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Data Evaluation for
^{19}F, ^{35}Cl, ^{37}Cl, ^{241}Pu, ^{238}U, and Gd Isotopes

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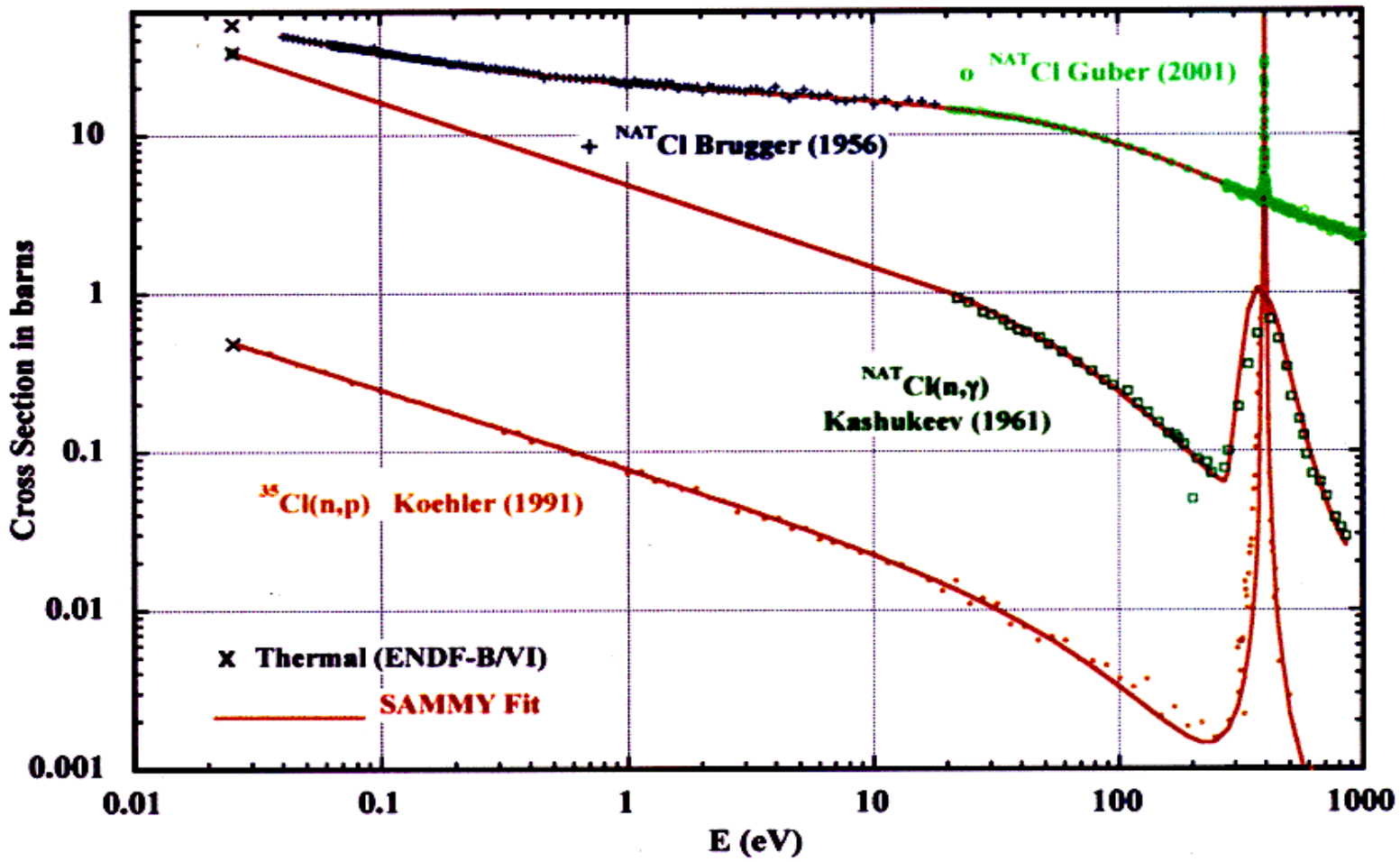
^{35}Cl and ^{37}Cl Resonance Evaluation

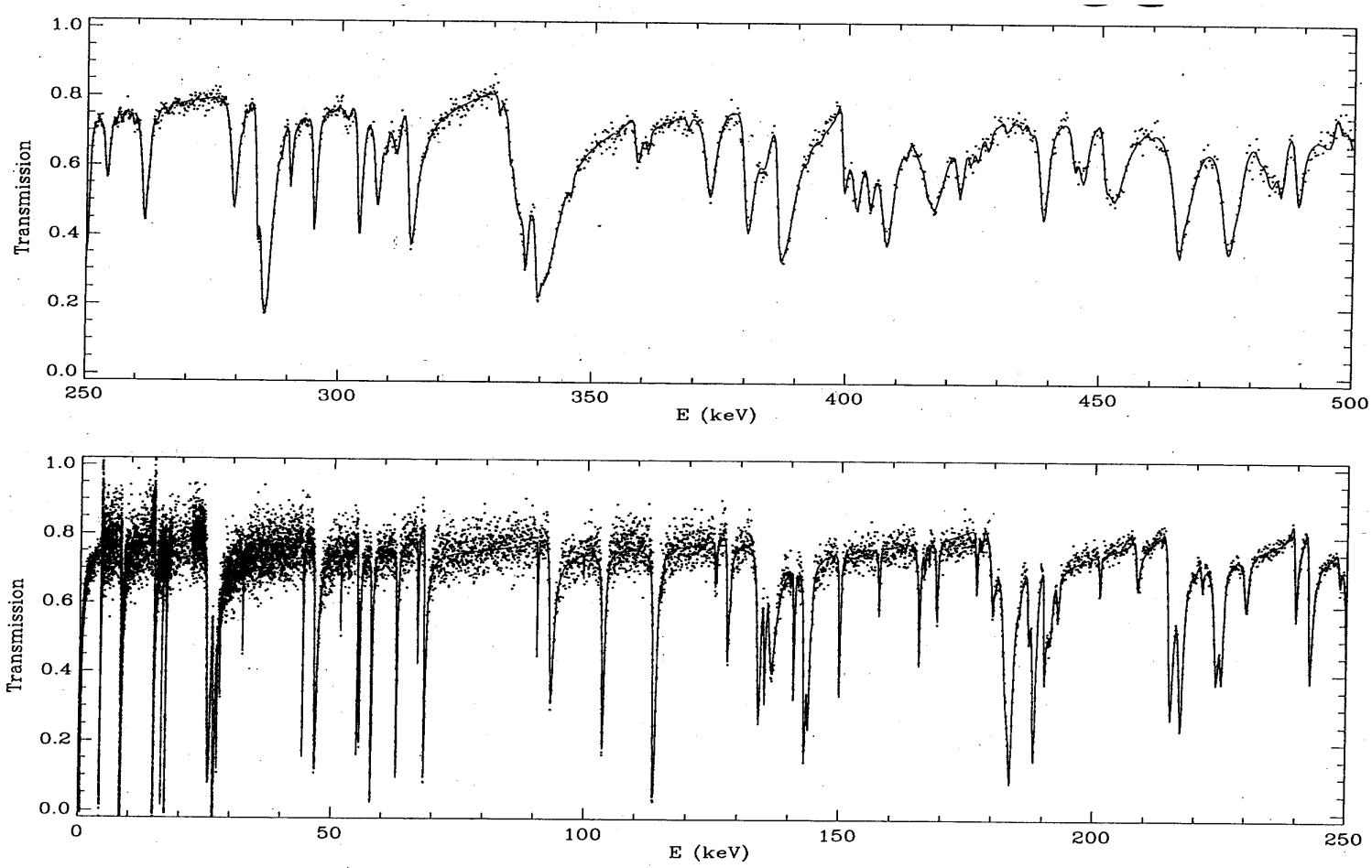
Features:

- Total cross section, capture cross section, and (n,p) cross section data measurements were used in the evaluation.
- Evaluation performed up to 1.2 MeV.
- 380 s- and p-wave. 244 for ^{35}Cl and 136 for ^{37}Cl.
- SAMMY: Reich-Moore formalism was used.
- Charge particle (n,p) exit channel not accommodated in existing ENDF format: Format modification proposed !!

