IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety

Nuclear Data Evaluation Work at IRSN

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EUROPEAN TECHNICAL SAFETY ORGANISATIONS NETWORK

OUTLINE

1. Evaluations Performed at IRSN
2. Measurements Efforts
3. Concluding remarks

Appendix B
Nuclear Data

Priority Needs */ Additional Needs*	Thermal scattering (Paraffinic Oil, HF, Silicone Oil, UO_2F_2, PuH_2, UH_3, Paraffin, U_3O_8, U_3Si_2, UC, PuO_2, etc.), ^{239}Pu, Fe, Cr, ^{237}Np, Pb, ^{55}Mn, Ti, ^{240}Pu/^{233}U, Th, Be, ^{51}V, Zr, F, K, Ca, Mo, Na, La
Completed Evaluations (FY)	Minor Actinides (13), SiC(17), SiO_2 (17), $C_5O_2H_8$ (16), CH_2 (17), Be (17), BeO (17), Graphite (17), UO_2 (17), UN (17), ^{55}Mn (12), ^{58,60}Ni (14), ^{180,128,183,184,186}W (14), Ca (16), ^{59}Co (17), ^{63,65}Cu(17)

	Materials	Pre FY2018	FY2018	FY2019	FY2020	FY2021	FY2022	Post-FY2022
Measurements	Calcium (Ca)							
	Cerium (Ce)							
	Iron (Fe)							
	Molybdenum (Mo)							
	Tantalum (Ta)							
	Vanadium (V)							
	Zirconium (Zr)							
	Polyethylene (CH_2)	H_2O / CH_2						
	Lucite ($C_5O_2H_8$)							

	Materials	Pre FY2018	FY2018	FY2019	FY2020	FY2021	FY2022	Post-FY2022
Evaluations	Calcium (Ca)							
	Cerium (Ce)							
	Cobalt (Co)							
	Copper (Cu)							
	Dysprosium (Dy)							
	Gadolinium (Gd)							
	Iron (Fe)							
	Lead (Pb)							
	Oxygen (O)							
	Rhodium (Rh)							
	Plutonium-239							
	Tantalum (Ta)							
	Uranium-234							
	Uranium-235							
	Uranium-236							
	Uranium-238							
	Vanadium (V)							
	Zirconium (Zr)							
	Lucite ($C_5O_2H_8$)							
	Polyethylene (CH_2)							
	Beryllium (metal)							
	Beryllium Oxide (BeO)							
	Crystal Graphite							
	Reactor Graphite							
	Silicon Carbide (SiC)							
	Silicon Dioxide (SiO_2)							
	Uranium Dioxide (UO_2)							

Extract from five year plan 2018-2022

Evaluation Work

Isotope	Energy Range	Resonance Covariance Evaluation	Target date for delivery the evaluation
^{233}U	Thermal to 2 keV	RP + CV	Ongoing
^{239}Pu	Thermal to 4 keV	RP + CV	Ongoing
Gd isotopes	Varies according to the isotopes	RP + CV	Completed
^{56}Fe, ^{54}Fe	Thermal to 2 MeV Thermal to 1.2 MeV	RP + CV	Ongoing
Pb isotopes (204, 206, 207, 208)	Varies according to the isotopes **Common task IRSN-ORNL**	RP + CV	Ongoing
Mo isotopes	Varies according to the isotopes	RP + CV	Ongoing

