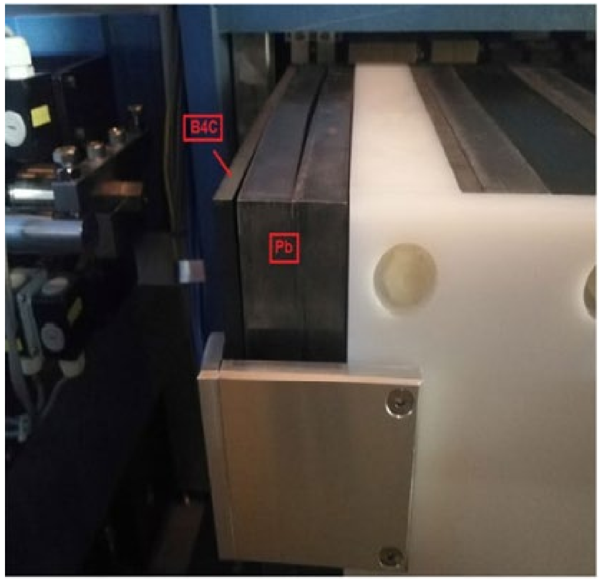
1. MEDAPP multi-leaf neutron beam collimator
2. BPE front shielding (d= 30 cm)
3. Detector collimator (∅= 6 cm)
4. Teflon (C_nF_{2n}) sample holder
5. Iron support frame





FaNGaS neutron collimator

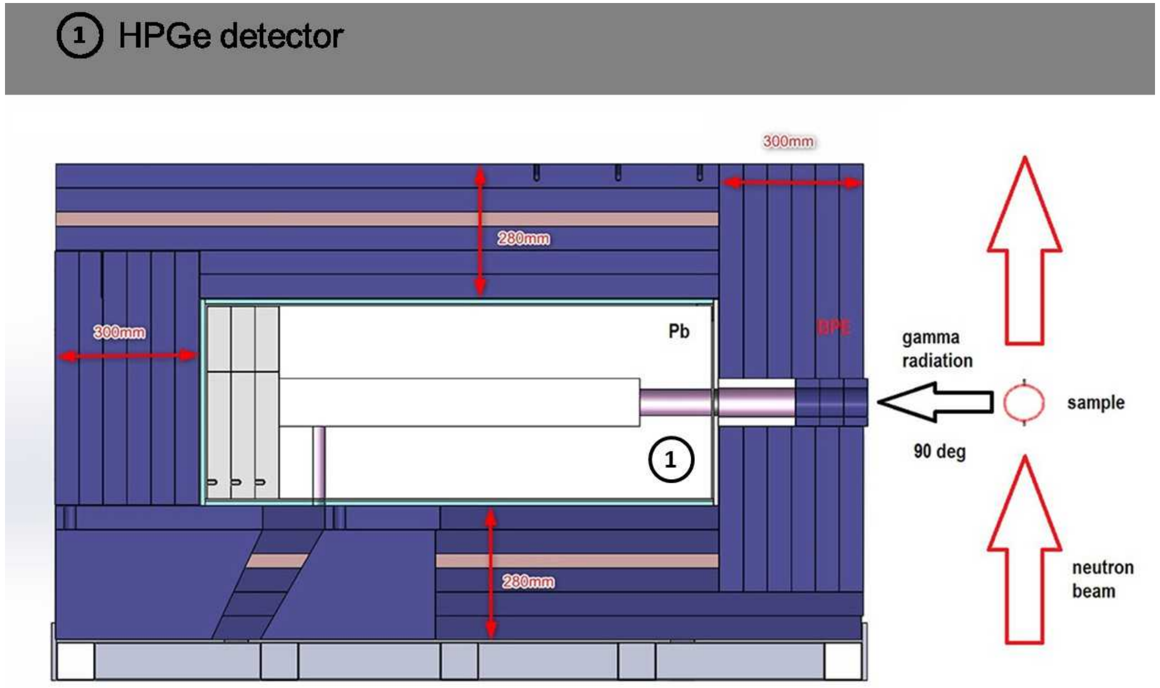




JÜLICH Forschungszentrum

FANGAS INSTRUMENT

- $\theta_{beam\text{-}detector}$ = 90°
- n-type HPGe detector (electromechanically cooled)
- 50% rel. efficiency
- Energy resolution: 2.1 keV @ 1.33 MeV
- Distance sample-HPGe detector: 67 cm
- Beam size: 6x6 cm^2
- Gamma collimation: ∅= 6 cm
- Gamma/Neutron attuenator: 1 -10 cm BPE

