

Resonance Evaluation for FENDL-3 at ORNL



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**FENDL-3 Meeting
November 2011**

50,52,53,54Cr Resonance Evaluation at ORNL



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Cr isotope evaluation

- Transmission and capture cross section measurements done at ORELA for ^{53}Cr and natural Cr for energy below 500 keV (Guber);
- Early high resolution transmission measurements done by Harvey at ORELA above 100 keV for all Cr isotopes;
- Evaluation performed with SAMMY;
- Preliminary resolved resonance parameters determined for all Cr isotopes;

Computer Code SAMMY

- **Used for analysis of neutron, charged-particle cross-section data.**
- **Uses Bayes' method (generalized least squares) to find parameter values.**
- **Uses R-matrix theory, Reich-Moore approximation (default) or multi- or single-level Breit-Wigner theory.**
- **Generates covariance and sensitivity parameters for resonance region.**

Cr isotope evaluation

Energy Range for ^{52}Cr

Resolved (OLD): 10^{-5} eV – 1.2 MeV

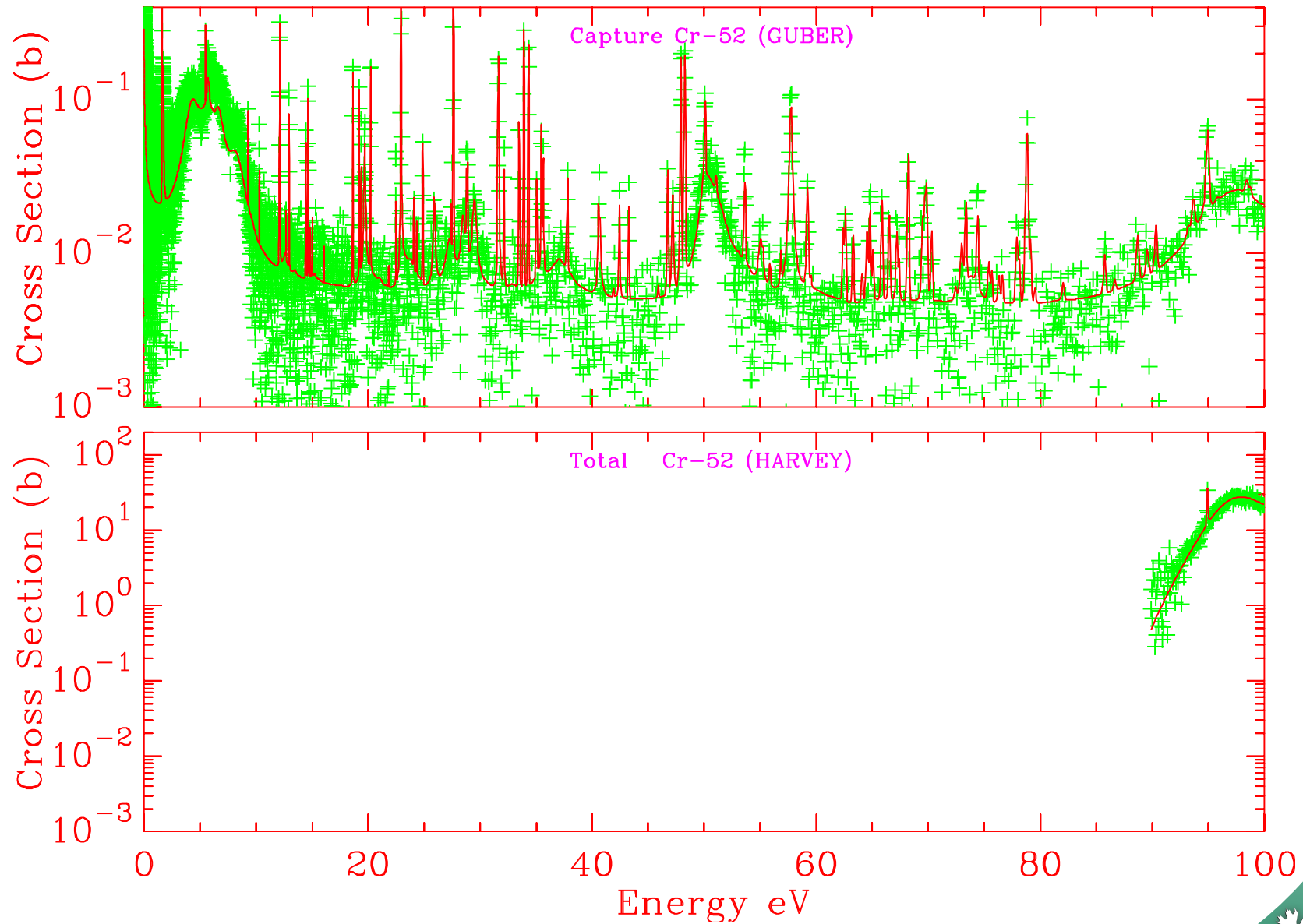
Resolved (ORNL): 10^{-5} eV – 1.43 MeV