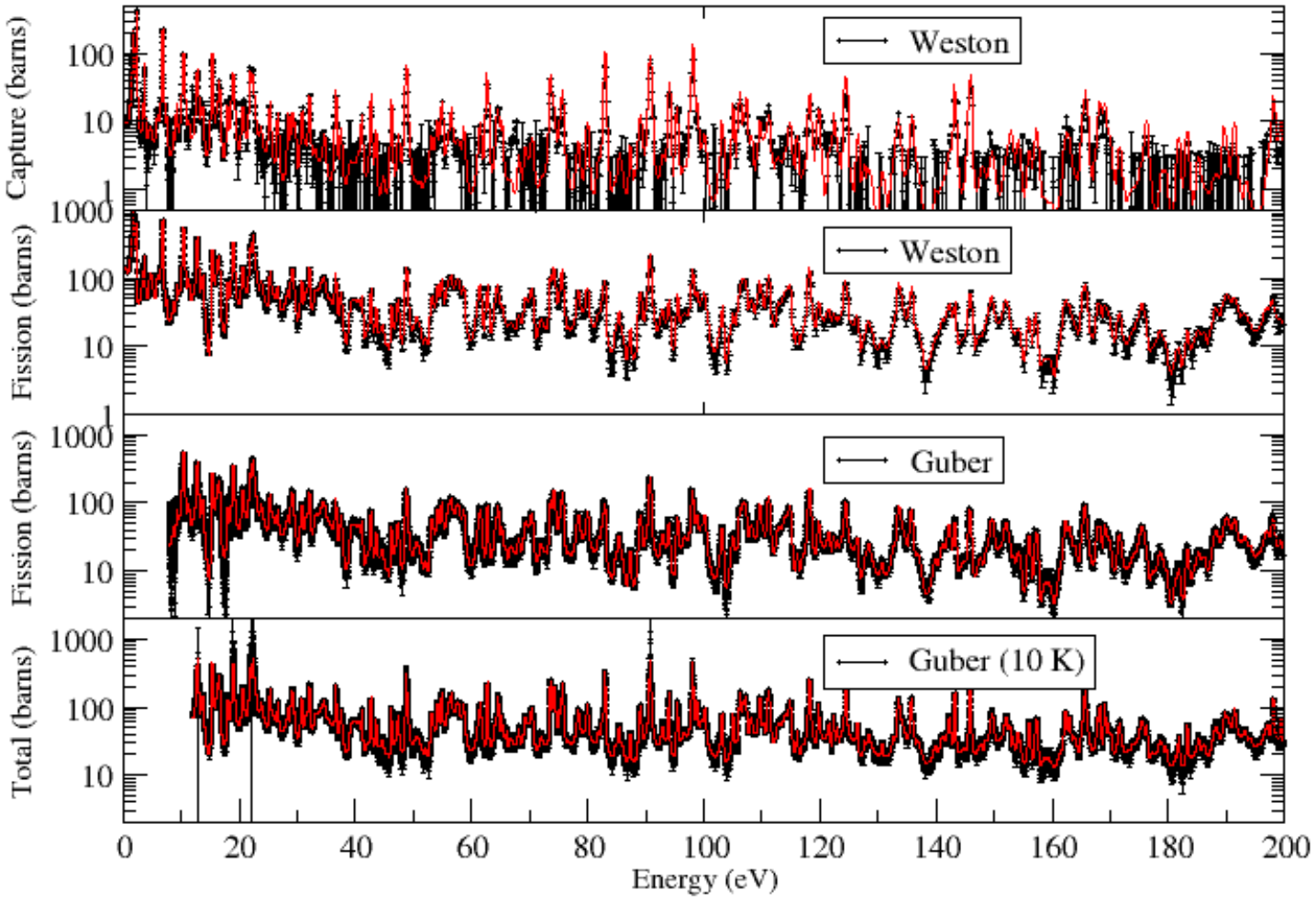
Project Activities

I. ^{233}U resolved resonance region evaluation:

a) Extension of the resolved resonance region from 600 eV to 2 keV;
b) Use of high resolution transmission data measured at the Oak Ridge Linear accelerator (ORELA) at helium liquid temperature ~ 10 K;
c) Use of high resolution fission cross section data measured at ORELA;
d) Use existing capture data up to 1 keV. This data include impurities and questionable resolution;
e) Recent alpha measurements done at n_TOF will be included in the evaluation;

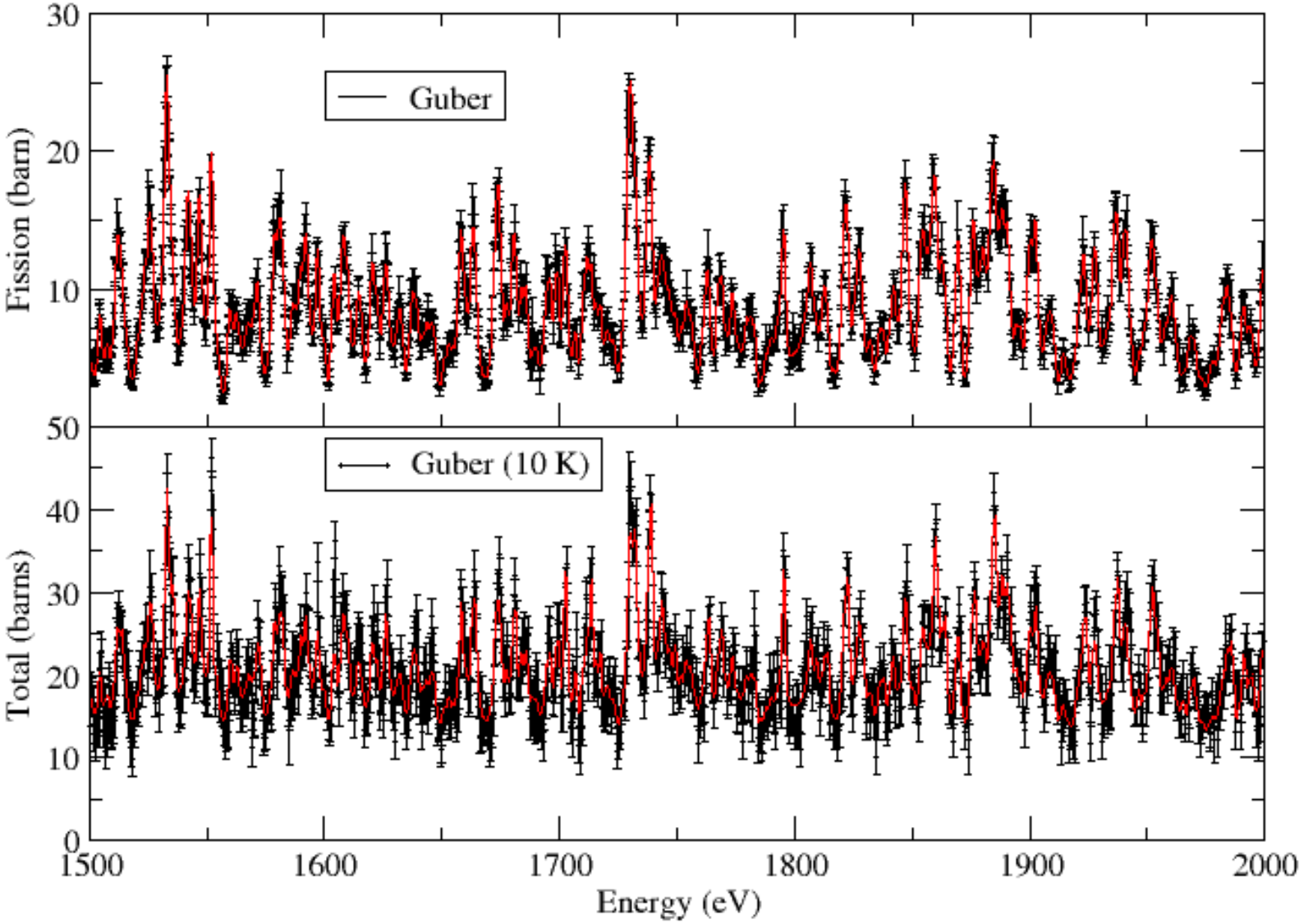
II. ^{233}U unsolved resonance region: Task under development !!

