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γ-ray production cross sections of inelastic neutron scattering on natural molybdenum

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Outline

- Introduction
- The GELINA facility
- The GAINS spectrometer
- The (n,n'γ) technique
- Data analysis
- Results

Introduction

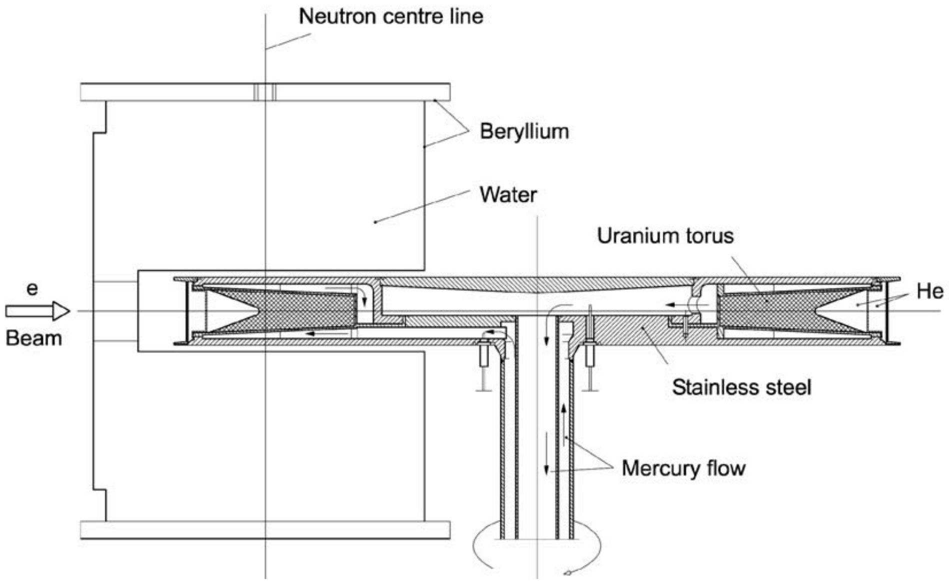
- Mo and/or Zr are being considered as inert fuel components for advanced reactor concepts
- Alloys containing Mo can be used as structural materials
- Inelastic scattering will play a significant role in modifying reaction rates by changing the neutron spectrum
- Measurements of inelastic neutron scattering cross sections were carried out on natural Mo and Zr samples at the GELINA facility at the IRMM, Geel

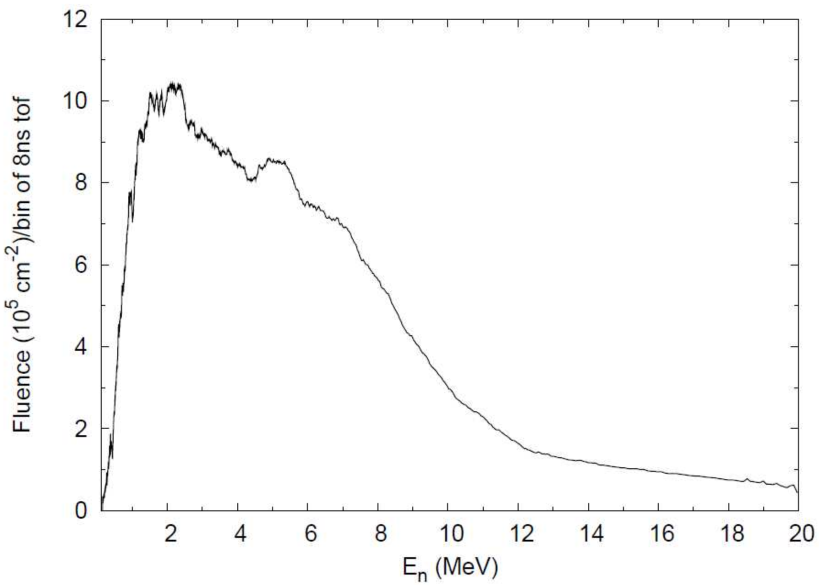
The GELINA facility

- Geel Electron LINear Accelerator
- Pulsed white neutron source (800 Hz), FWHM < 1 ns
- Electron beam hits a uranium target
- Neutrons produced in the target by photon induced reactions (bremsstrahlung)
- Flight paths from 8 m up to 400 m in length
- These experiments were done at FP3 / 200 m station