Energy Range for ^{53}Cr

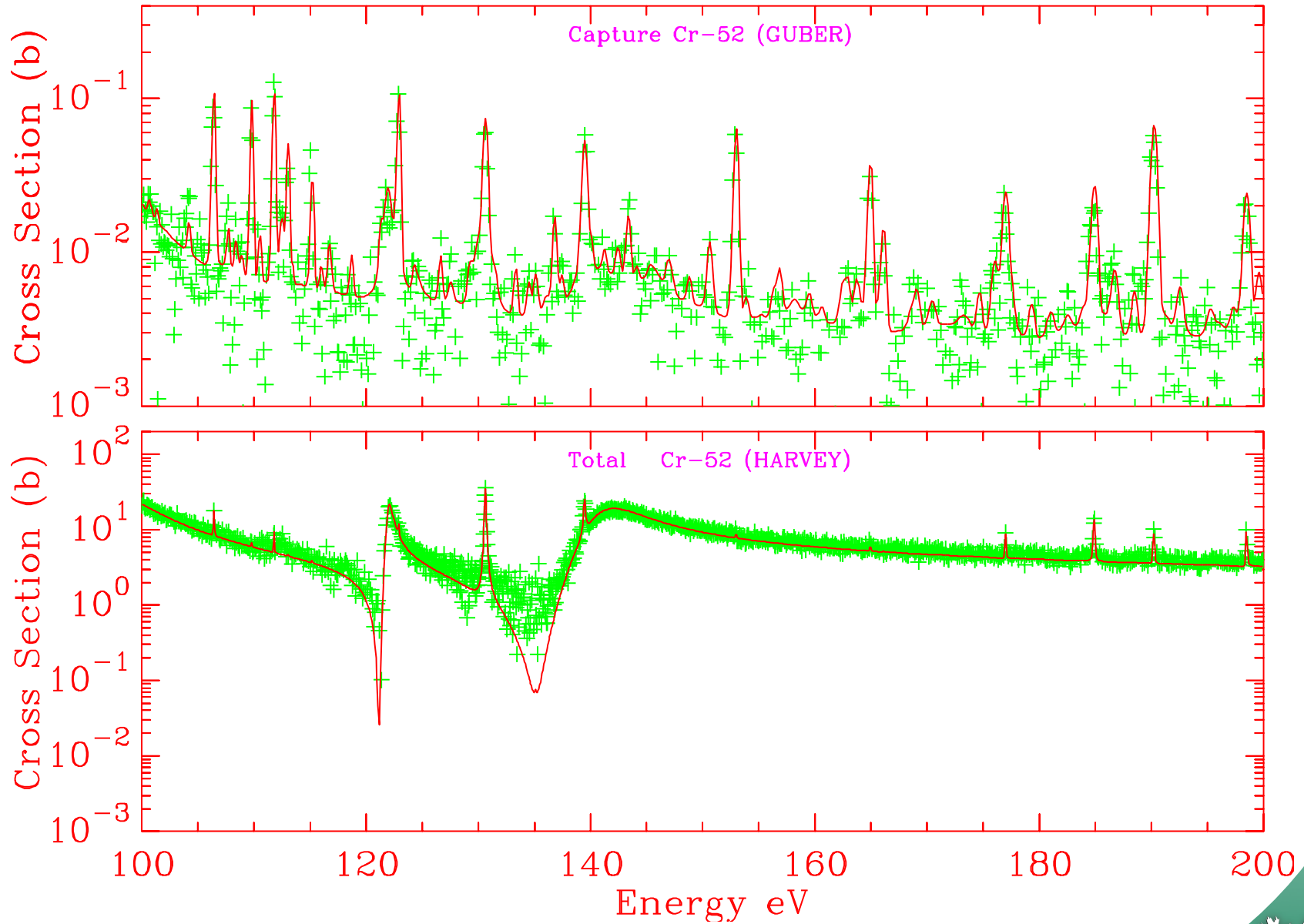
Resolved (OLD): 10^{-5} eV – 245 keV

Resolved (ORNL): 10^{-5} eV – 564 keV

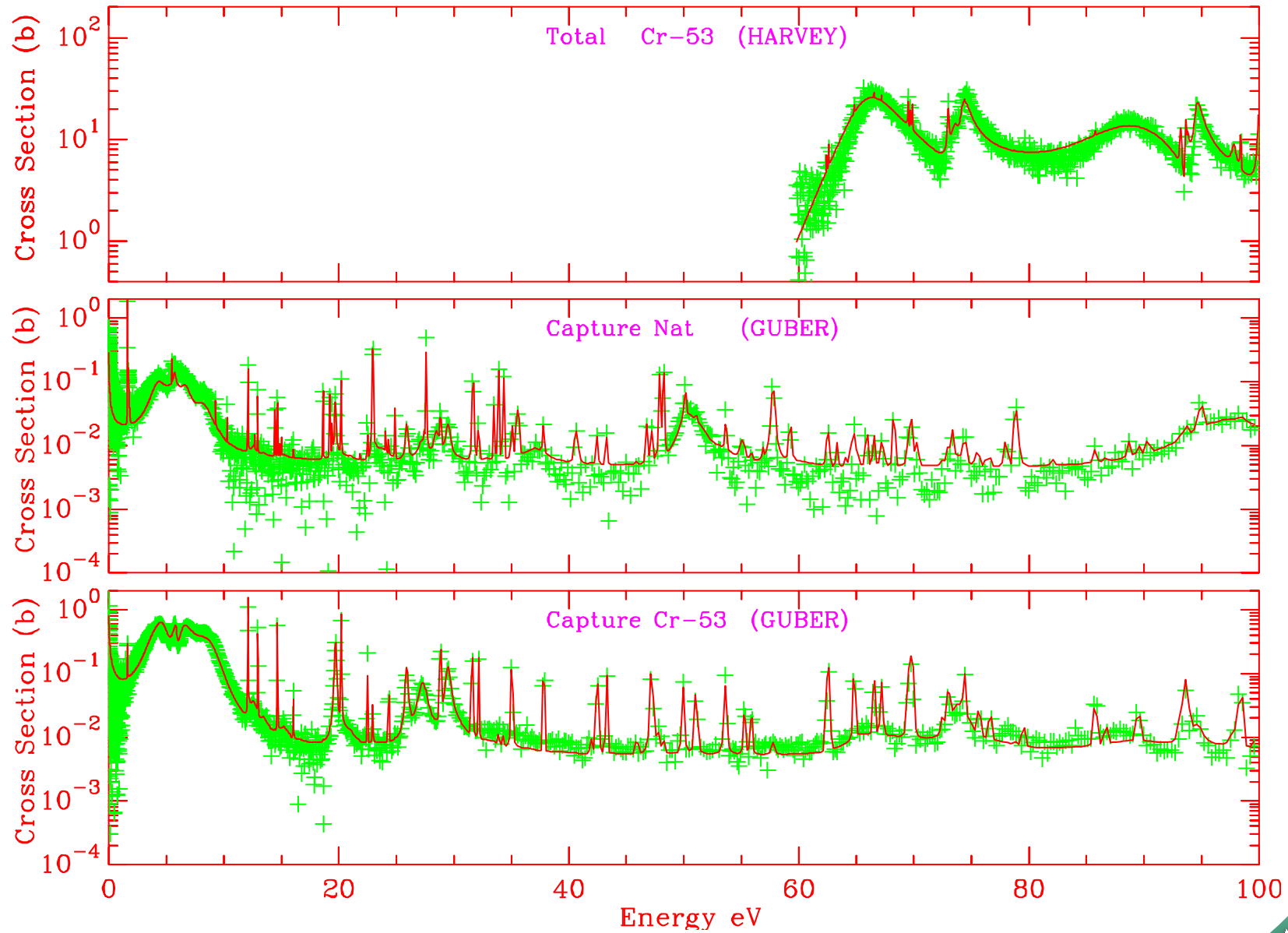
^{52}Cr Resonance Evaluation



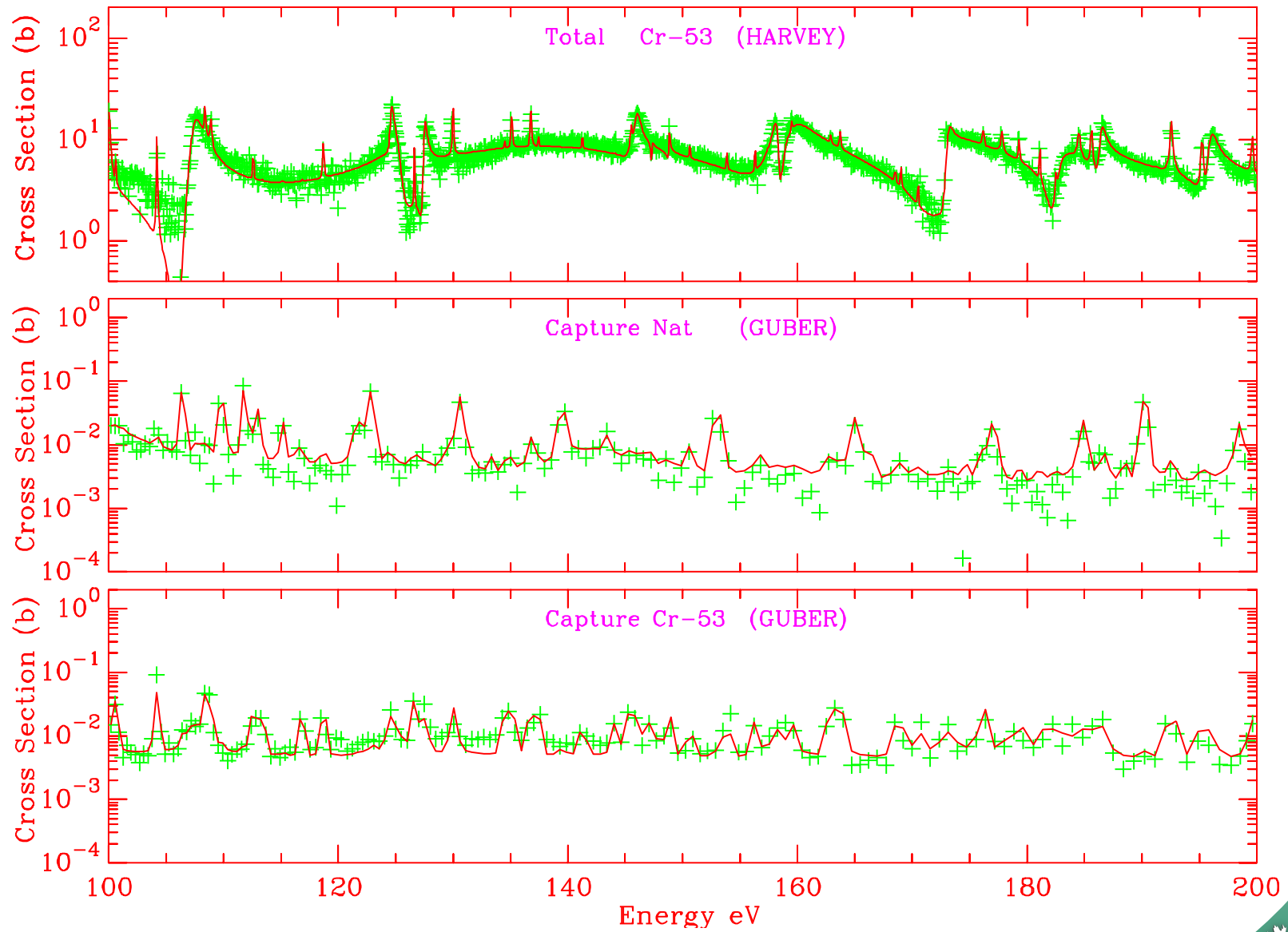
^{52}Cr Resonance Evaluation



^{53}Cr Resonance Evaluation



^{53}Cr Resonance Evaluation



^{52}Cr thermal cross section compared to the values listed in the Atlas of Neutron Resonances

Cross Section	ORNL		Atlas
	Resonance	Direct	
Capture	0.75+/-0.02	0.82	0.86+/-0.02
Total	3.82+/-0.01	3.93	3.82+/-0.03
Scattering	3.07+/-0.07	-	2.96+/-0.02

^{53}Cr thermal cross section compared to the values listed in the Atlas of Neutron Resonances

Cross Section	ORNL		Atlas
	Resonance	Direct	
Capture	18.09+/-0.42	18.41	18.60+/-0.60
Total	26.07+/-0.51	26.39	26.38+/-0.62
Scattering	7.98+/-0.28	-	7.78+/-0.20

$^{50,54}\text{Cr}$ isotope evaluation

Energy Range for ^{50}Cr

Resolved (OLD): 10^{-5} eV – 600 keV

Resolved (ORNL): 10^{-5} eV – **783** keV

Energy Range for ^{54}Cr

Resolved (OLD): 10^{-5} eV – 750 keV

Resolved (ORNL): 10^{-5} eV – **834** keV

$^{58,60}\text{Ni}$ Resonance Evaluation at ORNL



