

New setup for measurement of prompt gammas from neutron interactions

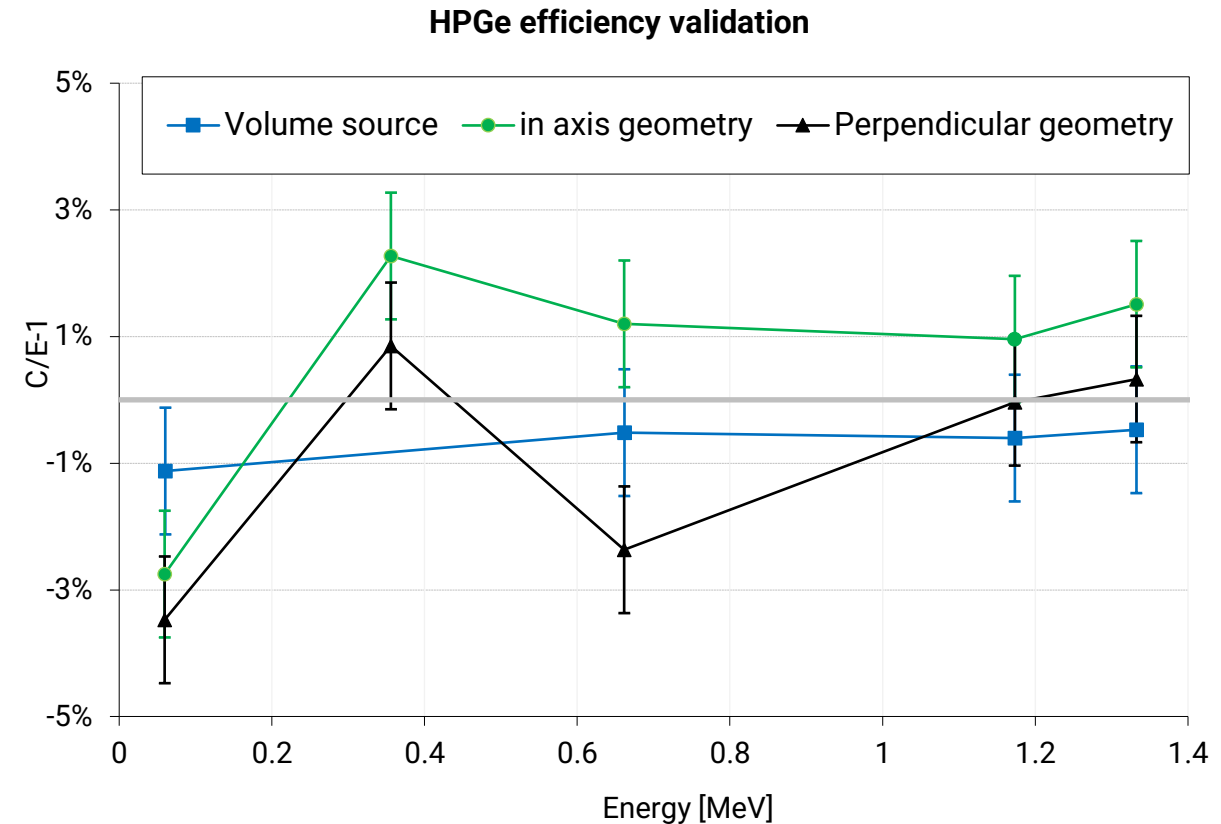
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Motivation – prompt gamma

- Produced by capture reactions and inelastic scattering
- Important for reactor operations (radiation damage)
- Several applications (mainly element identification – also in space)
- Generally, poorly described in current nuclear data libraries
- Lack of precise experiments (but a few published recently)