The GELINA target

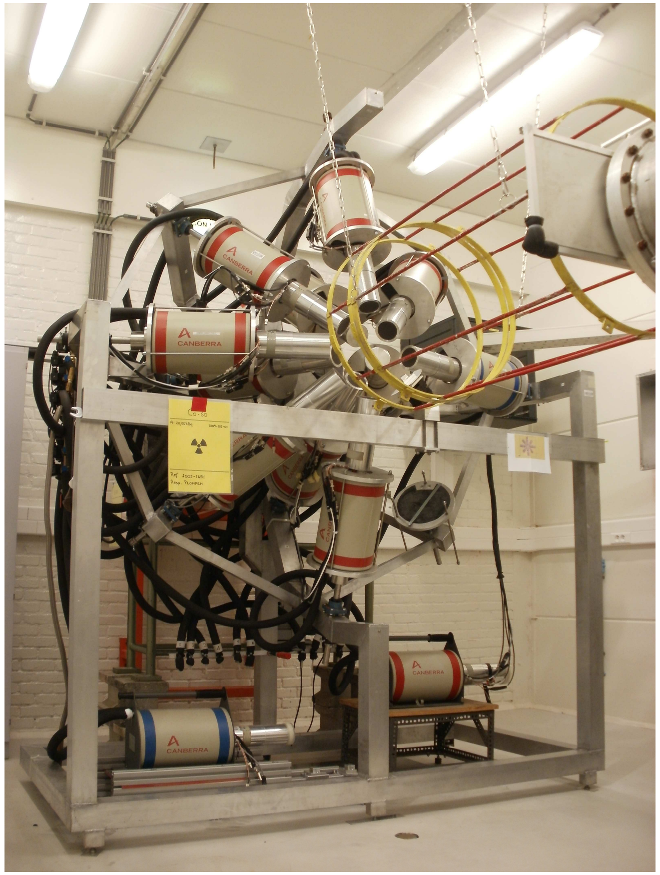
- Fast and moderated neutron spectra available for different flight paths





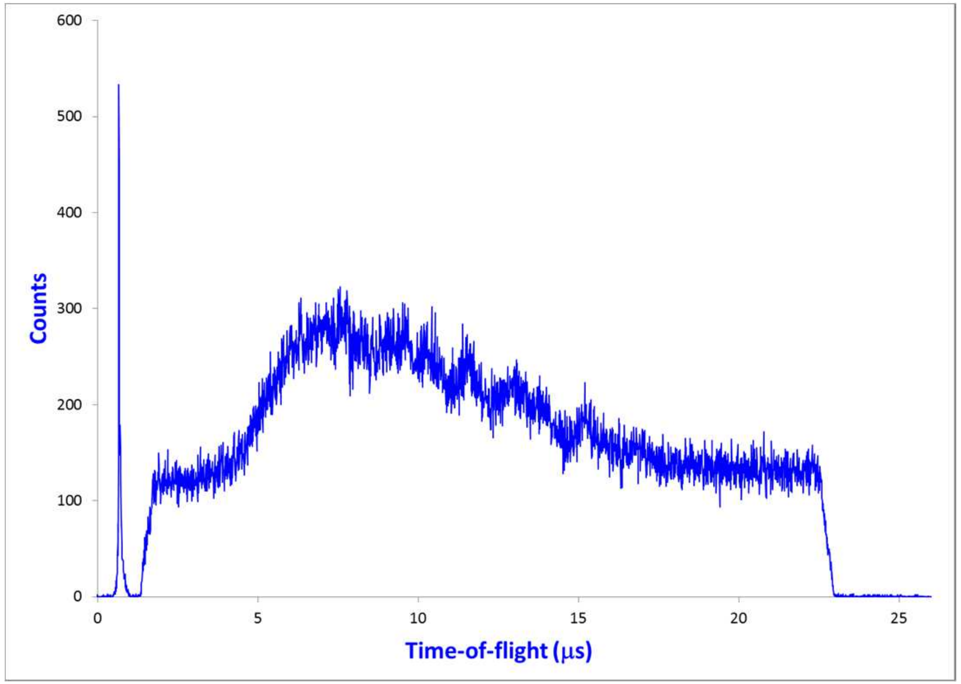
Gamma Array for Inelastic Neutron Scattering

- Recently upgraded to 12 HPGe detectors, about 100% relative efficiency
- Detectors at 110, 125, and 150 degrees, four detectors at each angle
- Fission chamber 1.3 m upstream from the sample position to monitor neutron flux
- 8 UF_4 deposits (Ø 70 mm) on 5 Al foils (20 μm)
- 3 Acquiris DC440 digitizers, 12 bit amplitude resolution, 440 MS/s



