Covariance Data in the Resonance Region

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Average Group Cross Section

$$\Phi_g \, \overline{\sigma}_{xg} = \int_{E_g}^{E_{g+1}} \sigma_x(E)\,\Phi(E)\,dE$$

with

$$\Phi_g = \int_{E_g}^{E_{g+1}} \Phi(E)\,dE$$

Covariance Matrix for Group Cross Sections

If $p_1, p_2, \ldots, p_n$ are evaluated resonance parameters such that

$$\sigma_x = \sigma_x (p_1, p_2, \ldots, p_n)$$

Then

$$\delta\overline{\sigma}_{xg} = \sum_j \frac{\partial\sigma_{xj}}{\partial p_j} \delta p_j$$

Group Covariance Matrix

$$< \delta\bar{\sigma}_{xg} \; \delta\bar{\sigma}_{xg'} > = \sum_{j\,k} \frac{\partial\sigma_{xj}}{\partial p_j} < \delta p_j \; \delta p_k > \frac{\partial\sigma_{xk}}{\partial p_k}$$

Covariance of the group cross sections depends on the covariance of the resonance parameters *p as*

$$< \delta p_j \; \delta p_k >$$

These quantities are calculated in SAMMY and are stored in the ENDF library

Covariance Processing Tools

- **NJOY**
  - **Not capable of processing Reich-Moore covariance data**

- **PUFF**
  - **Capable of processing Reich-Moore covariance data**

    Dorothea Wiarda: Massive Upgrade !!

- **ERRORJ**
  - **Process most of R-matrix covariance data**

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**
  - **"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**

ERRORJ processing of ^{152}GD (44-group structure)

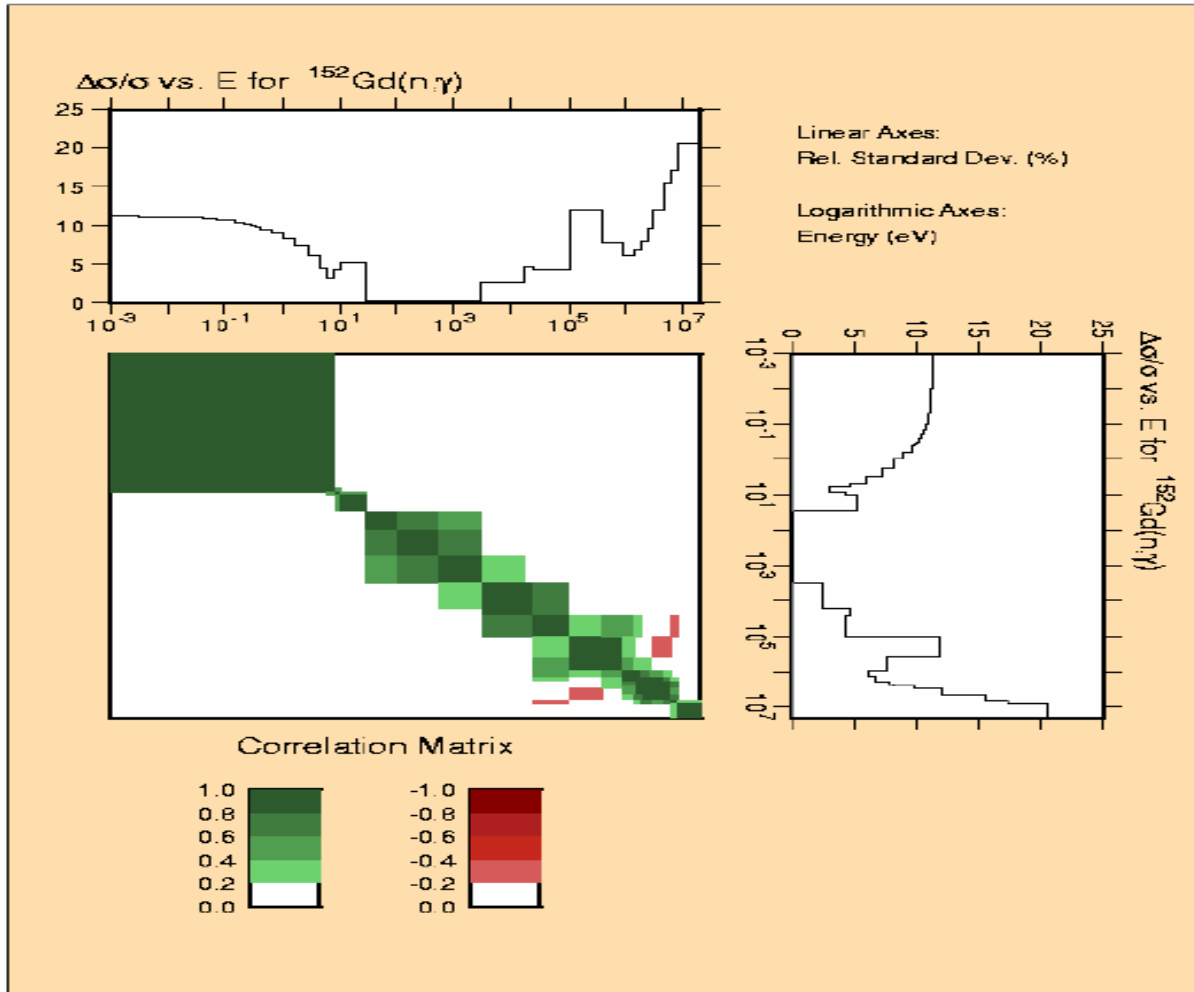...contribution from resonance parameters (mf=32)...

