
Uncertainty Evaluations with Covariance Data in the Fast Reactors

Choong Sup Gil, Do Heon Kim, Young Ouk Lee

Korea Atomic Energy Research Institute

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- ✓ Fast reactor benchmarks
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1. Status of covariance data in ENDF

❖ Covariance data in available evaluated nuclear data files

Data Files	No. of nuclides	No. of reactions (MT)	Covariance data (MF=30~40)										
			30	31	32	33	34	35	36	37	38	39	40
ENDF/B-VI.8	46	745	0	8	4	731	0	0	0	0	0	0	2
JENDL-3.3	20	454	0	16	6	415	12	5	0	0	0	0	0
JEF-2.2	15	241	0	1	0	240	0	0	0	0	0	0	0
CENDL-2.0	8	46	0	3	2	40	0	0	0	0	0	0	0
BROND-2.0	3	54	0	0	0	54	0	0	0	0	0	0	0

❖ Contents of File Types (MF)

- MF=30: introduction to data covariance files
- MF=31: covariances for average number of neutrons per fissions
- MF=32: covariances for resonance parameters
- MF=33: covariances for reaction cross sections
- MF=34: covariances for angular distributions
- MF=35: covariances for energy distributions
- MF=36: covariances for angle-energy distributions
- MF=37~38: null
- MF=39: covariances for radionuclide production yields
- MF=40: covariances for radionuclide production cross sections

- Covariance data of U-233 in ENDF

	MF=31	MF=32	MF=33	MF=34	MF=35
ENDF/B-V					
ENDF/B-VI.8					
ENDF/B-VIIb1					
JEF-2.2					
JEFF-3.0					
JEFF-3.1	452, 455, 456	151	1, 2, 4, 16, 17, 18, 102	2	18
JENDL-3.2	452, 455, 456	151	1, 2, 4, 16, 17, 18, 102	2	18
JENDL-3.3	452, 455, 456	151	1, 2, 4, 16, 17, 18, 102	2	18

■ covariance data of U-235 in ENDF

	MF=31	MF=32	MF=33	MF=34	MF=35
CENDL-2.1	452, 456				
ENDF/B-V	452		18, 102		
ENDF/B-VI.8	452, 456				
ENDF/B-VIIb1	452, 456				
JEF-2.2	452		18, 102		
JEFF-3.0	452, 456				
JEFF-3.1	452, 456				
JENDL-3.2	452, 455, 456	151	1, 2, 4, 16, 17, 18, 37, 51-79, 91, 102	2	18
JENDL-3.3	452, 455, 456		1, 2, 4, 16, 17, 18, 37, 51-79, 91, 102	2	18

▪ Covariance data of U-238 in ENDF

	MF=31	MF=32	MF=33	MF=34	MF=35
CENDL-2.1	452, 455, 456	151	1, 2, 4, 16, 17, 18, 51-57, 102		
ENDF/B-V	452, 455, 456		1, 2, 4, 16, 17, 18, 51-57, 102		
ENDF/B-VI.8	452, 455, 456		51-57		
ENDF/B-VIIb1	452, 455, 456		51-57		
JEF-2.2			1, 2, 4, 18, 51, 52, 102		
JEFF-3.0			1, 2, 4, 18, 51, 52, 102		
JEFF-3.1					
JENDL-3.2	452, 455, 456	151	1, 2, 4, 16, 17, 18, 51-83, 91, 102	2	18
JENDL-3.3	452, 455, 456	151	1, 2, 4, 16, 17, 18, 37, 51-77, 91, 102	2	18

▪ Covariance data of Pu-239 in ENDF

	MF=31	MF=32	MF=33	MF=34	MF=35
CENDL-2.1					
ENDF/B-V	452		18, 102		
ENDF/B-VI.8					
ENDF/B-VIIb1					
JEF-2.2					
JEFF-3.0					
JEFF-3.1					
JENDL-3.2	452, 455, 456	151	1, 2, 4, 16, 17, 18, 37, 51-68, 91, 102	2	18
JENDL-3.3	452, 455, 456	151	1, 2, 4, 16, 17, 18, 37, 51-68, 91, 102	2	18