The (n,n'γ) technique

- E_n from the time-of-flight between the electron beam hitting the target and the detection of γ rays from inelastic scattering
- At 200 m tof = 3.3 – 20.5 μs for E_n = 20 – 0.5 MeV
- Time resolution of about 10 ns corresponds to a neutron energy resolution of about 1 keV at 1 MeV

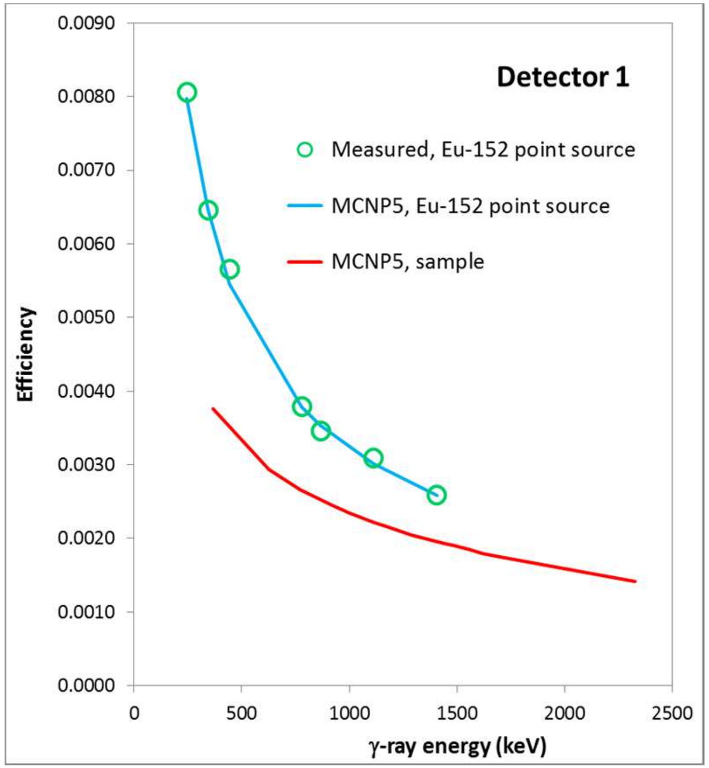


Data analysis

- Data is sorted into tof vs. E_γ matrices
- The primary experimental quantities are the differential γ-ray production cross sections
- These can be angle integrated to give the total γ-ray production cross sections
- Level cross sections are determined from σ_γ by subtracting feeding from higher levels
- As long as at least one γ ray per level is observed, the total inelastic cross section can be deduced
- Knowledge of the level scheme is necessary

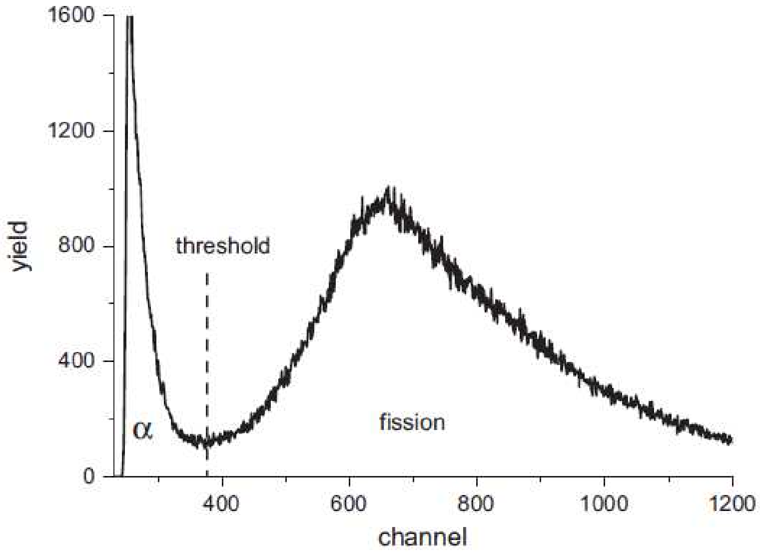
HPGe efficiency calibration

- An accurate efficiency calibration for the HPGe detectors is essential
- The calibration procedure:
  - An Eu-152 point source is used to determine ε in that geometry
  - MCNP5 simulation is the used to fix a model of the setup until ε_{SIM} matches ε_{EXP} for the point source
  - After this the point source in the simulation is replaced with the measured sample and the MCNP5 simulation is repeated
  - For details: D. Deleanu et al., Nucl. Inst. and Meth. A 624 130 (2010)