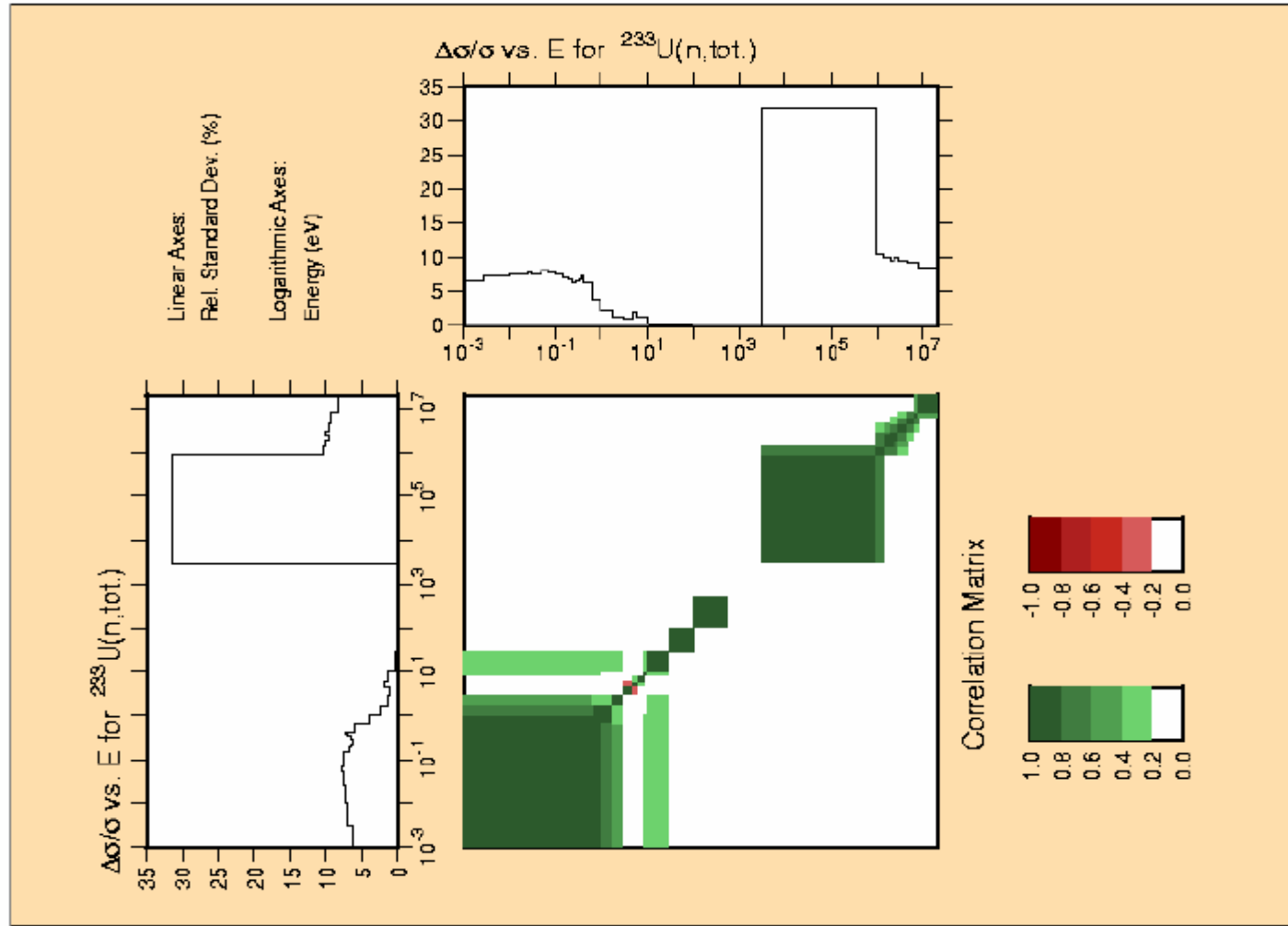| ig	igp	resolved	unresolved
1	1	2.233E-05	0.000E+00
2	2	2.224E-05	0.000E+00
3	3	2.263E-05	0.000E+00
4	4	2.447E-05	0.000E+00
5	5	2.907E-05	0.000E+00
6	6	3.107E-05	0.000E+00
7	7	3.192E-05	0.000E+00
8	8	2.912E-05	0.000E+00
9	9	2.806E-05	0.000E+00
10	10	3.488E-05	0.000E+00
11	11	4.966E-05	0.000E+00
12	12	5.460E-05	0.000E+00
13	13	5.651E-05	0.000E+00
14	14	5.791E-05	0.000E+00
15	15	5.931E-05	0.000E+00
16	16	6.039E-05	0.000E+00
17	17	6.083E-05	0.000E+00
18	18	6.114E-05	0.000E+00
19	19	6.149E-05	0.000E+00
20	20	5.945E-05	0.000E+00
21	21	4.880E-05	0.000E+00
22	22	4.481E-05	0.000E+00
23	23	4.858E-05	0.000E+00
24	24	5.439E-06	0.000E+00
25	25	3.169E-06	0.000E+00
26	26	2.883E-06	0.000E+00
27	27	1.675E-05	0.000E+00
28	28	9.108E-06	0.000E+00
29	29	7.049E-06	7.413E-06
30	30	0.000E+00	1.626E-05
31	31	0.000E+00	1.004E-05
32	32	0.000E+00	7.790E-06
33	33	0.000E+00	1.063E-05