▪ Covariance data of Pu-240 in ENDF

	MF=31	MF=32	MF=33	MF=34	MF=35
CENDL-2.1	452	151	102		
ENDF/B-V	452	151	18, 102		
ENDF/B-VI.8	452	151	102		
ENDF/B-VIIb1	452	151	102		
JEF-2.2					
JEFF-3.0					
JEFF-3.1					
JENDL-3.2		151	1, 2, 4, 16, 17, 18, 37, 51-78, 91, 102	2	18
JENDL-3.3	456	151	1, 2, 4, 16, 17, 18, 37, 51-77, 91, 102	2	18

▪ Covariance data of Pu-241 in ENDF

	MF=31	MF=32	MF=33	MF=34	MF=35
ENDF/B-V	452		18, 102		
ENDF/B-VI.8	452				
ENDF/B-VIIb1	452				
JEF-2.2					
JEFF-3.0					
JEFF-3.1					
JENDL-3.2	452, 455, 456	151	1, 2, 4, 16, 17, 18, 37, 51-61, 91, 102	2	
JENDL-3.3	452, 455, 456	151	1, 2, 4, 16, 17, 18, 37, 51-61, 91, 102	2	

2. Fast Reactor Benchmarks

- ✓ **GODIVA** (*HEU-MET-FAST-001 / CSEWG-F5*)
 - radius = 8.741 cm, bare, U-metal sphere core
 - Fuel of U-235(93.71 wt. %), U-238(5.27 wt. %), U-234(1.02 wt. %)

- ✓ **VNIIEF's Critical Test Facility (CTF), Russia (1994)**
(*IEU-MET-FAST-003*)
 - radius = 15.324 cm, bare, U-metal sphere core
 - Fuel of U-235(36.5 wt.%), U-238(63.1 wt.%), U-234(0.3 wt.%)

- ✓ **Pu-239 JEZEBEL** (*PU-MET-FAST-001 / CSEWG-F1*)
 - radius = 6.38493 cm, bare, Pu-metal sphere core
 - Fuel of Pu-239(95.2 wt. %), Pu-240(4.5 wt. %), Pu-241(0.3 wt. %)

- ✓ **Pu-240 JEZEBEL** (*PU-MET-FAST-002 / CSEWG-F21*)
 - radius = 6.6595 cm, bare, Pu-metal sphere core
 - Fuel of Pu-239(76.4 wt. %), Pu-240(20.1 wt. %), Pu-241(3.1 wt. %), Pu-242(0.4 wt.%)