Fission chamber efficiency

- An accurate efficiency calibration for the fission chamber is essential
- Corrections are made to account for the following:
  - Number of fission fragments below threshold
  - Polarity effect
  - Inhomogeneity of the UF_4 foils
  - Number of fission fragments stopping in the foil
  - For details: C. Rouki et al., Nucl. Inst. and Meth. A 672 82 (2012)



Inelastic neutron scattering on ^{NAT}Mo

- Experiment was done at the IRMM 6.4. – 15.6.2011
- Total molybdenum data taking time was 26 days
- Sample was 99.95 % molybdenum, from Alfa Aesar

Sample physical properties

Mass	114.32(1)	g
Diameter	80.404(2)	mm
Areal density	2.2515(1)	g/cm^2
Thickness	2.0(1)	mm
Density	11.3(6)	g/cm^3

Mo isotopic abundances (%)

Mo-92	14.77(31)
Mo-94	9.23(10)
Mo-95	15.90(9)
Mo-96	16.68(1)
Mo-97	9.56(5)
Mo-98	24.19(26)
Mo-100	9.67(20)

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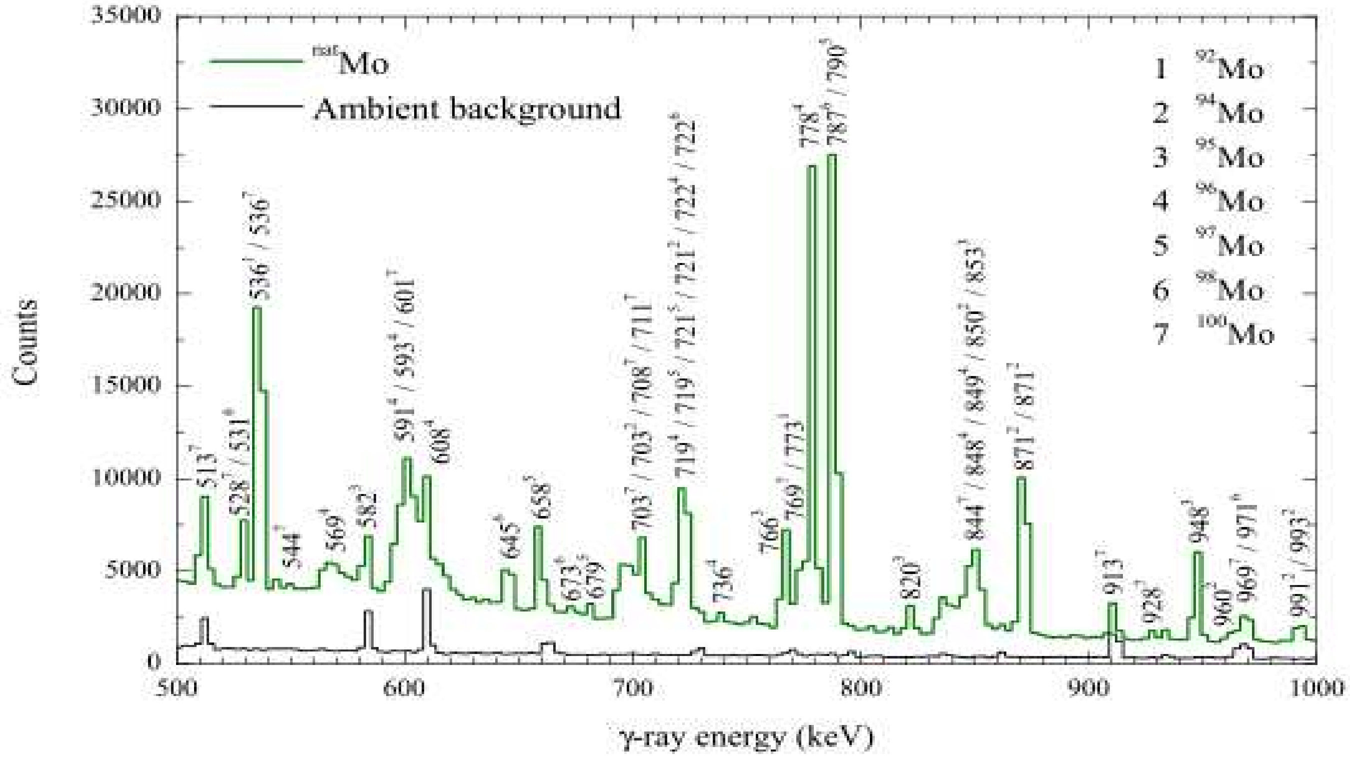
γ-ray spectrum from the reaction Mo(n,n'γ)Mo