Resolved

Unresolved

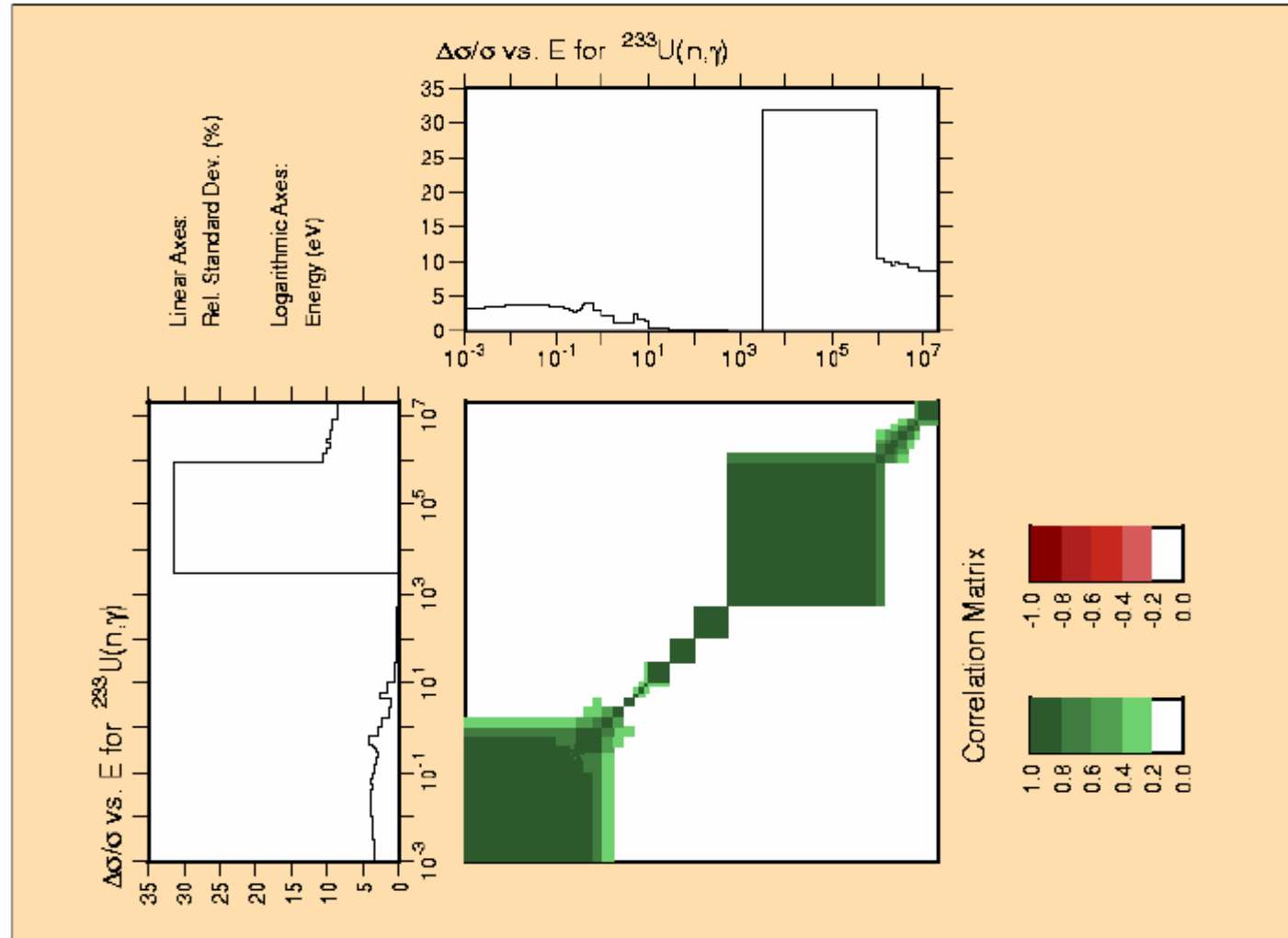# ^{152}Gd Covariance Evaluation Capture Cross Section

^{233}U Evaluation

- **Resolved Resonance Covariance Evaluation done with SAMMY**

  – **Actual experimental data uncertainty were used. Example: ORELA resolution function, TOF uncertainties, channel widths, jitters, etc**

