High-precision measurement of the inelastic neutron scattering cross section of ^{19}F at GELINA

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Neutrons for the next decade and beyond, 4-6 February 2019, iThemba LABS, Cape Town, South Africa

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Outline

- Introduction
  - Joint Research Centre
  - JRC Geel site
- Neutron measurements at JRC Geel
  - MONNET
  - GELINA
    - Different experimental setups
    - $^{19}F(n,n'\gamma)$ + $^{7}Li(n,n'\gamma)$ cross-section measurements at GELINA

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JRC's Mission – Measurements matter

"As the science and knowledge service of the Commission our mission is to support EU policies with independent evidence throughout the whole policy cycle"

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The JRC within the Commission

28 Commission Members

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President

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Strategy & Coordination

Knowledge Production

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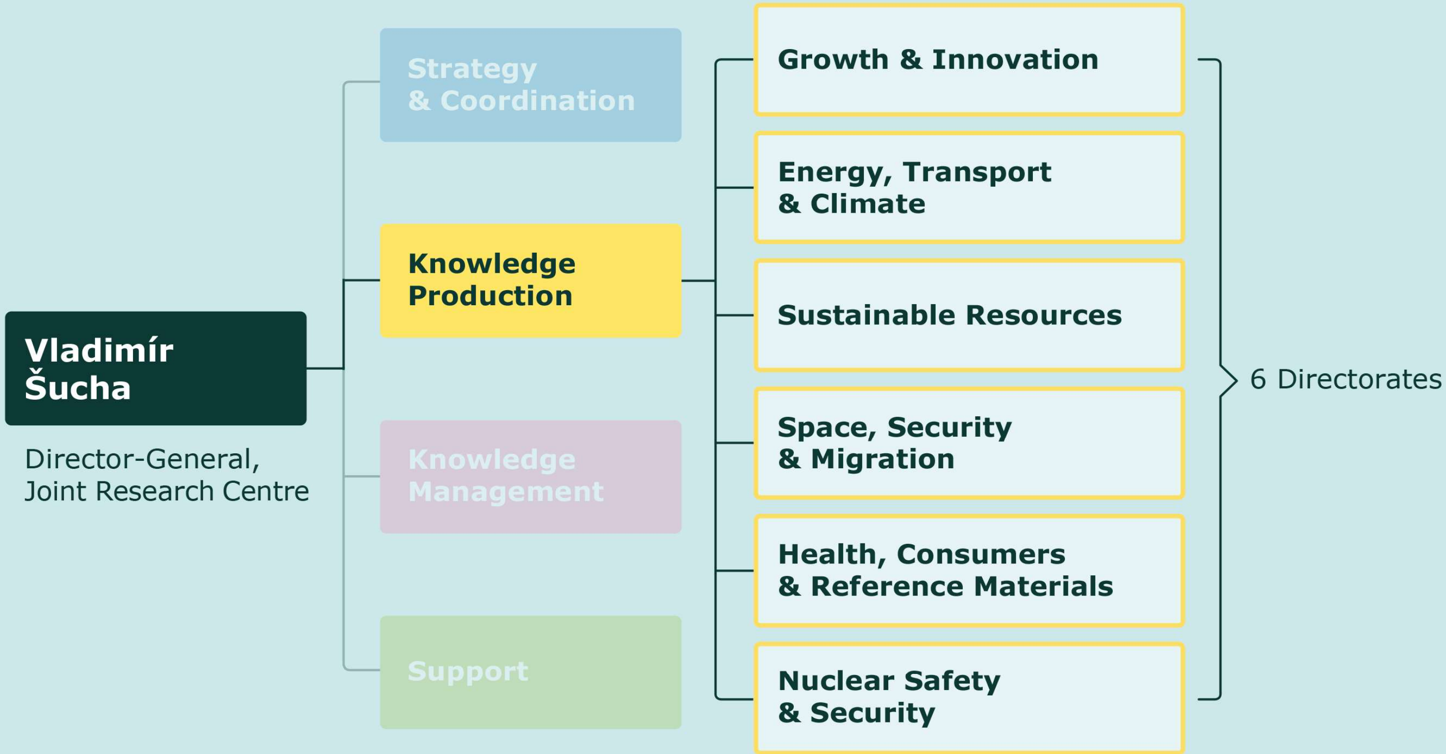
The JRC within the Commission



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JRC sites

Headquarters in Brussels and research facilities located in **5 Member States:**

- Belgium (Geel)
- Germany (Karlsruhe)
- Italy (Ispra)
- The Netherlands (Petten)
- Spain (Seville)

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Evolution of JRC-Geel site

1957	Euratom Treaty
1960	Central Bureau for Nuclear Measurements (CBNM)
1993	Renamed 'Institute for Reference Materials and Measurements' (IRMM)
2016	Hosting 5 JRC-Directorates: JRC.A / JRC.E / JRC.F / JRC.G / JRC.R + AMC-8 from DG HR

JRC-Geel site

Geel, Belgium

DIRECTORATE A
Strategy & Work Programme Coordination

DIRECTORATE D
Sustainable Resources

DIRECTORATE E
Space, Security & Migration

DIRECTORATE F
Health, Consumers & Reference Material

DIRECTORATE G
Nuclear Safety & Security

DG HR
Human Resources

DIRECTORATE I
Competences

DIRECTORATE R
Support Services

SCIENTIFIC AREAS

- Aviation Security and Chemical Threats
- Food & Feed Safety and Quality, Reference Materials
- Nuclear measurements & reference materials