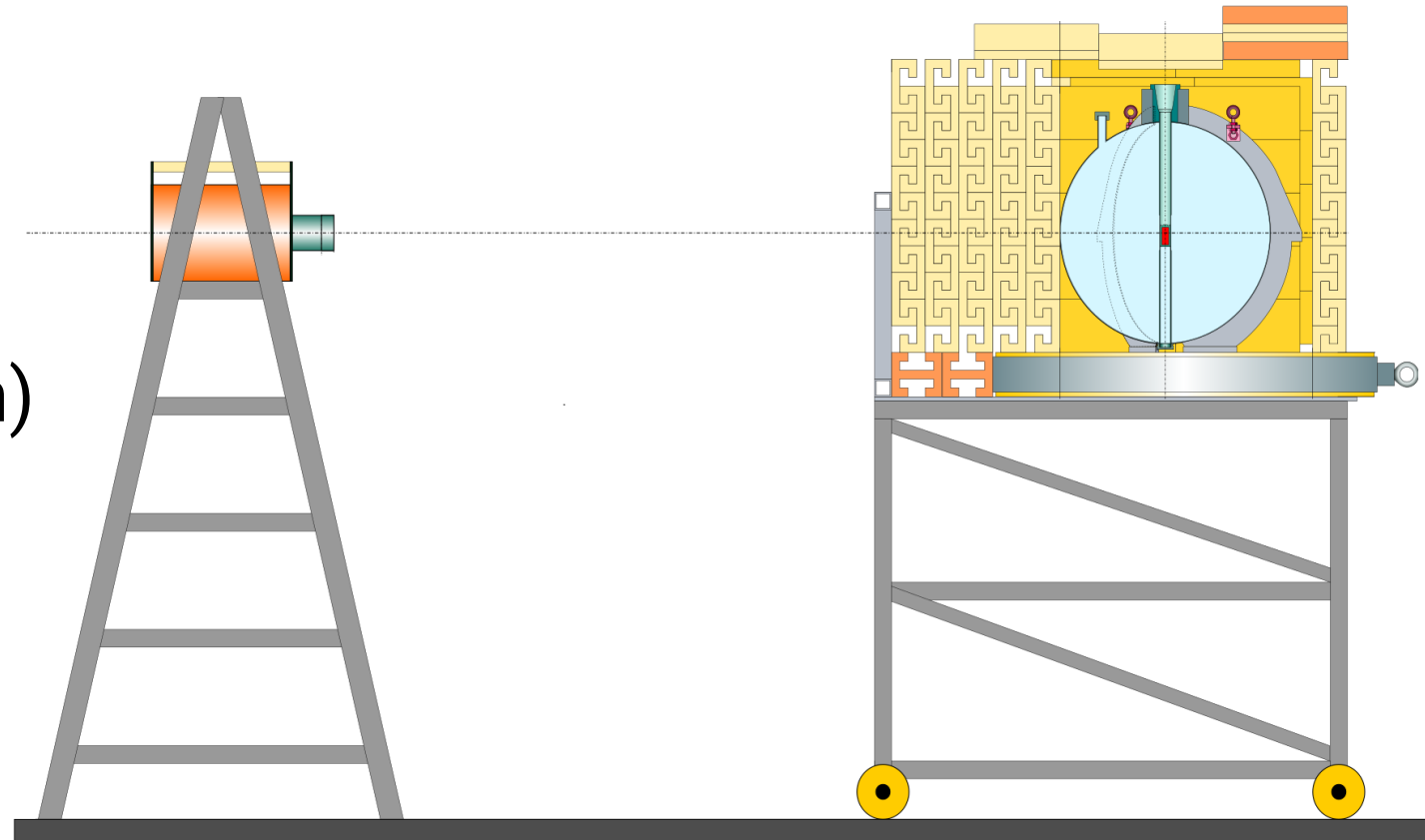
Measurement apparatus

- HPGe detector
 - Canberra Big MAC (GC2518 type)
 - Validated MCNP6.2 detector model with experimental dead layer
- Stilbene detector (45 × 45 mm)
 - NGA-01 spectrometric system
 - Pulse shape discrimination