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

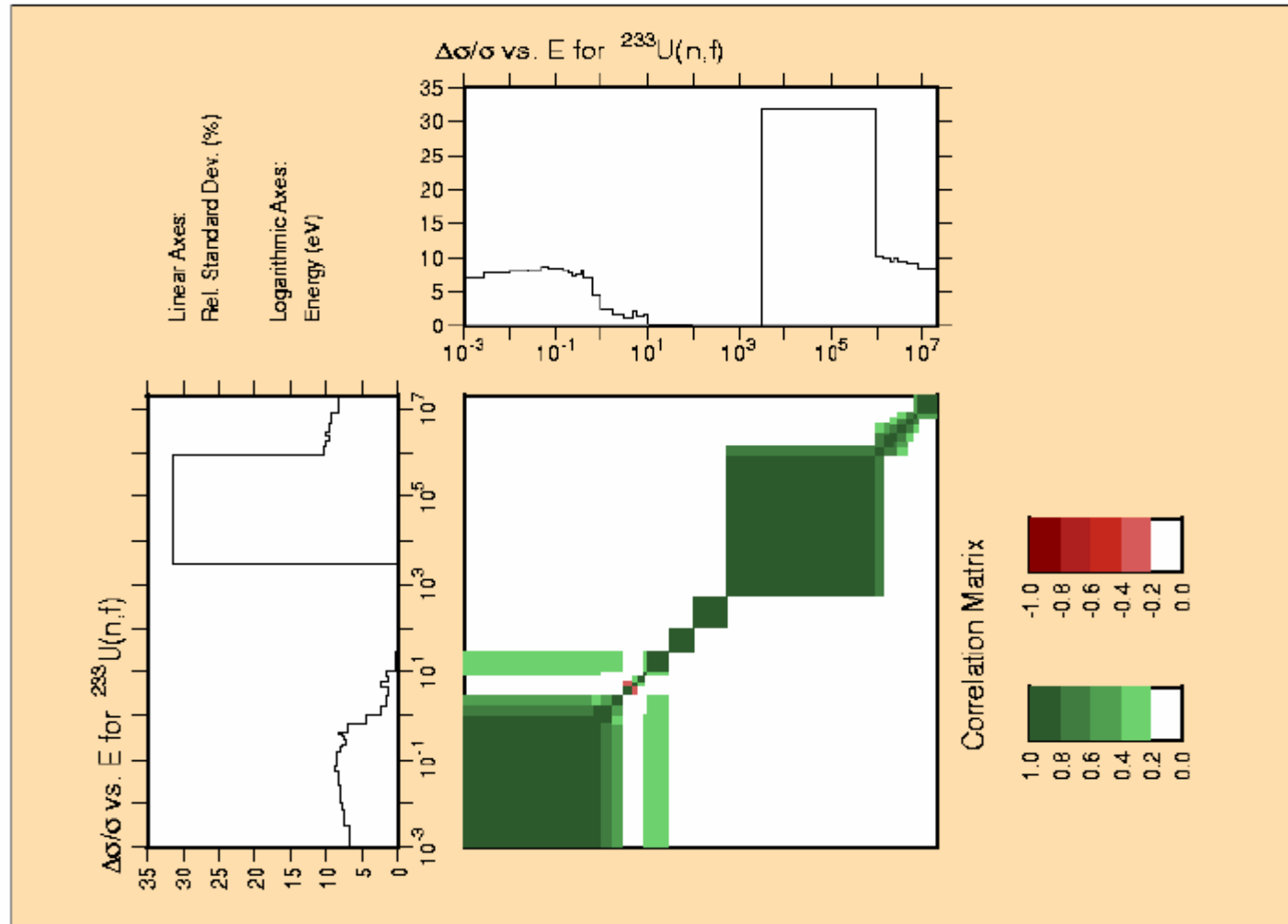- **Covariance in the high energy region temporarily inserted for file processing**