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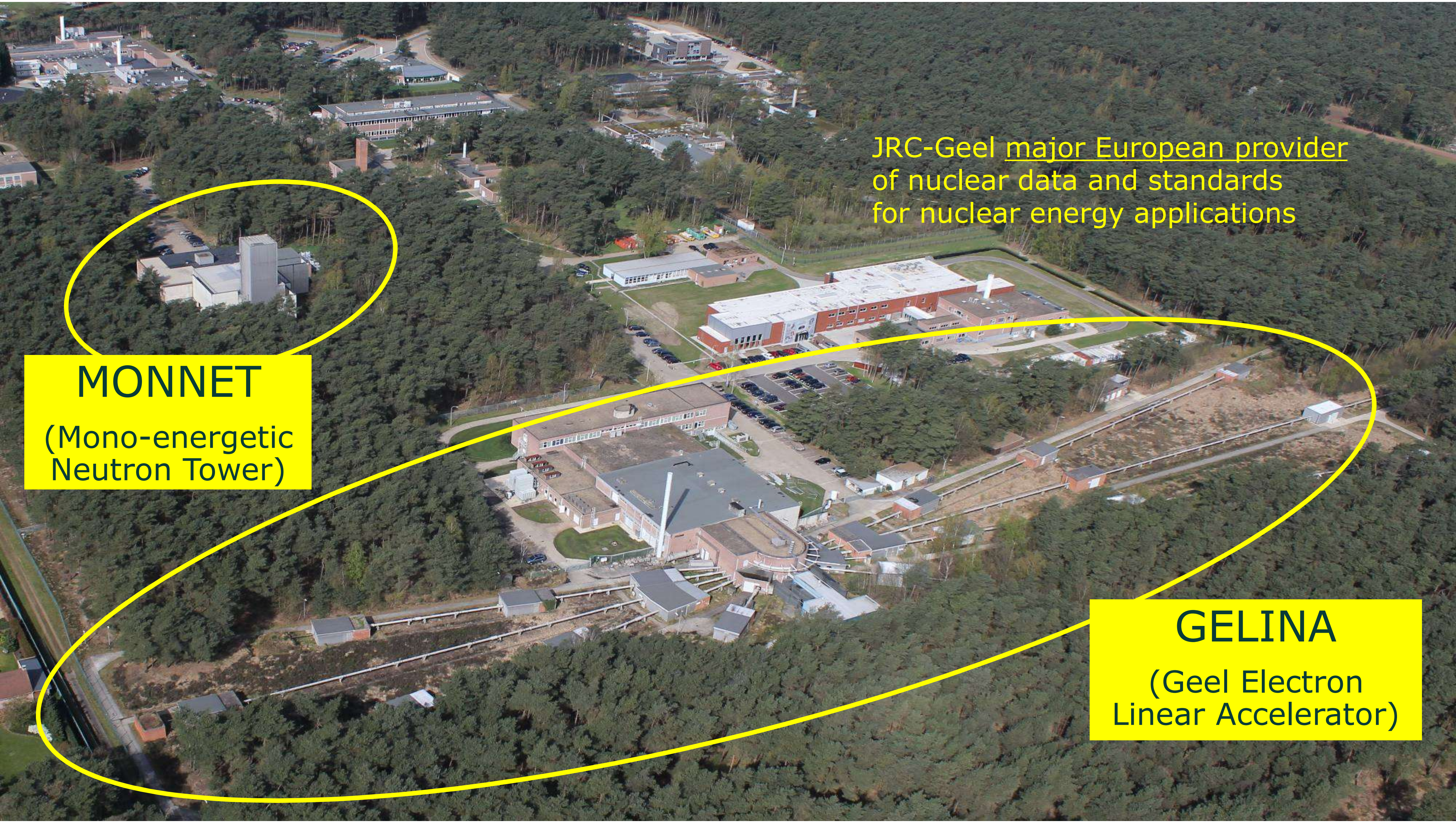
Nuclear measurements at JRC Geel

- Two neutron sources
  - GELINA = electron linac white neutron source
  - MONNET = quasi mono-energetic fast neutron source
- Radionuclide Metrology Laboratory
  - HADES underground ultra-low background facility at SCK•CEN
- Nuclear Mass Spectrometry
- Nuclear Chemistry
- Nuclear Target Preparation


JRC-Geel major European provider
of nuclear data and standards
for nuclear energy applications
MONNET
(Mono-energetic
Neutron Tower)
GELINA
(Geel Electron
Linear Accelerator)

MONNET

- Vertical 3.5 MV Tandem accelerator
- Continuous or pulsed ion beams
  - protons, deuterons or helium ions
  - lithium, deuterium or tritium targets
- Quasi mono-energetic neutrons up to 24 MeV
- Beam lines with dedicated experimental set-ups for activation, fission and scattering experiments

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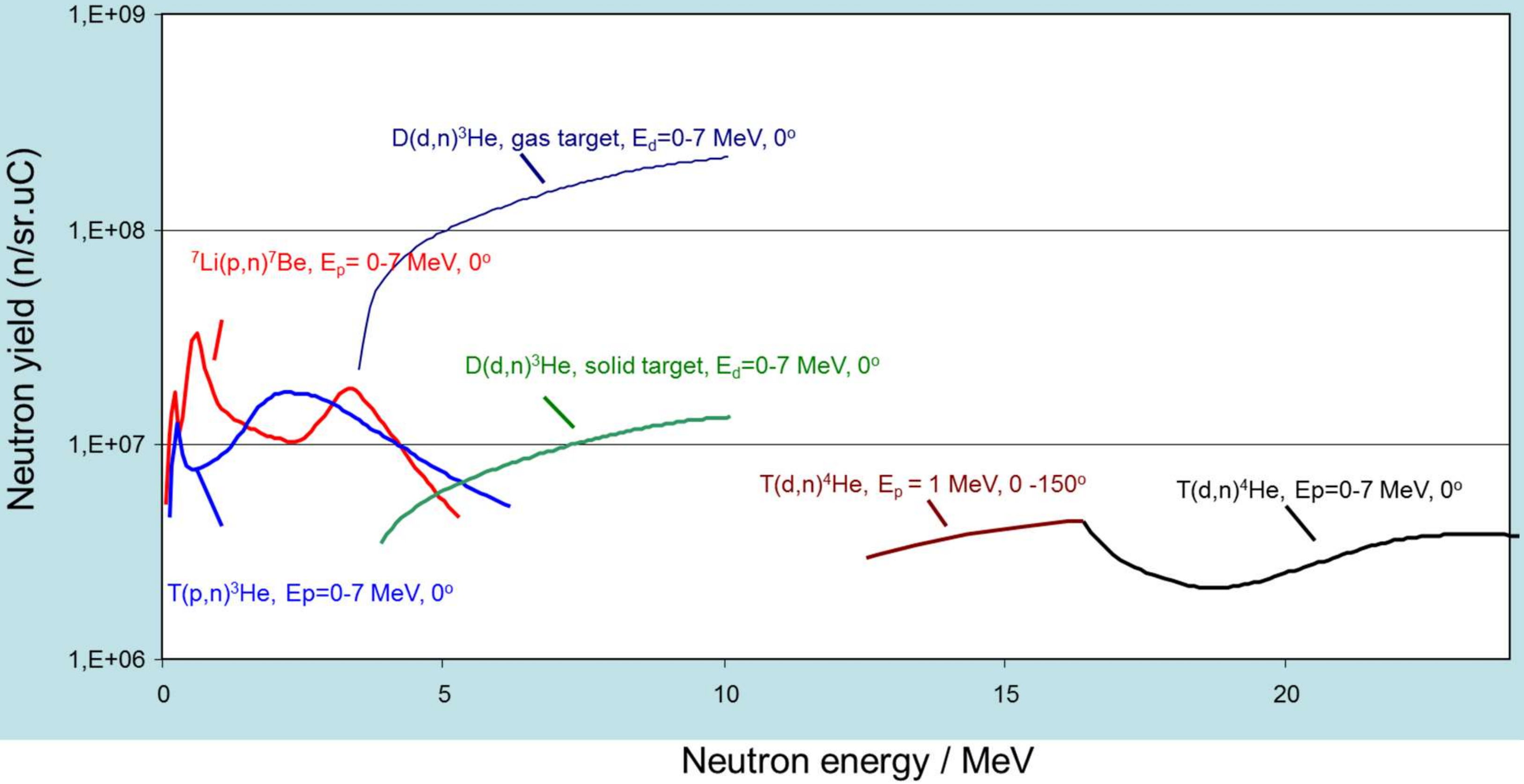
MONNET



Neutron yield (n/sr.uC)
1,E+09
1,E+08
1,E+07
1,E+06
D(d,n)3He, gas target, Ed=0-7 MeV, 0o
7Li(p,n)7Be, Ep= 0-7 MeV, 0o
D(d,n)3He, solid target, Ed=0-7 MeV, 0o
T(d,n)4He, Ep = 1 MeV, 0 -150o
T(d,n)4He, Ep=0-7 MeV, 0o
T(p,n)3He, Ep=0-7 MeV, 0o
0
5
10
15
20
Neutron energy / MeV

