Recent evaluations in the resolved and unresolved resonance region done at IRMM

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Stimulating innovation
Supporting legislation
• Evaluation in RRR - Cd
  ▪ Overview over literature
  ▪ Measurements
  ▪ results

• Evaluation in URR - Au
  ▪ Capture cross section
  ▪ Total cross section
Liou et al. – Transmission and self-indication measurements at Columbia University

nat. Cd samples
enriched samples: $^{110}$Cd, $^{112}$Cd, $^{114}$Cd and $^{116}$Cd

Resonance parameters:
- up to 10 keV for even isotopes
- up to 2.3 keV for odd isotopes

Data in EXFOR – but not enough experimental information available for use in resonance shape analysis (RSA)
**Mugrove et al.** – Capture measurements at 40m station of ORELA

Enriched samples: $^{106}\text{Cd}$, $^{108}\text{Cd}$, $^{110}\text{Cd}$, $^{112}\text{Cd}$, $^{114}\text{Cd}$ and $^{116}\text{Cd}$

Resonance energies and capture areas above 2.6 keV

Data not available in EXFOR
Wasson and Allen  - Capture measurements at 40m station of ORELA

enriched sample $^{111}$Cd

Capture areas up to 2300 eV

spin assignment below 1300 eV

Data not available in EXFOR
**Frankle et al** - Capture measurements at 40m station and transmission at 80m station ORELA

nat. sample and enriched sample $^{113}\text{Cd}$

data used in RSA below 15 keV to determined $g\Gamma_n$

spin assignment applying approach Bollinger and Thomas

for p-waves data of Gunsing et al (capture 12 m GELINA)

Data in EXFOR – can be used for RSA
Experiments at GELINA with natural Cd samples

<table>
<thead>
<tr>
<th>Weight (g)</th>
<th>Thickness (mm)</th>
<th>Areal density at/b</th>
<th>Trans. 25m</th>
<th>Trans 50m</th>
<th>Capt. 12.5m</th>
<th>Capt. 30m</th>
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<tbody>
<tr>
<td>1.281</td>
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</tbody>
</table>
Transmission

Sample and Bkg filters

Li-Glass scintillator

\[ B(t) = B_o + B_\gamma(t) + B_n(t) \]
C₆D₆ liquid scintillators
- 125°
- Total energy detection + PHWT

Fluence measurements (IC)
- ¹⁰B(n,α) (back–to–back)
Correction factor for $\gamma$ attenuation in the sample for different isotopes
Bound states initially adjust to match:

- thermal capture cross section from Mughabghab
- Coherent scattering lengths from Knopf and Waschkowski

To avoid the use of very strong bound states R’ was slightly adjusted

$^{110}\text{Cd}$ and $^{112}\text{Cd}$ fitted to interference dips of s-wave resonances

$^{114}\text{Cd}$ was adjusted to thick transmission measurement
Comparison energies

![Graphs showing comparison energies for different isotopes of Cd at various neutron energies. The graphs compare the ratios of Energies from GELINA to Energies from other sources.](image)
Comparison $\Gamma_n$

![Comparison $\Gamma_n$ diagram](image_url)

- Neutron energy / eV
- $g\Gamma_{n,GELINA}$ / $g\Gamma_{n,Frankle}$

Comparison of $\Gamma_n$ values for different neutron energies and isotopes. The graphs show the ratio of $g\Gamma_{n,GELINA}$ to $g\Gamma_{n,Frankle}$ for isotopes of Cd, with a focus on $^{113}$Cd.
Average $\Gamma_\gamma$

![Graph showing neutron binding energy vs. $\Gamma_{\gamma,s}$/meV with data points for Musgrove, s-wave, Musgrove, p-wave (URR), IRMM, s-wave (even), IRMM, s-wave (odd), and Frankle, p-wave ($^{113}$Cd).]
Spin assignment

Thomas –Bollinger approach of spin assignment compared to fixed cut-off in reduced neutron width

\( g_{\ell n}^{-1} = 0.047 \text{ eV} \)

\( g_{\ell n}^{-1} / \text{eV} \)