ERRORJ Processed Covariance (Total Cross Section)

$\Delta\sigma/\sigma$ vs. E for ^{233}U(n,tot.)

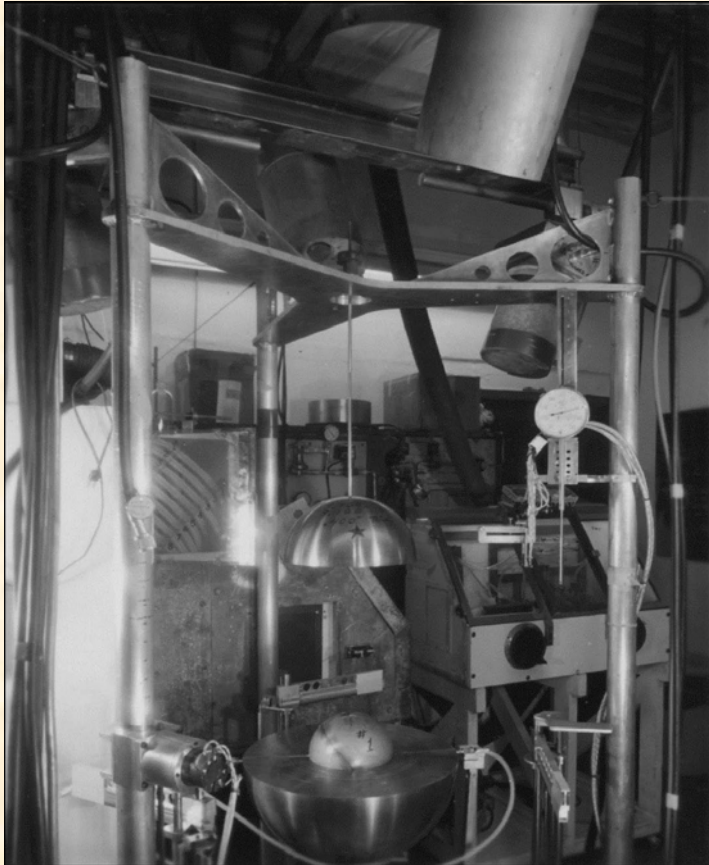# ERRORJ Processed Covariance (Capture Cross Section)