Some Results



Total, Fission and Capture Cross Section in the range 0 – 200 eV

Some Results



Total and Fission Cross Section in the range 1500 – 2000 eV

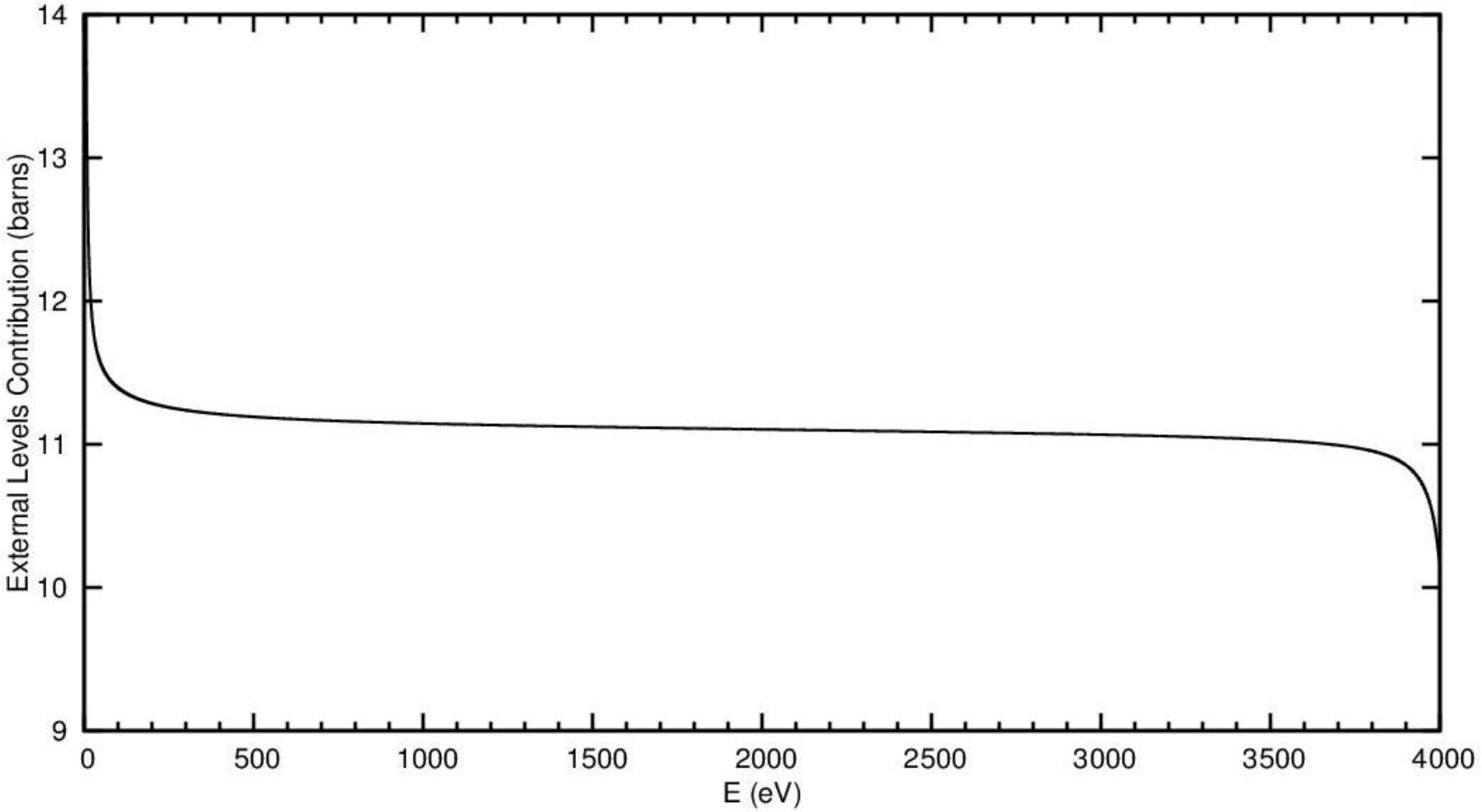
^{239}Pu Evaluation: Motivaions

1. Previous evaluation use LSSF=0 with no FILE3 added;
2. Issues on reproduction cross section from 2.5 keV to 4 keV;
3. Feasibility of extending the RR from 2.5 keV to 4 keV;
4. High resolution transmission and fission data used;
5. External energy levels determined;

Energy bound levels and energies above 2. 5 keV.

E_r (eV)	Γ_γ (meV)	Γ_n (meV)	Γ_{f1} (meV)	Γ_{f2} (meV)	J^π
Energy bound Levels					
-149.141	47.182	542.357	4226.105	0.0	1^+
-8.068	49.725	0.141	-1.499	0.0	1^+
-7.019	70.066	17.548	-117.345	223.288	0^+
-0.514	24.005	0.118	15.237	1189.353	0^+
-0.020	21.029	6.597×10^{-8}	-4.880	0.0	1^+
Energy levels above 4 keV					
4006.706	39.000	19.901	48.847	0.0	1^+
4022.478	39.000	4.963×10^{-6}	835.807	121.703	0^+
4035.401	39.000	2837.183	-181.877	0.0	1^+

External levels contribution on the scattering cross-section in the energy ranges 10^{-5} eV to 4 keV