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INTRODUCTION

- **PREVIOUS EVALUATION by C. M. Perey et al., for ENDF/B-V, VI**
 - not modified for B-VII-0
 - no COVARIANCE DATA available
 - ^{58}Ni thermal to 800 keV
 - ^{60}Ni thermal to 450 keV
- **HIGH RESOLUTION NEUTRON TRANSMISSION at GELINA**
 - Brusegan, 1994
- **NEW CAPTURE CROSS SECTION MEASUREMENT at ORELA Guber, 2008**
- **RE-EVALUATION NEEDED by UPDATING THE DATA BASE**
- **RPCM and CSCM CALCULATION**

EXPERIMENTAL DATA BASE

- **OLD ORELA TRANSMISSION DATA by Harvey, Larson, Perey**
 - **^{58}Ni Flight path 78 m, Sample 0.0764 at/b Low Energy**
 - **^{58}Ni Flight path 201 m, Sample 0.172 at/b High Energy**
 - **^{60}Ni Flight path 80 m, Sample 0.029 and 0.084 at/b $E < 200$ keV**
 - **^{60}Ni Flight path 80 m, Sample 0.0744 at/b $E > 200\text{keV}$**

EXPERIMENTAL DATA BASE

- **GELINA TRANSMISSION DATA by Brusegan et al.**
 - **58Ni Flight path 388 m Sample 0.044 at/b**
 - **60Ni Flight path 388 m Sample 0.0744 at/b**

- **ORELA CAPTURE DATA by Guber**
 - **58Ni Flight path 40 m Samples 0.360 at/b**
 - **60Ni Flight path 40 m Samples 0.364 at/b**