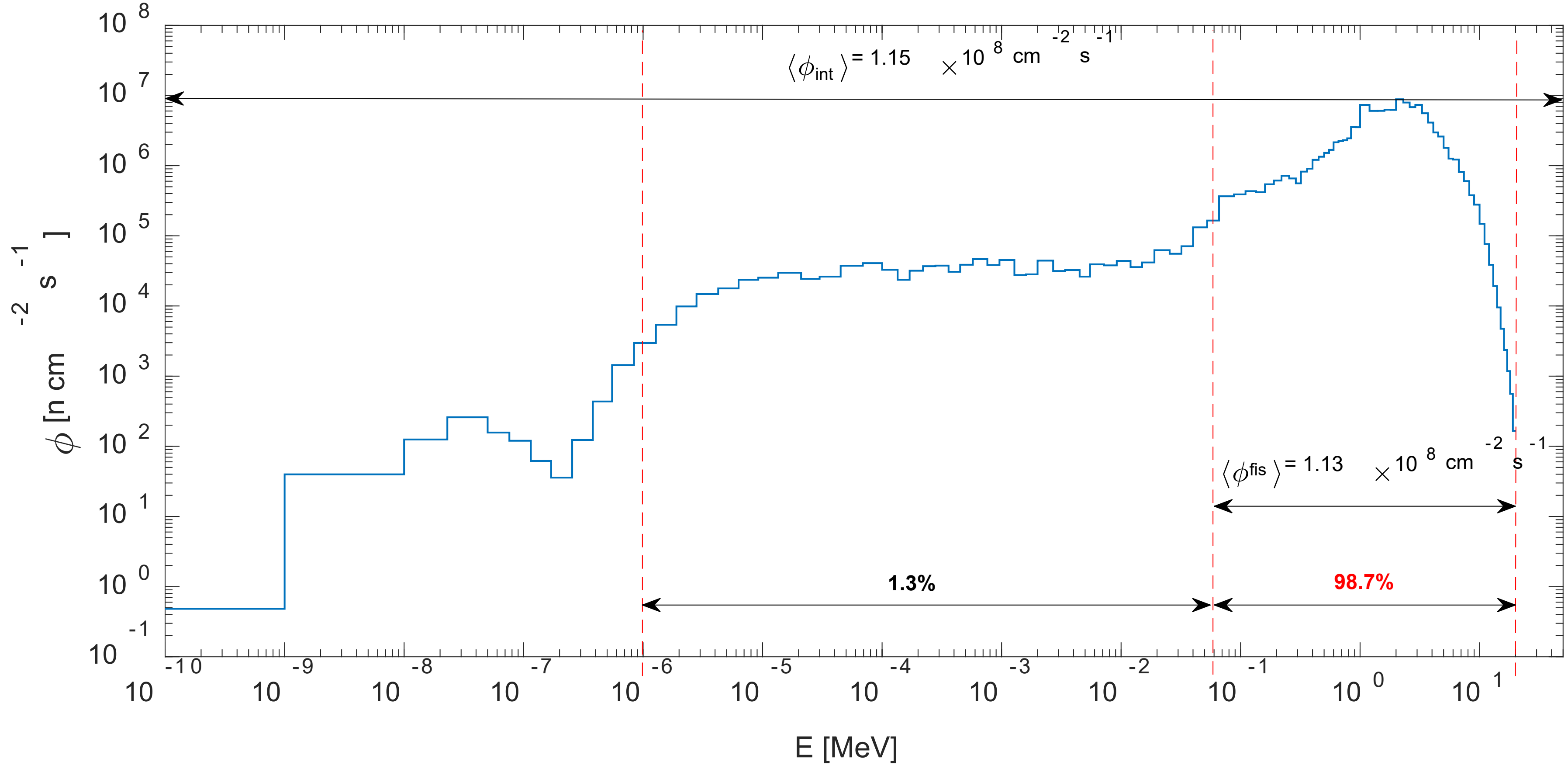


Source: J. Feil

FANGAS INSTRUMENT

Neutron spectrum (@ sample position)

Obtained by foil activation method and spectrum unfolding with software STASYL PNNL (by Z. Ilic)