ERRORJ Processed Covariance (Fission Cross Section)
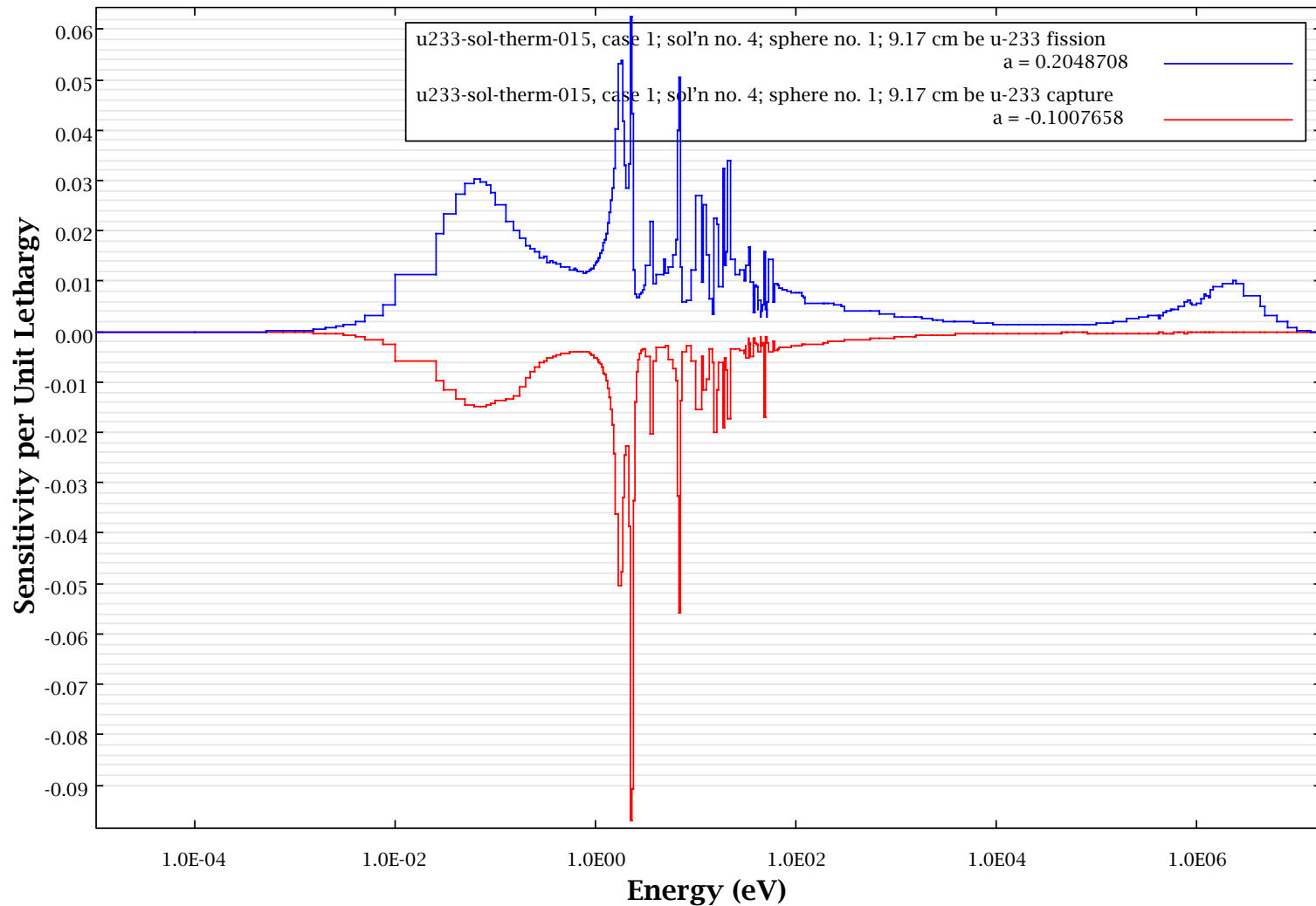
Benchmark Calculations