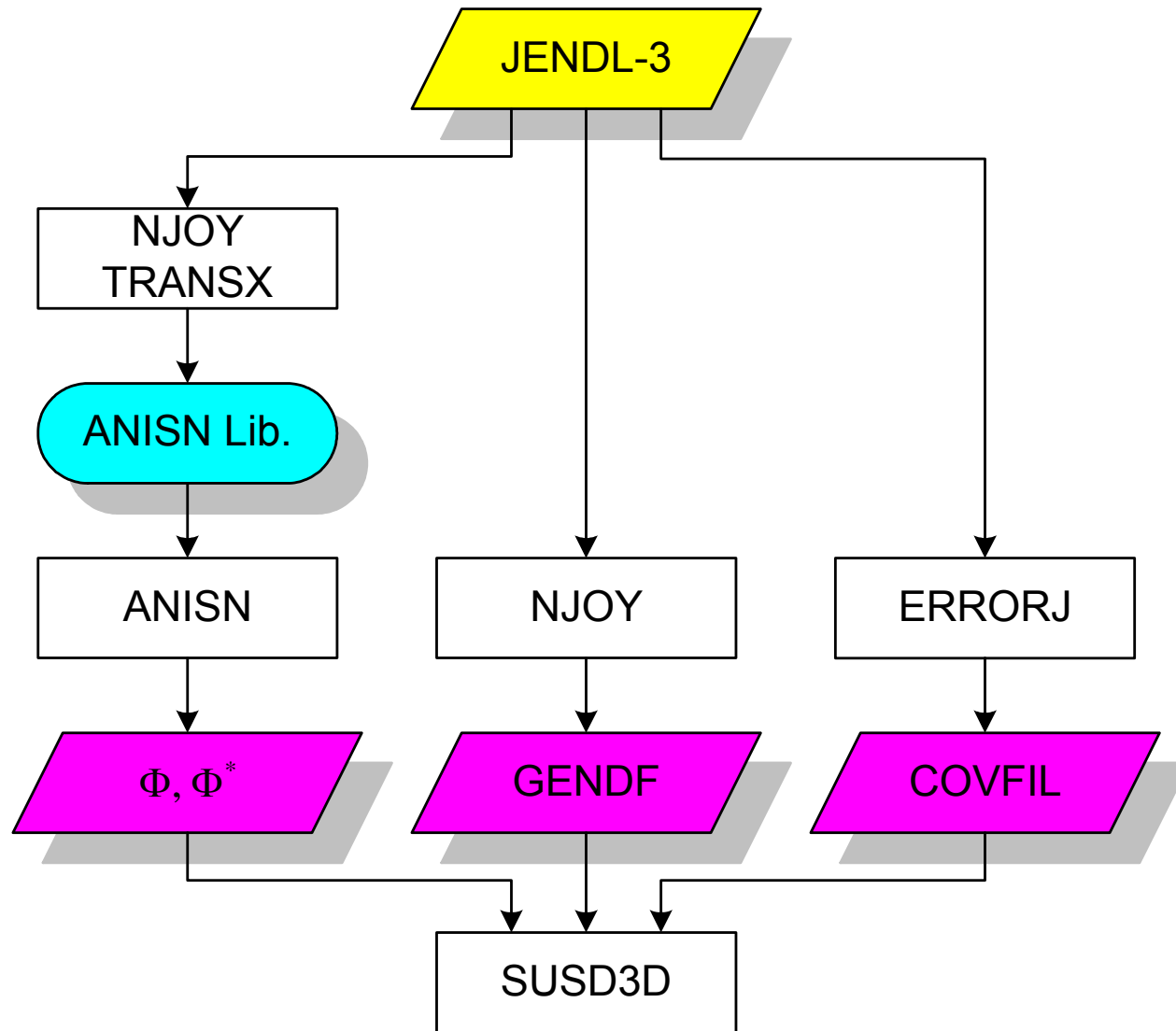
- ✓ **U-233 JEZEBEL** (*U233-MET-FAST-001*)
 - radius = 5.9838 cm, bare, U-metal sphere core
 - Fuel of U-233(98.13 wt. %), U-234(1.24 wt. %), U-235(0.03 wt. %), U-238(0.60 wt.%)

3. Sensitivity and uncertainty calculation

❖ Data generation for sensitivity and uncertainty analyses

- ✓ Generation of 30 group cross section data for the spectra and sensitivity calculation using NJOY code
- ✓ 30 group direct and adjoint flux calculations in 5 fast reactor cores with ANISN
- ✓ Generation of the correlation coefficients of U-233, -238, -235, Pu-239, -240, -241 from the covariance data of JENDL-3.3 with ERRORJ

