IRSN-ORNL Data Evaluation in Support of Criticality Safety: ^{235}U, ^{239}Pu, ^{56}Fe, ^{16}O, ^{54}Fe, ^{103}Rh

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

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NCSP/TPR
Sandia National Laboratory
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OUTLINE

1. IRSN-NCSP collaboration organization for nuclear data evaluation work;
2. Evaluations: General description and highlights;
3. IRSN and ORNL collaboration results end perspectives;
4. Concluding remarks;

Nuclear Data

Priority Needs / Additional Needs	Thermal scattering (BeO, HF, D_2O, SiO_2, CH_2, C_2F_4, $C_5O_2H_8$, etc.), ^{239}Pu, 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), SiO_2 (12), ^{55}Mn (12), ^{180,128,183,184,186}W (10)

	Materials	Pre FY2014	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	Post-FY2020
Measurements	Calcium (Ca)									
	Cerium (Ce)									
	Copper (Cu)									
	Iron (Fe)									
	Lucite ($C_5O_2H_8$)									
	Strontium (Sr)									
	Tungsten (W)									
	Vanadium (V)									
	Zirconium (Zr)									
	Polyethylene (CH_2)		H_2O / CH_2							
	Materials	Pre FY2014	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	Post-FY2020
Complete Evaluations	Calcium (Ca)									
	Cerium (Ce)									
	Cobalt (Co)									
	Copper (Cu)									
	Dysprosium (Dy)									
	Gadolinium (Gd)									
	Iron (Fe)									
	Lead (Pb)									
	Nickel (Ni)									
	Oxygen (O)									
	Rhodium (Rh)									
	Plutonium-239									
	Strontium (Sr)									
	Tungsten (W)									
	Uranium-235									
	Uranium-238									
	Vanadium (V)									
	Zirconium (Zr)									
	Hydrofluoric Acid (HF)									
	Lucite ($C_5O_2H_8$)									
	Polyethylene (CH_2)									
		ORNL		RPI		LANL		LLNL/NCSU		

- Requests for additional IE measurements: Ni, Mo, Cr (Fe-Cr alloys), Mn in intermediate energy range (VNIITF, NCERC).
- Request for measurements and evaluation of angular distributions at high energy for Cu.
- Continuing need for thermal scattering data.

IRSN-ORNL Tasks

ISOTOPE	ABUNDANCE %	THERMAL (barns)	LAB
^{152}Gd	0.2	735 ± 20	ORNL
^{154}Gd	2.15	85 ± 12	ORNL
^{155}Gd	14.73	60900 ± 500	IRSN
^{156}Gd	20.47	1.8 ± 0.7	ORNL
^{157}Gd	15.68	254000 ± 815	IRSN
^{158}Gd	24.87	2.2 ± 0.2	ORNL
^{160}Gd	21.9	1.4 ± 0.3	ORNL

IRSN-ORNL Tasks

ISOTOPE	ABUNDANCE %	THERMAL (barns)	LAB
^{90}Zr	51.45	0.077 ± 0.016	IRSN
^{91}Zr	11.22	0.83 ± 0.08	ORNL
^{92}Zr	17.15	0.260 ± 0.080	IRSN
^{94}Zr	17.38	0.0494 ± 0.0017	ORNL

IRSN-ORNL Tasks

- ORNL staff member visit to IRSN (V. Sobes)
- Work performed:
  - Finalization of the resonance evaluation for ^{63}Cu and ^{65}Cu;
  - Development of a new approach to represent angular data in ENDF (ANS abstract)
  - Work on the covariance generation for ^{63}Cu and ^{65}Cu using the LCOMP=2 ENDF option;