GELINA

- GELINA (Geel Electron Linear Accelerator)
  - Pulsed white neutron source, e^- beam → $^{dep}U(Mo)$ target → neutrons from (γ,xn) and (γ,F) reactions
  - Neutron pulse FWHM < 1 ns when leaving the target, neutron energy determined from the time – of – flight (TOF)
  - Can be operated at different frequencies, typically 50 Hz or 400 (800) Hz
  - Multi-user facility: 12 flight paths (10 m – 400 m)
  - Dedicated flight paths for fast (200 keV – 20 MeV) or moderated (1 meV – 300 keV) neutrons

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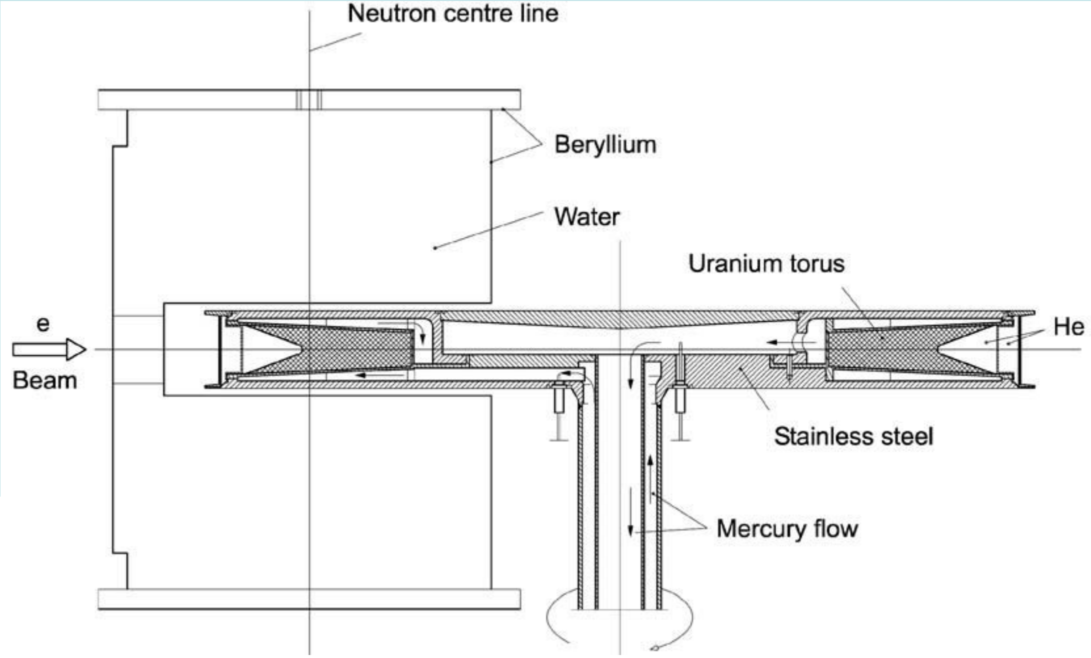
GELINA target

- Rotating target wheel cooled with mercury
- Average total neutron production rate 3.4×10^{13} neutrons/s
- Water moderators



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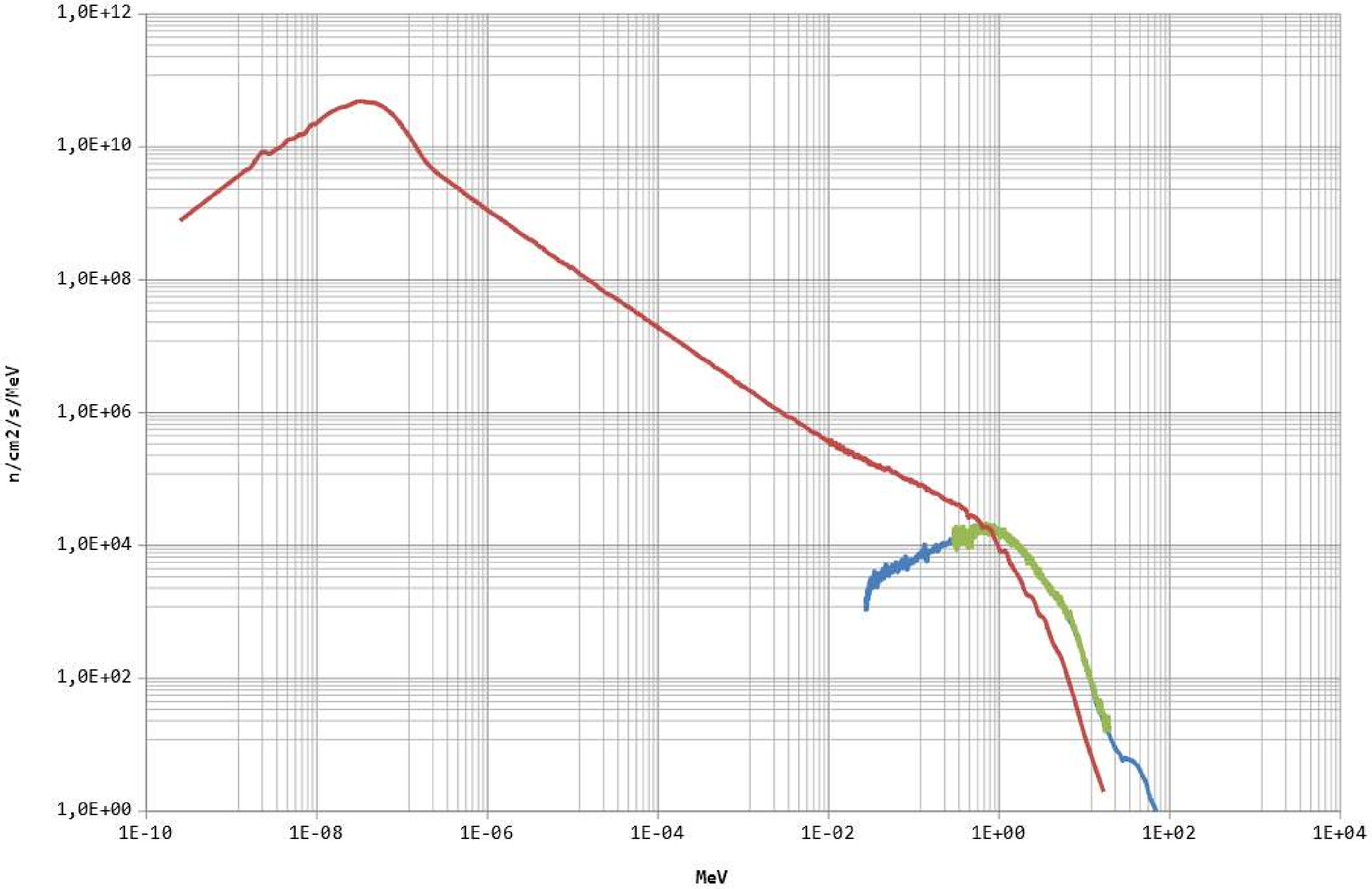
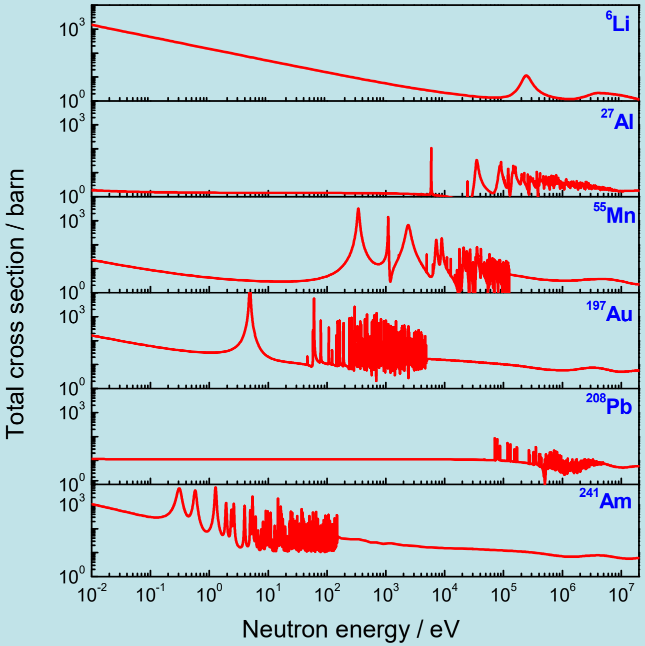
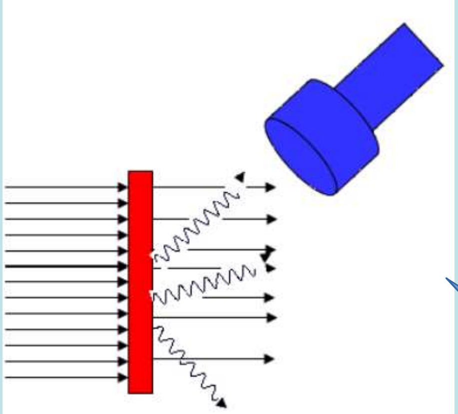
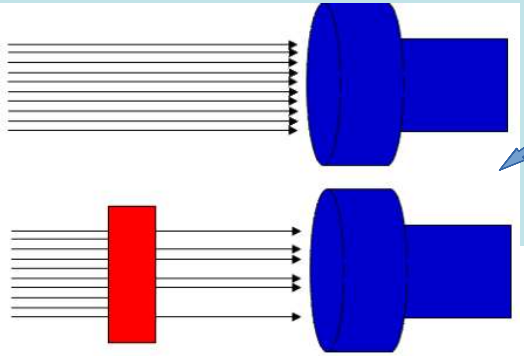
GELINA fast and moderated neutron spectra