98.7% fission neutrons

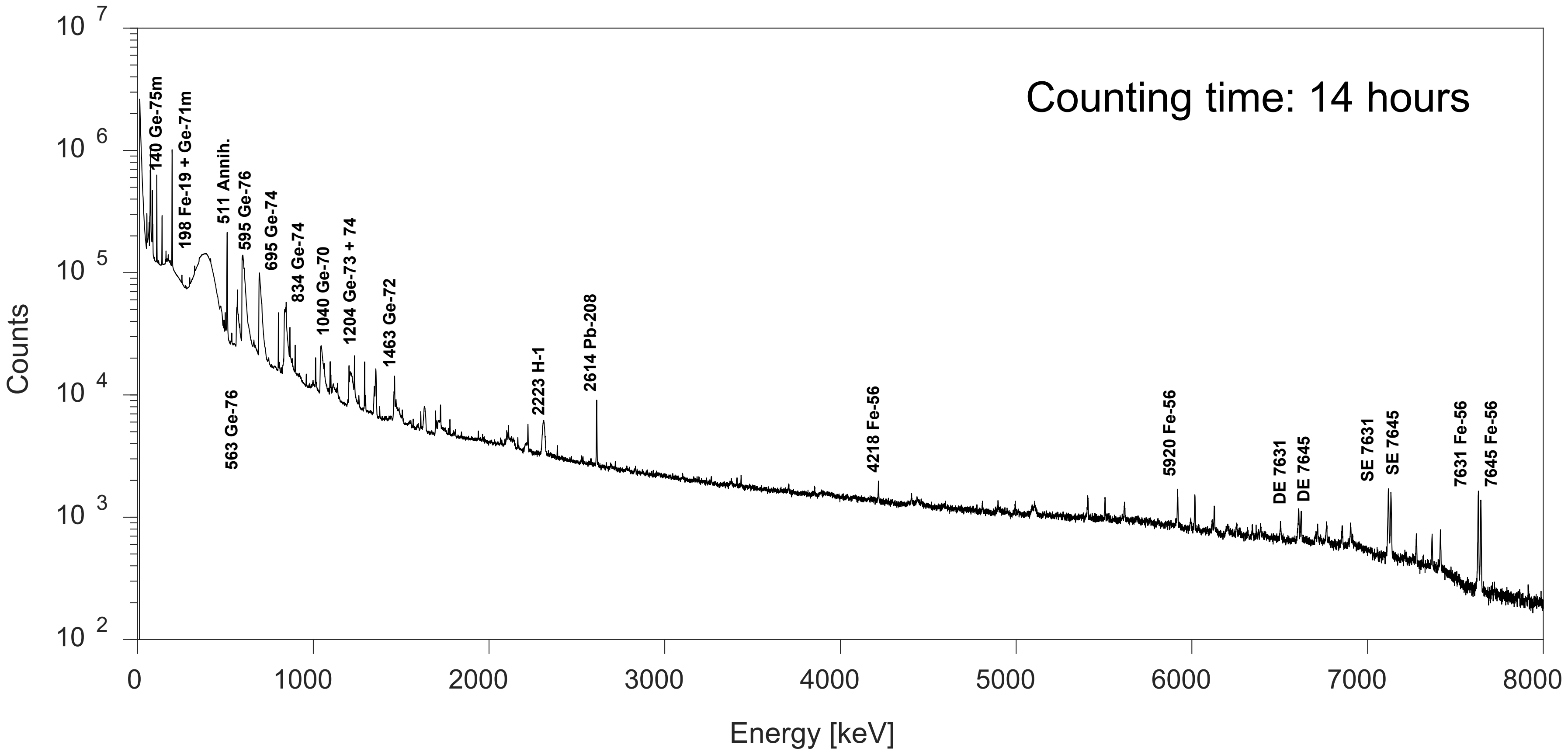
- 0.06 MeV to 20 MeV

1.3% resonance neutrons

- 0.1 eV to 0.06 MeV

Mean energy: **2.3 MeV**

BACKGROUND SPECTRUM



Z. Ilic et al., JRNC (2020)

QUANTIFICATION

$$P_{E\gamma}(90°) = \frac{m}{M} \cdot N_{Av} \cdot h \cdot \varepsilon_{E\gamma} \cdot f_n \cdot f_{E\gamma} \cdot \langle \sigma_{E\gamma}(90°) \rangle \cdot \Phi_{fast} \cdot t_c$$