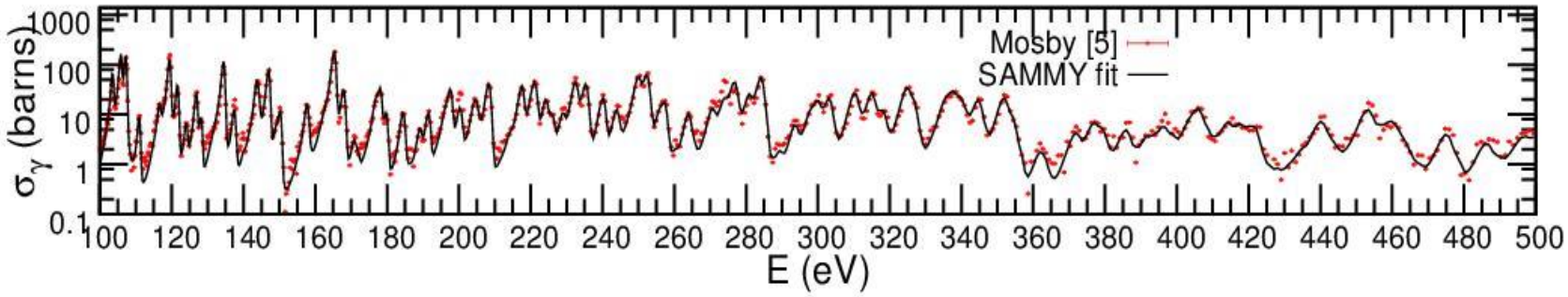
Experimental Data

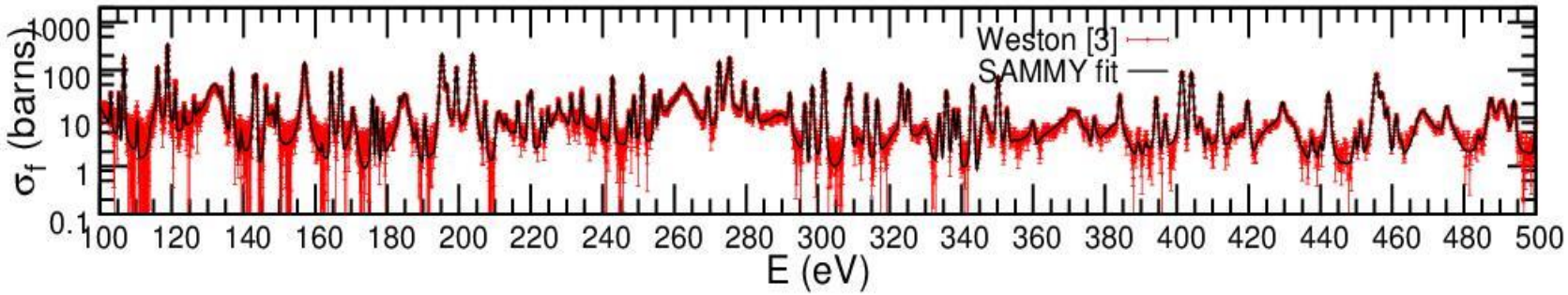
Transmission (Total Cross Section)		
Data Set	Energy (eV)	Flight-Path (meter)
Bollinger et al.[4]	0.01 – 1.0	Fast Chopper
Harvey (0.00638 atoms/barn) [2]	0.3 – 40.0	18.0
Harvey (0.01803 atoms/barn) [2]	0.3 – 100.0	18.0
Harvey (0.07471 atoms/barn) [2] (77 K)	30.0 – 4000.0	80.4
Fission		
Gwin [6]	0.01 – 4.0	25.6
Gwin [8]	0.01 – 20.0	8.0
Weston [3]	100.0 – 4000.0	86.5
Weston [9]	0.02 – 40.0	18.9
	Capture	
Gwin [6]	0.01 – 2.0	25.6
Gwin [7]	0.01 – 100.0	40.0
Mosby [5]	10.0 – 1000.0	25.6

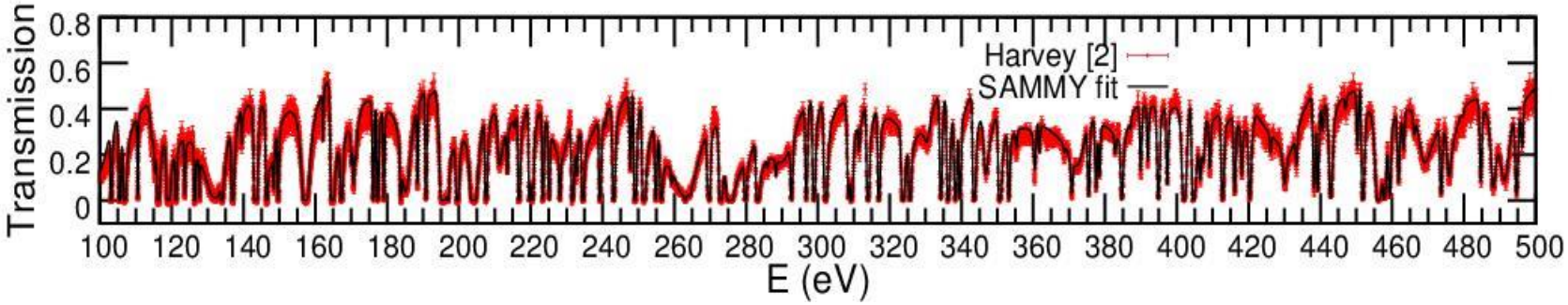
^{239}Pu Thermal Values

Quantity (barns)	Standard	ENDF/B-VIII (barns)	^{239}Pu (Rev) (barns)
σ_f	752.4 ± 2.2	747.2	750.4
σ_γ	269.8 ± 2.5	270.1	269.9
σ_s	7.8 ± 1.0	8.1	7.9

SAMMY Fit of the Data







Benchmark k_{eff} results for TEX experiments

Case	Thickness of CH_2 (inches)	Number of CH_2 moderating layers	Benchmark k_{eff}	Uncertainty	EALF (MeV)	k_{eff}	
						ENDF/B-VIII.0	This work
1	0	0	0.99991	0.00256	7.59E-02	1.00319	1.00441
2	1/16	17	1.00078	0.00228	5.37E-03	1.00075	1.00151
3	3/16	12	1.00081	0.00212	2.45E-04	1.01137	1.00708
4	7/16	8	1.00112	0.00266	3.35E-05	1.00352	0.99916
5	1	6	1.00006	0.00178	2.08E-06	1.00626	1.00211