Experimental setups at GELINA - NRA







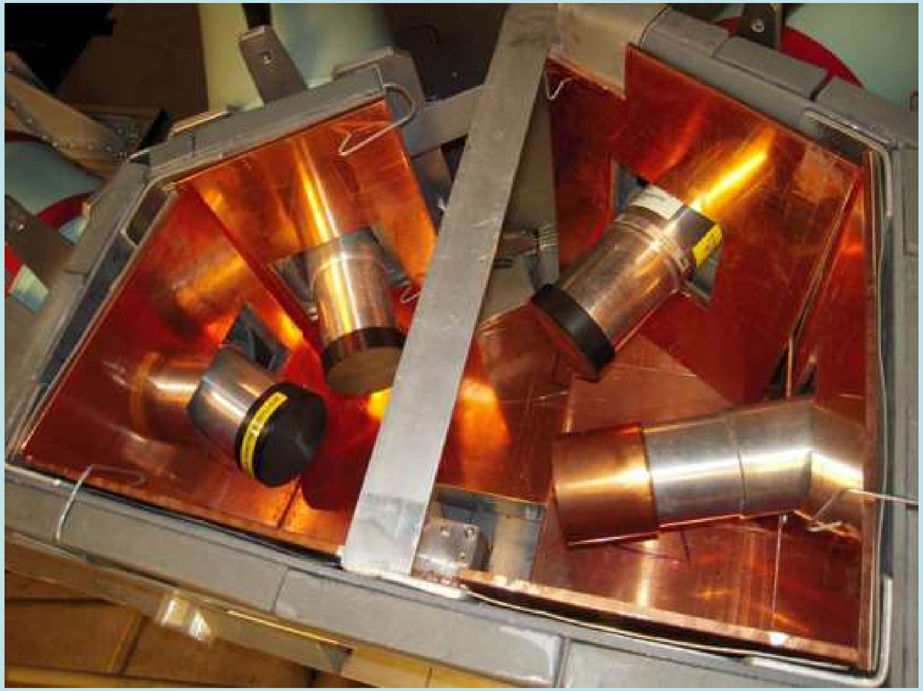
- Neutron Resonance Analysis
  - Resonances can be used as fingerprints to determine the elemental & isotopic composition of a material (from archaeological samples to melted fuel)
  - Neutron Resonance Capture Analysis (NRCA)
    - Capture γ rays
  - Neutron Resonance Transmission Analysis (NRTA)
    - Transmission measurement

Experimental setups at GELINA - NRA

- NRCA measurement of a bronze-age sword

- New NRTA measurement station

Experimental setups at GELINA - GRAPhEME



- For (n,n'γ) cross section measurements of actinides
- 5 planar HPGe + 1 segmented (to reduce count rate per pixel for radioactive samples)
- Thin samples → setup close to the neutron source (30 m)
- ^{235}U fission chamber for neutron flux
- Digital data acquisition

Experimental setups at GELINA – ELISA

- For angular distribution and (in)elastic scattering cross section measurements
- 32 liquid organic scintillators
  - EJ301 (NE213) and EJ315 (C6D6)
  - Proton / deuterium based
- n/γ separation by pulse-shape analysis
- elastic/inelastic separation by unfolding the pulse-height spectrum
- ^{235}U fission chamber and digital DAQ

Four days ago: https://doi.org/10.1103/PhysRevC.99.024601

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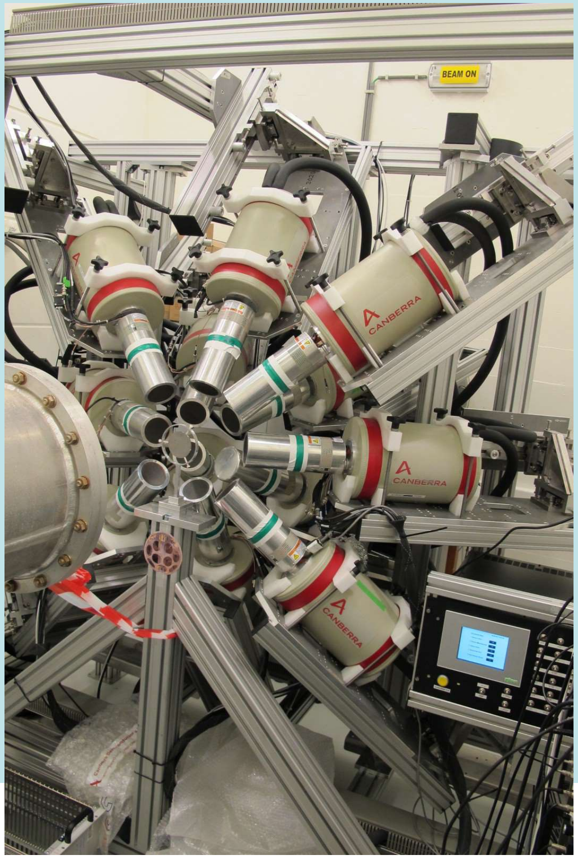
GAINS (Gamma Array for Inelastic Neutron Scattering)