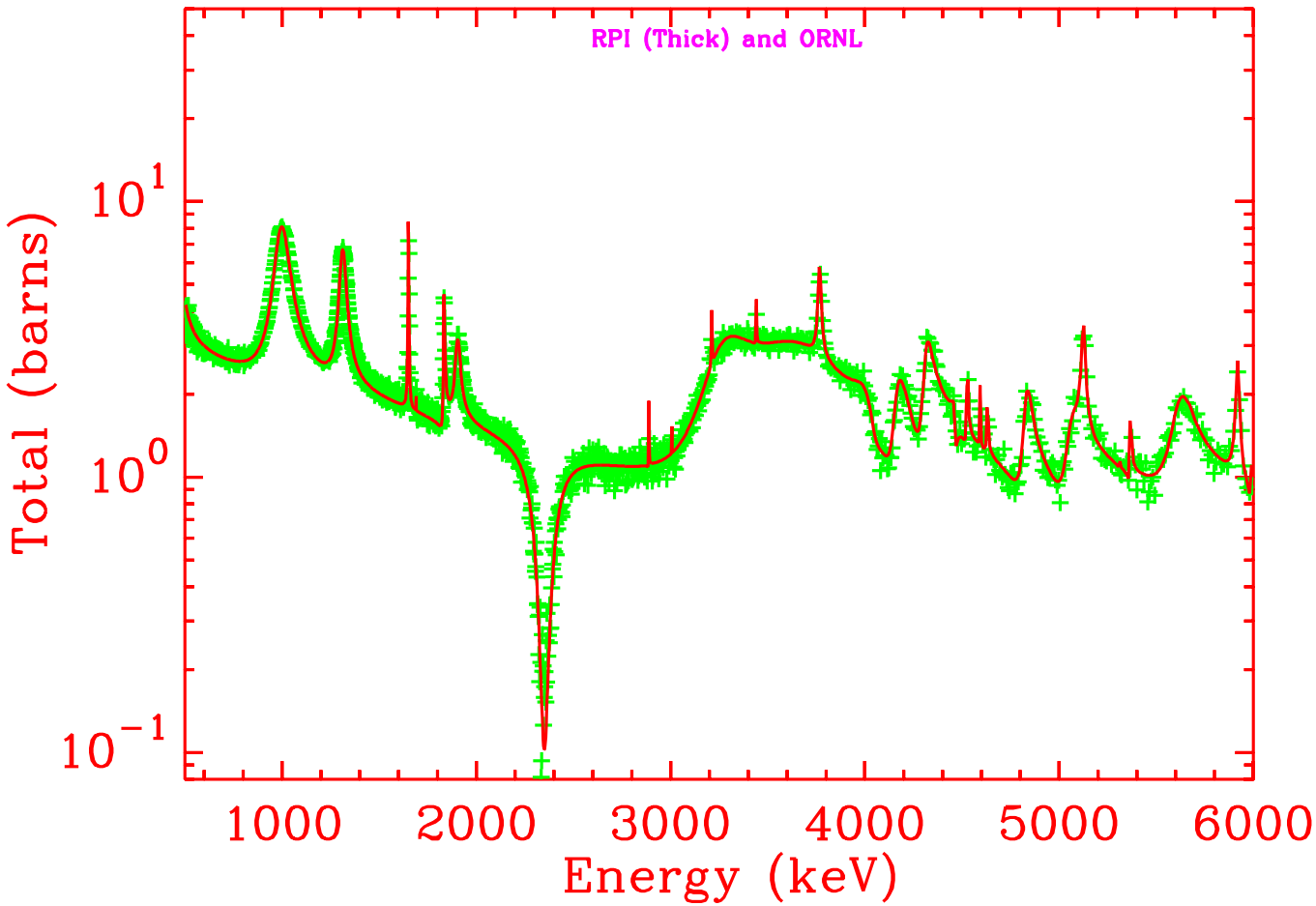
Resonance Evaluations and deliverables

Isotope	Energy Range	Resonance Covariance Evaluation	Target date for delivery the evaluation
^{16}O	Thermal to 6 MeV	Yes	Completed
^{239}Pu	Thermal to 4.0 keV	Yes	Completed
^{235}U	Thermal to 2.25 keV	Yes	Completed
^{56}Fe	Thermal to 2 MeV	Yes	Ongoing
^{54}Fe	Thermal to 1.5 MeV	Yes	Ongoing
^{103}Rh	Thermal to 8 keV	Yes	Ongoing

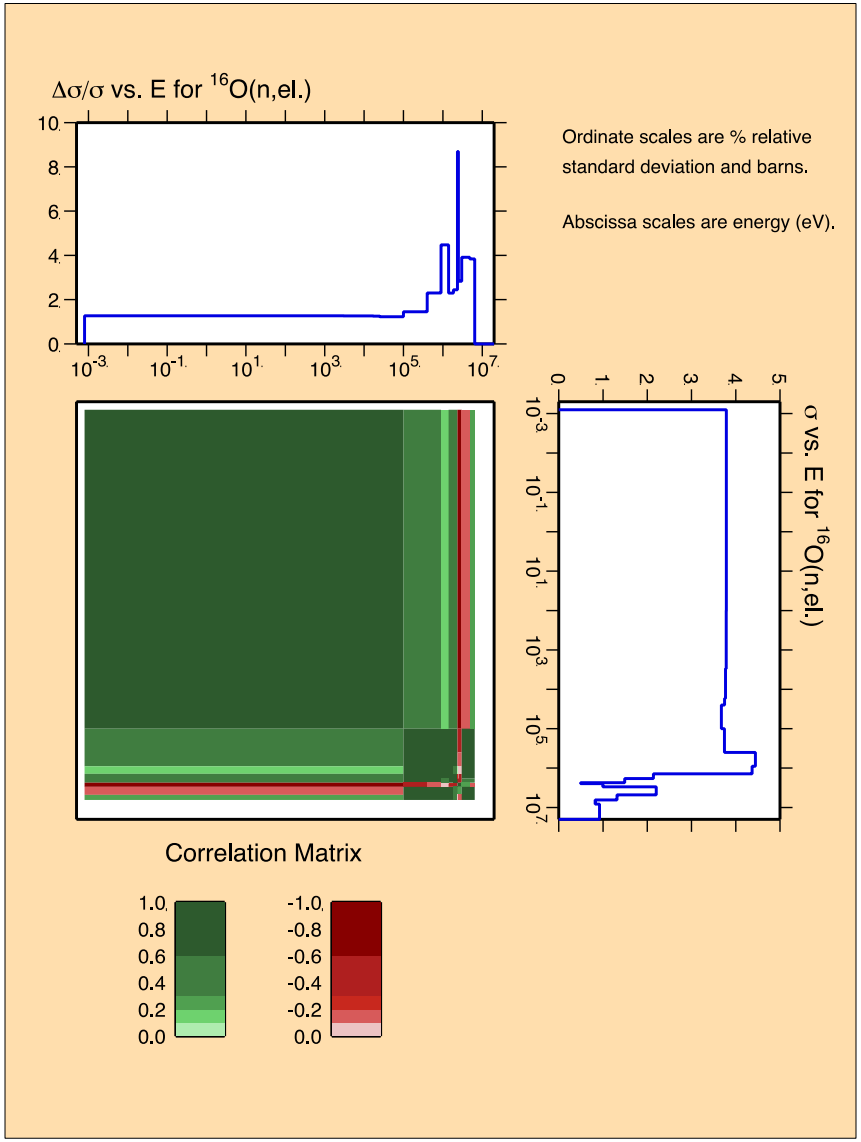
^{16}O Resonance Evaluation

- Evaluation processed with the nuclear data processing codes NJOY, PREPRO, AMPX and GAIA;
- The resolved resonance included in the ENDF/B-VII.1;
- (n, total), (n, n), (n, γ), scattering, (n,α), angular distributions are calculated from resonance parameters;
- Resonance parameter covariance is available. Not included in the library;
- Updated thermal scattering cross section according to the CIELO suggested value (3.765 b at 0K);
- 16O(n, α) data (Giorginis, et al., IRMM) and 13C(α, n) data (Harissopulos, et al.) give about 30% lower 16O (n, α) cross section values than the Bair-Haas.