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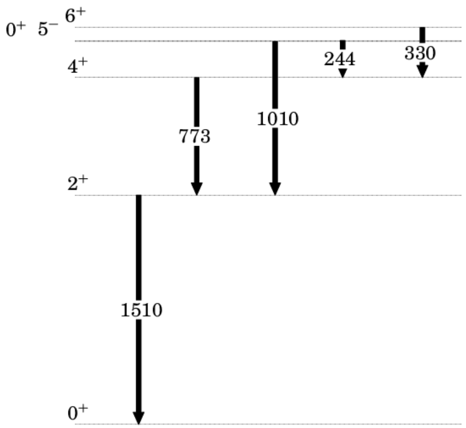
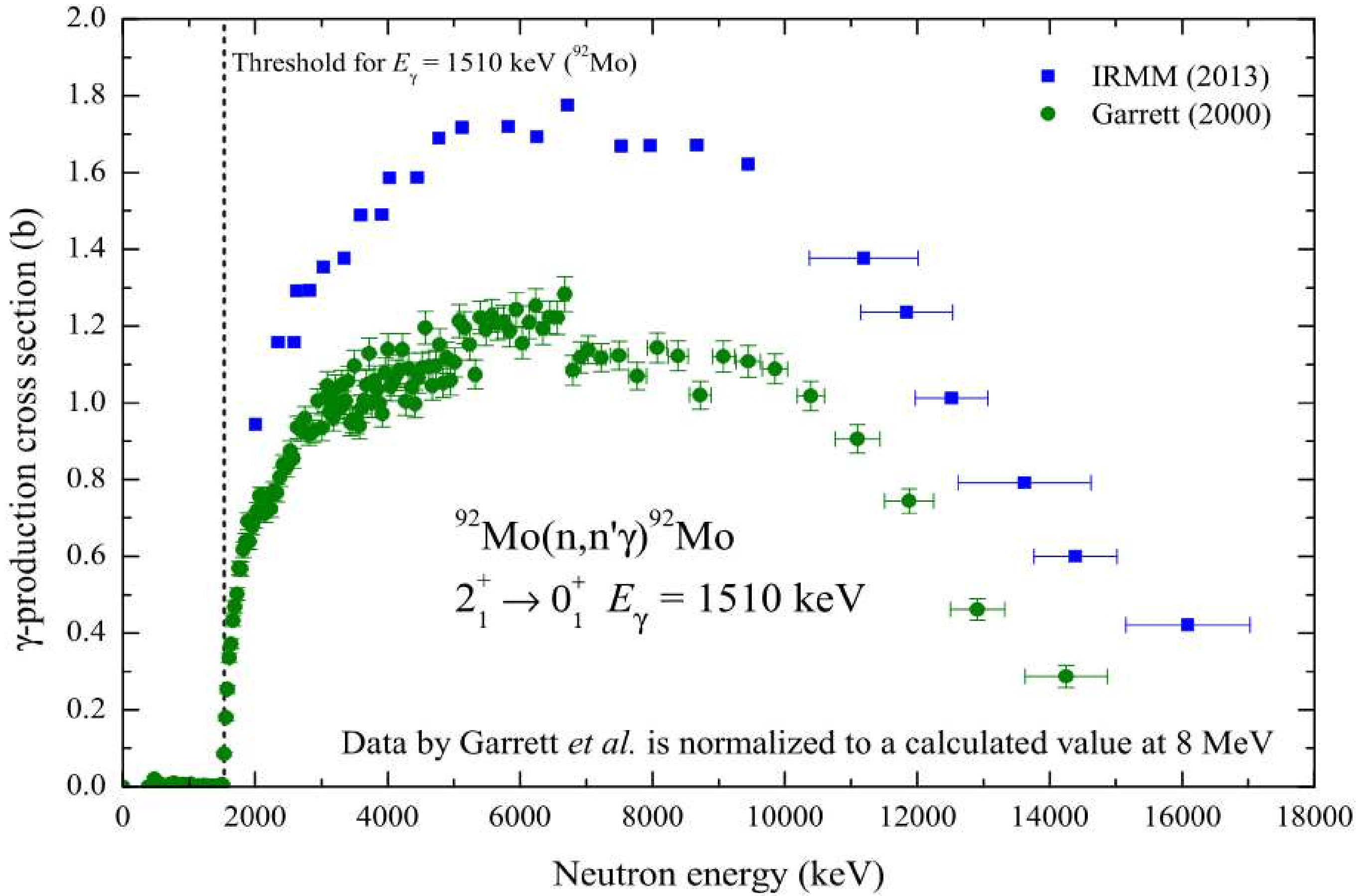