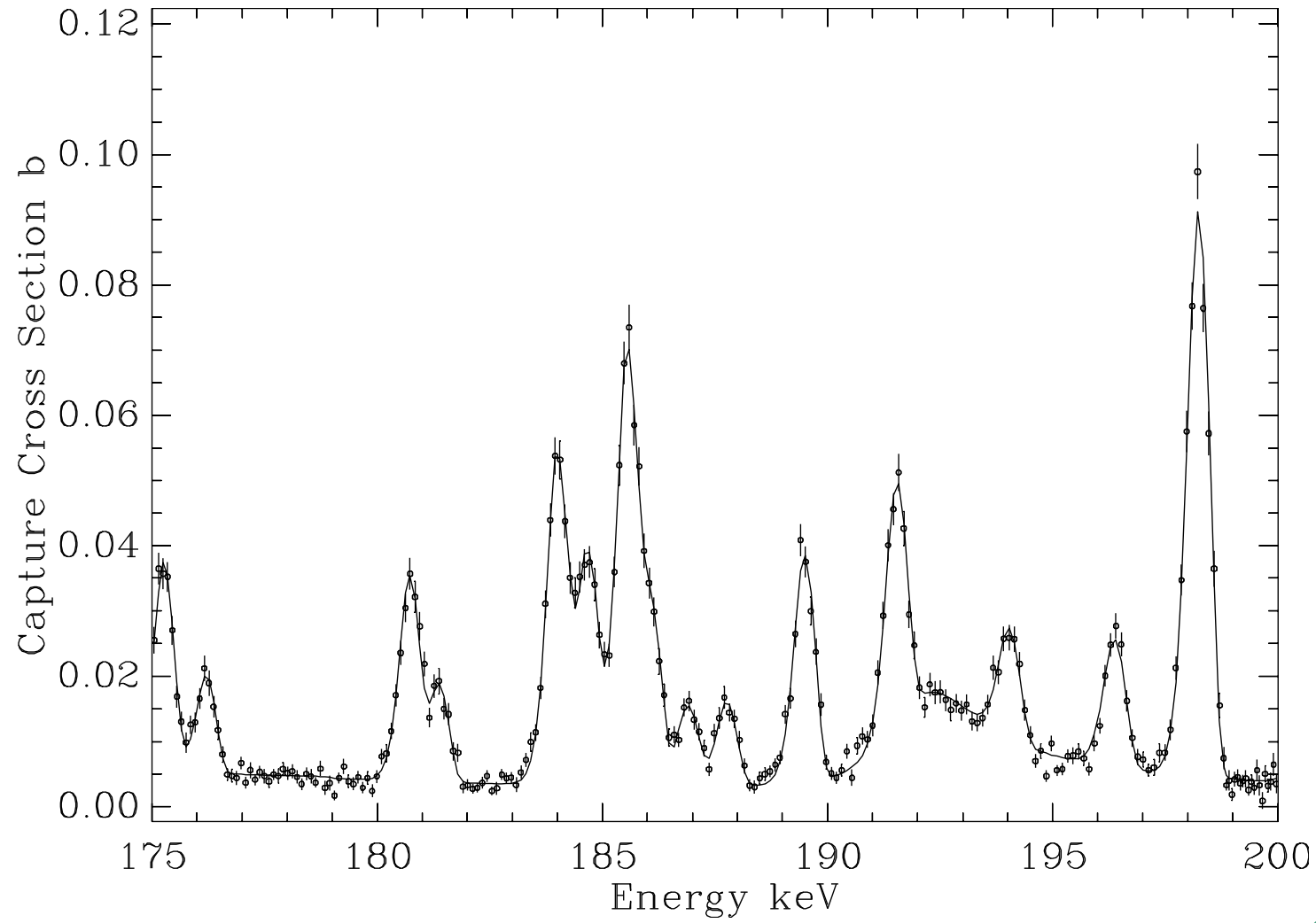
RESULTS

- Resonance Parameters

	ENDF/B.VII.0 (keV)	ORNL (keV)
^{58}Ni	$10^{-2} - 812.0$	$10^{-2} - 812.0$
^{60}Ni	$10^{-2} - 450.0$	$10^{-2} - 812.0$

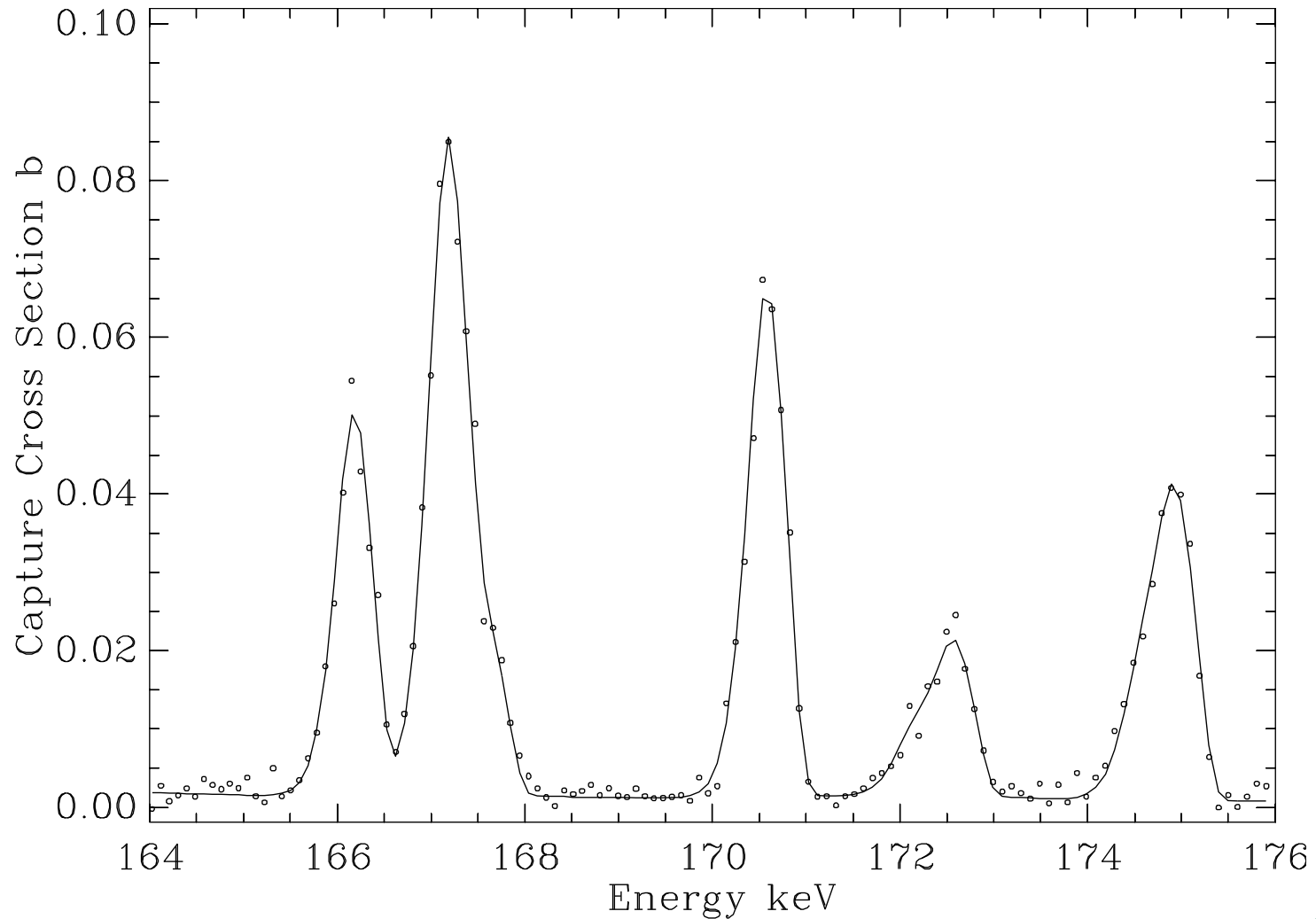
RESULTS

- ^{58}Ni effective capture cross section in the energy range 175 keV to 200 keV from Guber et al. The smooth curve represents the effective cross section calculated by SAMMY from the resonance parameters