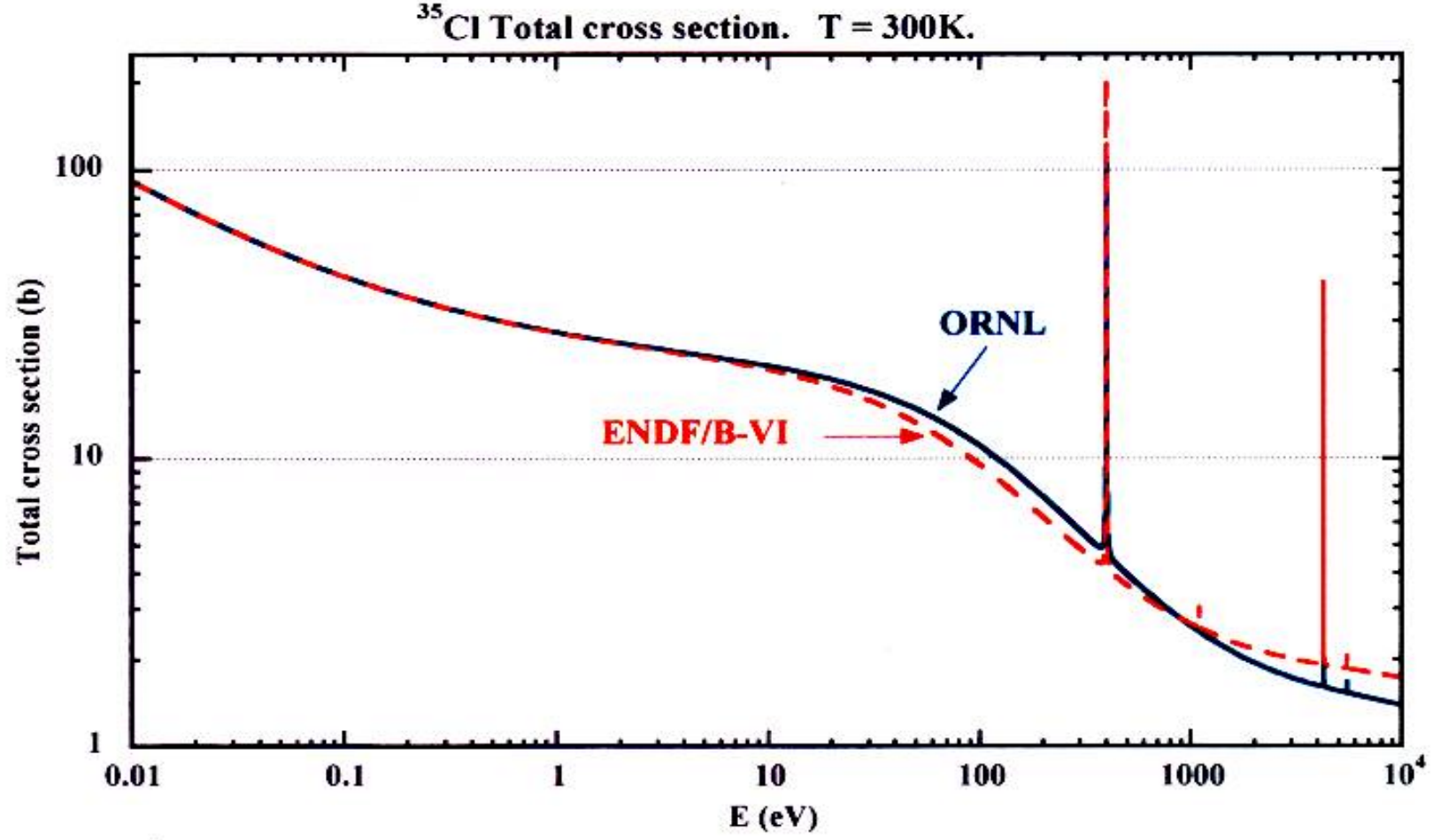
Chlorine Cross Section



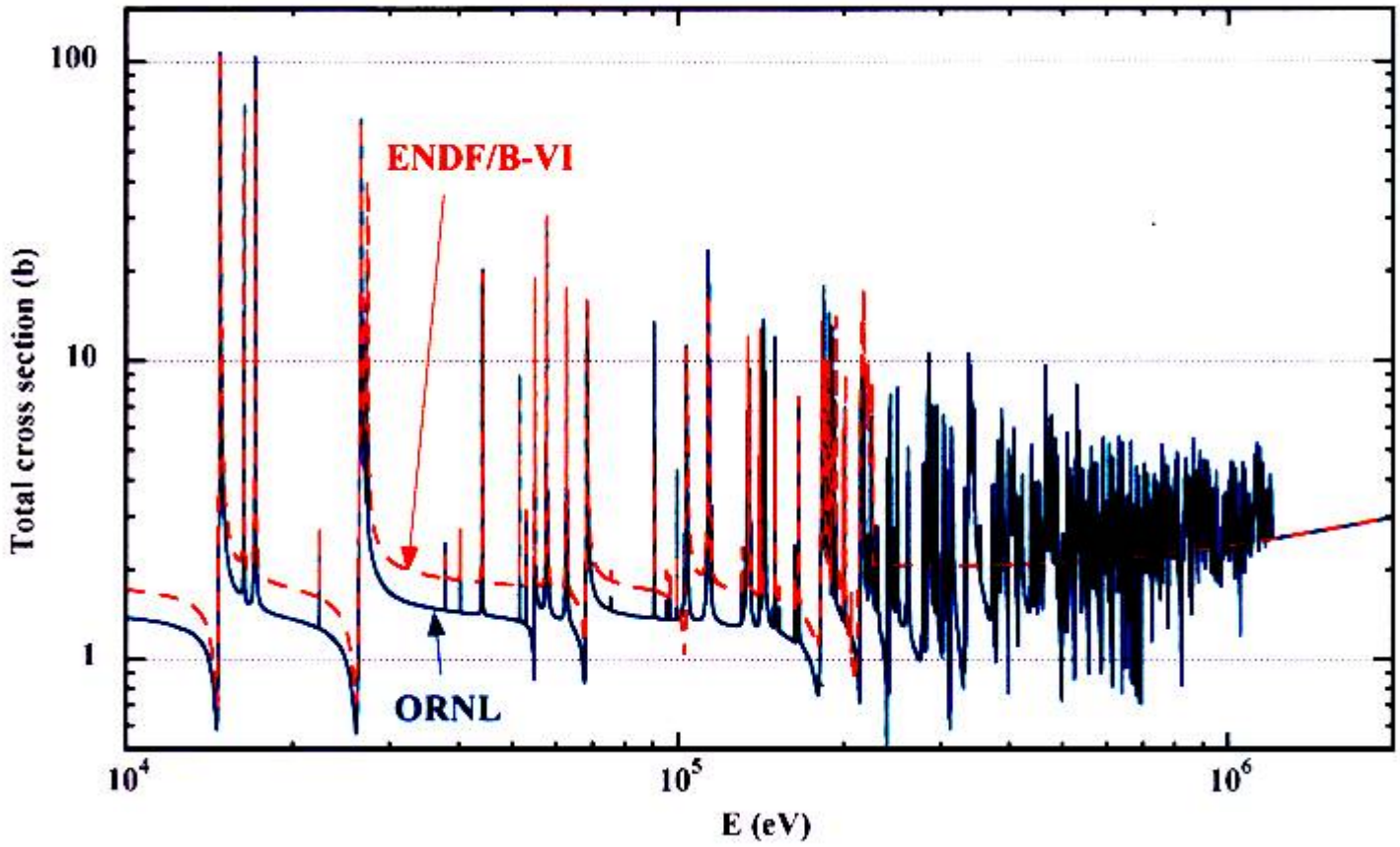
Chlorine Cross Section



Comparison with ENDF



Comparison with ENDF



^{19}F Evaluation

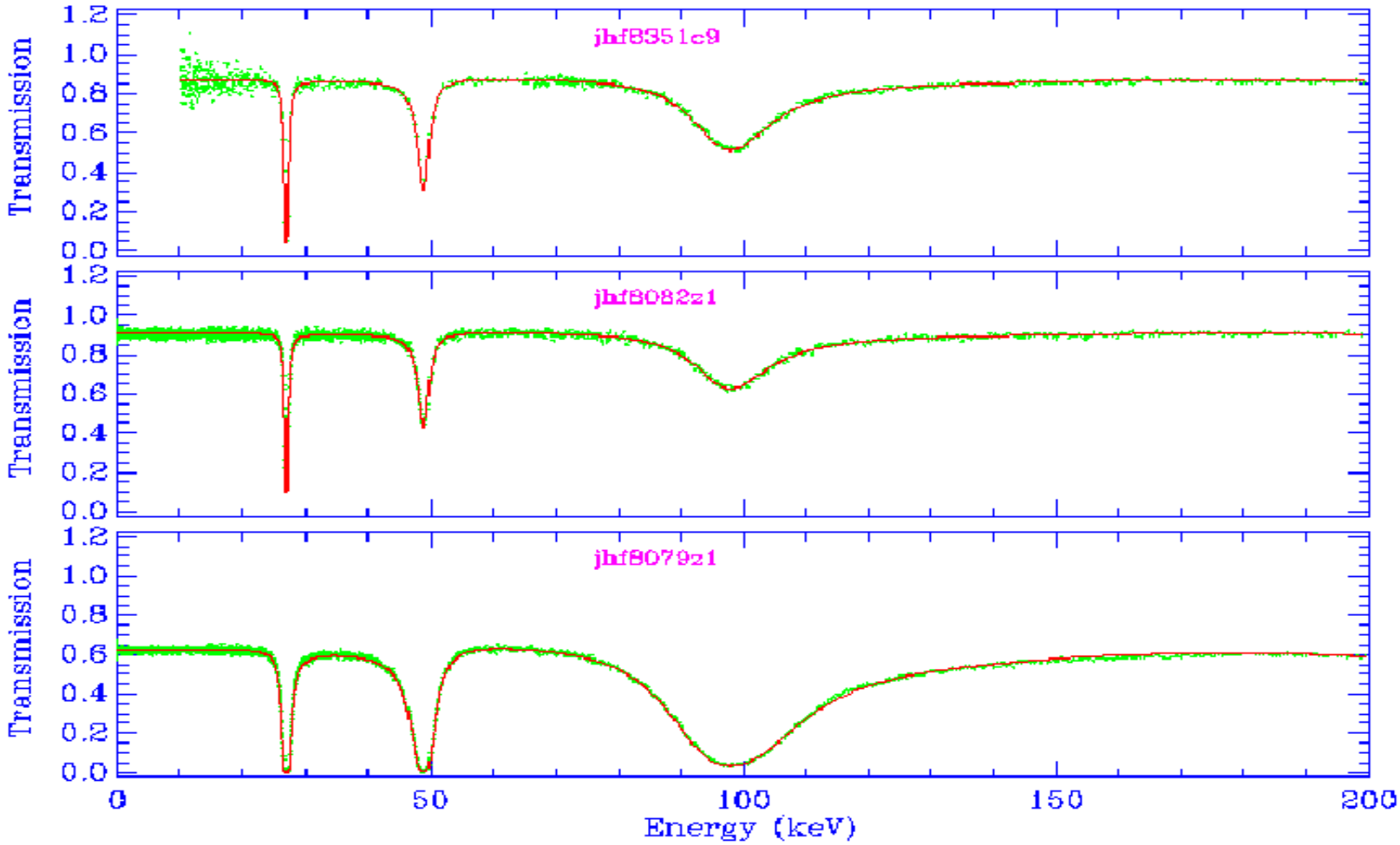
Experimental Data

- **Three Transmission Data Measurements of Larson *et al.* made at ORELA 80 meters flight path with sample thicknesses 0.13093 at/b, 0.016886 at/b, and 0.024184 at/b, respectively in the energy range 5 ev to 20 MeV.**