Gamma from inelastic scattering on oxygen

- Gamma of $E=6.128$ MeV
- Am-Be neutron source
- Aluminum sphere ($\varnothing=50$ cm) filled with heavy water
- HDPE+B neutron shielding
- 2 measurement distances



Gamma from inelastic scattering on oxygen

- MCNP6.2
 - Neutron library: ENDF/B-VII.1, ENDF/B-VIII.0, JEFF-3.3, CENDL3.1, JENDL-4.0, TENDL-2019
 - Gamma library: MCPLIB04
 - Stilbene measured neutron spectrum
 - Only for 1.0 – 12 MeV
 - Correction for lower energies – neutron share below 1 MeV in ISO 8529-1:2021

Gamma from inelastic scattering on oxygen

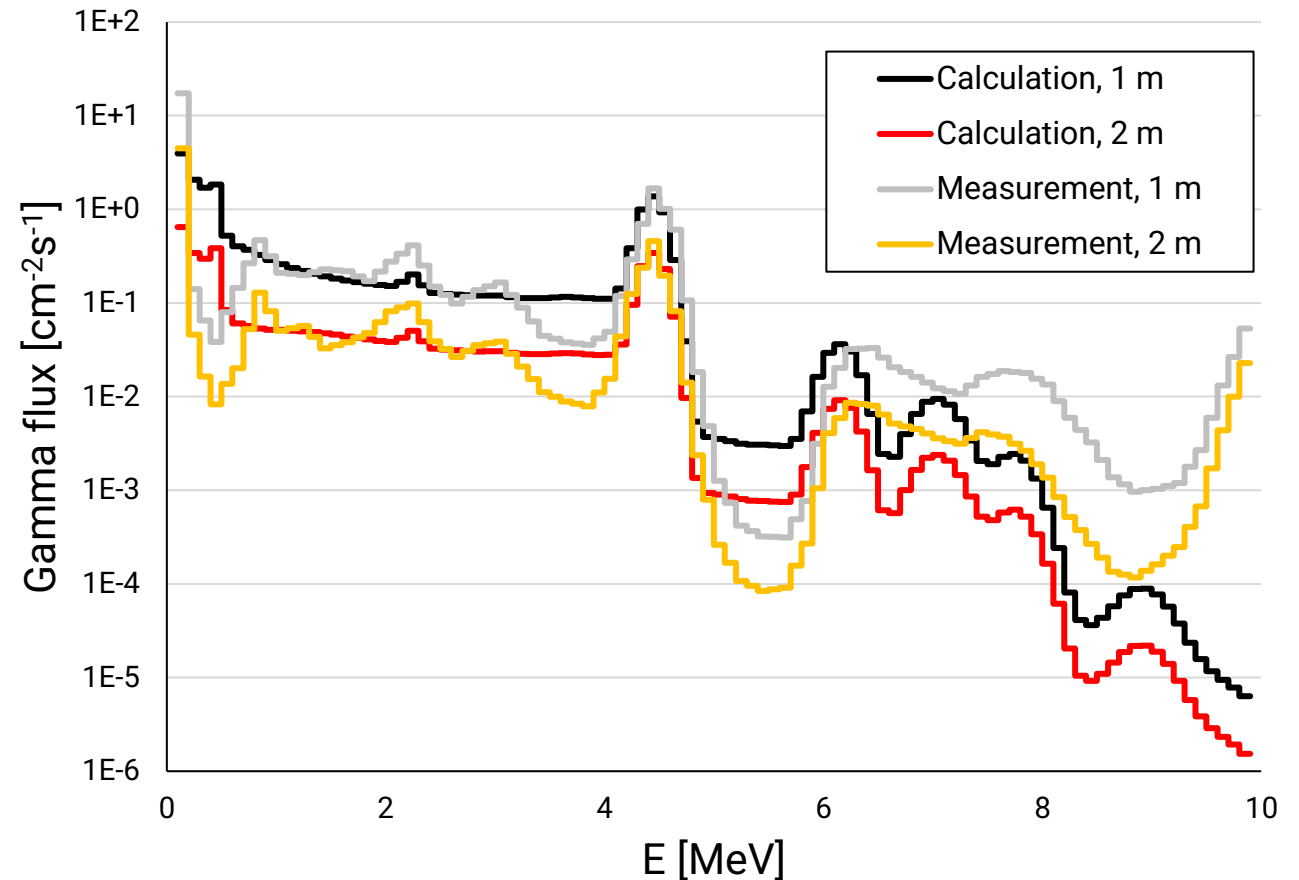
101 cm			
Neutron library	Calculated flux [$\text{cm}^{-2}\text{s}^{-1}$]	C/E-1	C/E uncertainty
ENDF/B-VIII.0	0.1185	30.6%	8.7%
ENDF/B-VII.1	0.1184	30.5%	8.7%
JEFF-3.3	0.1198	32.0%	8.7%
CENDL-3.1	0.1158	27.7%	8.7%
JENDL-4.0	0.1083	19.4%	8.7%
TENDL-2019	0.1186	30.7%	8.7%