RESULTS

- ^{60}Ni effective capture cross section in the energy range 164 keV to 176 keV from Guber et al. The smooth curve represents the effective cross section calculated by SAMMY from the resonance parameters



RESULTS

- ^{58}Ni average capture cross sections. The cross sections are given in mb

Energy keV	Present	B-VII-0	Perey[1]	Froehner[10]
6.31-7.94	13.28±3.17	13.38	13.0±1.0	2.6±0.3
7.94-10.00	6.46±1.34	4.80	3.3±0.6	3.3±3.3
10.00-12.59	8.87±1.51	6.86	6.2±1.6	6.6±1.0
12.59-15.85	179.35±11.5	193.86	196.0±19.	195.0±25.
15.85-20.00	23.63±2.71	21.43	20.9±4.0	26.3±3.2
20.00-25.10	42.08±4.24	42.68	45.8±1.9	35.2±4.4
25.10-31.60	28.83±2.28	33.63	36.3±1.5	26.2±3.9
31.60-39.80	62.13±3.72	75.21	78.6±3.2	55.7±5.0
39.80-50.10	12.75±0.87	13.89	14.5±0.6	10.6±1.3
50.10-63.10	31.01±1.97	39.59	41.7±2.2	31.4±2.3
63.10-79.40	10.79±1.13	13.66	14.2±1.5	9.8±0.7
79.40-100.00	19.93±1.27	24.43	25.5±1.0	17.3±1.7
100.00-125.90	25.82±0.88	34.11	35.2±1.5	22.0±2.1
125.90-158.50	16.35±0.60	20.78	21.3±1.5	12.6±1.0
158.50-199.50	16.80±0.59	22.73	23.6±1.0	16.5±2.4
199,50=251.20	12.36±0.45	18.77	19.3±0.5	13.1±3.3

RESULTS

- ^{60}Ni average capture cross sections. The cross sections are given in mb

Energy keV	Present mb	Uncertainties	ENDF/B-VII-0	Ratio
1.0-2.0	9.85	5.50	10.57	1.07
2.0-3.0	106.25	7.53	109.58	1.03
3.0-5.0	9.02	4.50	9.57	1.06
5.0-10.0	27.55	3.80	27.24	0.99
10.0-15.0	167.82	9.15	163.60	0.97
15.0-20.0	15.11	2.70	14.17	0.94
20.0-27.0	22.85	2.41	23.70	1.04
27.0-38.0	21.91	2.11	27.06	1.23
38.0-47.0	15.86	2.01	17.22	1.09
47.0-70.0	15.32	1.82	17.52	1.14
70.0-100.0	13.47	1.61	15.56	1.16
100.0-150.0	12.57	1.11	14.35	1.14
150.0-200.0	8.75	0.91	13.66	1.33
200.0-250.0	8.05	0.90	9.61	1.19
250.0-300.0	8.63	0.81	9.55	1.11
300.0-350.0	9.88	0.81	11.27	1.14
350.0-400.0	8.28	0.71	10.37	1.25
600.0-450.0	8.06	0.61	8.86	1.10

RESONANCE EVALUATION OF $^{46,47,48,49,50}\text{Ti}$ INCLUDING COVARIANCE FOR CRITICALITY SAFETY APPLICATIONS

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Titanium Data

Isotope Name	Abundance (%)	σ_{γ} (thermal)	$\delta\sigma_{\gamma}/\sigma_{\gamma}$ (%)
^{46}Ti	8.25	0.59 ± 0.18	30.5
^{47}Ti	7.44	1.63 ± 0.04	2.4
^{48}Ti	73.72	8.32 ± 0.16	1.9
^{49}Ti	5.41	1.87 ± 0.04	2.2
^{50}Ti	5.18	0.18 ± 0.03	16.7

Method of Analyze

- **Nuclear data base used in the evaluation**
 - **High-resolution transmission and capture cross section measurements for enriched ^{48}Ti done at ORELA;**
 - **High-resolution transmission and capture cross section measurements done for natural Ti done at ORELA;**
- **Initial set of resonance parameters from ENDF/B-VII.0;**
- **Thermal cross section and resonance integral listed in the Atlas of Neutron Resonances (ANR);**
- **Use of Reich-Moore formalism and the Bayes' methodology of the SAMMY code to fit the experimental data;**
- **Evaluation done in the energy region 10^{-5} eV to 400 keV;**