Limit of detection

Solving for m with $P_{E\gamma}(90°)$ as:

$$P_{E\gamma}(c) = \sqrt{2 \cdot B_{E_\gamma}}$$ (Interference free)

$$P_{E\gamma}(c) = \frac{\sqrt{2 \cdot \left(P_{int} + 2 \cdot B_{E_\gamma}\right)}}{c}$$ (With interference)

c= 0.5, i.e. 50% uncertainty using beam background spectrum

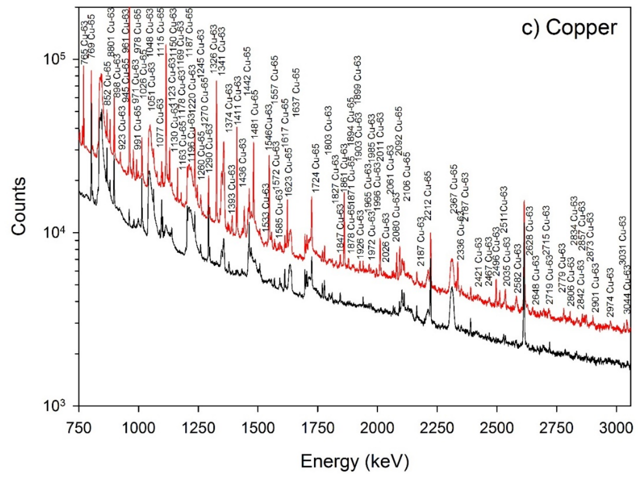
$B_{E\gamma}$ determined with **HYPERMET-PC**

Parameters:
$P_{E\gamma}$: Gamma-ray peak area
m: Element mass [g]
M: Molar mass [g mol^{-1}]
N_{Av}: Avogadro constant (6.022 x 10^{-23} mol^{-1})
h: Isotopic abundance
$\varepsilon_{E\gamma}$: Full-energy-peak (FEP) efficiency
f_n: Neutron self-shielding factor
$f_{E\gamma}$: Gamma self-absorption factor
$\langle \sigma_{E\gamma}(90°) \rangle$: Isotopic partial gamma-ray production cross section [b]
Φ_{fast}: Fast neutron flux [cm^{-2} s^{-1}]
t_c: Counting live time [s]
$B_{E\gamma}$: Area of background below gamma line
P_{int}: Net area of interfering peak
c: Predefined parameter (c= 0.5)

MEASUREMENTS (2016-2019)

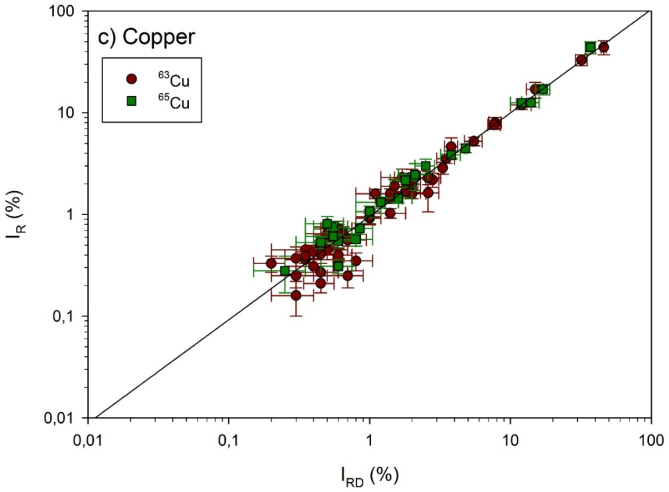
Relative intensities and partial cross section of gamma-rays for:

**C, O, Na, Al, Si, S, Cl, K, Ca, Ti, Fe,
Ni, Cu, Zr, In, La, Ce, Pr, Sm, Tb**



- Comparison with Demidov data (1978):

- Good agreement (0.6 – 1.6σ level)
- Some gamma-rays wrongly assigned or unassigned by Demidov
- More gamma-rays detected due to better detector resolution and higher neutron excitation energy (2.3 MeV vs. 0.6 MeV)



- Limit of detection for 12 h counting time:

mg i.e μg/g range

WORKS IN PROGRESS – FUTURE WORKS

- Development of the method for chemical analysis of large samples (PhD-work Niklas Ophoven)
- Determination of partial cross sections for the FaNGaS neutron spectrum from the Demidov´s data
- Characterization of permanent magnets for industrial sorting/recycling using fast neutrons (GNeuS-Project, Iaroslav Meleshenkovkii)

- Measurement of Sc, V, Co, Zn, Y, Eu, Gd, Ho, Er, Tm and Lu (planed from 2020)
- Developement of advanced gamma-ray software (SimLab, Marina Ganeva)
- Coupling of Fast Neutron Imaging with FaNGaS

THANK YOU!

Jülich Centre for Neutron Science

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