- **One Capture measurement done at ORELA 40 meters flight path performed by Guber *et al.* up to 700 KeV;**

- **Inelastic Cross Section Measurements Performed by Broder *et al.* at Obninsk up to 1 MeV. (Format modification proposed)**

Transmission



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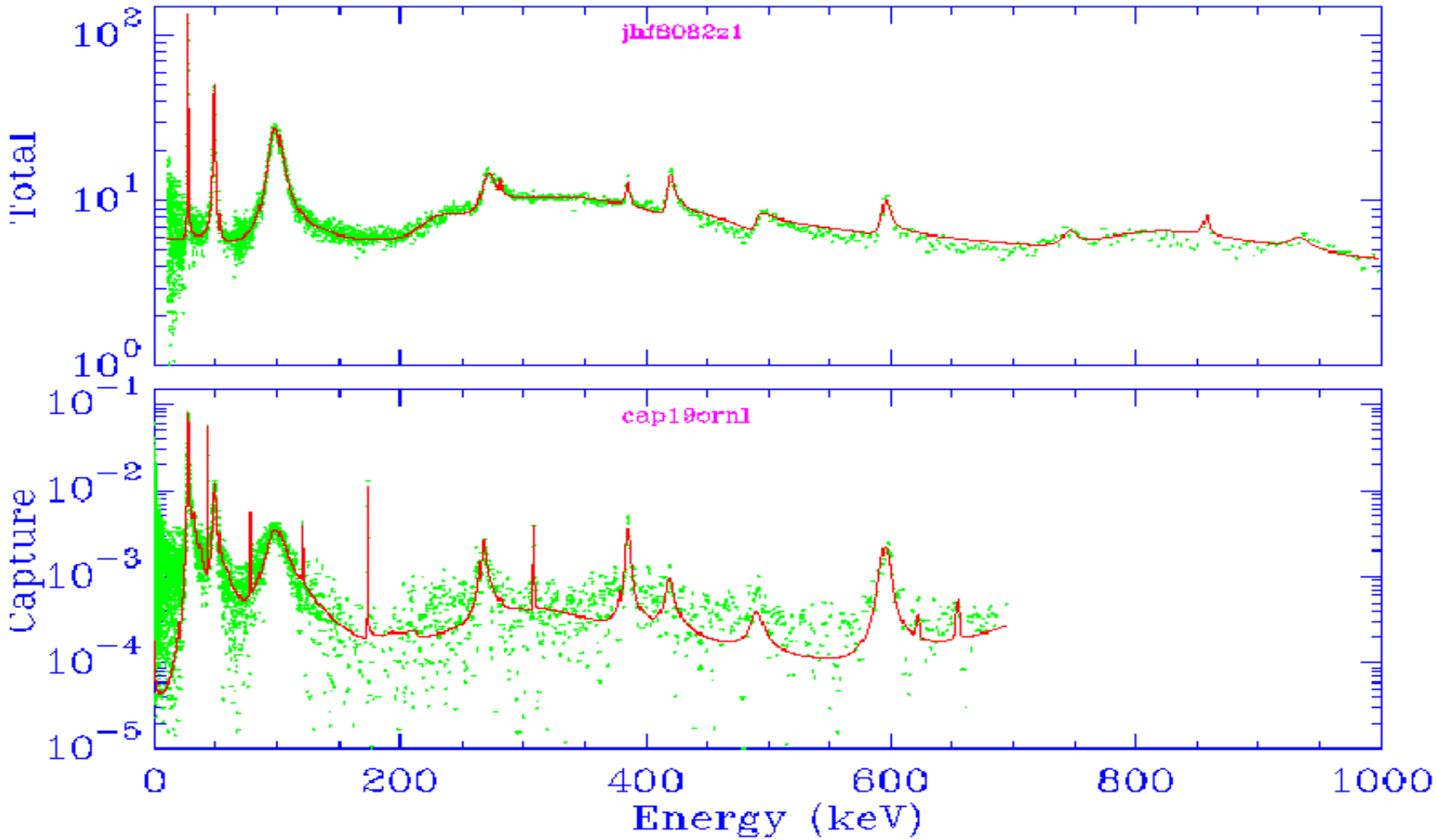
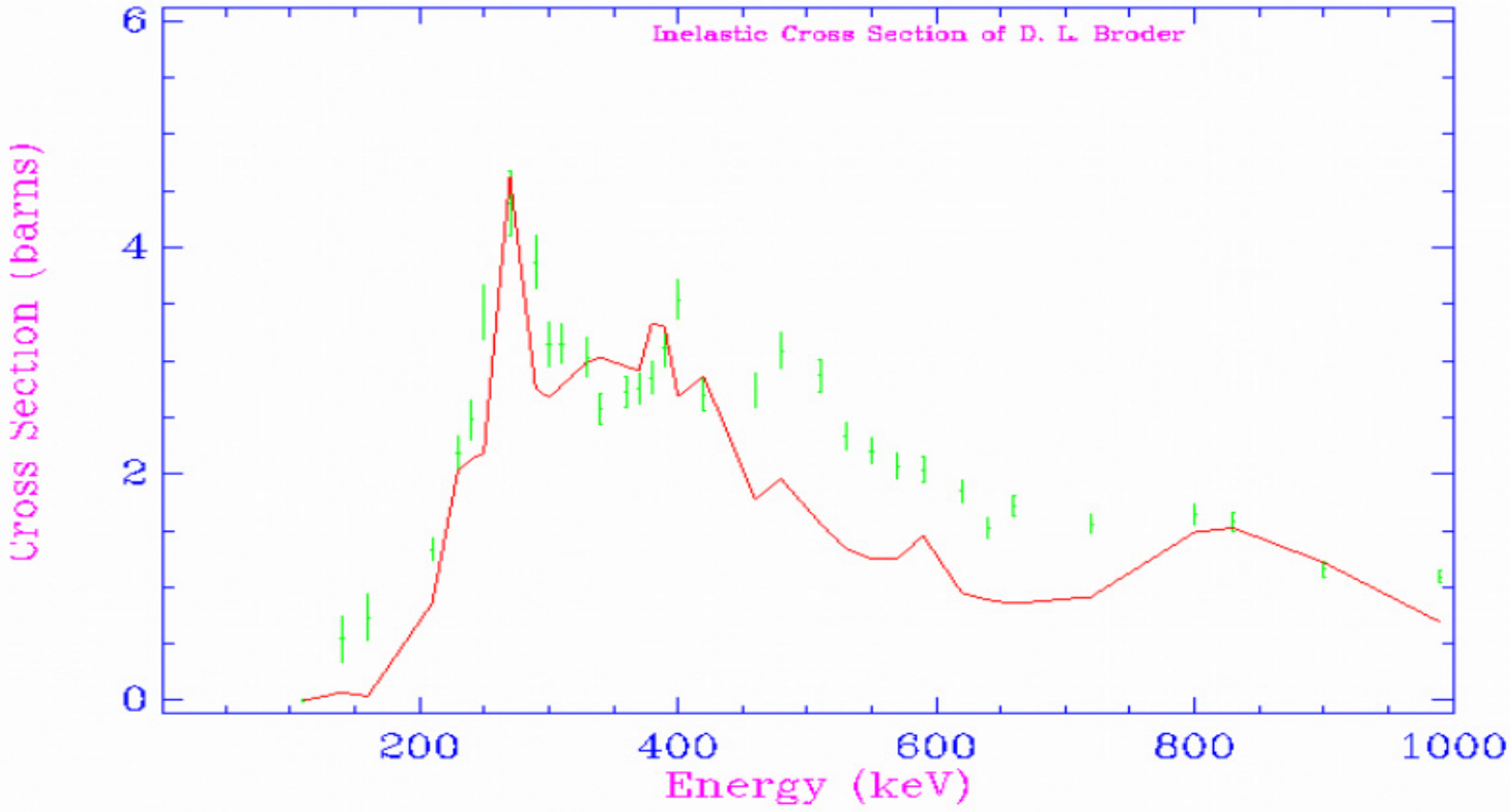
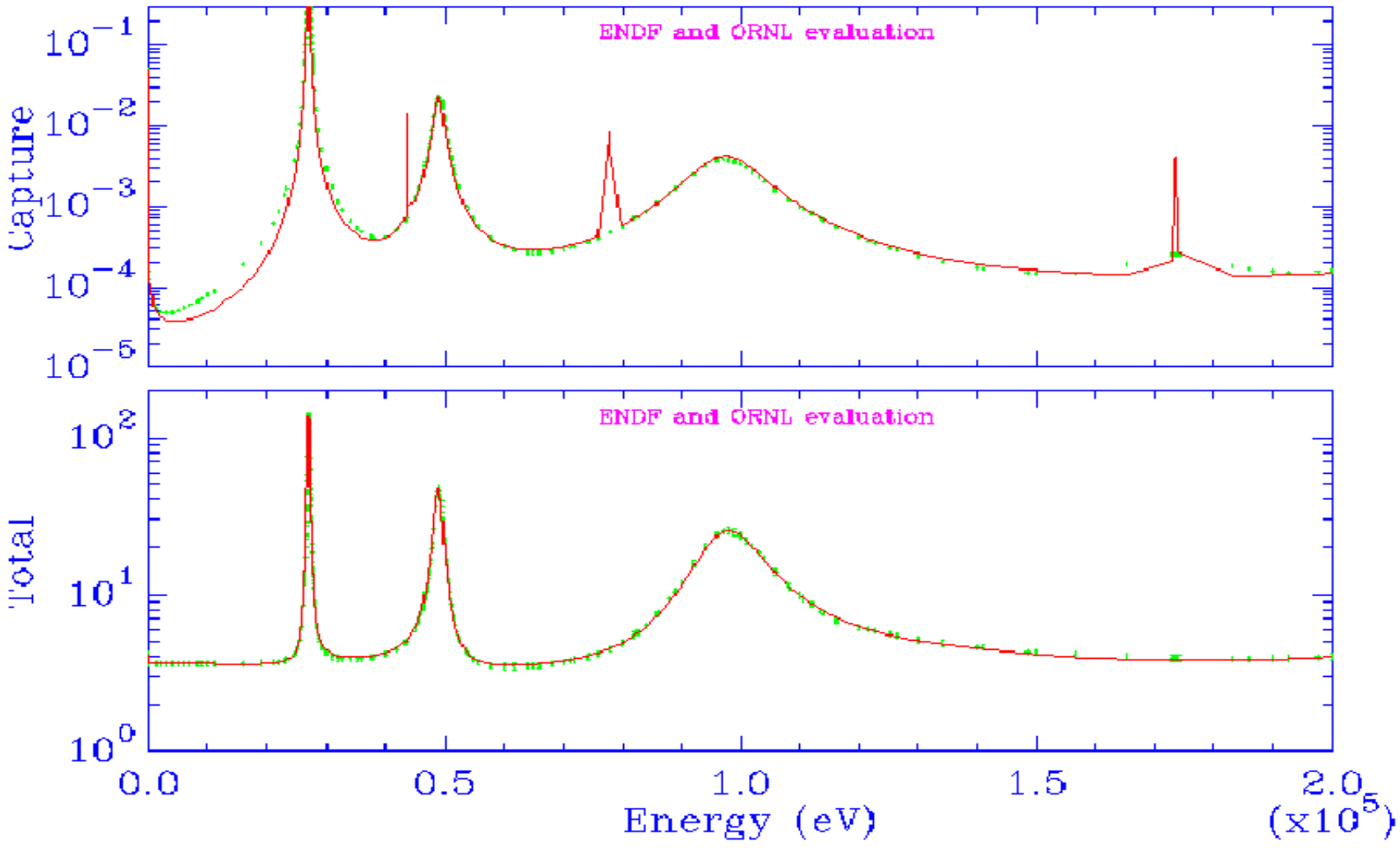
Total and Capture Cross Sections