Total cross section measurements from RPI. SAMMY comparison including resolution effects



RRP Covariance for the Scattering Cross Section



^{239}Pu evaluation work

- Extension of the resolved resonance region from 2.5 keV to 4 keV.
  - Purpose: eliminate issues with the unresolved resonance representation by using resolved resonance parameters;

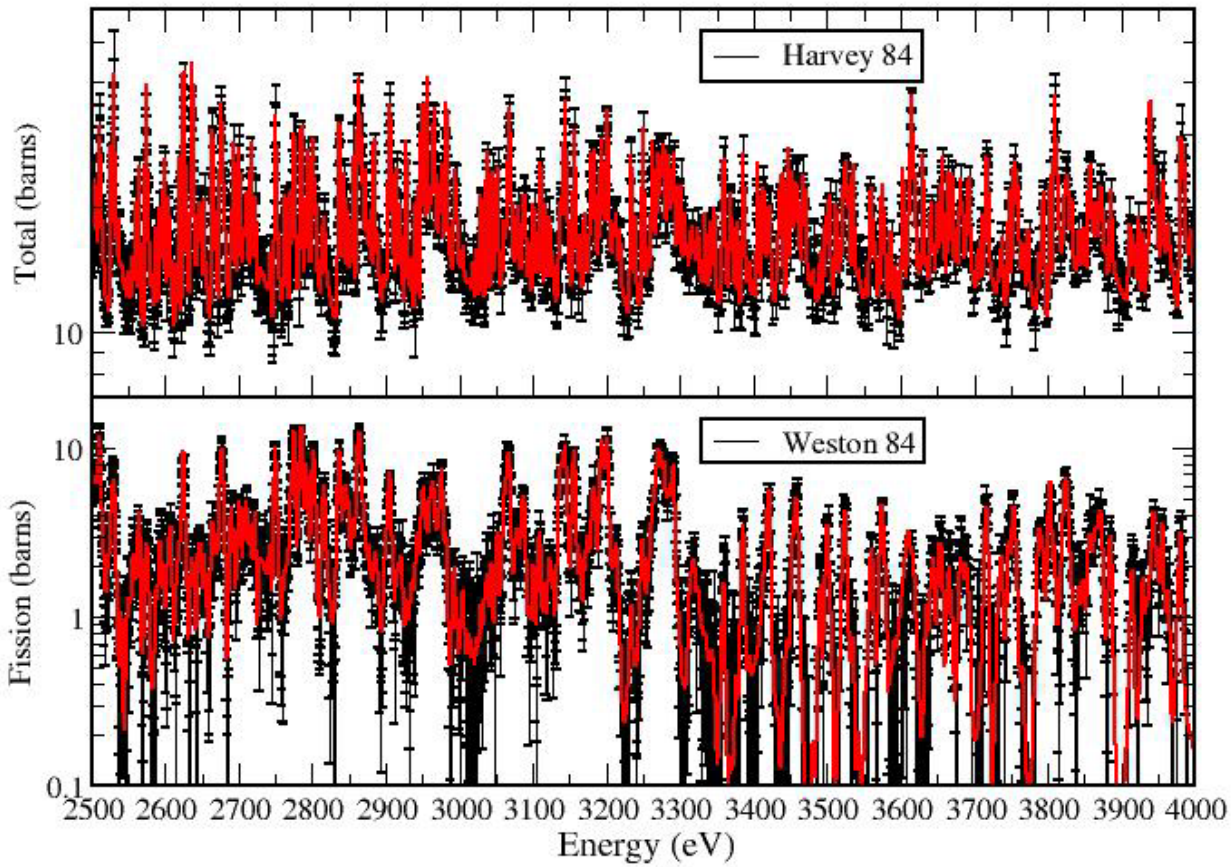
- High-resolution transmission data of Harvey and fission of Weston were used in the SAMMY fitting;

- Fission cross section of Weston (1984) normalized according to the NEA-WPEC-5 subgroup on the fission of 239Pu. Recommendation that the fission cross section integral in 100 eV – 1000 eV is 9275 b.eV

What is new:

- Fitting of the capture cross section above 2 keV using data measured at LANL recently;
- Fitting of thermal values to the standards;
- Fitting of average fission values to the standards;
- The evaluation indicates the fitted standard values a more consistent with benchmark results !!

SAMMY fit to the experimental data



^{235}U evaluation work:

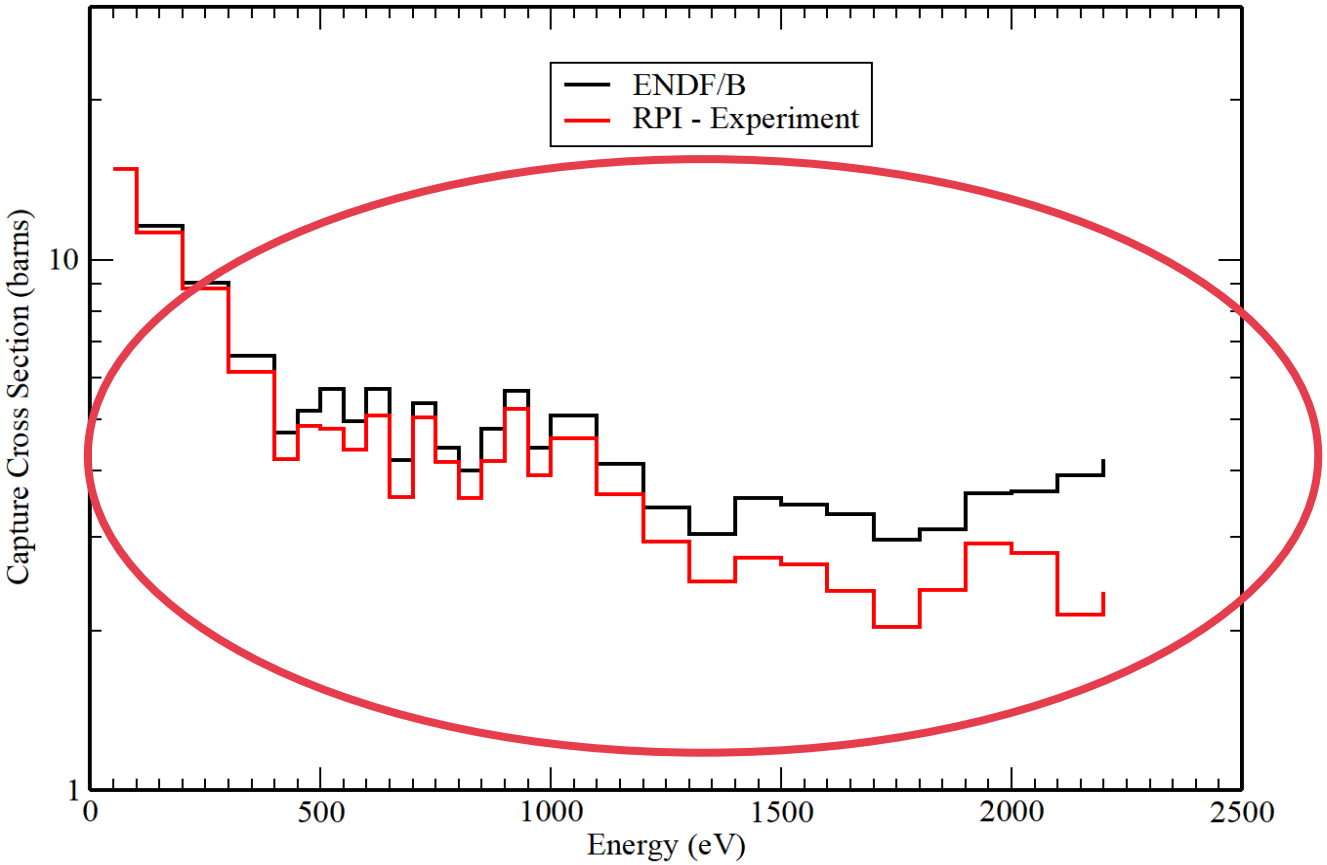
Issues:

- Overestimation of ^{235}U capture cross-section in the resonance region range (0.1 to 2.25 keV).

Recommendation:

- New measurements of capture and fission cross-section in the keV region;
- Perform new resonance analysis in the 0.1 to 2.25 keV region;
- Investigate the reason for the overestimation of criticalities for some benchmarks.