- 12 coaxial HPGe detectors (8 cm x 8 cm) at 110º, 125º, and 150º, four at each angle
- 3 Acquiris DC440 digitizers for the HPGe detectors, 12 bit amplitude resolution, 420 MS/s
- ^{235}U Fission chamber 2.1 m upstream from the sample position to monitor the neutron flux
  - 8 UF_4 deposits (Ø 70 mm) on 5 Al foils (20 mm)
- Located at flight path 3, 100 m

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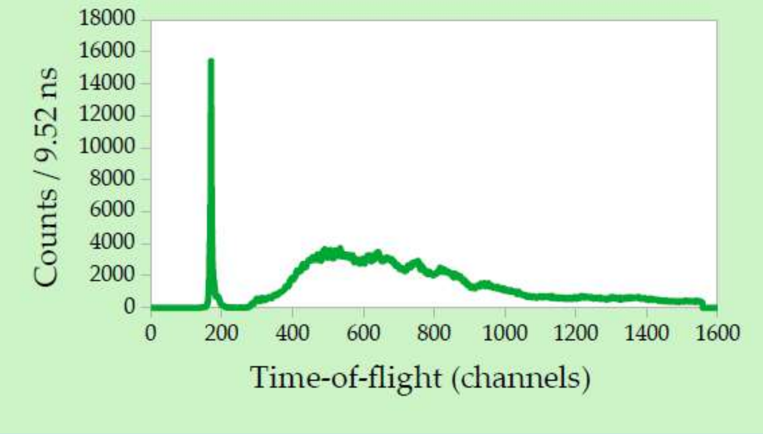
Time-of-flight technique

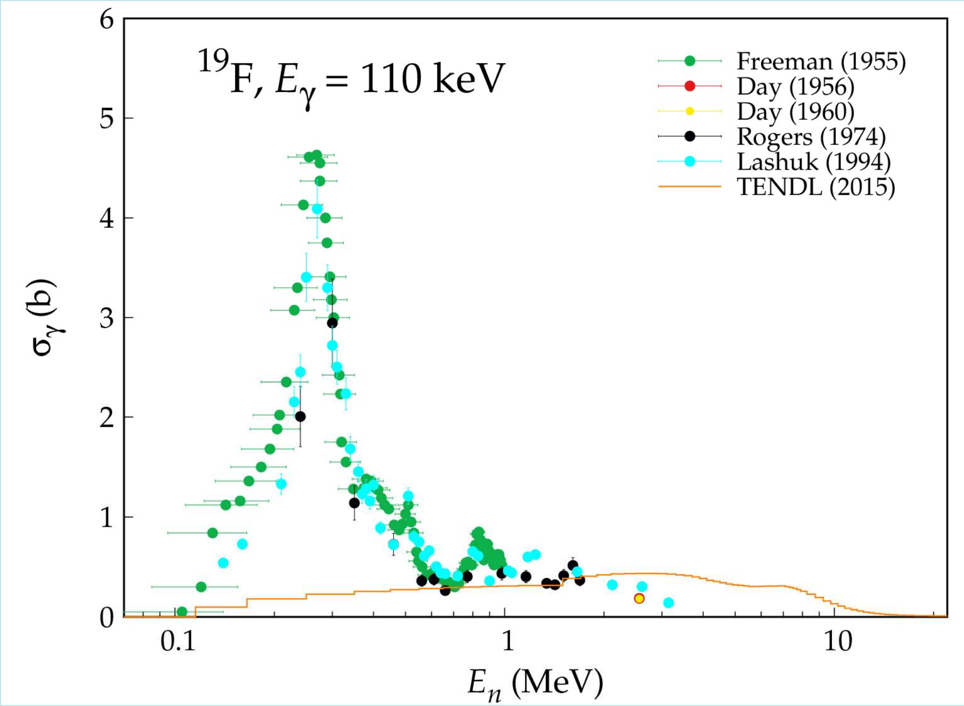
- E_n from the time difference between the electron beam hitting the target and the detection of γ rays
- The time resolution achievable with our HPGe detectors is about 10 ns
- → neutron energy resolution ~ 3 keV (E_n = 1 MeV) and 90 keV (E_n = 10 MeV) at 100 m
- Bremsstrahlung from the production target ("γ-flash") provides the time reference



$^{19}F(n,n'\gamma)$ cross-section measurement at GELINA

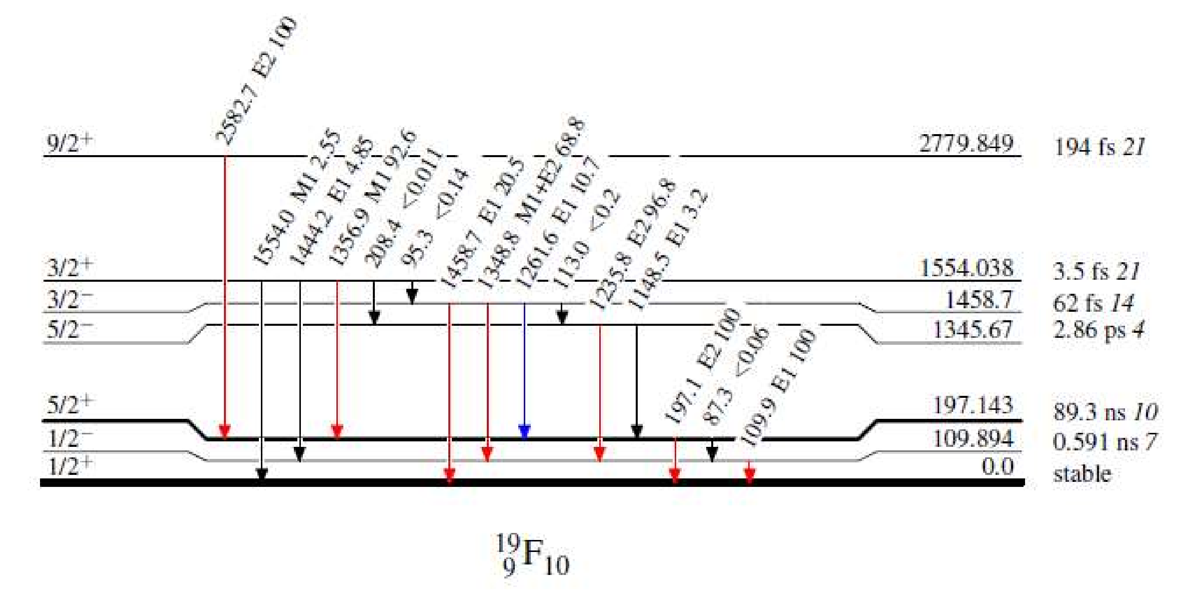
- Application: Molten salt reactors (MSR)
  - Use molten fluorides or chlorides as fuel mixtures or coolants
  - Advantages: good neutron economy, high temperature, safety (low pressure, passive cooling),...
  - In the GEN IV MSR (MSFR) the fuel is dissolved in molten fluoride salt
  - In the fluoride salt-cooled high-temperature reactor (FHR) the molten salt is the coolant for a solid-fuelled core