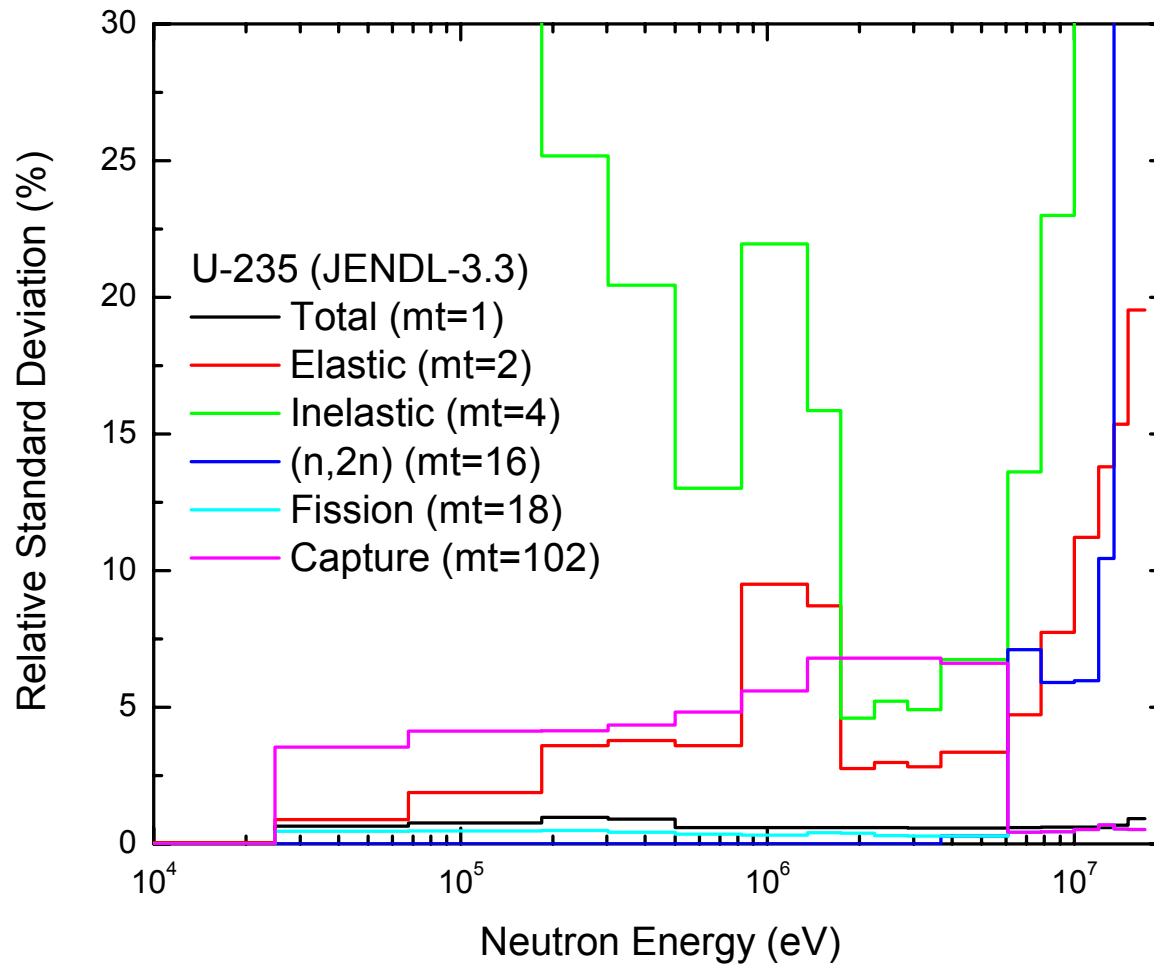
Data flow for sensitivity and uncertainty calculation



- LANL 30-Group Structure

Group #	E-lower (eV)	E-upper (eV)	Group #	E-lower (eV)	E-upper (eV)
1	1.390E-04	1.520E-01	16	1.840E+05	3.030E+05
2	1.520E-01	4.140E-01	17	3.030E+05	5.000E+05
3	4.140E-01	1.130E+00	18	5.000E+05	8.230E+05
4	1.130E+00	3.060E+00	19	8.230E+05	1.353E+06
5	3.060E+00	8.320E+00	20	1.353E+06	1.738E+06
6	8.320E+00	2.260E+01	21	1.738E+06	2.232E+06
7	2.260E+01	6.140E+01	22	2.232E+06	2.865E+06
8	6.140E+01	1.670E+02	23	2.865E+06	3.680E+06
9	1.670E+02	4.540E+02	24	3.680E+06	6.070E+06
10	4.540E+02	1.235E+03	25	6.070E+06	7.790E+06
11	1.235E+03	3.350E+03	26	7.790E+06	1.000E+07
12	3.350E+03	9.120E+03	27	1.000E+07	1.200E+07
13	9.120E+03	2.480E+04	28	1.200E+07	1.350E+07
14	2.480E+04	6.760E+04	29	1.350E+07	1.500E+07
15	6.760E+04	1.840E+05	30	1.500E+07	1.700E+07