194 cm			
Neutron library	Calculated flux [$\text{cm}^{-2}\text{s}^{-1}$]	C/E-1	C/E uncertainty
ENDF/B-VIII.0	0.0334	29.2%	5.9%
ENDF/B-VII.1	0.0334	29.0%	5.9%
JEFF-3.3	0.0338	30.5%	5.9%
CENDL-3.1	0.0327	26.3%	5.9%
JENDL-4.0	0.0306	18.3%	5.9%
TENDL-2019	0.0334	29.3%	5.9%

- Uncertainty include:
 - HPGe bias
 - Net Peak Area uncertainty
 - geometry uncertainty
 - neutron spectrum uncertainty
 - neutron source emission uncertainty
 - beam divergence uncertainty

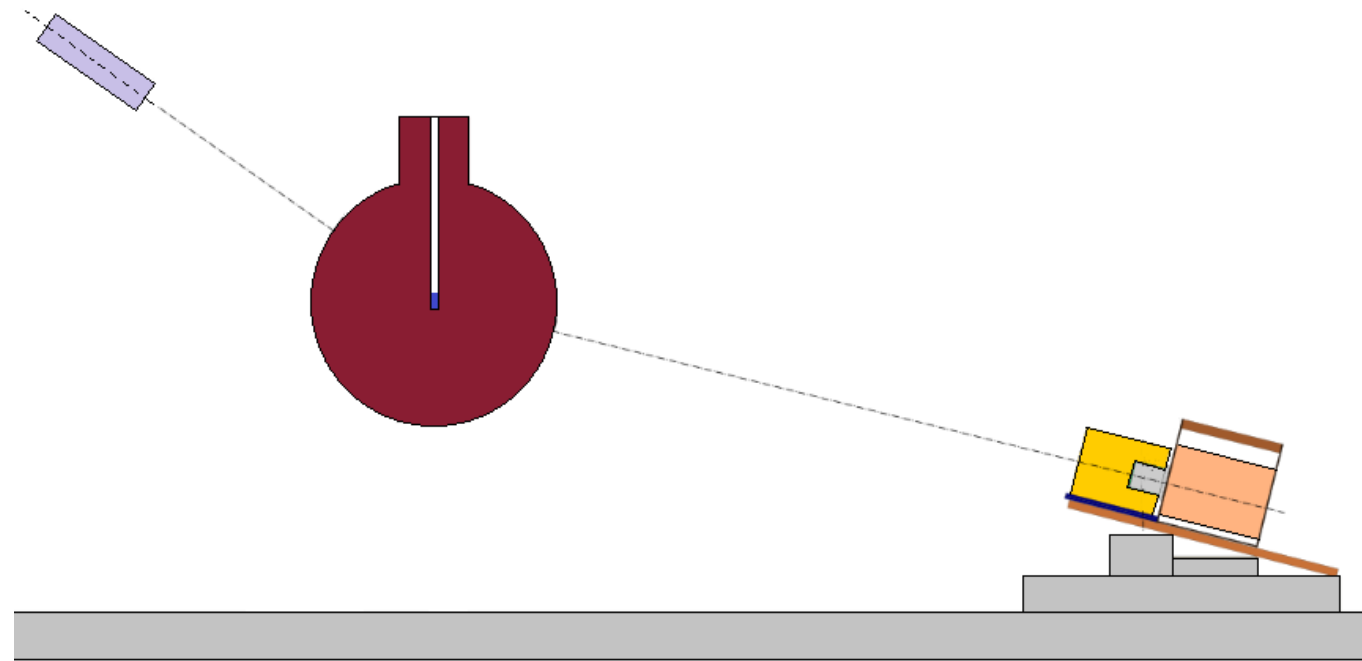
Gamma from inelastic scattering on oxygen