Inelastic Cross Sections



Comparison with ENDF evaluation



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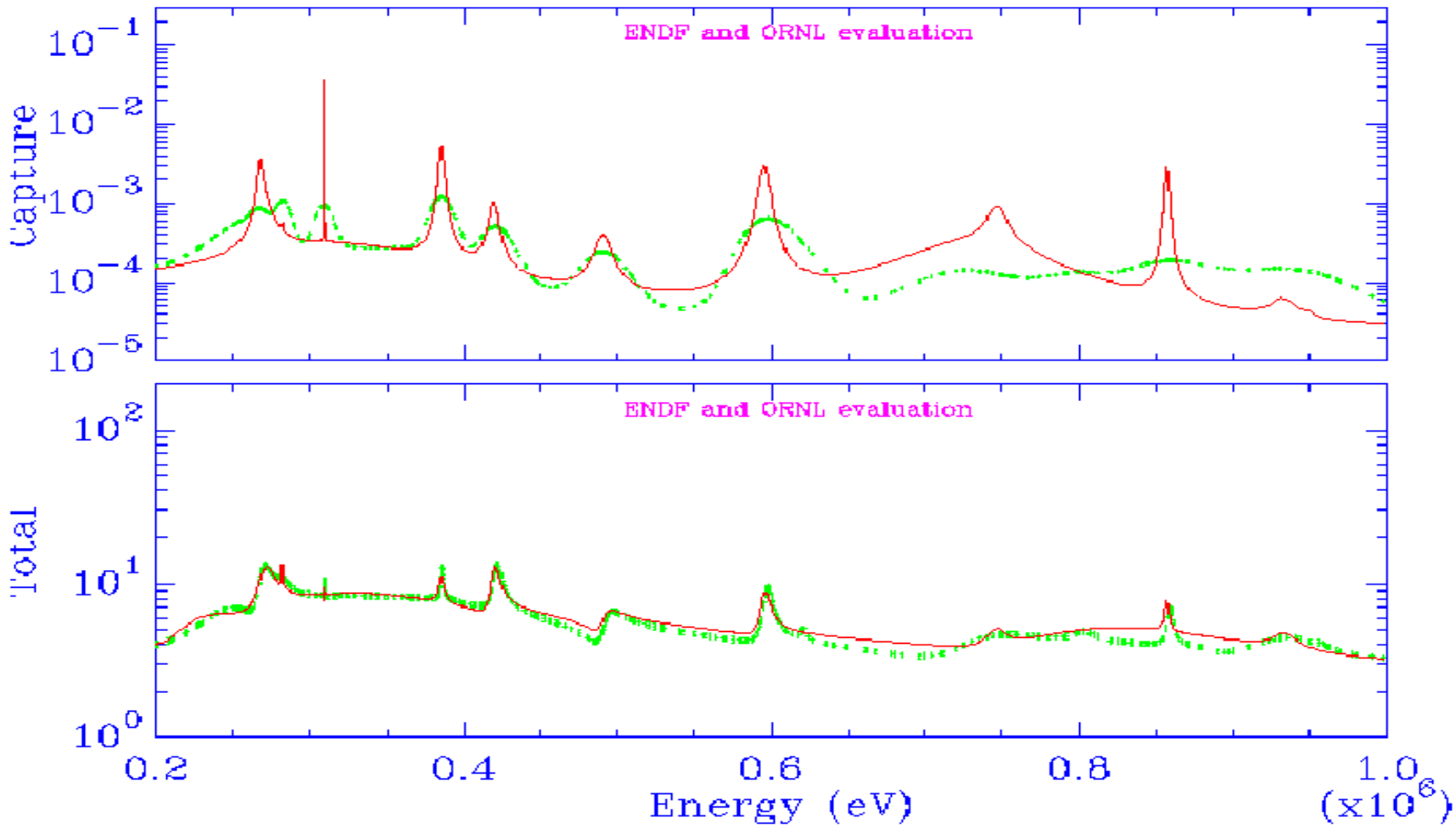
Comparison with ENDF evaluation



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Direct Capture Cross Section for ^{19}F

SAMMY allows the fit of the direct capture component of the cross section as suggested by Kerman and Dietrich