$^{19}F(n,n'\gamma)$ cross-section measurement at GELINA



- Inelastic neutron scattering is the main slowing-down mechanism for neutrons in nuclear reactors
- Therefore good knowledge of inelastic scattering cross sections is important for the design of more advanced systems
- Experimental data on the $^{19}F(n,n'\gamma)$ reaction is scarce and mostly from the fifties to seventies time period
- Data is especially lacking above few MeV neutron energy

$^{19}F(n,n'\gamma)$ cross-section measurement at GELINA



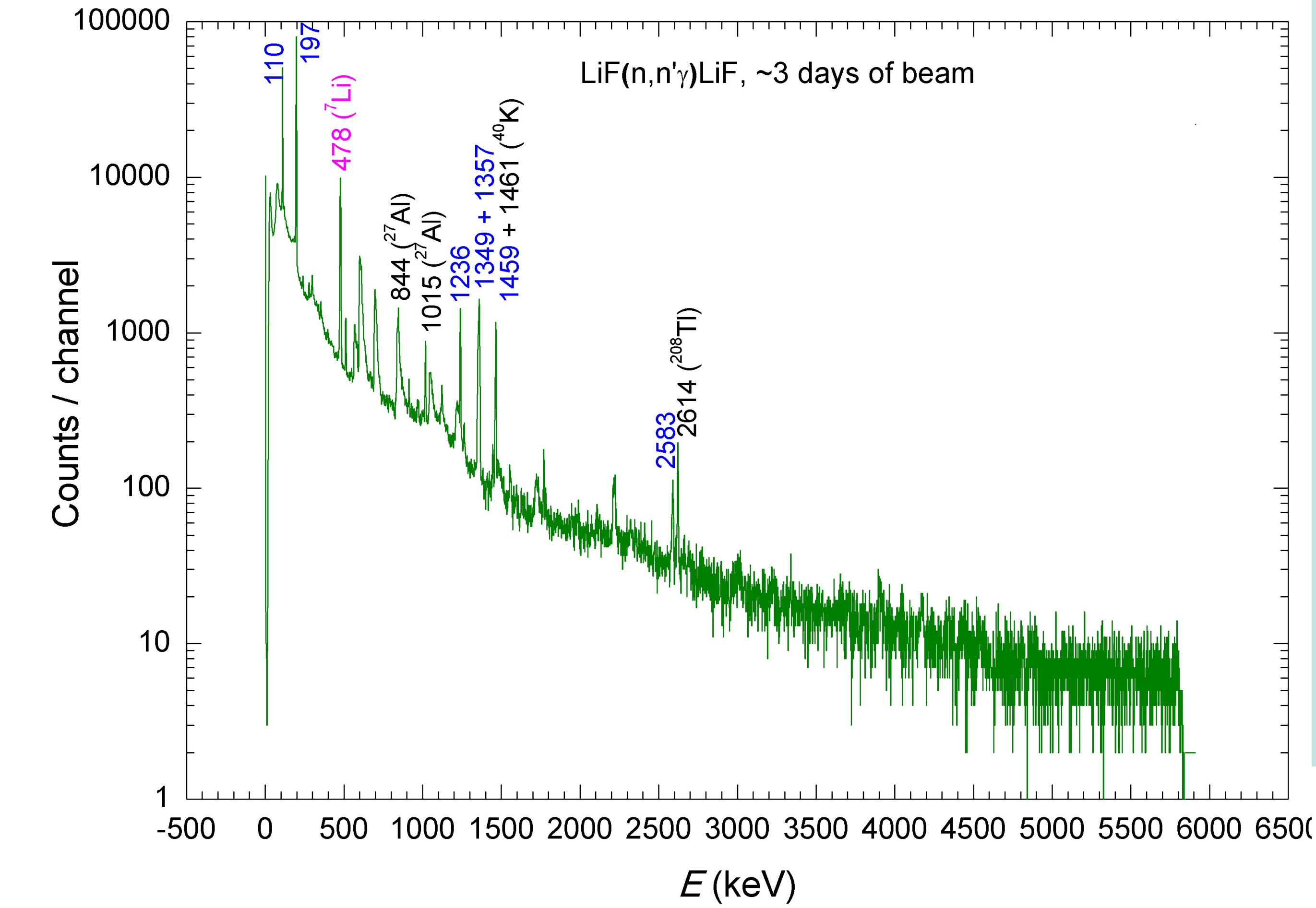
- Our aim was to measure the $^{19}F(n,n'\gamma)$ cross section for the first time with
  - Good neutron-energy resolution
  - Low total uncertainty (<5% for the most important transitions)
- We measure the individual γ-production cross sections
- Level and total inelastic cross sections are calculated from these (up to an excitation energy limited by observed gammas)

$^{19}F(n,n'\gamma)$ cross-section measurement at GELINA

Lithium fluoride sample:

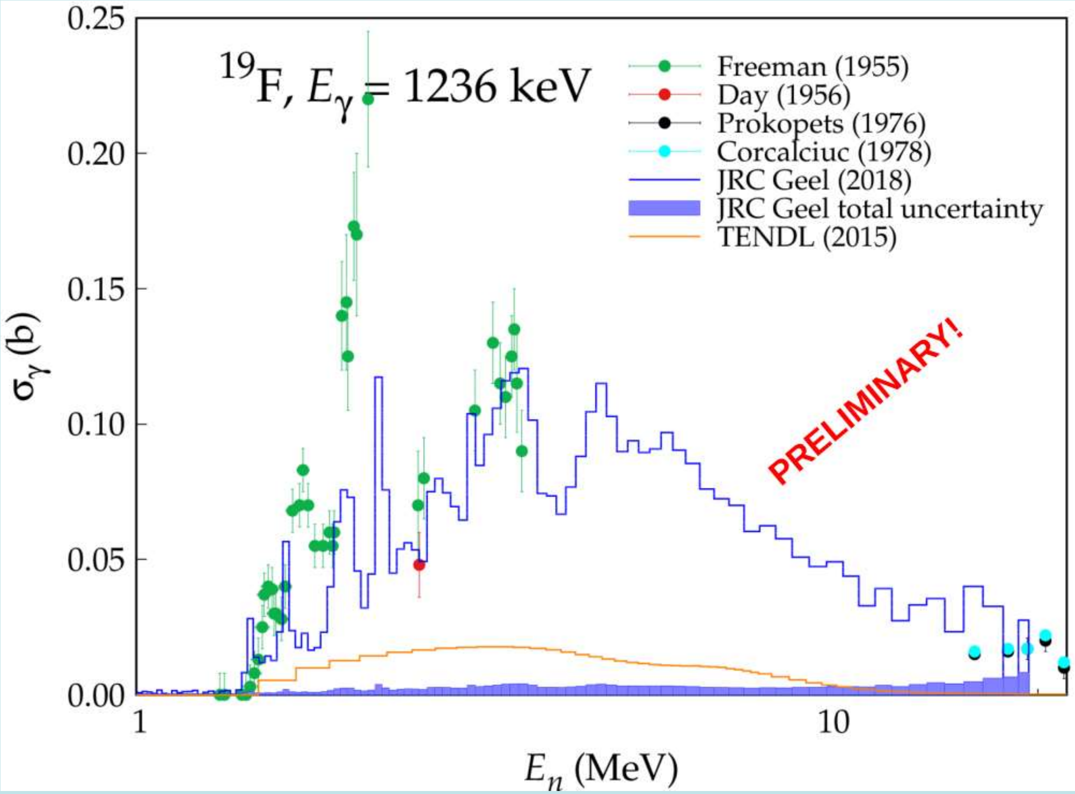
Area (mm^2)	5022.62(8)
Diameter (mm)	79.971(1)
Thickness (mm)	2.05(1)
Mass (g)	27.17(1)
Density (g/cm^3)	2.645(13)