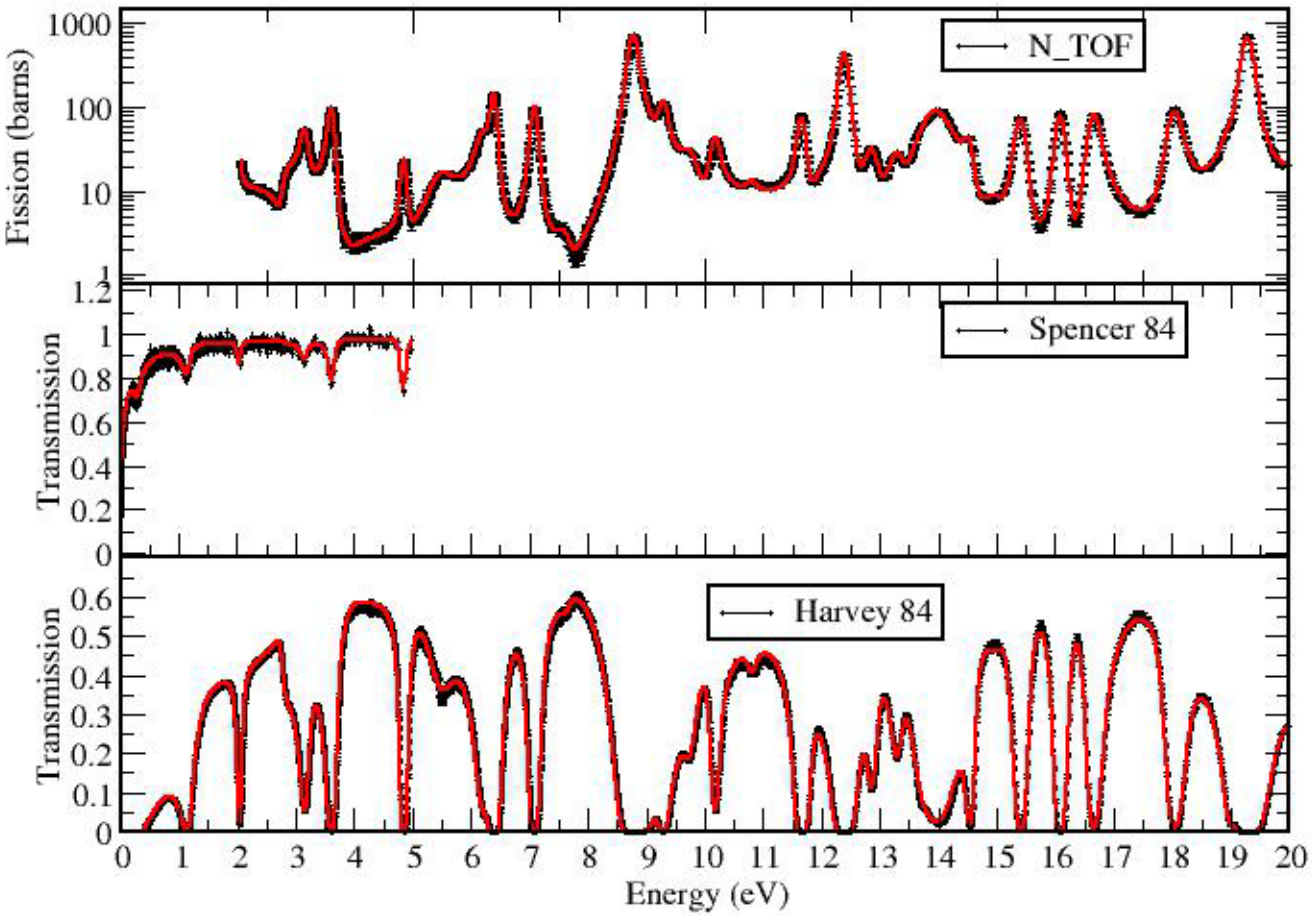
RPI capture data and ENDF evaluation



Selected Data

Author	Energy (eV)	Data
Weston (ORNL/1992)	100.0 - 2000.0	Fission at 86.5 meters
Moxon (ORNL/1992)	0.01 - 50.0	Fission Yield
Gwin (ORNL/1996)	0.01 - 4.0	Absorption and fission at 21.68 meters
Danon (RPI/2012)	100.0 – 5000	Fission and capture yield at 25.56 meters (burst 15 ns)
Jandel (LANL/2012)	100.0 - 5000	Capture at 25.45 meters (burst 125 ns)
N_TOF	2.0 - 60	Fission

SAMMY Fit of the Data



^{235}U Thermal Values

Quantity	Standard	B7 (barns)	JEFF3.2 (barns)	JENDL4 (barns)	IRSN (barns)
σ_f (barns)	584.380 ± 1.030	584.897	584.897	584.897	584.417
σ_γ (barns)	99.304 ± 0.725	98.665	98.665	98.665	99.231
σ_s (barns)	14.087 ± 0.219	15.115	15.115	15.115	14.086

235U Fission Integral in the Energy Range 7.8 eV to 11 eV

$$\int_{7.8\ eV}^{11\,eV} \sigma_f(E)\, dE$$

ΔE (eV)	Standard (b.eV)	B7 (b.eV)	JEFF3.2 (b.eV)	JENDL4 (b.eV)	IRSN (b.eV)
7.8 eV – 11 eV	246.40 ± 1.24	241.90	241.90	241.90	246.31

^{235}U Average Fission integral

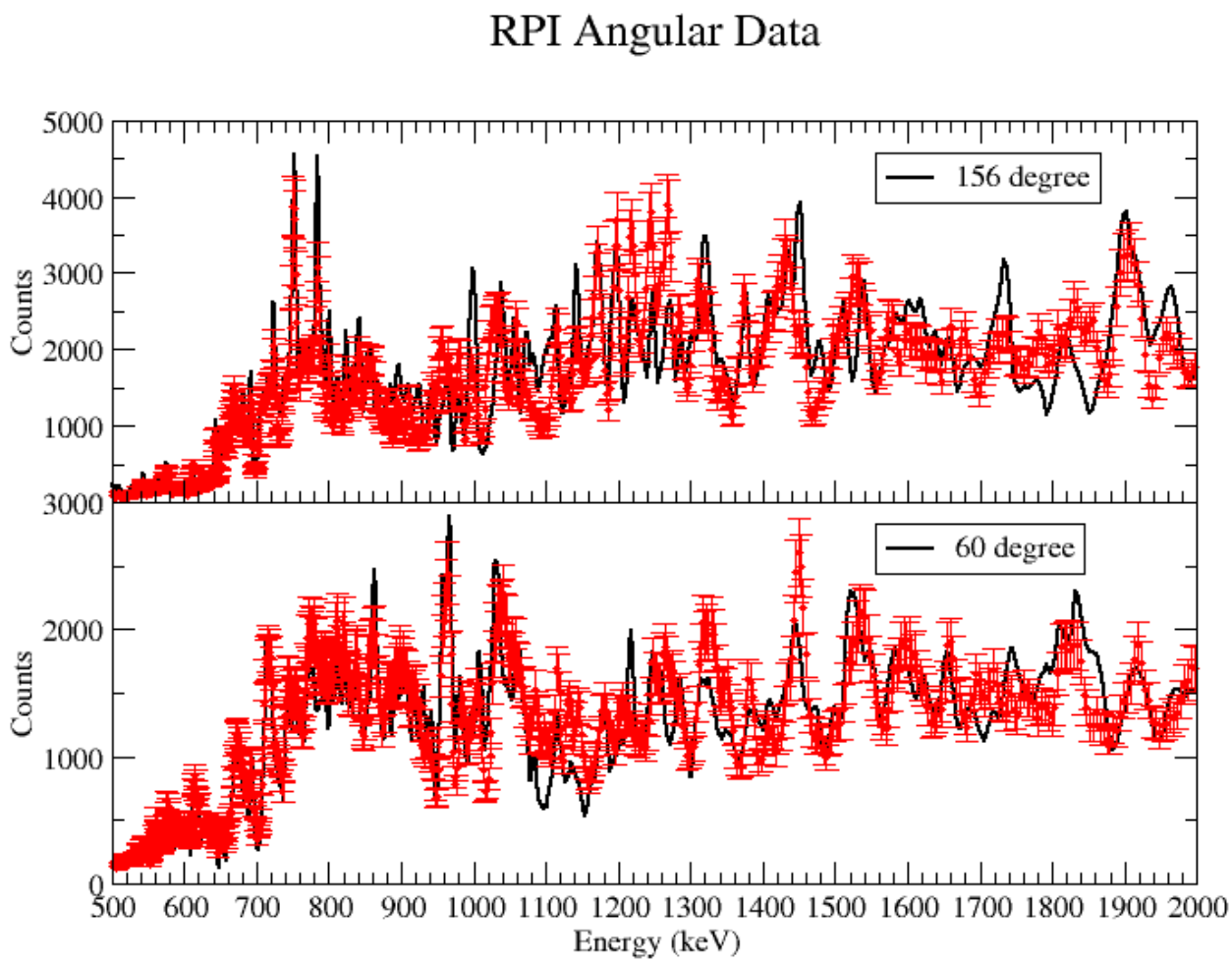
ΔE (eV)	Standard (barns)	B7 (barns)	JEFF3.2 (barns)	JENDL4 (barns	IRSN (barns)
100 – 200	21.17 (11)	20.33	20.33	20.29	20.81
200 – 300	20.69 (11)	20.62	20.62	20.66	21.04
300 – 400	13.13 (7)	12.81	12.81	12.81	13.22
400 – 500	13.78 (8)	13.33	13.33	13.31	13.51
500 – 600	15.17 (9)	14.89	14.89	14.73	15.21
600 - 700	11.51 (7)	11.26	11.26	11.13	11.52
700 – 800	11.10 (6)	10.89	10.89	11.06	11.11
800 – 900	8.21 (48)	7.98	7.98	7.93	8.12
900 – 1000	7.50 (44)	7.25	7.25	7.46	7.39
1000 - 2000	7.30 (40)	7.14	7.14	7.10	7.29