❖ Relative uncertainty of U-235 cross sections



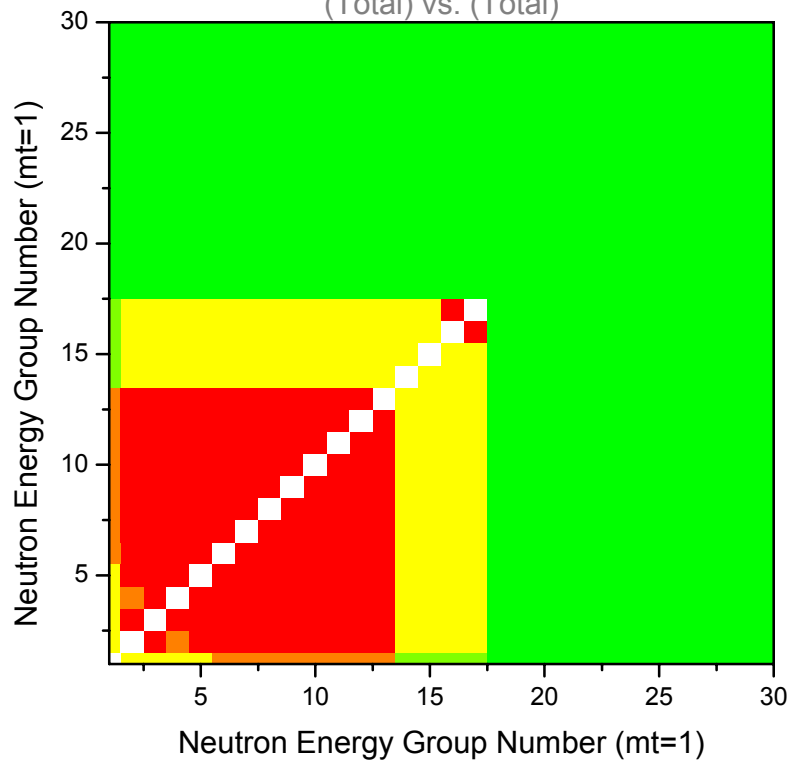
❖ The uncertainties of U-235 data (%)
 (from ANL covariance matrix analyses)

Energy	ν	σ_f	σ_{inel}	σ_{el}	σ_{capt}	$\Sigma_{n,2n}$
0.10 eV	0.3	1		5	1	
0.54 eV	0.5	1		5	1	
4.00 eV	0.5	3		5	3	
22.6 eV	0.5	3		5	5	
454 eV	0.5	3		5	5	
2.03 keV	0.5	3	30	5	5	
9.12 keV	1	5	25	5	5	
24.8 keV	1	5	25	5	10	
67.4 keV	1	5	20	5	10	
183 keV	1	5	15	5	15	
498 keV	1	5	15	5	15	
1.35 MeV	1	5	15	5	15	
2.23 MeV	1	5	10	5	15	
6.07 MeV	1	5	10	5	15	50
19.6 MeV	1	5	10	5	15	50
55.2 MeV	2	10	20	10	20	100
150 MeV	3	10	30	15	30	100