Gd Evaluation (collaboration with ORNL - V. Sobes)

RPI experimental data measured at the 25.59725 meters flight-path

Data	Energy range (eV)	Nature
Transmission	0.2 - 300.0	natural
Transmission	0.3 - 500.0	natural
Transmission	0.3 - 1000.0	natural
Capture	0.2 - 1000.0	91.74 % Gd155 enriched
Capture	0.2 - 1000.0	90.96 % Gd157 enriched
Capture	0.2 - 1000.0	natural

Gd Evaluation
(new capture measurements)

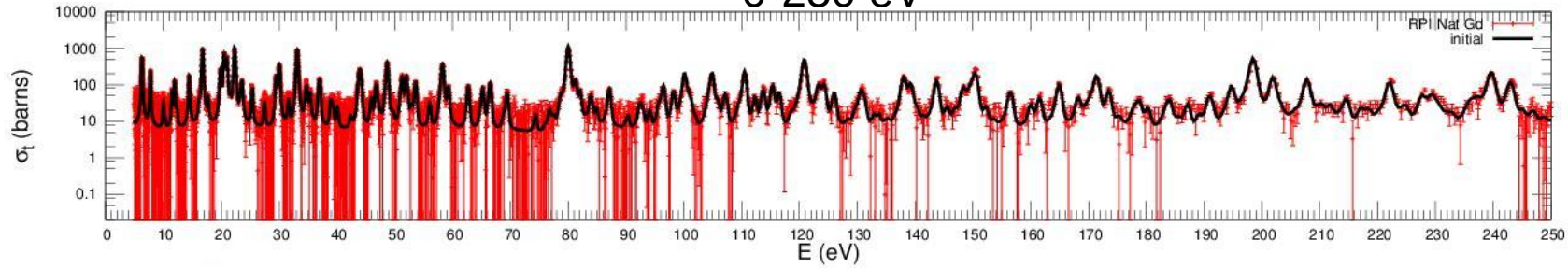
n-TOF experimental data measured at the 183.90 meters flight-path

Data	Energy range (eV)	Nature
Capture	1.0 - 1000.0	91.74 % Gd155 enriched
Capture	1.0 - 1000.0	88.32 % Gd157 enriched

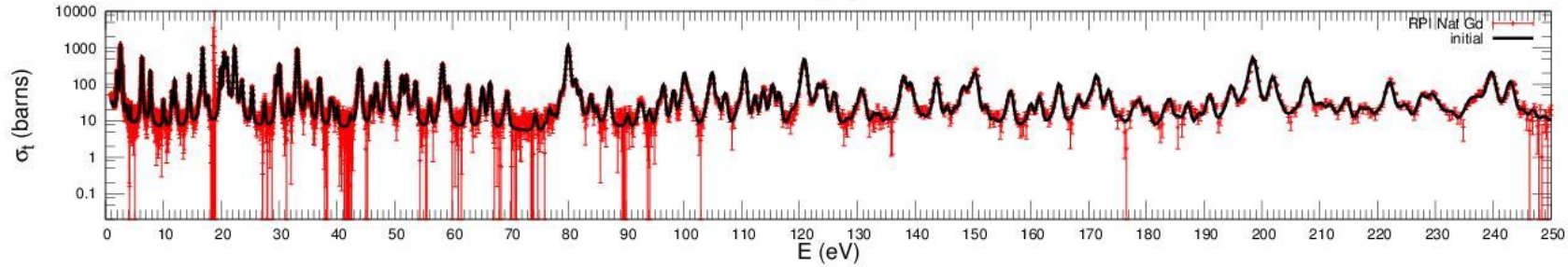
Gd RPI data (SAMMY Fitting) resonance range extended to 500 eV for ^{155,1557}Gd