- ^{12}C (4.439 MeV) peak
 - Good agreement
- Peaks above 6 MeV
 - $^{16}\text{O}(n,n')$ - 6.128 MeV + neutron capture (Al - 7.724 MeV)
 - Indistinguishable from each other
 - Deconvolution problem above 8 MeV at low count rates.
- Uncertainty 5-10%, in peaks up to 20%.



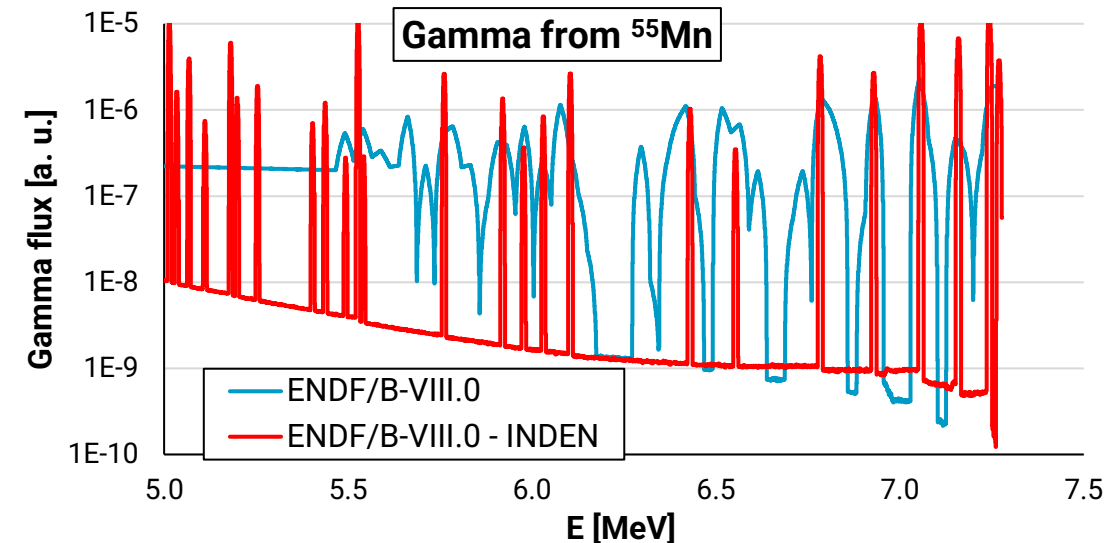
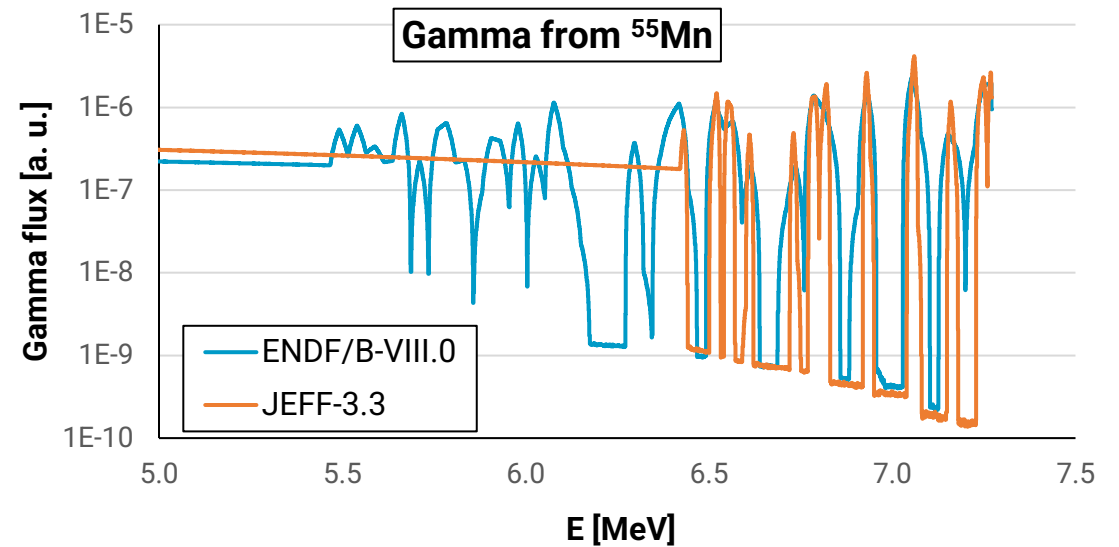
Gamma from radiative capture on Mn