Neutron energy / eV
Spin assignment

transmission and capture

\[ \Gamma_{\gamma} = \frac{1}{g_{J}} \frac{K_{I} K_{\gamma}}{K_{I} - K_{\gamma}} \]

\[ \Gamma_{\gamma} = \frac{K_{I}}{g_{J}} \]

only capture

\[ \Gamma_{\gamma} = \frac{\Gamma_{\gamma} K_{\gamma}}{g_{J} \Gamma_{\gamma} - K_{\gamma}} \]

\[ g_{J} > \frac{K_{\gamma}}{\Gamma_{\gamma}} \]
Results

- Yield
- Transmission

Neutron Energy / eV

Exp. (2 mm)
This work
JEFF 3.1.3
JENDL 4.0
ENDF/B-VII

Exp. (25 mm)
This work
JEFF 3.1.3
JENDL 4.0
ENDF/B-VII
Results

![Graph showing neutron transmission vs. energy]

- **Exp. (2 mm)**
- **Exp. (5 mm)**
- **Frankle et al.**
- **This work**
- **ENDF/B-VII**

The graph compares experimental data (Exp. (2 mm), Exp. (5 mm), and Frankle et al.) with theoretical predictions (This work and ENDF/B-VII) for neutron transmission as a function of energy. The peaks and troughs in the transmission values indicate specific energy ranges where neutrons are more or less likely to be transmitted through a material. The data points and curves highlight the agreement between experimental observations and theoretical models.
Results

Transmission

Neutron Energy / eV

- Exp. (Frankle et al.)
- This work
- ENDF/B-VII

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Results

![Graph showing neutron energy transmission](image)

- **Exp. (Frankle et al.)**
- **This work**
- **ENDF/B-VII**

Transmission vs. Neutron Energy (eV)
Results

![Graph showing neutron energy vs. transmission with various datasets and models: Exp. (25 mm), This work, JEFF 3.1.3, JENDL 4.0, ENDF/B-VII, and ENDF/B-VII.1.](image-url)
Results
Results

![Graph showing neutron energy vs. yield with experimental data and calculations from different libraries.]
Thermal cross section

$\sigma_{(n_{th},tot)} / \text{barn}$

- nat Cd(n,tot)
- Literature (exp)
- GELINA
- ENDF/B-VII
- ENDF/B-VI.8 (JEFF 3.1.1)
- JENDL 4.0
- IRDF 2002

Year

1960 1980 2000 2020
• $^{113}$Cd Improved resonance parameter from thermal up to 10 keV
• Impossible to describe thermal cross section and first resonance

This file puts higher importance on the shape of first resonance (Cd cut-off) than on thermal cross section

• Low abundant isotopes $^{106,108,116}$Cd – quality files adequate
• $^{114}$Cd measurements with enriched sample might give improvement

Covariance will be provided by CEA Cadarache
Discrepancy between Standard file for neutron reaction cross section and “astrophysical” Standard

Borella et al agree with standard

Trend confirmed by Feinberg et al Lederer et al
\[ B(t) = B_0 + B_1(t) + B_2(t) \]
BKG Au- capture

Counts (1/ns) vs. TOF (ns)

- $^{197}$Au 1.0 mm
- $^{197}$Au 0.5 mm
- $^{197}$Au 0.01 mm
- $^{208}$Pb 0.5 mm

FP5_10m 800Hz
Gold URR Capture

\[
\sigma(n,\gamma) \ E^{1/2} \bigg/ \text{(barn eV}^{1/2}\text{)}
\]

Neutron Energy / eV

- IAEA eval.
- GELINA 12 m
- GELINA 30 m
- nTOF

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Gold URR Total Status

\[ \sigma(n,\text{tot}) \text{ / barn} \]

Neutron Energy / eV

\[ 10^4 \quad 10^5 \]

Seth et al.
Purtov et al.
Wishak (avg.)
ENDF

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$B(t) = B_0 + B_1(t) + B_2(t)$
Self Shielding correction calculated with MCNP

Still to be done:

SESH
Comparison with literature data and OM calculation

Gold URR Total Results
• Capture measurements with two thicknesses agree with standard evaluation

• Only small data base for URR total cross section
  - Later measurements seem to disagree with evaluation

• Transmission measurements with 3mm sample
  - Agreement with data of Purtov et al.