- **Cross section and covariance evaluation in the resonance region were done with SAMMY**

- **NJOY/AMPX were used to process the cross section data;**

- **Covariance data were processed using the ERRORJ code;**

- **ERRORJ produces covariance data in the COVERX format;**

- **Benchmark calculations were done with the TSUNAMI code;**

Overview of Experiment (u233-sol-therm-015)

A series of criticality studies were performed at Lawrence Livermore National Laboratory in the late 1950's using aqueous solutions of ^{233}U in the form of UO_2F_2 stabilized with 0.3% by weight of HF.

Sensitivity to the capture and fission cross section for the u233-sol-therm-015 benchmark

Benchmark Calculations with ENDF/B-VI 238 Group Structure (ICSBEP)

uct001 (2 cases) not used	ust003 (10 cases)
umf001 (1 case)	ust004 (8 cases)
umf002 (2 cases)	ust005 (2 cases)
umf003 (2 cases)	ust006 (25 cases)
umf004 (2 cases)	ust008 (1 case)
umf005 (2 cases)	ust009 (4 cases)
umf006 (1 case)	ust012 (8 cases)
usi001 (33 cases)	ust013 (2 cases)
ust001 (5 cases)	ust014 (16 cases)
ust002 (16 cases)	ust015 (31 cases)
Total: 175 cases	

Results of Benchmarks Using ENDF/B-VI 238 Group

- **SCALE system run to get TSUNAMI-1D/TSUNAMI-3D-K5 output and SAMS output**

- **Propagate cross section uncertainties to k_{eff} for all benchmark problems**

Results from u233-sol-therm-015 benchmark (case 1)

Forward Calculation k_{eff} : 0.99470367

Adjoint Calculation k_{eff} : 0.99451532

^{233}U contribution to standard deviation of k_{eff} : 0.5112%

^{233}U Contributions $*10^4$ by reaction pairs to relative covariance of k_{eff}

	fission	n, gamma	elastic
fission	3.9622E-01	-1.0552E-01	-2.4250E-06
n, gamma	-1.0552E-01	7.9620E-02	9.8695E-07
elastic	-2.4250E-06	9.8695E-07	3.0737E-08

Results from u233-sol-therm-015 benchmark (case 1) with new cross section library

Forward Calculation k_{eff}	**0.99584665**
Adjoint Calculation k_{eff}	**0.99565516**
Experimental k_{eff}	**1.0000 ± 0.0075**
Standard deviation of k_{eff} attributable to ^{233}U	**0.5007 ± 0.0001 %**

Results from u233-sol-therm-006 benchmark (case 6) with new cross section library

Calculation k_{eff}	**0.99186 ± 0.00040**
Experimental k_{eff}	**1.0000 ± 0.0028**
Standard deviation of k_{eff} due to ^{233}U	**0.5953 ± 0.0001 %**

Results from u233-sol-therm-014 benchmark (case 3) with new cross section library

Calculation k_{eff}	**1.007697 ± 0.000364**
Experimental k_{eff}	**1.0000 ± 0.0089**
Standard deviation of k_{eff} attributable to ^{233}U	**0.6898 ± 0.0001 %**

Other Results
Red: k_{eff}
Blue: Std of k_{eff} due to ^{233}U

usi001c1	**0.989906** **0.2650 +/- 0.0000 percent**
ust002c15	**1.003387 +/- 0.000296** **2.0063 +/- 0.0001 percent**
ust003c1	**0.996082 +/- 0.000391** **0.6147 +/- 0.0000 percent**
ust004c33	**1.004273 +/- 0.000368** **0.9672 +/- 0.0001 percent**
ust014c12	**1.002819 +/- 0.000404** **0.6947 +/- 0.0001 percent**

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Uncertainties Due to ^{233}U Cross Section

Concluding Remarks

- **Cross section and covariance evaluation in the resonance region were done for Gd and ^{233}U**

- **NJOY/AMPX were used to process the new evaluation;**

- **Covariance data were processed using the ERRORJ code;**

- **ERRORJ produces covariance data in the COVERX format;**

- **Benchmark calculations were done with the TSUNAMI code;**