- ^{252}Cf neutron source
- Manganese bath ($\phi=70$ cm)
- Small HDPE+B neutron shielding
- HPGe - bath distance ~ 2 m



Gamma from radiative capture on Mn

- MCNP6.2
 - Neutron library: ENDF/B-VIII.0, JEFF-3.3
 - Significantly discrepant
 - INDEN updated data for ^{55}Mn
 - Can be used
 - Gamma library: MCPLIB04



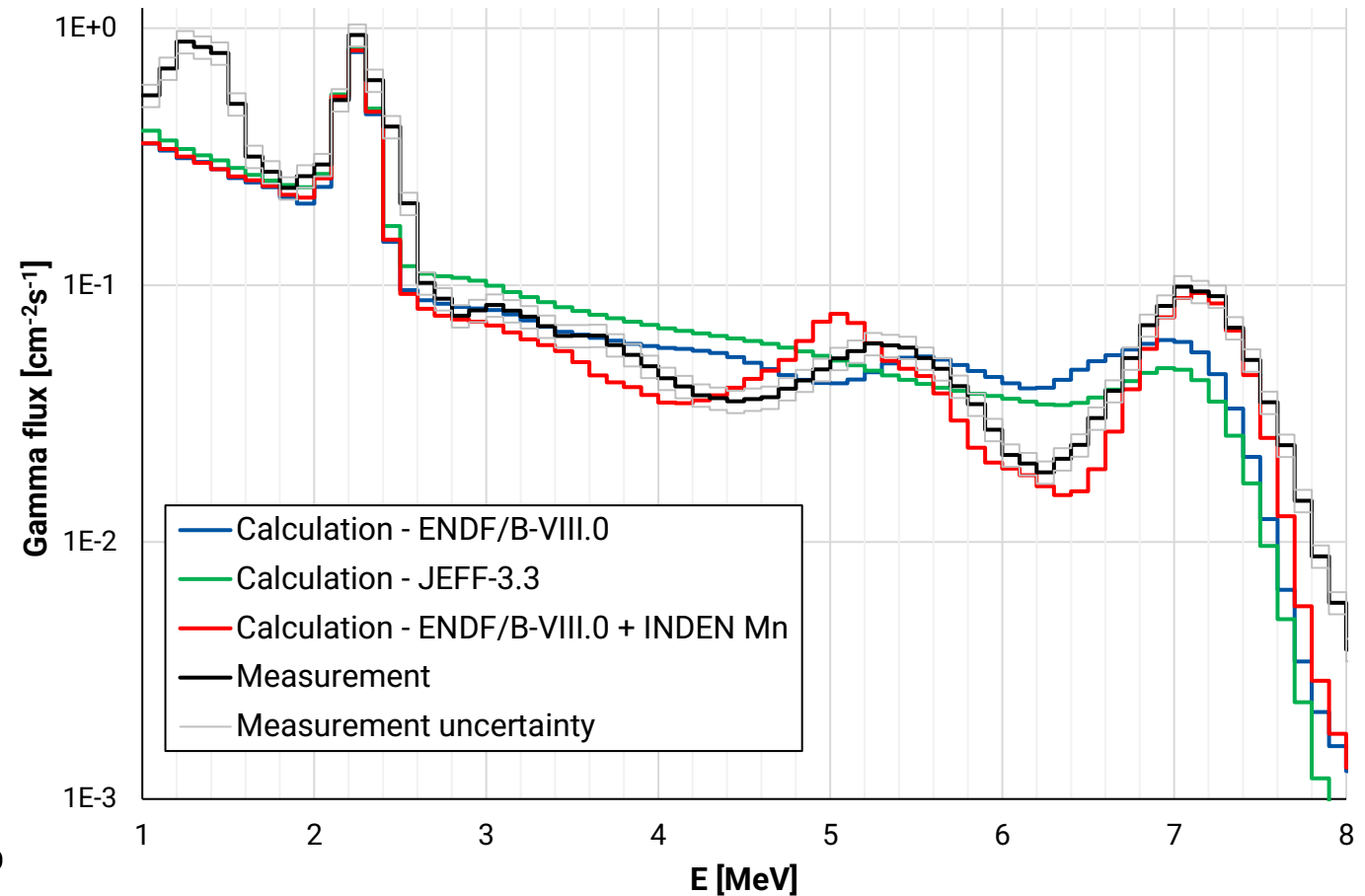
Gamma from radiative capture on Mn

- For peaks NPA found in the measurement
- Problem of separation of 7.271 MeV NPA in calculation
- Uncertainty include:
 - Net Peak Area uncertainty
 - uncertainty in the position of the detector
 - manganese bath model uncertainty
 - neutron emission uncertainty
 - HPGe model uncertainty
 - beam divergence uncertainty

E [MeV]	Calculated flux [cm ⁻² .s ⁻¹]	Measured flux [cm ⁻² .s ⁻¹]	C/E-1	C/E-1 uncertainty
3.409	3.40E-3	2.20E-3	54.3%	14.8%
4.725	4.42E-3	3.52E-3	25.6%	12.6%
5.015	1.21E-2	1.89E-2	-36.2%	6.4%
5.068	4.41E-3	4.34E-3	1.7%	13.1%