0-250 eV

Total

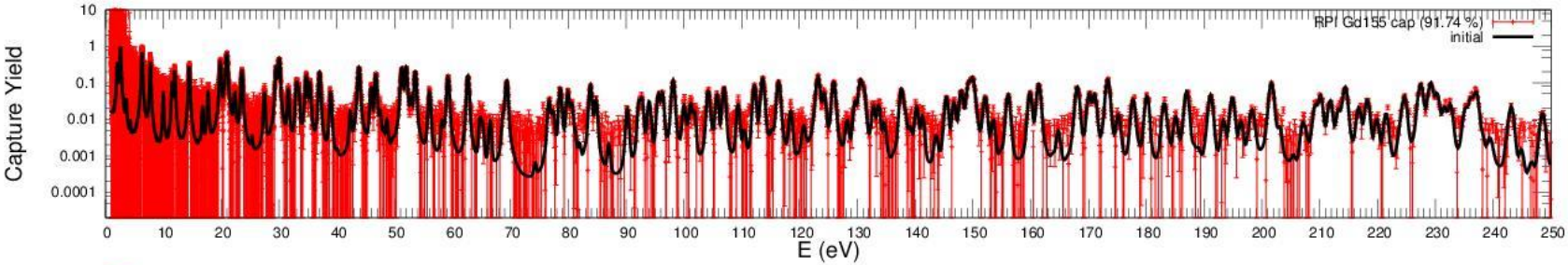


Gd nat

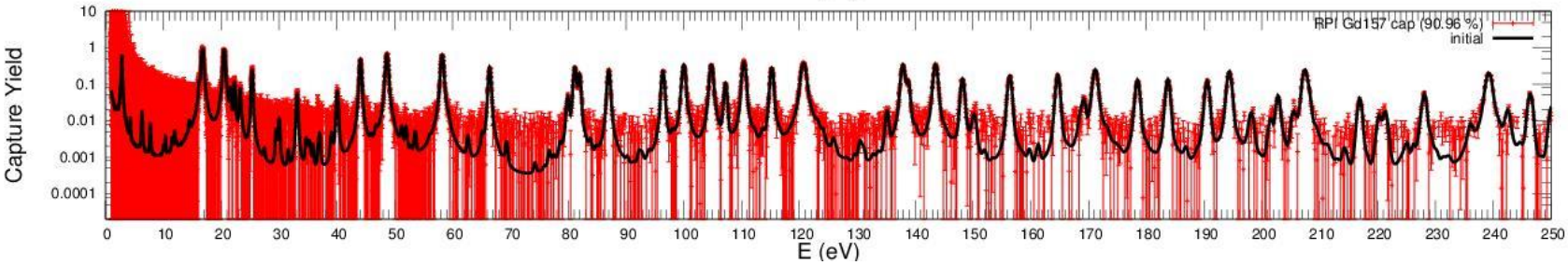


Gd nat

capture



Gd 155

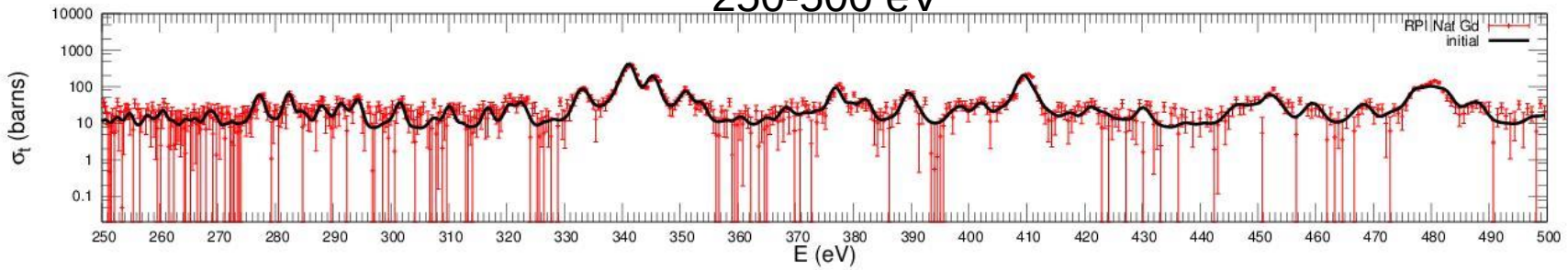


Gd 157

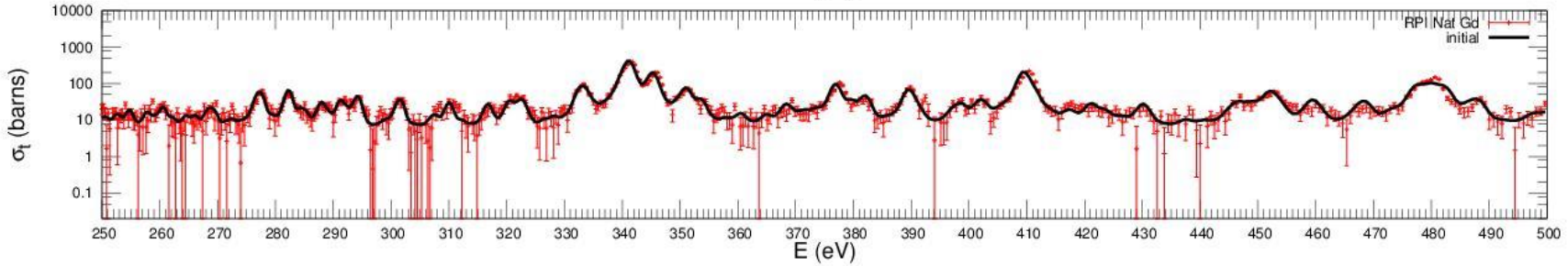
Gd RPI data (SAMMY Fitting) resonance range extended to 500 eV for ^{155,1557}Gd