Experimental Data

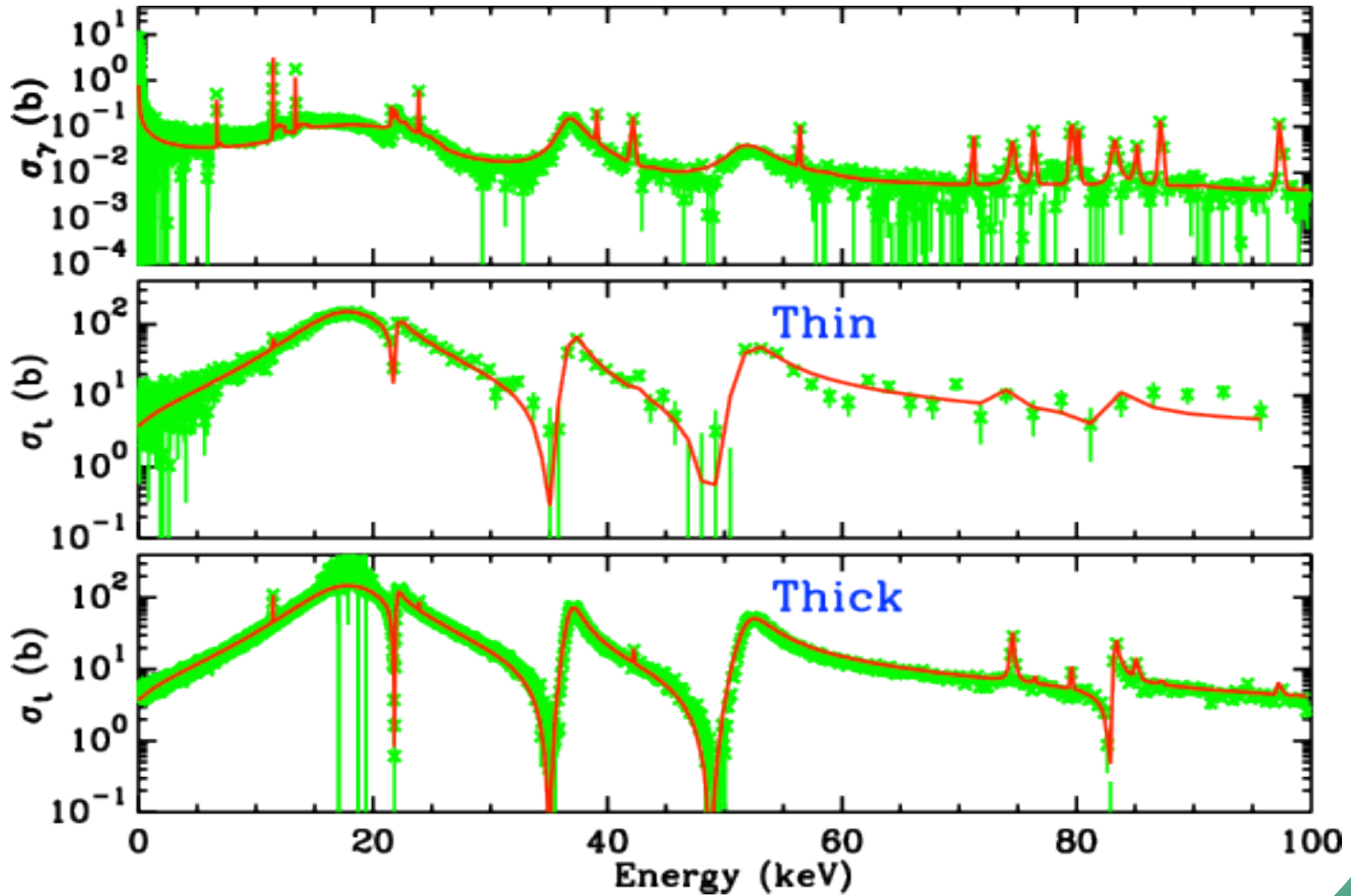
Data Set	Energy Range (keV)	Flight Path (m)	Density (at/b)
Natural Titanium			
Transmission	0.01 – 500.0	79.827	0.052966 (thick)
Transmission	0.01 – 500.0	79.827	0.008785 (Thin)
Capture	0.01 – 500.0	40.116	0.035158

Experimental Data

Data Set	Energy Range (keV)	Flight Path (m)	Density (at/b)
Enriched ^{48}Ti			
Transmission	0.01 – 500.0	79.827	0.028185 (Thick)
Transmission	0.01 – 500.0	79.827	0.0011821 (Thin)
Capture	0.01 – 500.0	40.116	0.0091386