❖ Correlation Matrices of U-235

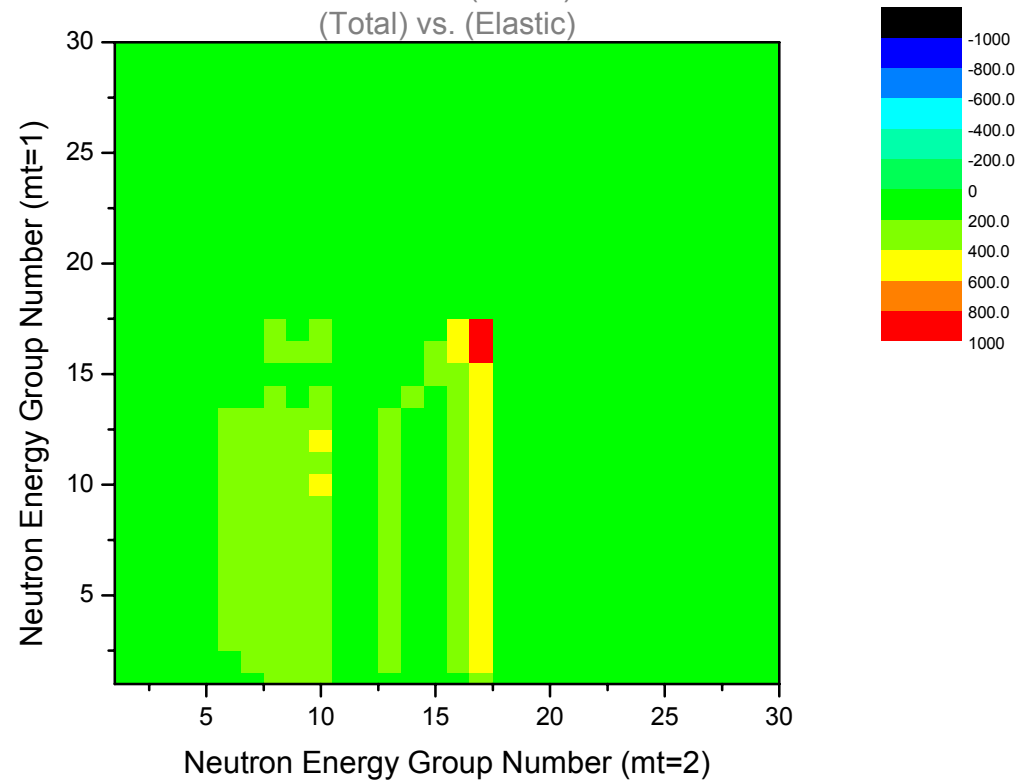
Total vs. Total

Correlation Matrices (x1000) for U-235
(Total) vs. (Total)



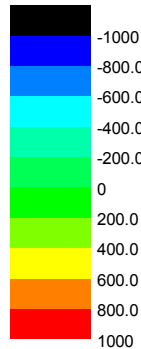
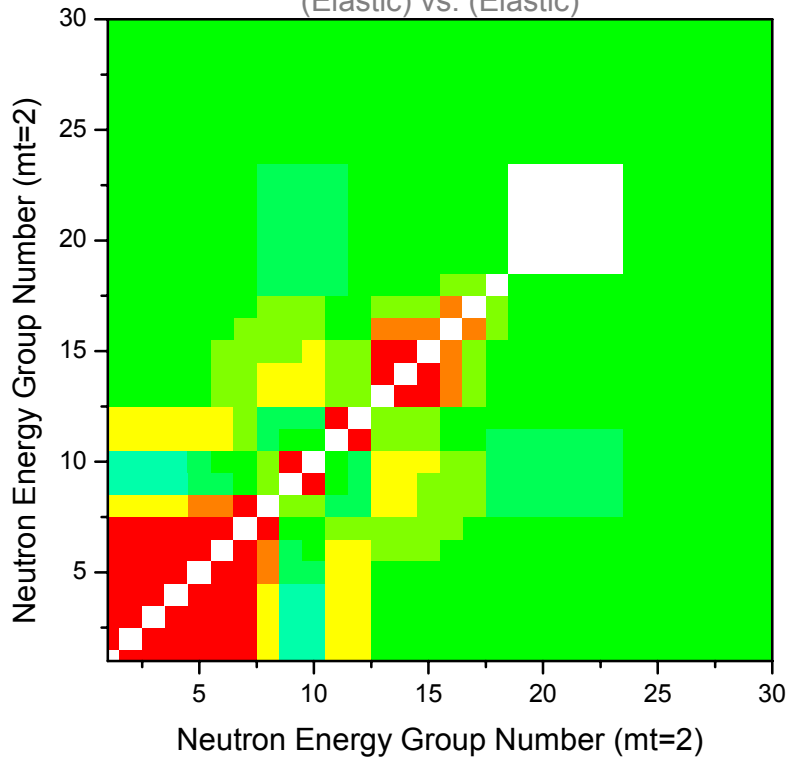
Total vs. Elastic