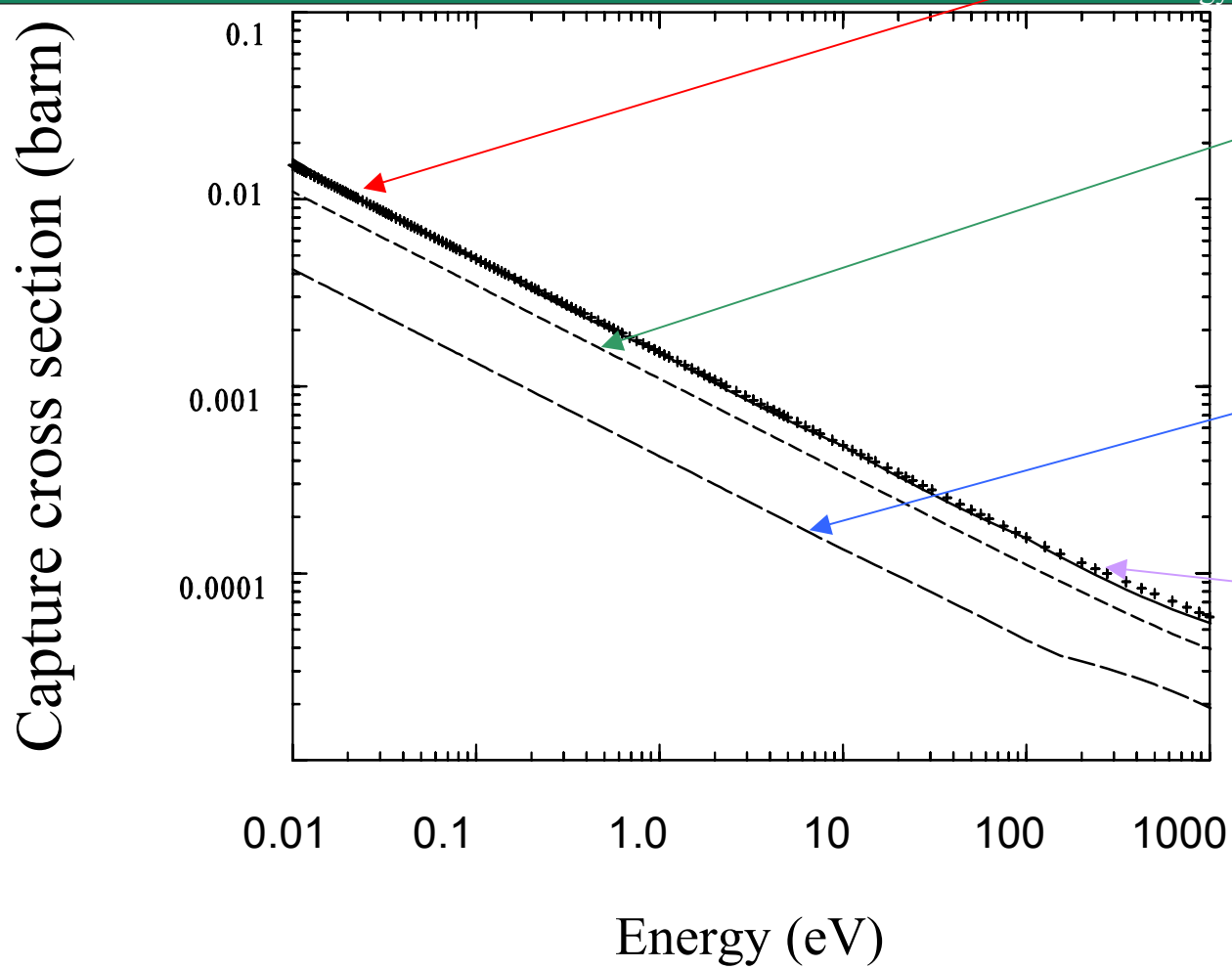
Total Capture = resonance component + direct capture component

$$\sigma_\gamma^{tot} = \sigma_\gamma^{res}(E_n, \Gamma_n, \Gamma_\gamma) + C \times \sigma_\gamma^{direct}$$

Example: ^{19}F

- Model calculations by Goran Arbanas, ORNL
- Analysis by Luiz Leal, ORNL
  - Multiplier initially at 1.0, fitted to 0.547

^{19}F (continued)



+ = data

dash = R-matrix contribution

long dash = direct component

solid line = sum of the two components

^{241}Pu Evaluation

Motivation

- **Investigation of the French Post-Irradiation Experiments (PIE) on PWR Indicates Significant Underestimation of the ^{241}Pu Capture Cross Section;**

- **Underestimation in the build-up prediction of ^{243}Am, ^{244}Cm, and ^{245}Cm;**

The Evaluation was performed in the energy range thermal to 20 eV;

Paper submitted to Nuclear Science and Engineering.

^{241}Pu Evaluation

Experimental Data Bank

- **Weston fission and capture data (1976);**
- **Wagemans fission data (1991);**
- **Young and Smith total cross section (1968);**

All data normalized in the energy range 0.01 eV to 1 eV according to Wagemans fission and Young total cross section.

Results

E_r 0.26 eV	Γ_γ meV	Γ_n meV	Γ_{f1} meV	Γ_{f2} meV
1988	32.555	0.04371	-78.04	-0.481
1993	33.350	0.04252	-50.42	25.36
This Work	34.630	0.04367	-42.71	32.06

Results

E_r 0.0253 eV	Standard (barns)	Present work (barns)
Fission	1012.68 ± 6.58	1012.20
Capture	361.29 ± 4.95	363.0
Scattering	12.17 ± 2.62	11.3
Total	1386.14 ± 8.64	1386.5

Results

(C/E-1 in % using JEF2.2, JENDL3.2, and ORNL evaluation)

BU (Gwd/t)	26.9	38.4	50.3	59.8
Pu241/U238(JEF2.2)	-6.3 ± 2.3	-5.0 ± 1.8	-3.8 ± 1.6	-3.1 ± 1.6
Pu242/U238(JEF2.2)	-10.5 ± 4.0	-9.7 ± 3.4	-8.8 ± 3.1	-8.6 ± 2.8
Am243/U238(JEF2.2)	-18.0 ± 6.2	-11.6 ± 5.2		-8.8 ± 4.4
Pu241/U238(JENDL3.2)	-5.4 ± 2.3	-3.8 ± 1.8	-2.5 ± 1.6	-1.6 ± 1.6
Pu242/U238(JENDL3.2)	-9.0 ± 4.0	-7.9 ± 3.4	-6.8 ± 3.1	-6.4 ± 2.8
Am243/U238(JENDL3.2)	-16.6 ± 6.2	-9.9 ± 5.2		-6.8 ± 4.4
Pu241/U238(ORNL)	-5.9 ± 2.3	-4.4 ± 1.8	-3.1 ± 1.6	-2.4 ± 1.6
Pu242/U238(ORNL)	-5.2 ± 4.0	-4.3 ± 3.4	-3.2 ± 3.1	-2.9 ± 2.8
Am243/U238(ORNL)	-12.8 ± 6.2	-6.5 ± 5.2		-3.7 ± 4.4

^{238}U Evaluation

- Resonance Analysis done in the Energy Region From 10^{-5} eV to 20 keV;
- Two Sets of Resonance Parameters: 0 to 10 keV and 10 keV to 20 keV;
- ENDF/B-VI Resonance Parameters below 10 keV were used for Starting Values;
- Extension of the ENDF/B-VI Resolved Resonance Region from 10 keV up to 20 keV;
- Evaluation done with the Reich-Moore formalism in the code SAMMY;
- High Resolution Data of Harvey et al. and Capture Cross Section Data of DeSaussure were used.
- Accurate Self-Shielding and Multiple Scattering Correction for Capture Data were done with an Improved Version of SAMMY;

Energy Range 1 keV to 10 keV

- Starting with the ENDF/B-VI Resonance Parameters (Moxon-Sowerby Evaluation);

- Experimental Data Used:
  - Olsen transmission data (1977) (four thicknesses)
  - Harvey Transmission Data: Three thicknesses: 0.1748, 0.0396, and 0.0125 atoms/b; Data measured at ORELA on the 200 m flight path
  - Capture Data of DeSaussure measured at ORELA on the 40 m flight path

Results for the evaluation energy region 1 keV to 10 keV

- Modification of the external resonance parameters for accurate description of the transmission data between resonances. The average scattering cross section increases by 2.8 %;
- Scattering Radius of 9.450 fm in agreement with the Olsen ORNL Evaluation;
- Better description of the Capture data. The average capture cross section increases by 3.8 % in the energy range 1 keV to 10 keV;

Average ^{238}U Cross Sections (1 keV to 10 keV)

Energy Range (keV)	Capture (b)		Elastic (b)	
	ENDF/B-VI	ORNL	ENDF/B-VI	ORNL
1 – 2	1.87	1.94	21.68	22.25
2 – 3	1.36	1.41	21.57	22.12
3 – 4	1.15	1.20	19.82	20.36
4 – 5	0.88	0.89	14.79	15.03
5 – 6	0.90	0.90	14.20	14.38
6 – 7	0.87	0.88	16.66	16.37
7 – 8	0.68	0.74	13.79	14.07
8 – 9	0.63	0.65	15.03	15.71
9 – 10	0.65	0.71	13.07	13.89
1 - 10	1.00	1.04	16.73	17.12