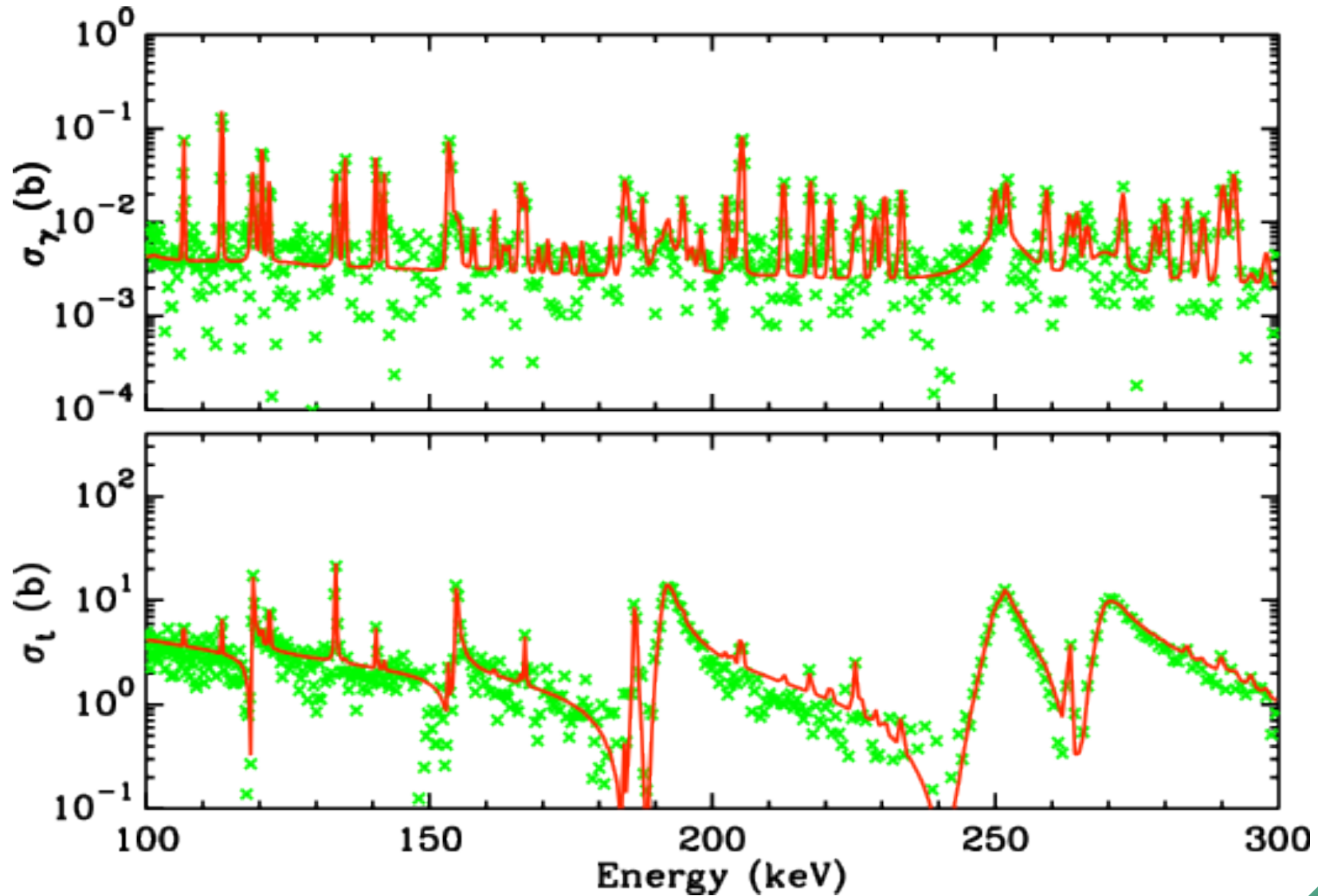
Results

^{48}Ti total and capture cross sections

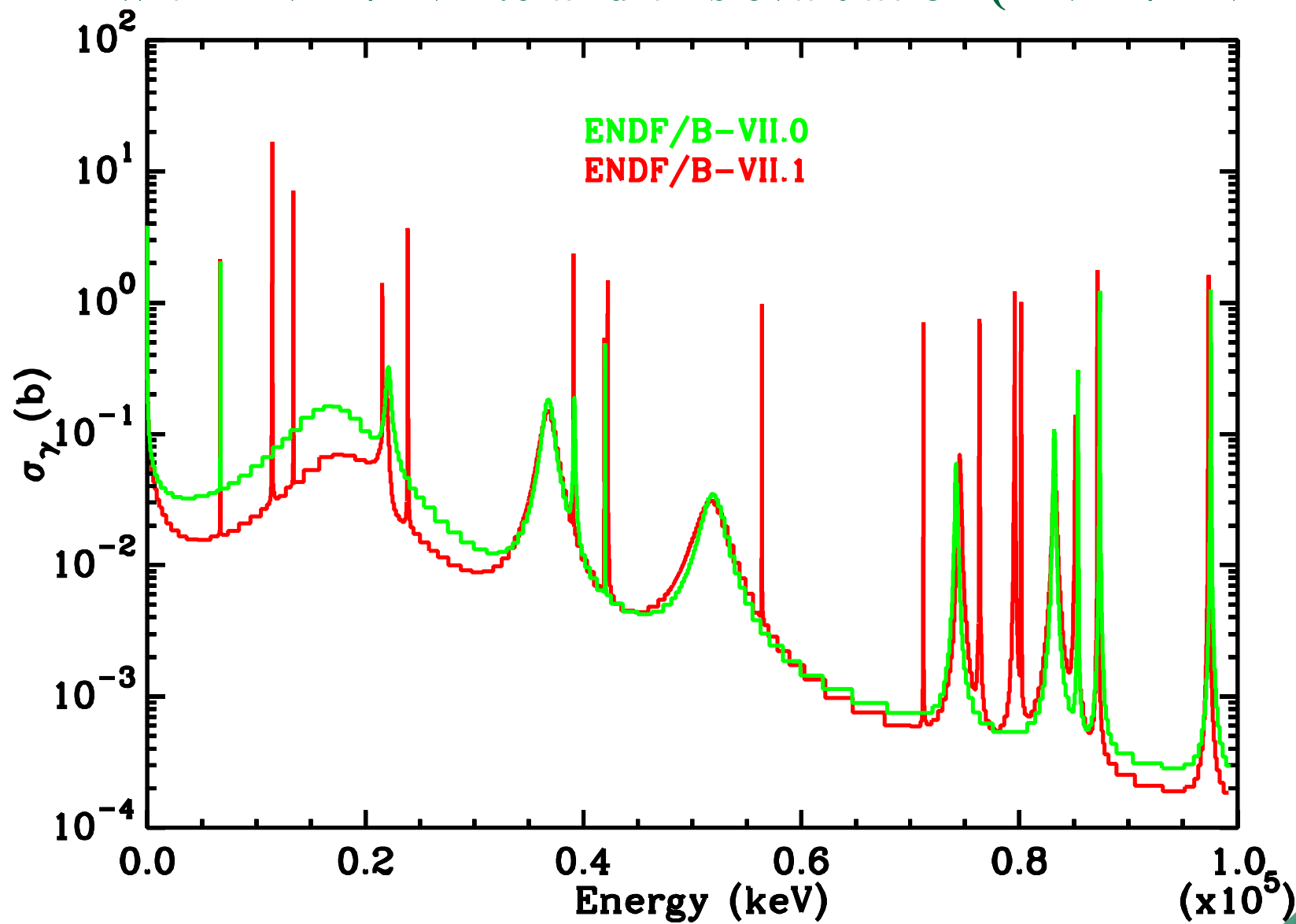


Results

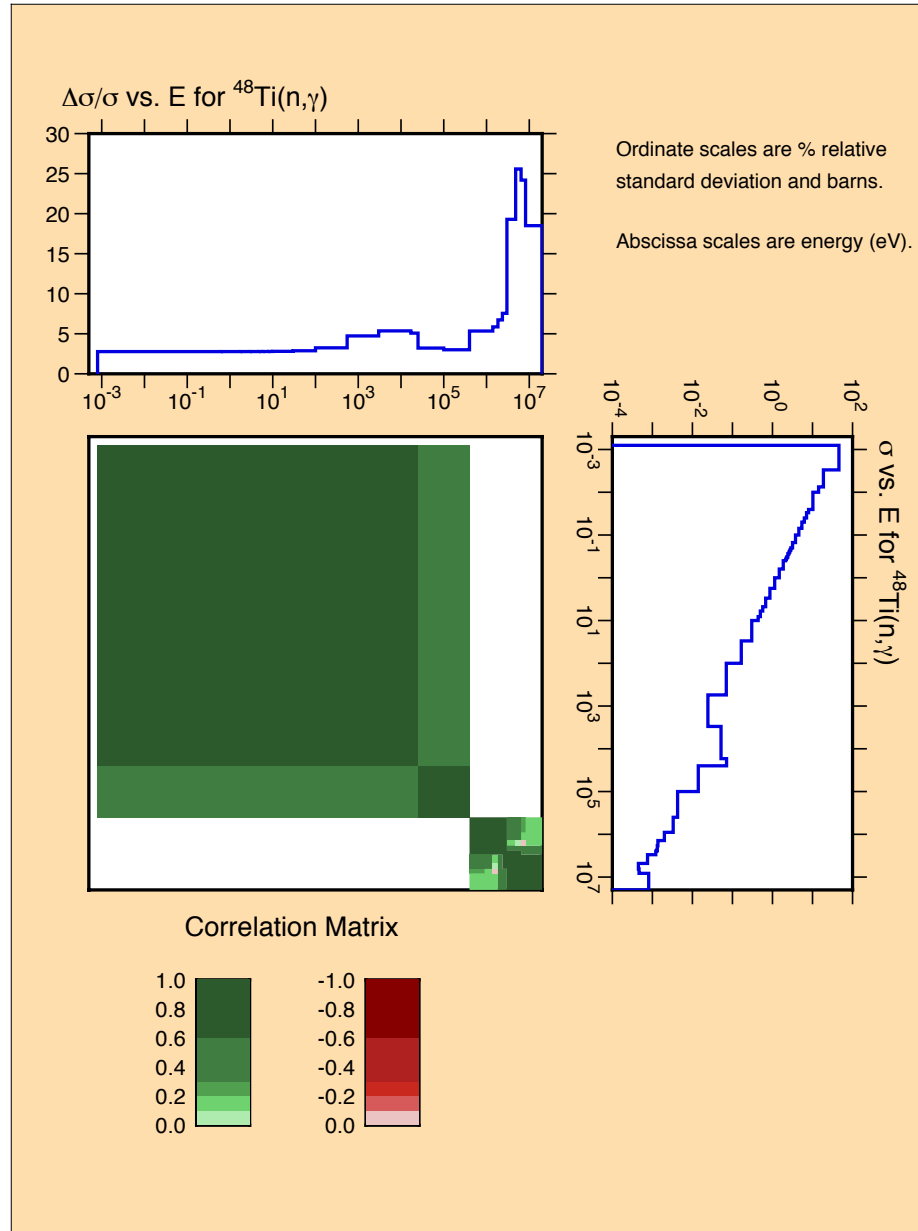
^{48}Ti total and capture cross sections