250-500 eV

Total

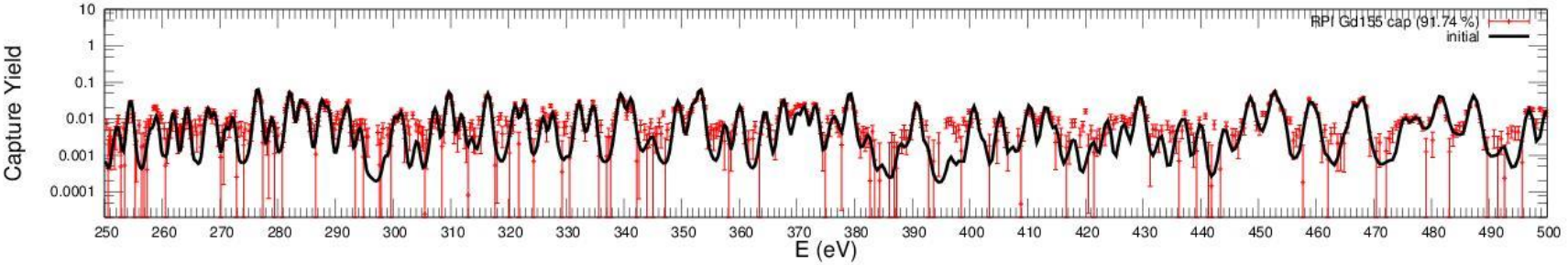


Gd nat

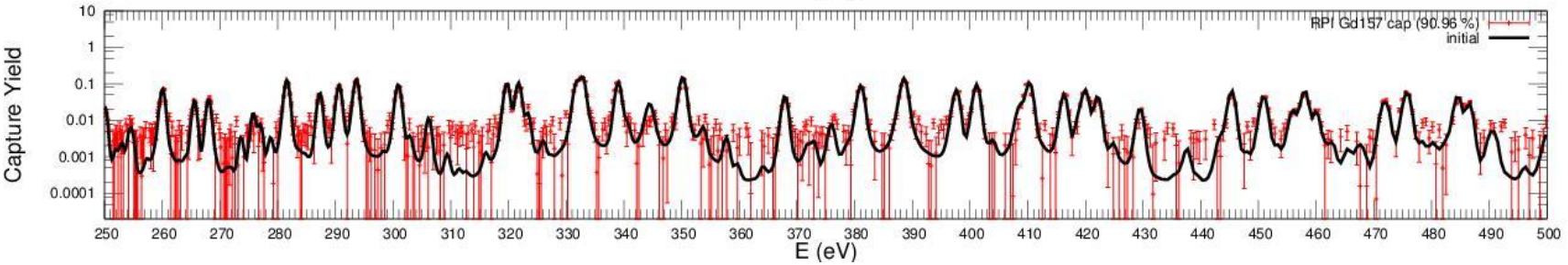


Gd nat

capture

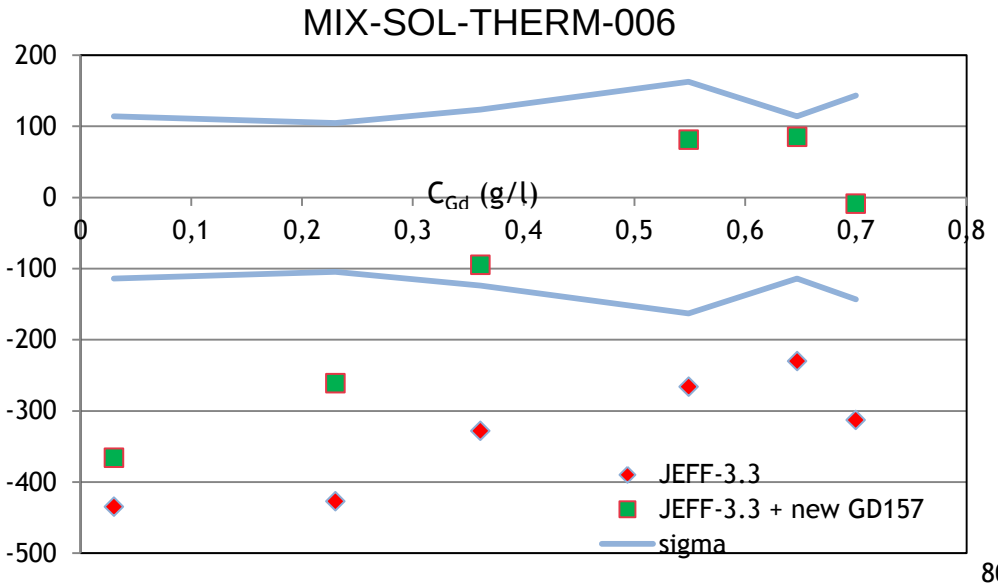


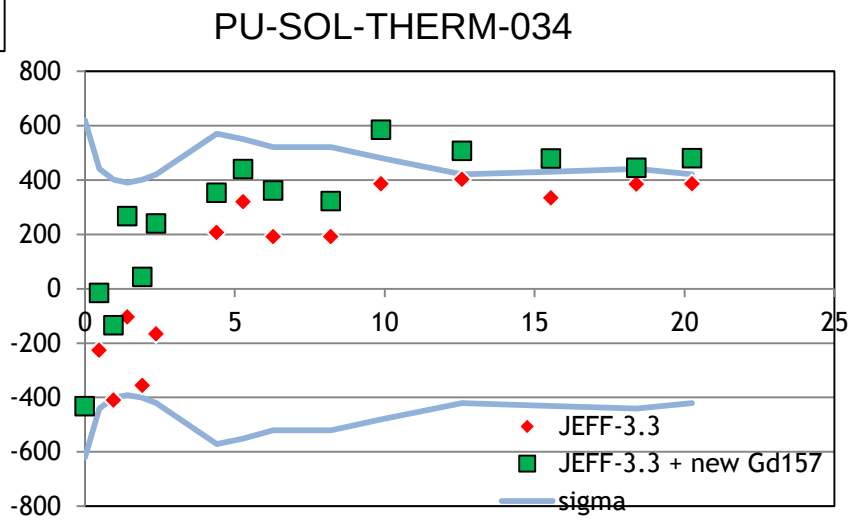
Gd 155



Gd 157

^{157}Gd preliminary test





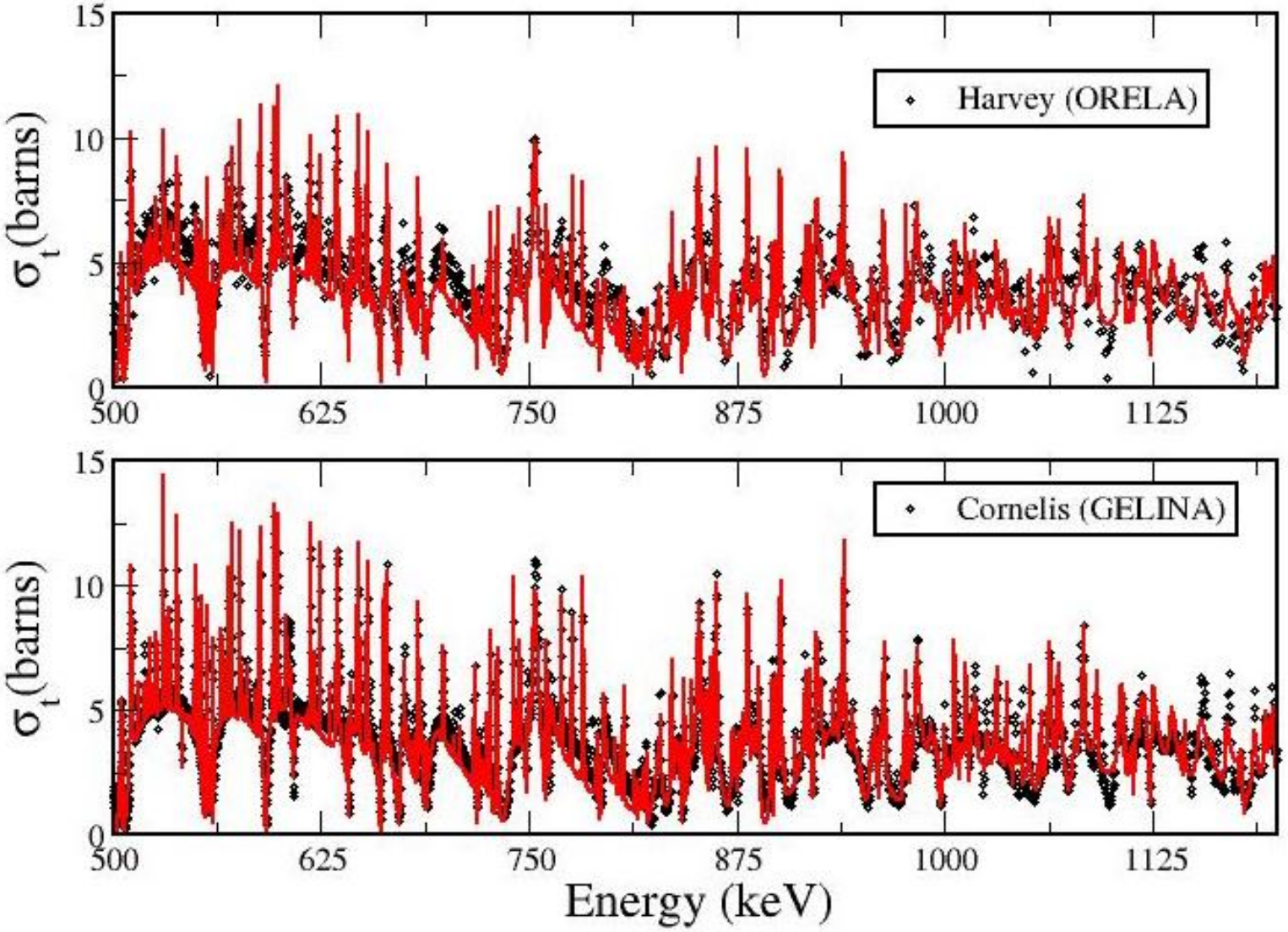
New ^{157}Gd: effect up to 400 pcm

^{54}Fe Evaluation in the Resolved Resonance*

- Natural Iron: ^{56}Fe(91.75 %), ^{54}Fe(5.85 %) and ^{57}Fe(2.12 %);
- Resonance region extended from 700 keV to 2 MeV;
- High resolution transmission data of Cornelis (GELINA) and Harvey (ORELA);
- Calculated direct capture with the CUPIDO code from G. Arbanas (ORNL) included;
- Capture and DDX Scattering cross section needed;
- First inelastic channel opens 1.434 MeV;

*Task on hold due to:
a) Lack of good transmission data above 1 MeV !!
b) No capture data with good resolution available !!

^{54}Fe Resolved Resonance



Motivation for evaluating ^{56}Fe in the Resolved Resonance Region up 2 MeV

- New high resolution transmission measurements done at the RPI extending the resonance region up to 5 MeV;
- Inelastic cross-section measurements done at IRMM;
- Use the SAMMY/RML feature to include inelastic channel in the R-matrix analysis
- Improve results of benchmark systems calculations

Ten days beam time awarded at J-PARC to measure transmission and capture cross section below 50 keV for ^{54}Fe, ^{56}Fe, and ^{57}Fe. Enriched samples provided by J-PARC.

Pb Resonance Evaluation (204, 206, 207, 208) (collaboration with ORNL - Vladimir Sobes)

- Motivation :
  - Transport casks
  - Shielding in fuel cycle nuclear facilities and laboratories