$$< \sigma_f > = \frac{1}{E_f - E_i} \int_{E_i}^{E_f} \sigma_f(E)\, d\,E$$

^{56}Fe Evaluation

- New high resolution transmission measurements done at the RPI extending the resonance region up to 5 MeV;
- New inelastic cross-section measurements done at IRMM/GELINA;
- New RPI angular scattering data (presented in this meeting);
- Use the SAMMY/RML feature to include inelastic channel in the R-matrix analysis and evaluation;
- Elastic and Inelastic angular data derived from resonance parameters

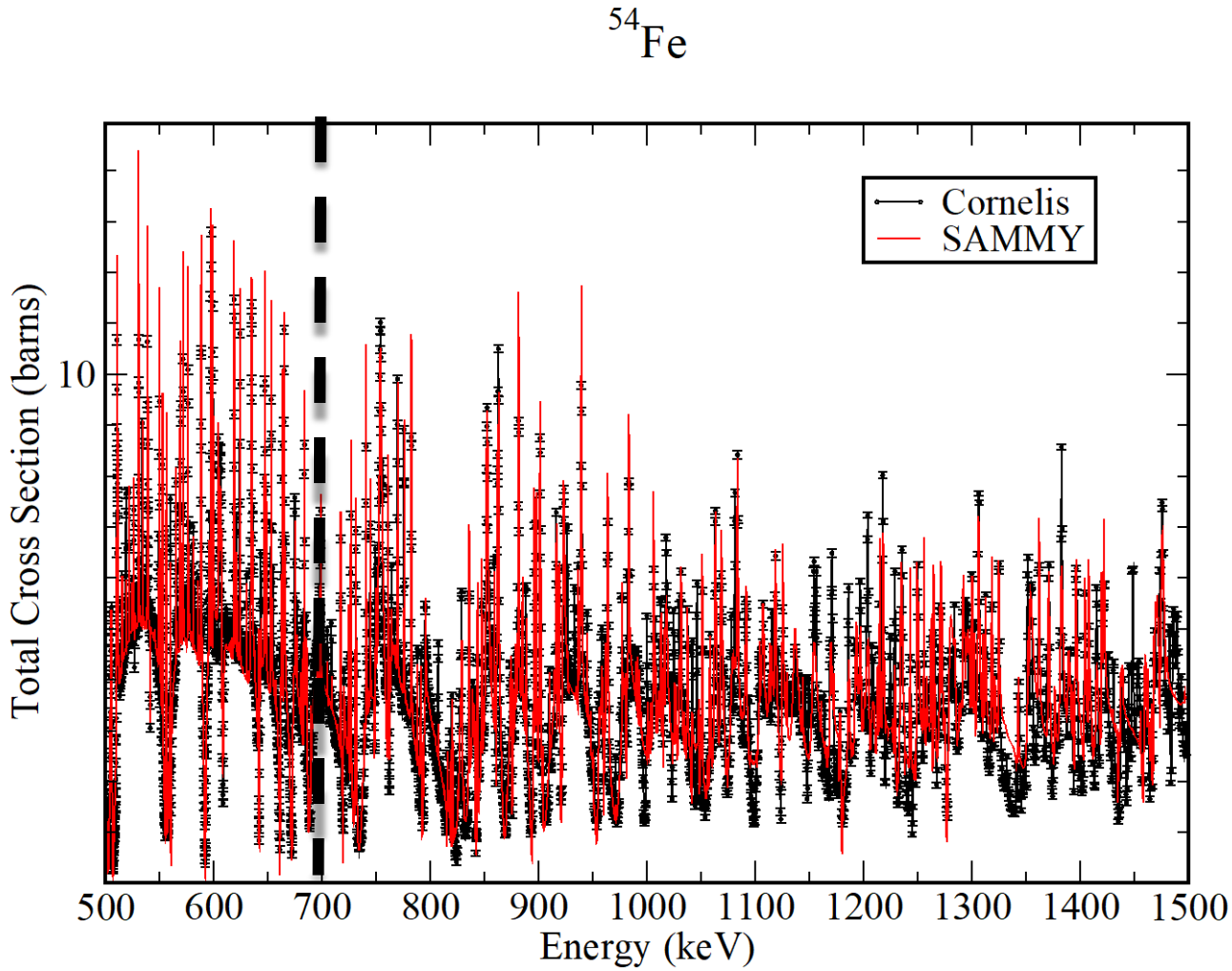
SAMMY calculations and RPI Experimental data