Comparisons of the capture cross-section of ^{48}Ti calculated with ENDF/BVII.0 and this evaluation (ENDF/B-VII.1)



Covariance Results for ^{48}Ti



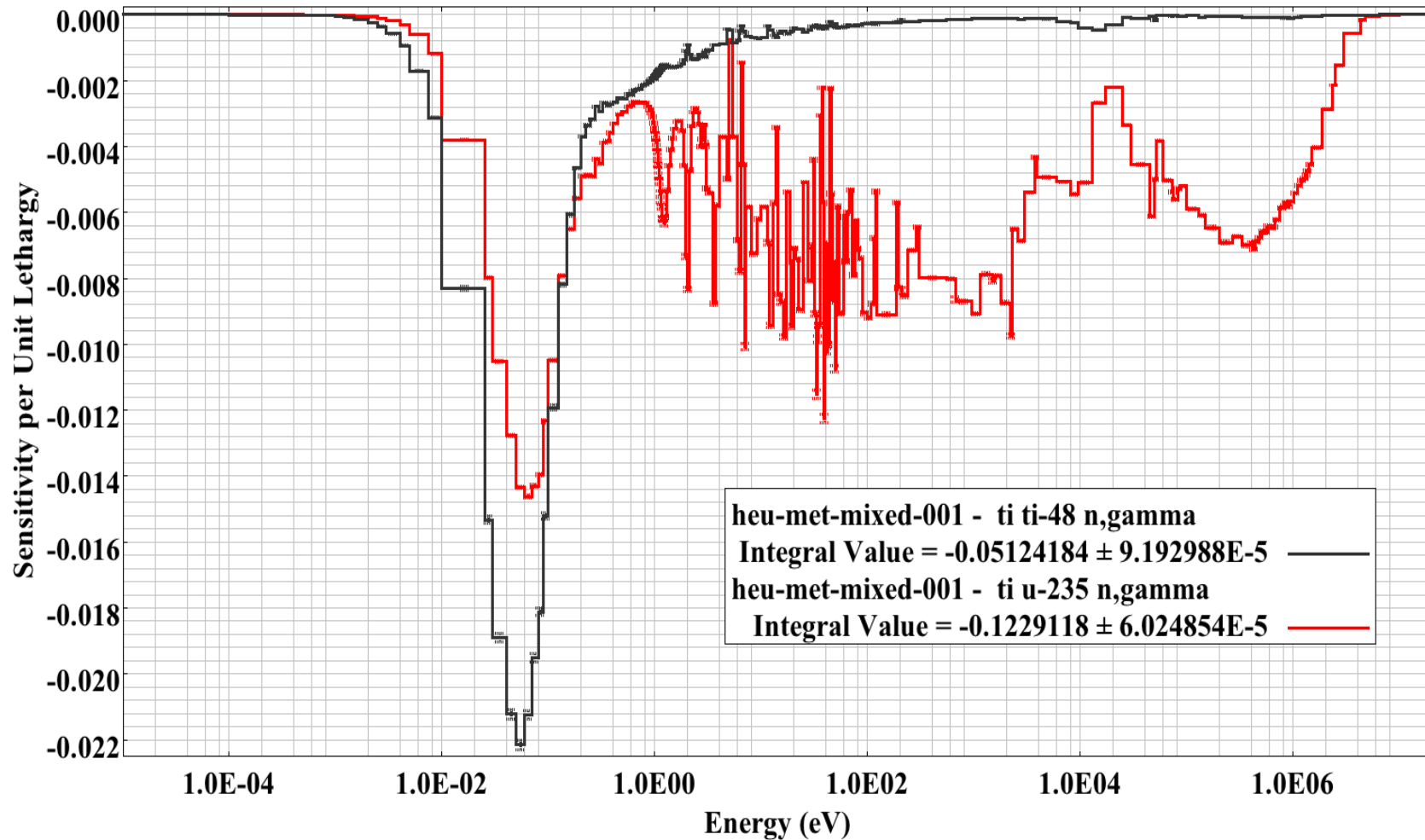
^{48}Ti thermal cross sections and uncertainties

Cross Section	ENDF/B-VII.0 (barns)	ANR (barns)	This Work (barns)
Capture	7.84	8.32 ± 0.16	8.32 ± 0.23
Total	12.16	12.42 ± 0.25	12.35 ± 0.30
Scattering	4.32	4.10 ± 0.20	4.03 ± 0.20

Benchmark Calculation and Uncertainty Propagation

- ✓ **Uncertainty propagation in k_{eff} calculation**
- ✓ **ICSBEP benchmark: HEU-MET-MIXED-001**
- ✓ **Uncertainty processed with PUFF-IV**
- ✓ **Error propagation to k_{eff} done with TSUNAMI**

Sensitivity of the multiplication factor to the capture cross sections of ^{48}Ti and ^{235}U for the HEU-MET-MIXED-001 benchmark system



Benchmark Calculation and Uncertainty Propagation

	k_{eff}	Total uncertainty in the k_{eff}	Uncertainty in the k_{eff} due to ^{48}Ti
ENDF/B-VII.0	1.0083	1.1880	0.1139
	\pm 0.0001		
ENDF/B-VII.1 (including ORNL ^{48}Ti evaluation)	1.0053	0.0001	0.0001
	\pm 0.0001		

The uncertainty in k_{eff} due to ^{48}Ti is ~11% of the total uncertainty

$^{46,47,49,50}\text{Ti}$ Resonance Covariance Generation



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Resonance Parameter Covariance Generation

- Resolved resonance parameters of the ENDF/B.VII.0 were converted from MLBW into the RM representation. The resonances were checked against the resonance parameters given in the Atlas of Neutron Resonances.
- For Ti-46 a resonance at 55.67 keV with $j=1/2$ ($l=1$) was repeated. According to the Atlas it should be at the energy 56.66 with $g_t=0.48$ eV, $g_n=0.1$ eV and $g_g=0.38$.
- Resonance fit with SAMMY.

COVARIANCE:

Resolved resonance covariance data were generate with the SAMMY code for Ti isotopes.

Concluding Remarks

- Resonance parameter and covariance evaluation have been performed at ORNL;
- New transmission and capture cross section measurements done at ORNL used in the evaluation;
- Evaluation done with the SAMMY code using the Reich-Moore formalism;
- Thermal cross section and uncertainties well represented;
- Evaluation adopted in the recently released ENDF/B-VII.1