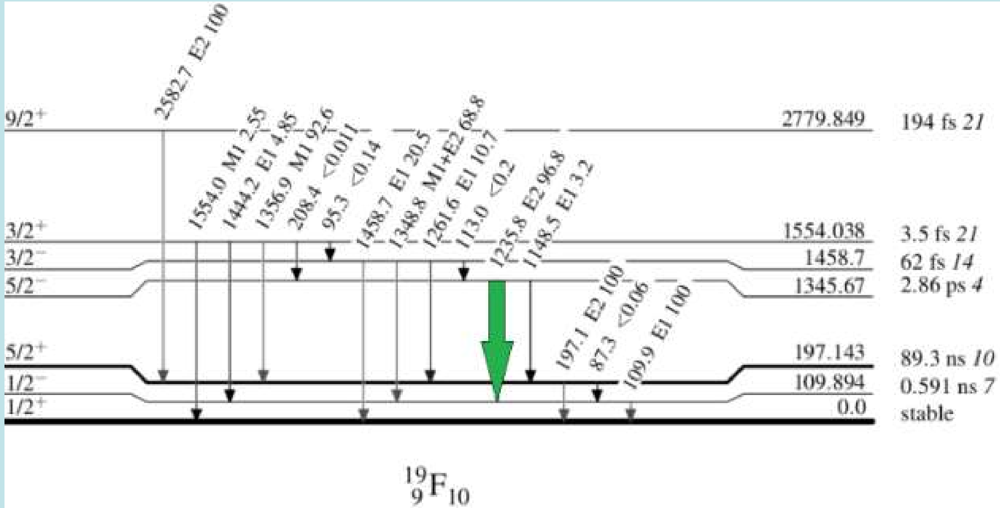
$^{19}F(n,n'\gamma)$ cross-section measurement at GELINA



A gamma-ray spectrum from the LiF(n,n'γ) reaction

$^{19}F(n,n'\gamma)$ cross-section measurement at GELINA





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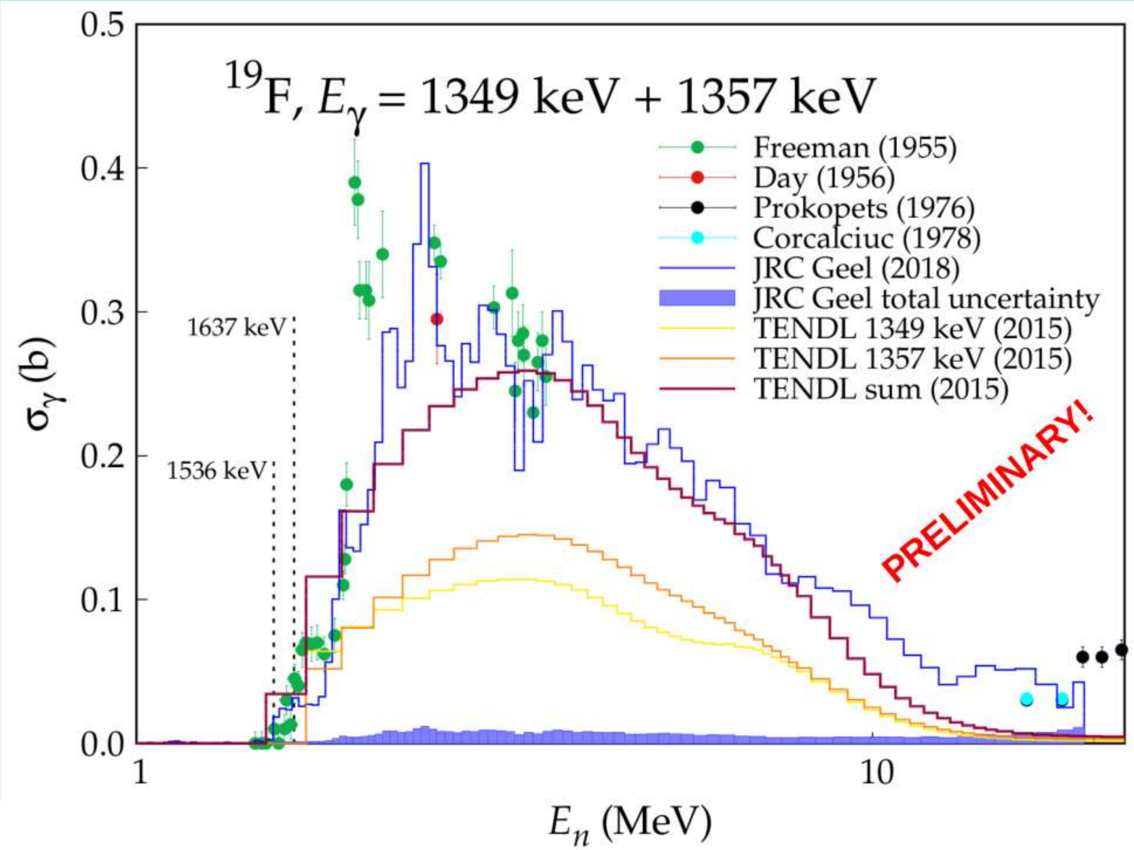
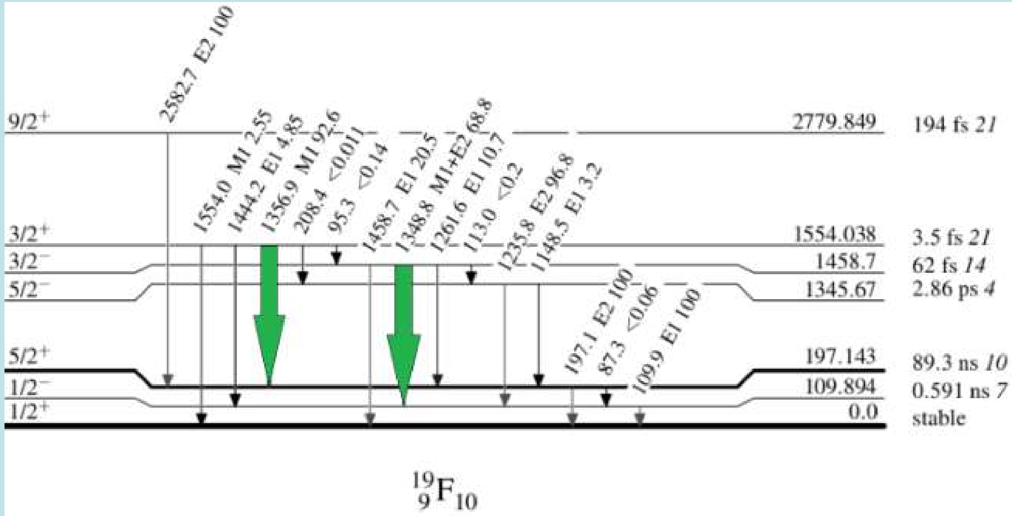
$^{19}F(n,n'\gamma)$ cross-section measurement at GELINA