5.181	6.98E-3	5.40E-3	29.3%	11.4%
5.528	1.41E-2	1.29E-2	9.5%	7.0%
6.784	7.90E-3	6.35E-3	24.3%	11.4%
6.930	5.29E-3	4.86E-3	8.7%	14.0%
7.058	2.62E-2	2.28E-2	14.6%	6.2%
7.160	1.39E-2	1.27E-2	9.3%	6.5%
7.244	2.97E-2	2.47E-2	20.0%	5.9%
7.271	-	6.89E-3	-	-

Gamma from radiative capture on Mn

- Necessity to include ^{252}Cf gamma spectrum
- Stilbene measured
- Good agreement with INDEN
- But mostly underestimation
- Discrepant for other libraries
- Measurement uncertainty $\sim 10\%$



Conclusions

- Two experiments on prompt gamma
- 6.128 MeV $^{16}\text{O}(n,n')$
 - 20-30 % overestimation in present libraries (6-9% uncertainty)
 - Best results in JENDL-4.0
- $^{55}\text{Mn}(n,\gamma)$
 - Current ND libraries – significantly discrepant
 - INDEN updated data for ^{55}Mn
 - C/E-1 from -36% to 55%
 - Plan to publish as benchmark
- Plan to continue with similar experiments on prompt gamma

Thank you for your attention

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