Correlation Matrices (x1000) for U-235
(Total) vs. (Elastic)



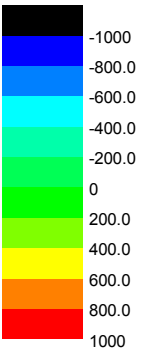
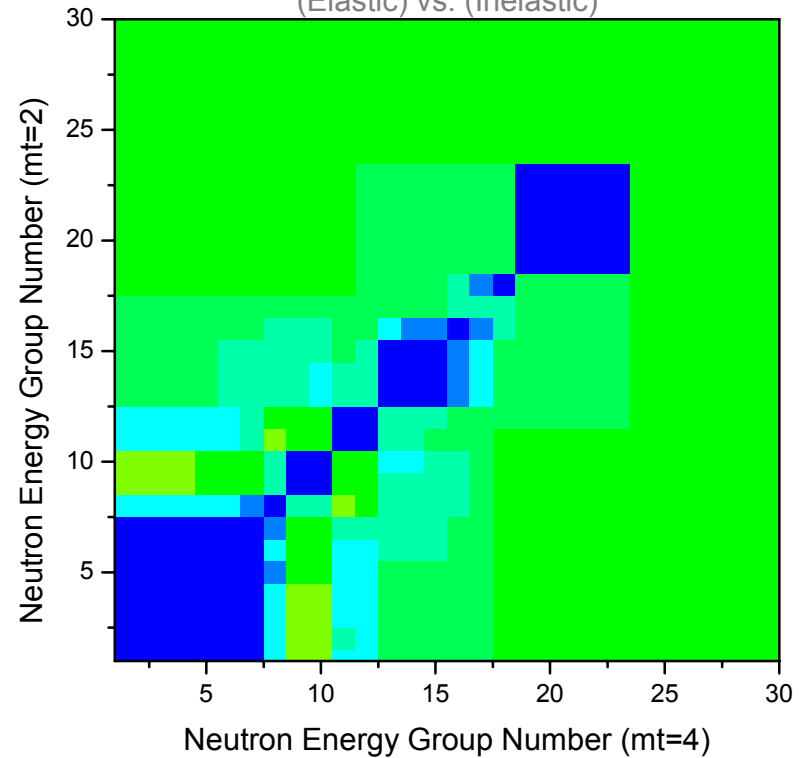
Elastic vs. Elastic

Correlation Matrices (x1000) for U-235
(Elastic) vs. (Elastic)