^{54}Fe Evaluation in the Resolved Resonance

- Natural Iron: ^{56}Fe(91.75 %), ^{54}Fe(5.85 %) and ^{57}Fe(2.12 %);
- Resonance region in existing nuclear data libraries is 10^{-5} eV to 700 keV;
- Transmission, capture data needed to extend the evaluation up to 2 MeV;
- DDX Scattering cross section needed;
- First inelastic channel opens 1.434 MeV;
- Inelastic cross section data needed;

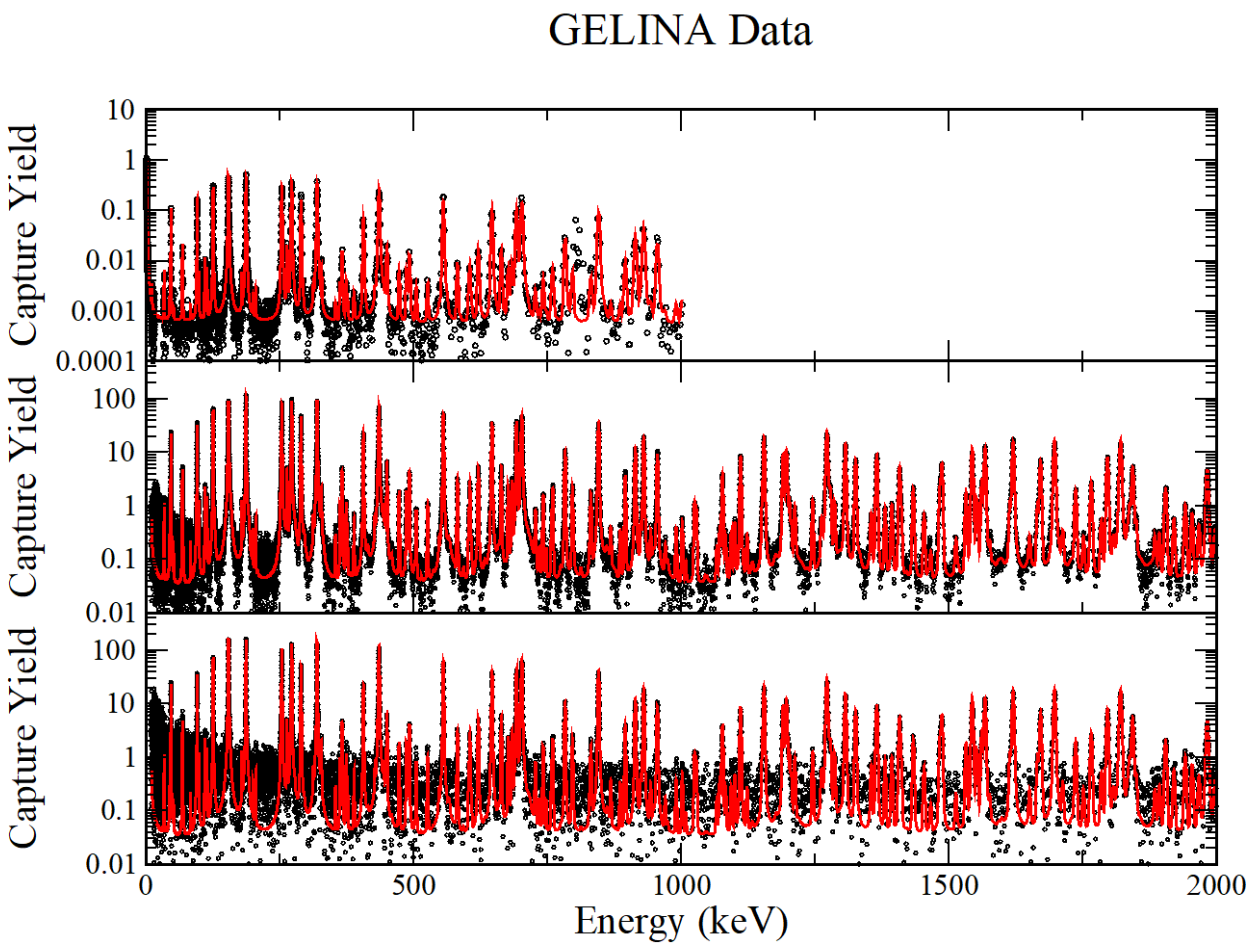
^{54}Fe Evaluation in the Resolved Resonance