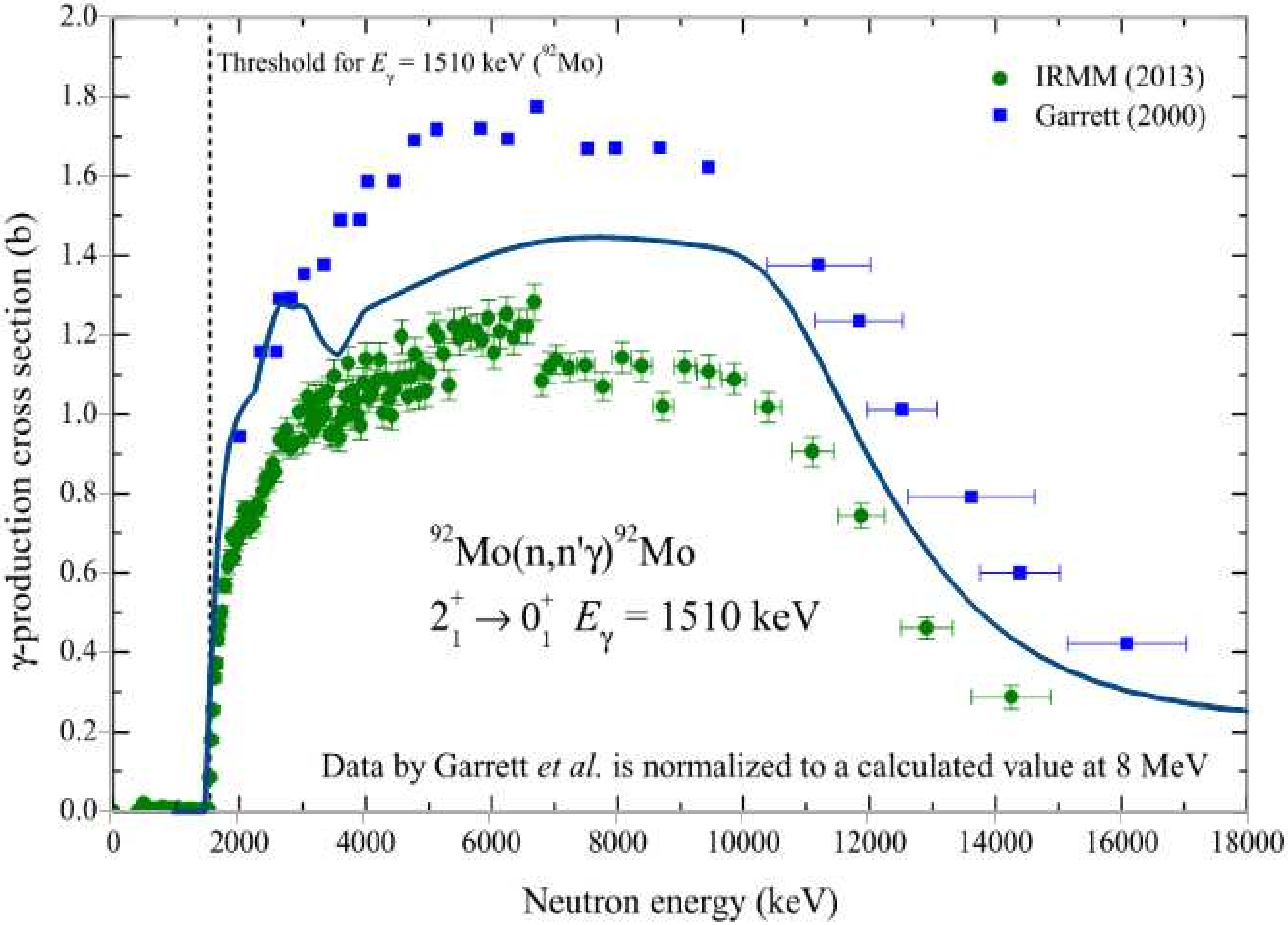
γ-ray production cross section, $2^+ \rightarrow 0^+$ ^{92}Mo