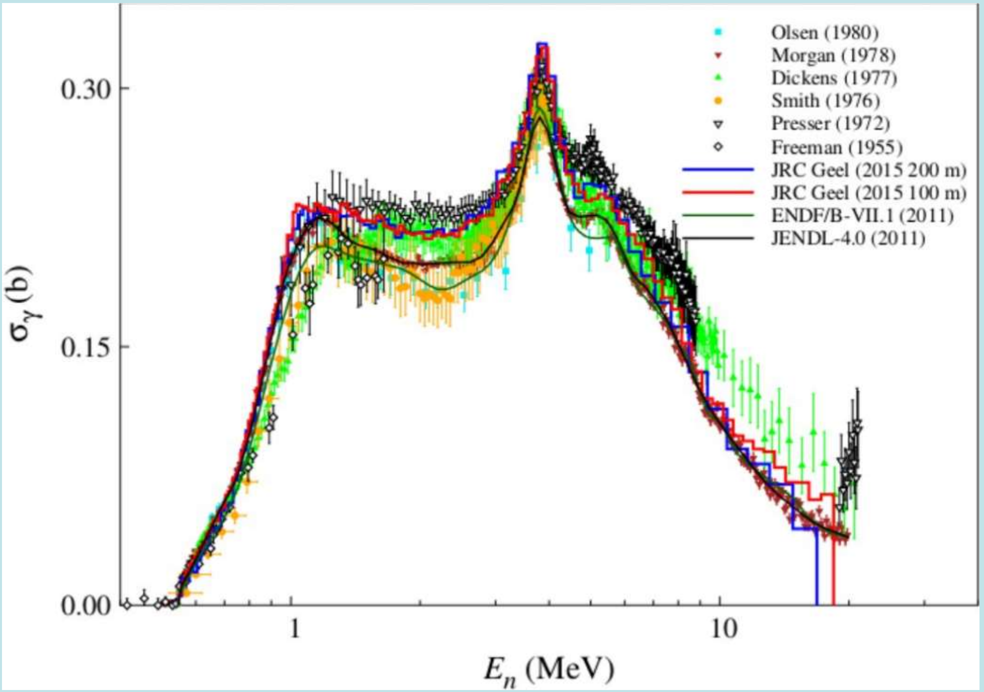


^{7}Li 478-keV γ-production cross section

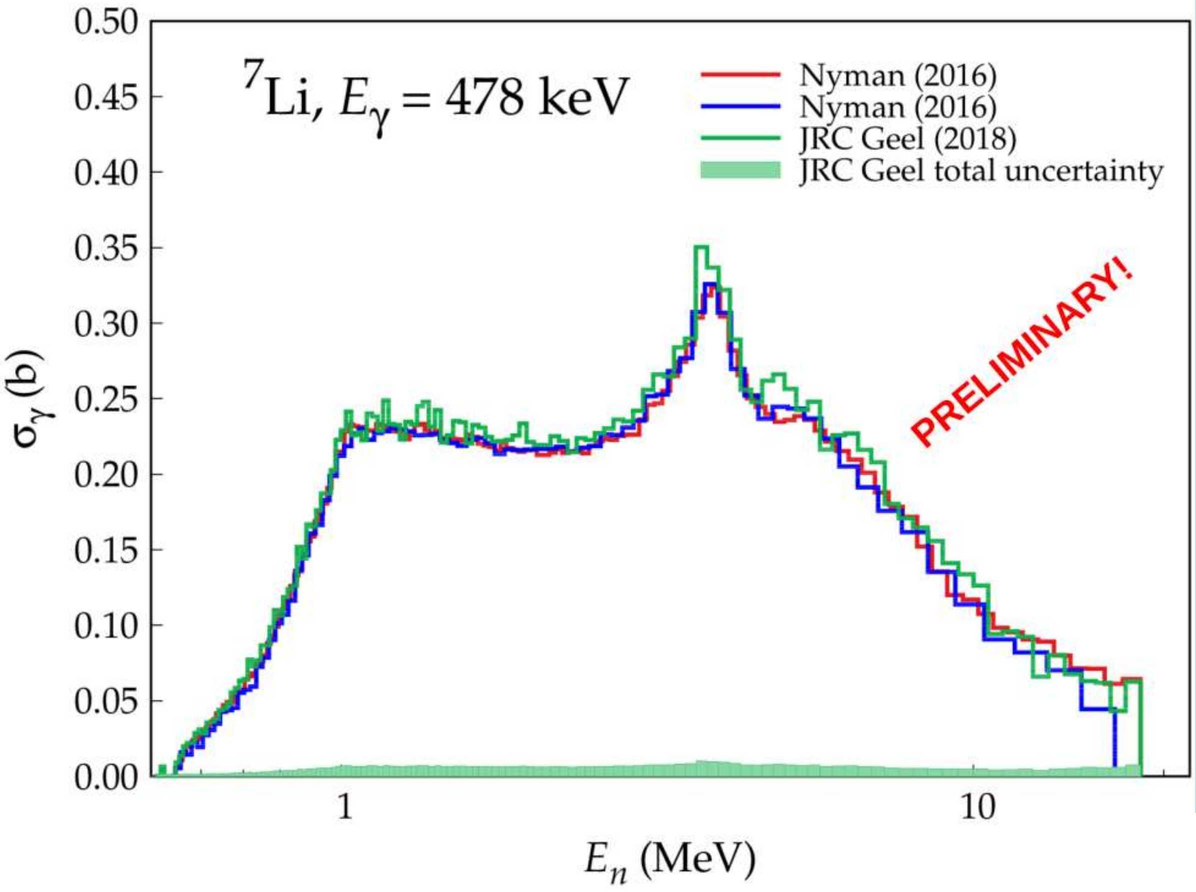
- The γ-ray production cross section of the 477.6-keV transition in ^{7}Li is a good candidate for a standard:
  - Isotropic γ-ray emission
  - Negligible IC coefficient
  - Low inelastic threshold (546 keV)
  - Fairly smooth energy dependence of the cross section
  - Material readily available as LiF optical windows

^{7}Li 478-keV γ-production cross section

- Two experiments were carried out at JRC Geel in 2015 (one at FP3/200m and one at FP3/100m)
- The results agreed with each other, but there are significant discrepancies between earlier data sets
- An attempt was made in 2016 to confirm JRC Geel results at nELBE in HZDR Dresden – with conflicting results…
- Another measurement at nELBE with improved setup was made, results pending
- The ^{19}F experiment gave us another chance to look at this transition



^{7}Li 478-keV γ-production cross section



- Very good agreement with previous data from JRC Geel
- If I am getting it wrong at least I am doing so very consistently!

Open access to JRC Research Infrastructures

https://ec.europa.eu/jrc/en/research-facility/open-access

- The JRC offers access to its nuclear facilities to EU Member States, candidate countries (on the conditions established in the relevant agreement or decision) and countries associated to the Euratom Research Programme
- For use of JRC Geel facilities: European research infrastructure for nuclear reaction, radioactivity, radiation and technology studies in science and applications (EUFRAT)
- Some collaboration outside EU through bilateral agreements (ORNL-DoE and JAEA)

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Collaborators (a non-exhaustive list)

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THANK YOU!

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