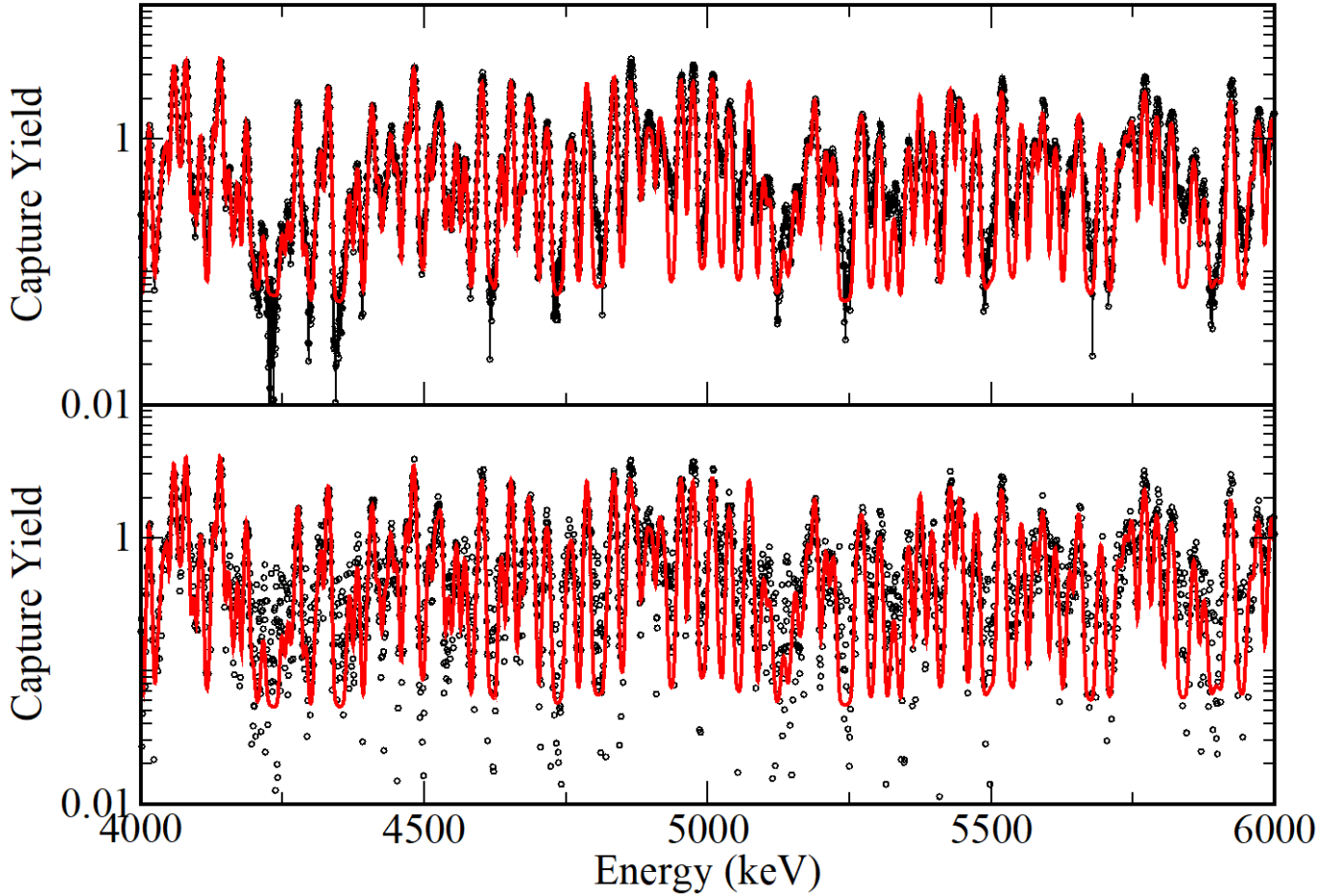
^{103}Rh Evaluation

- Resonance region in existing nuclear data libraries is 1.0-5 eV to 4 keV;
- Transmission, capture data from GELINA used to extend the evaluation up to 8 keV;
- There are transmission and capture data from RPI.
- Evaluation will be released at the end of FY2016 including resonance parameters and resonance parameters covariance

^{103}Rh Evaluation in the Resolved Resonance

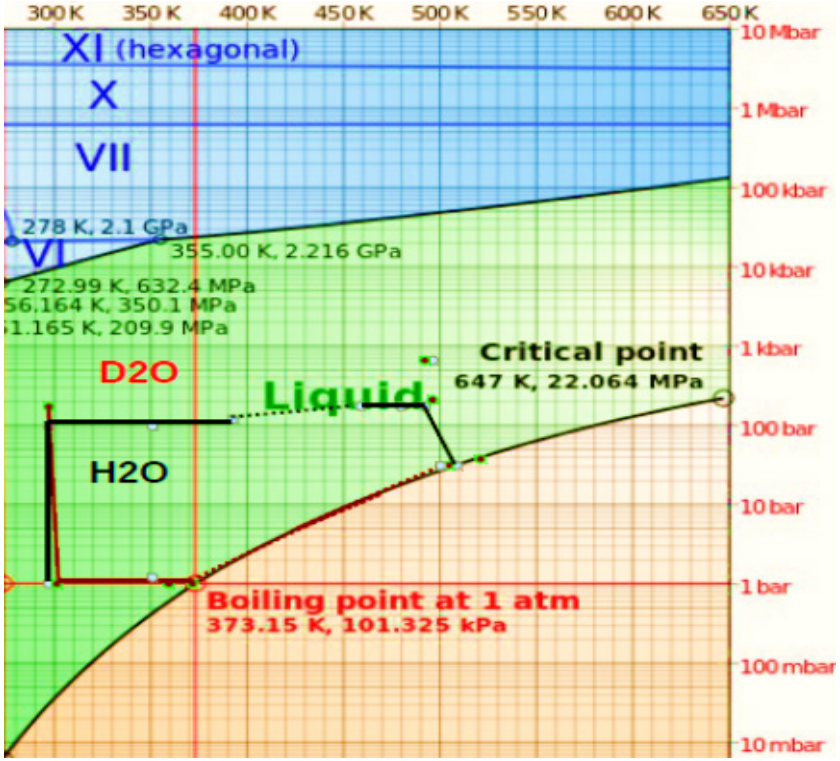


^{103}Rh Evaluation in the Resolved Resonance



For light water:

Measurements at several temperature and pressure combinations



Experimental conditions with IN4c		
Wavelength	Temperature (K)	Pressure (bars)
2.4 A° Ei=14.20 meV	300	1
	300	88-100
	350	115
	392-466	128-165
	479-485	172-180
	490-497	185
	517	42

Experimental conditions with IN6		
Wavelength	Temperature (K)	Pressure (bars)
5.1 A° Ei=3.145 meV	350	1
	494	70
	494	600-340

Concluding Remarks

- Evaluations and validations work for isotopes listed in the NCSP Appendix D are under the schedule;
- Issues on sample preparation for ^{54}Fe for transmission data, capture and inelastic cross section measurements needs to be resolved to avoid delay in completing the evaluation task;
- Data evaluation for ^{54}Fe is needed to fully complete the ^{56}Fe evaluation;
- Final evaluation includes resonance parameters and resonance parameter covariance;
- Continue IRSN and ORNL collaboration efforts;