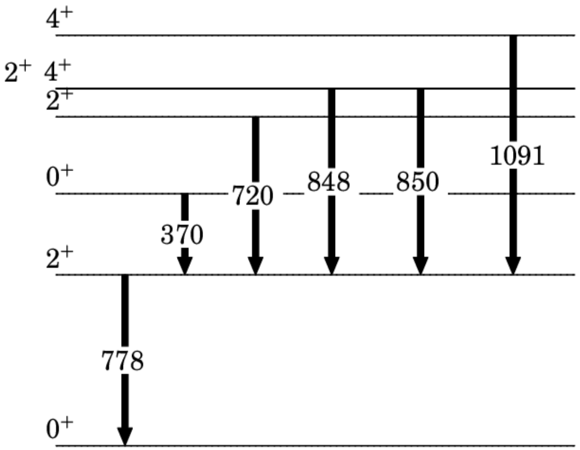


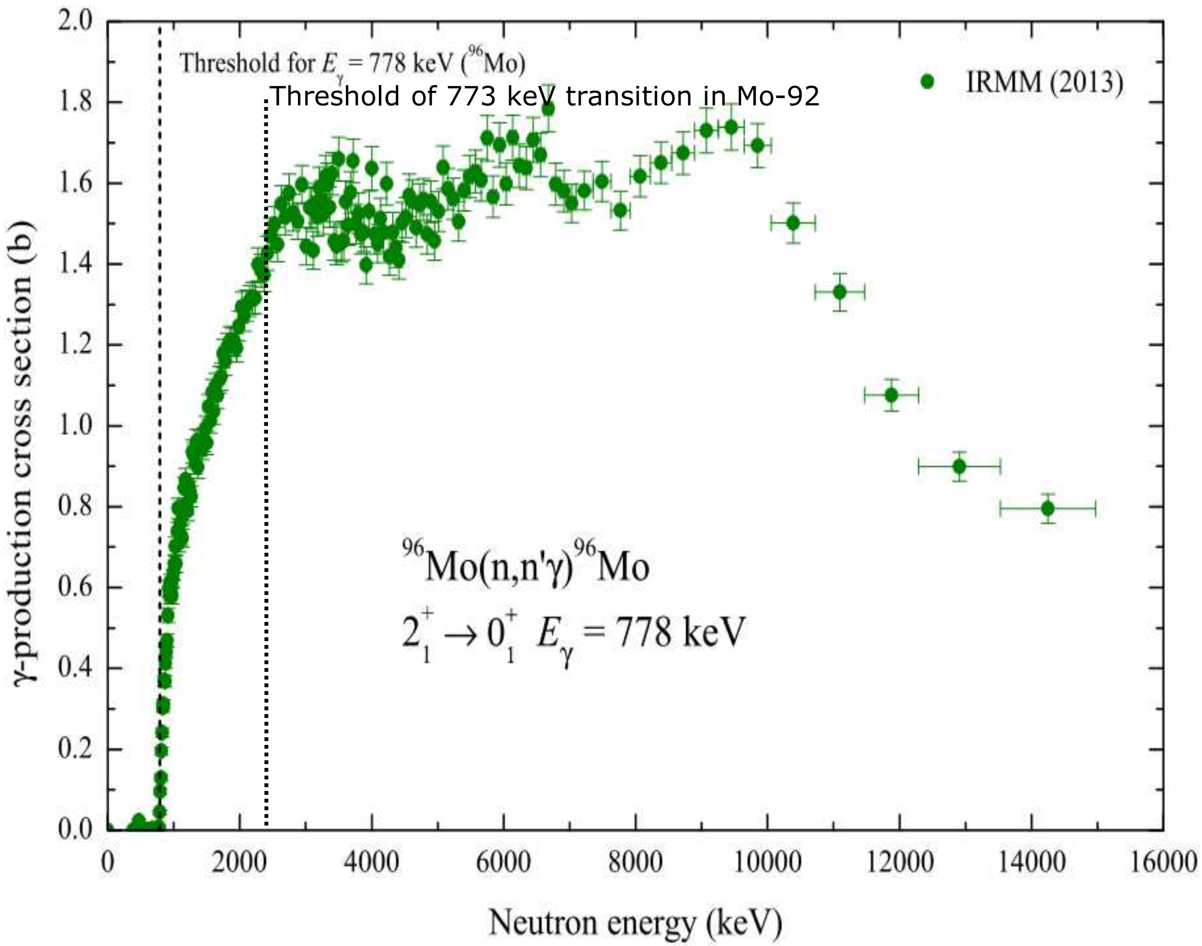
P. E. Garrett et al., Phys. Rev. C 62 054608 (2000)