Energy Range 10 keV to 20 keV

- **No prior values of the resonance parameters existed;**

- **Experimental Data Used:**

  - **Harvey Transmission Data: Three thicknesses: 0.1748, 0.0396, and 0.0125 atoms/b; Data measured at ORELA on the 200 m flight path**

  - **Capture Data of DeSaussure measured at ORELA on the 40 m flight path**

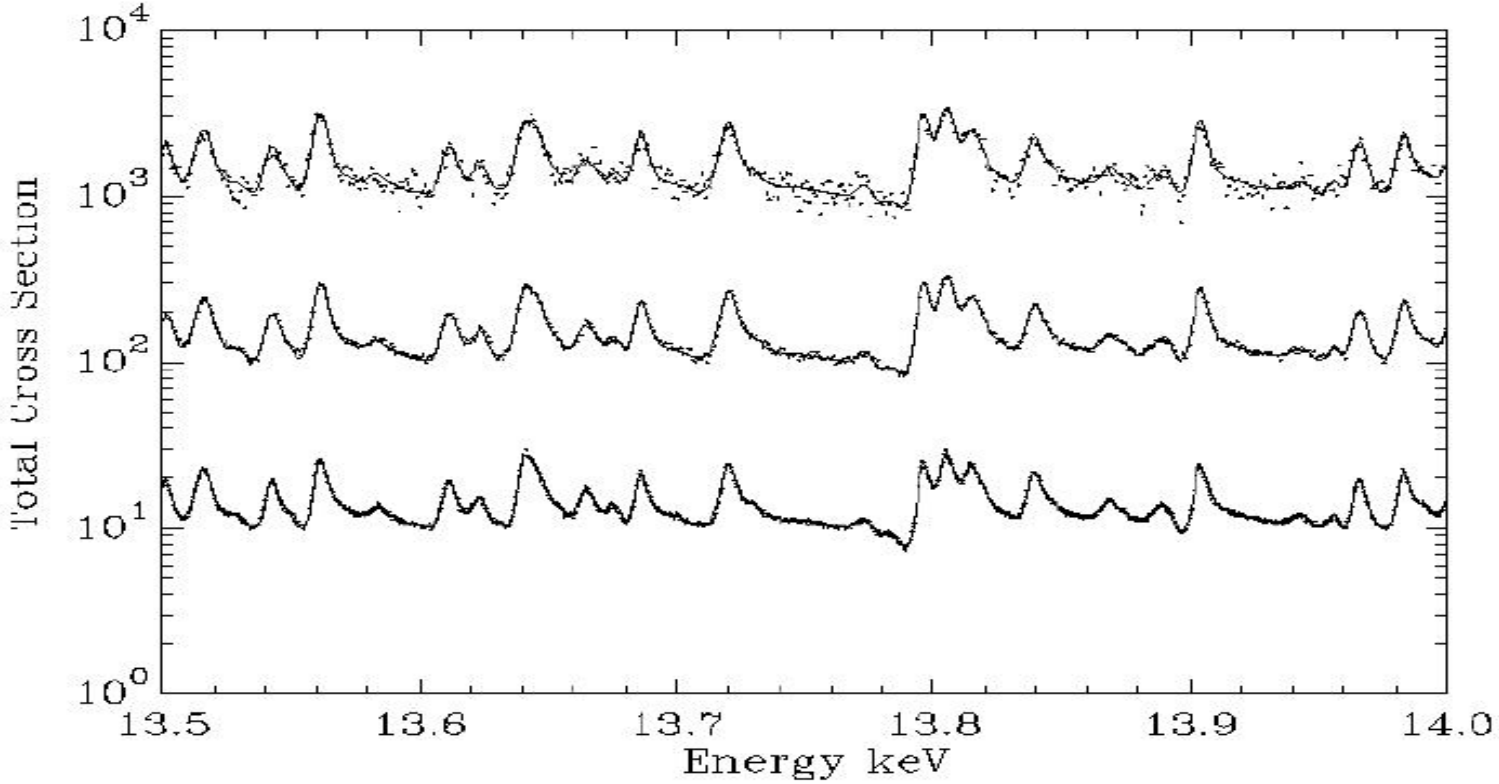
Results for the evaluation energy region 10 keV to 20 keV

- 457 s-wave resonances and 1228 p-wave resonances obtained with SAMMY analysis of Harvey transmission data and DeSaussure Capture cross section data

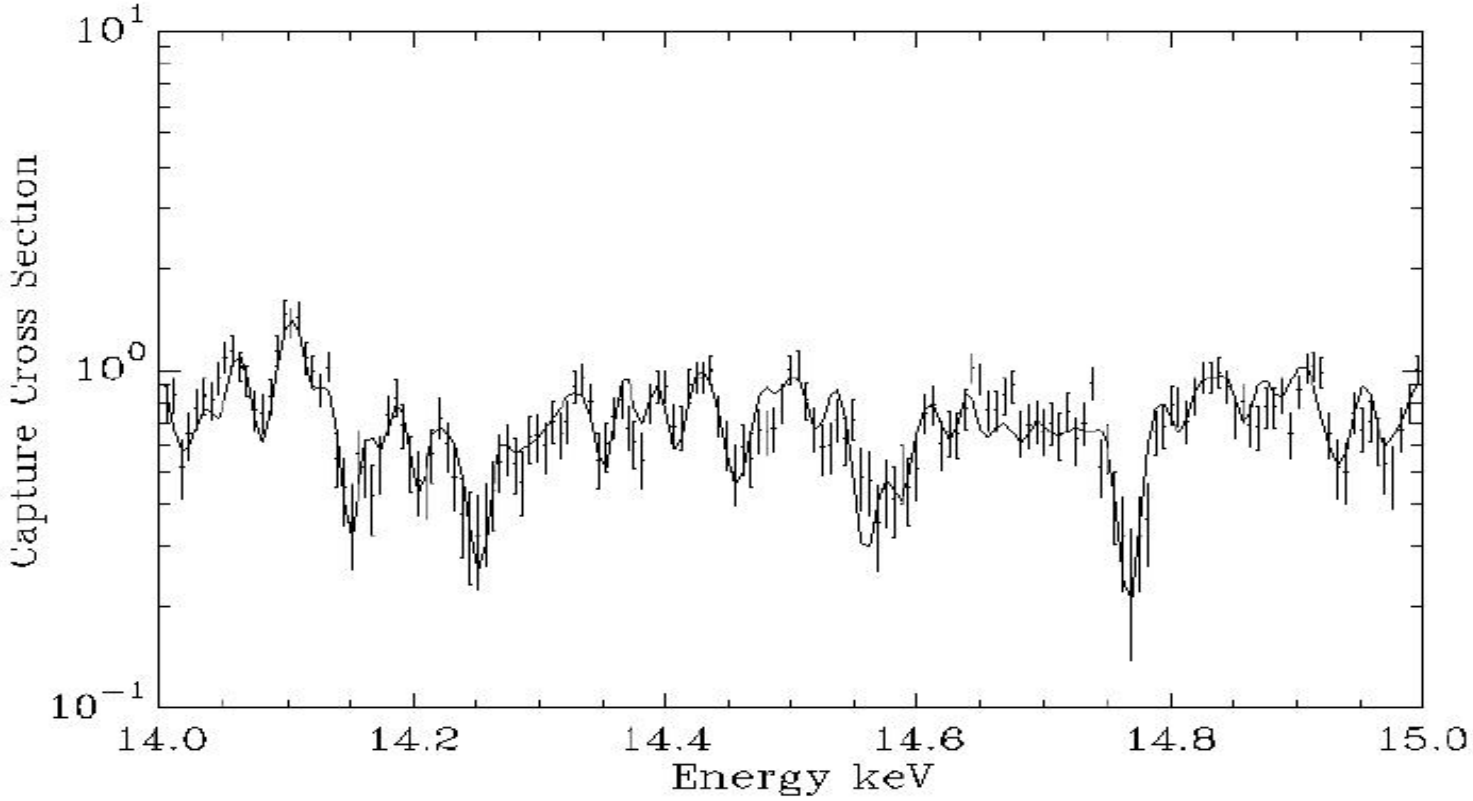
- The average capture cross section agrees with the ENDF/B-VI evaluation;

- The average elastic cross section is larger than the ENDF/B-VI evaluation by 3.1 %;

Effective Total Cross Section from the Transmission Data (upper curve x 100, middle curve x 10)



Effective Capture Cross Sections



Average ^{238}U Cross Sections (10 keV to 20 keV)