Isotope	Abundance	Thermal Capture (mbarns)
Pb-204	1.4%	703± 35
Pb-206	24.1%	26.6± 1.2
Pb-207	22.1%	622 ± 14
Pb-208	52.4%	0.23± 0.02

- Assessment of existing evaluations (ENDF, JEFF, JENDL) is being conducted.
- Transmission and capture data for enriched samples are needed!

Mo Resonance Evaluation ($^{95,\ 96}$Mo)

- Motivation :
  - Research and naval reactors fuel
  - Burn-up credit (one of the major absorbers)
  - UPuMoZr residues in reprocessing plants

Isotope	Composition (%)	Thermal Cross Section (barns)	Resonance Integral (barns)
^{92}Mo	14.84	0.08±0.02	0.83
^{94}Mo	9.25	0.34±0.02	1.12
^{95}Mo	15.92	13.4±0.3	118±7
^{96}Mo	16.68	0.5±0.3	17±3
^{97}Mo	9.55	2.2±0.2	14.4±3.0
^{98}Mo	24.13	0.130±0.006	6.7±0.3
^{100}Mo	9.63	0.199±0.002	3.76±0.15

- Transmission data and Capture cross section measurements have been carried out recently at J-PARC by IRSN and JAEA

- Assessment of existing evaluations (ENDF, JEFF, JENDL) is being conducted.
- RPI transmission data for enriched ^{95,96}Mo are needed;
- Transmission and capture measurements for ^{95}Mo done by Paul Koehler not yet available.

Concluding Remarks

- IRSN continues to work close to the NCSP agenda on differential data evaluation;
- Final evaluation includes resonance parameters and resonance parameter covariance;

IRSN priority list *(to be completed)*

Pu-239 (***see TEX preliminary results***),
Pu-240, Pu-241, Am-241,
U-235, U-238, U-234
Gd isotopes, Mo isotopes, Fe-54, Fe56, Pb-204, Pb-206, Pb-207, Pb-208
Cl-35, Cl-37, F-19, Nickel isotopes, Sm-149, Sm-152, Cs-133, Si isotopes, Ca isotopes, Mn-55, Nd-143