$2^+ \rightarrow 0^+$ ^{92}Mo, comparison with Talys 1.6

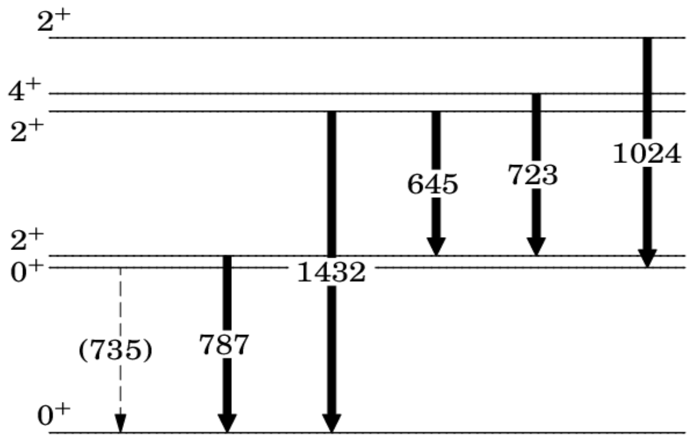


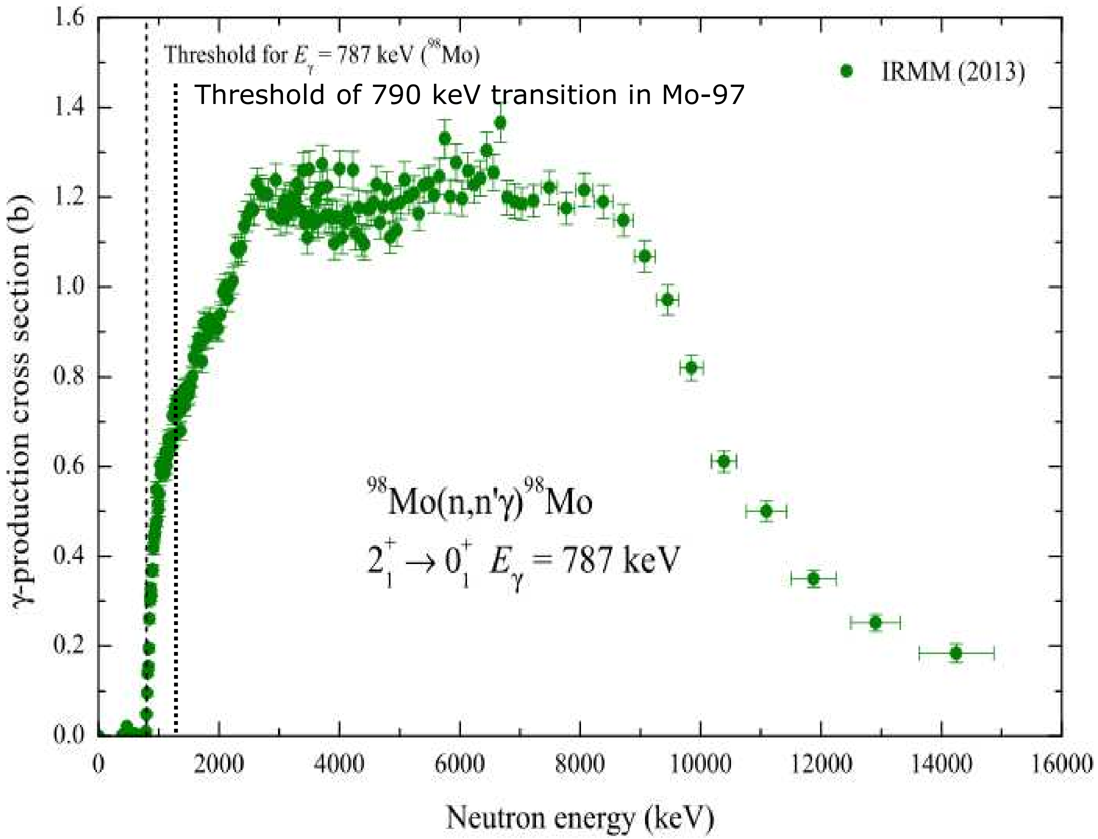
γ-ray production cross section, $2^+ \rightarrow 0^+$ ^{96}Mo





γ-ray production cross section, $2^+ \rightarrow 0^+$ ^{98}Mo





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Conclusions

Gamma-ray production cross sections have been measured for several transitions in ^{NAT}Mo (and ^{NAT}Zr)

Due to overlapping gamma lines, in many cases clean data is only available in a limited neutron energy range

Accurate measurements require enriched samples

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