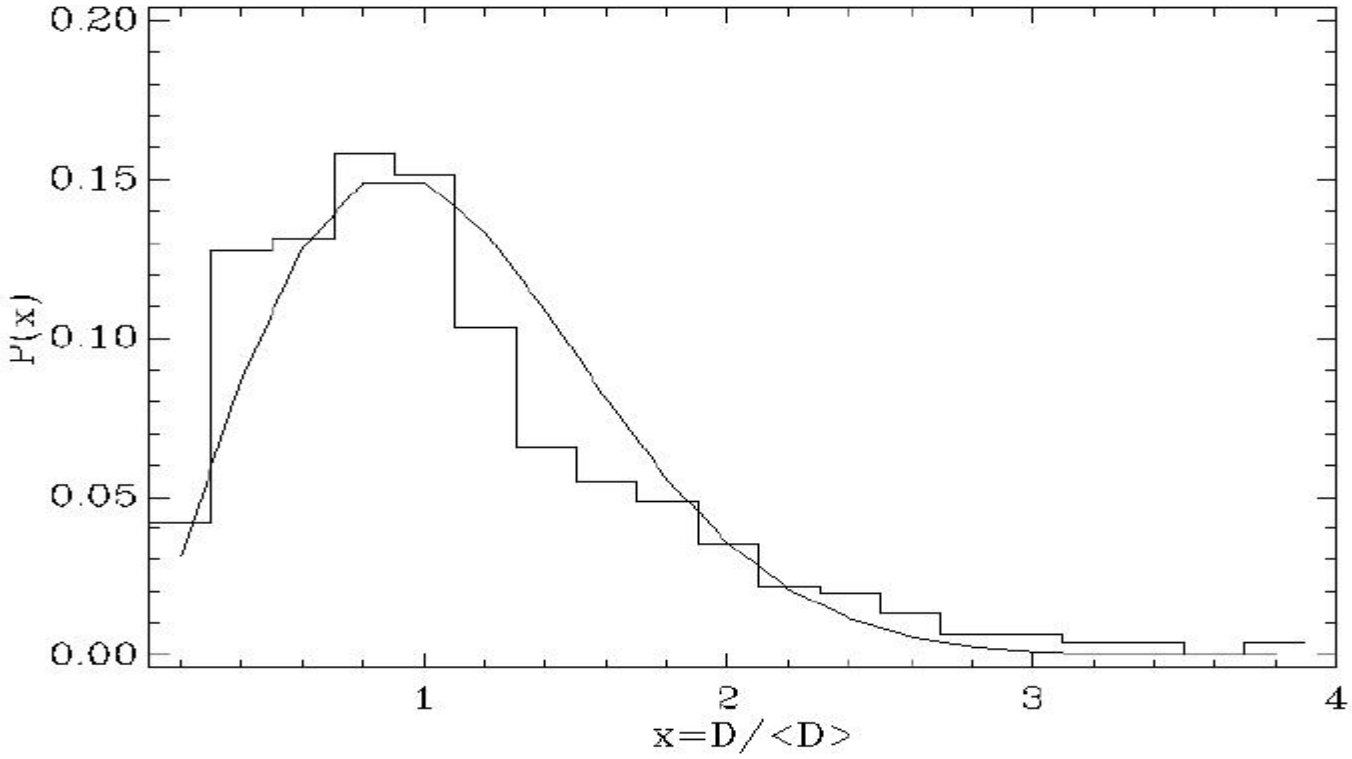
Energy Range (keV)	Capture (b)		Elastic (b)	
	ENDF/B-VI	ORNL	ENDF/B-VI	ORNL
10 – 11	0.71	0.68	14.67	14.72
11 – 12	0.68	0.65	14.53	13.91
12 – 13	0.66	0.65	14.40	15.32
13 – 14	0.64	0.72	14.29	14.56
14 – 15	0.62	0.62	14.18	15.54
15 – 16	0.60	0.58	14.09	14.60
16 – 17	0.58	0.58	14.01	13.79
17 – 18	0.57	0.58	13.93	16.25
18 – 19	0.55	0.53	13.86	14.57
19 - 20	0.54	0.52	13.79	12.91
10 - 20	0.615	0.611	14.17	14.62

Statistical Properties of Resonance Parameters in the Energy Range 10 keV to 20 keV

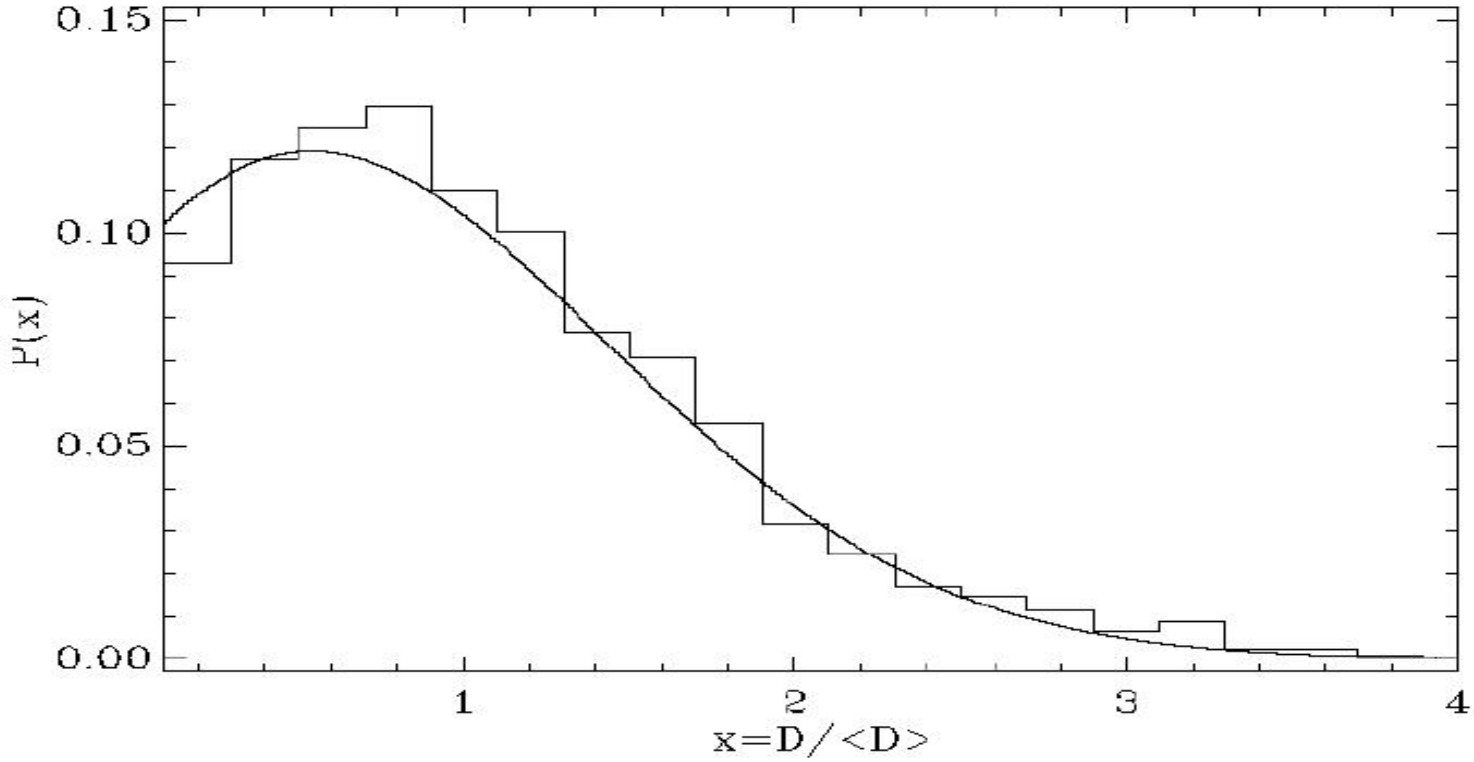
- Number of Resonances used to fit the data are 457 s-wave and 1228 p-wave;
- Below 10 keV ENDF/B evaluation uses 473 s-wave and 1228 p-wave;

- Spin Assignment:
  - Large resonances are assigned s-wave from their shape;
  - Small resonances are distributed among 3 families: s-wave, p-wave p1/2 and p3/2 following the 2J+1 spin dependence of the population;

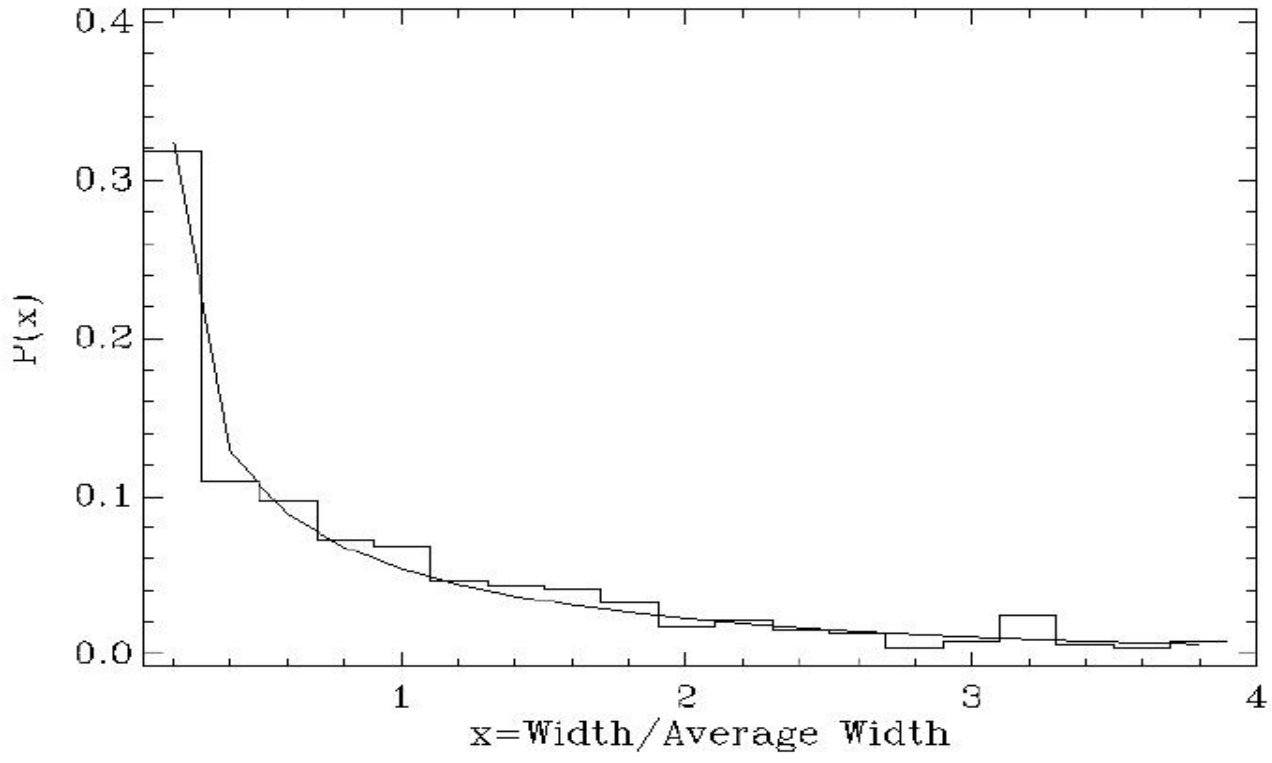
Distribution of s-wave Level Spacings



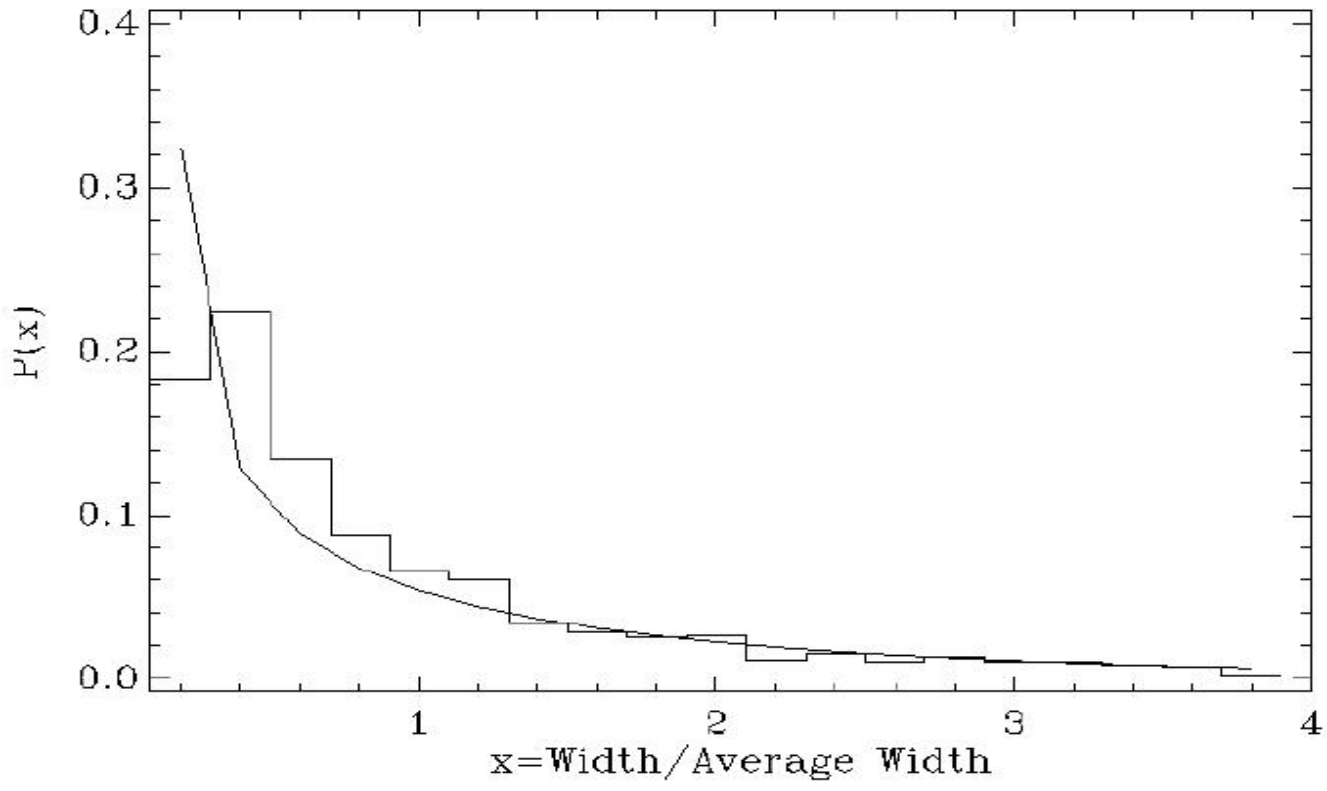
Distribution of p-wave Level Spacings



Porter-Thomas Distribution of s-wave neutron widths



Porter-Thomas Distribution of p-wave neutron widths



Neutron Strength Functions

ORNL Results 10 keV to 20 keV	ENDF/B-VI From Thermal to 10 keV
S_0 $(1.120 \pm 0.074)\ 10^{-4}$	S_0 $(0.947 \pm 0.07)\ 10^{-4}$
S_1 $(1.693 \pm 0.068)\ 10^{-4}$	S_1 $(1.577 \pm 0.06)\ 10^{-4}$

Benchmark results using ^{238}U ORNL Evaluation

Thermal benchmark (Leu-Comp-Therm Series)

Thermal Benchmark Experiments Performed at the Tank-type Critical Assembly TCA facility (JAERI, Japan) from 1963 to 1975

TCA

Tank-type Critical Assembly, light water moderated and fueled with low enriched uranium (2.6 wt % of UO_2) with a size of 1.8m in diameter and 2m long, controlled by reactor core water level. The water to fuel volume ratio ranges from 1.5 to 3.0

Benchmark Results

- Calculations done with MCNP4C code
- Base library used was the ENDF/B-VI release Five
- Calculations done with 1000 histories per cycle with 3000 cycles
- Two sets of results:

  a) Calculations with MCNP library based on ENDF/B-VI.5

  b) Calculations with MCNP library based on ENDF/B-VI.5 replacing ^{238}U evaluation with ORNL evaluation

Benchmark Results

Case	ENDF/B-VI.5	ENDF/B-VI.5 with ^{238}U ORNL Evaluation
LCT-01	0.99276 ± 0.00043	0.99506 ± 0.00043
LCT-02	0.99359 ± 0.00042	0.99429 ± 0.00043
LCT-03	0.99245 ± 0.00044	0.99568 ± 0.00042
LCT-04	0.99376 ± 0.00042	0.99534 ± 0.00041
LCT-05	0.99383 ± 0.00043	0.99471 ± 0.00042
LCT-06	0.99345 ± 0.00043	0.99654 ± 0.00042
LCT-07	0.99400 ± 0.00042	0.99604 ± 0.00042
LCT-08	0.99358 ± 0.00043	0.99610 ± 0.00043
LCT-09	0.99429 ± 0.00042	0.99582 ± 0.00041
LCT-10	0.99502 ± 0.00042	0.99767 ± 0.00041
LCT-11	0.99535 ± 0.00041	0.99704 ± 0.00041
LCT-12	0.99472 ± 0.00041	0.99619 ± 0.00042
LCT-13	0.99420 ± 0.00042	0.99557 ± 0.00042

Benchmark Results

Case	ENDF/B-VI.5	ENDF/B-VI.5 with ^{238}U ORNL Evaluation
Average	0.99392 ± 0.00042	0.99585 ± 0.00042
An improvement of 193 pcm On average !!		

Gd Evaluation
^{152}Gd, ^{154}Gd, ^{155}Gd, ^{156}Gd, ^{157}Gd, ^{158}Gd, and ^{160}Gd

- **Resolved and Unresolved Resonance Evaluations Revised**
  - **MLBW resonance parameters converted to RM parameters;**
  - **Unresolved resonance evaluation done with SAMMY: Average SLBW parameters obtained.**
  - **SAMMY used to reevaluate the RM parameters.**

- **Resolved and Unresolved Resonance Covariance Evaluation done with SAMMY**
  - **Uncertainty in the Resonance Parameters reported on "Mughabghab's Book" used as input;**
  - **"Typical" data uncertainty on "data" were used. Example: ORELA resolution function, TOF uncertainties, channel widths, jitters, etc.**

- **Use SAMMY Retroactive Scheme to Generate Covariance Data.**