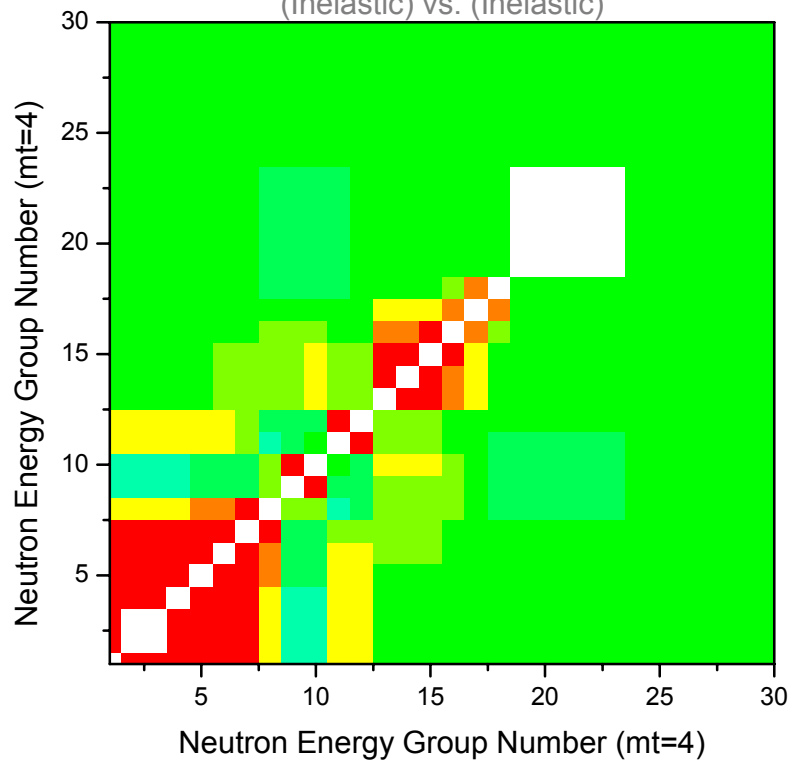
Elastic vs. Inelastic

Correlation Matrices (x1000) for U-235
(Elastic) vs. (Inelastic)



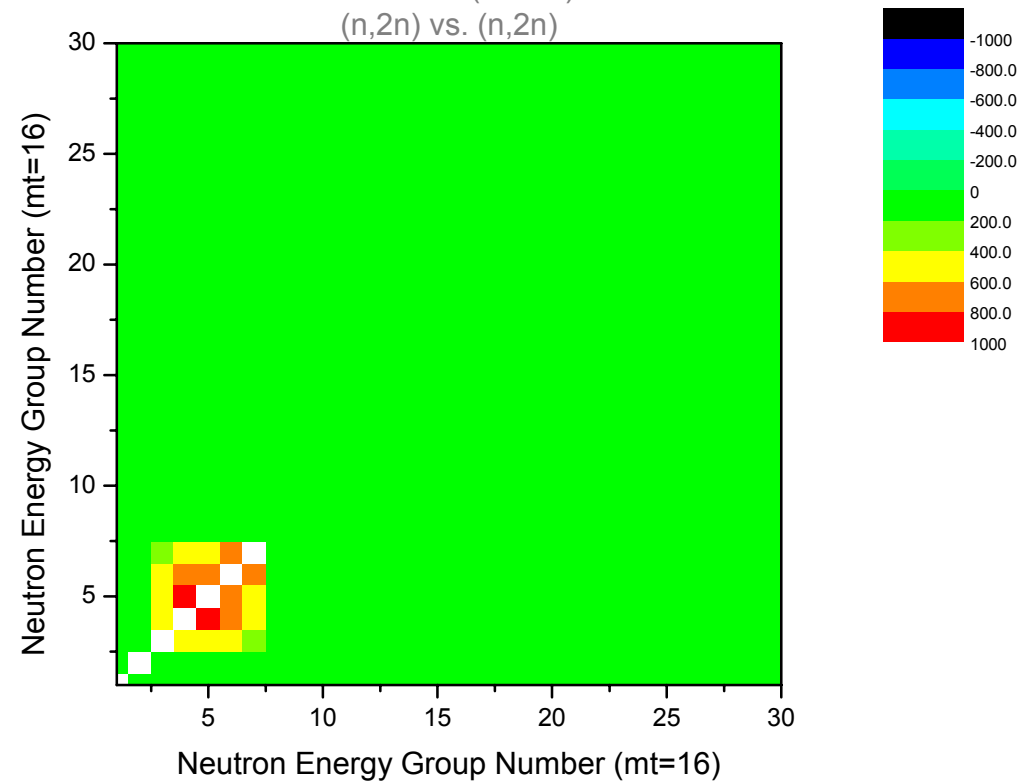
Inelastic vs. Inelastic

Correlation Matrices (x1000) for U-235
(Inelastic) vs. (Inelastic)



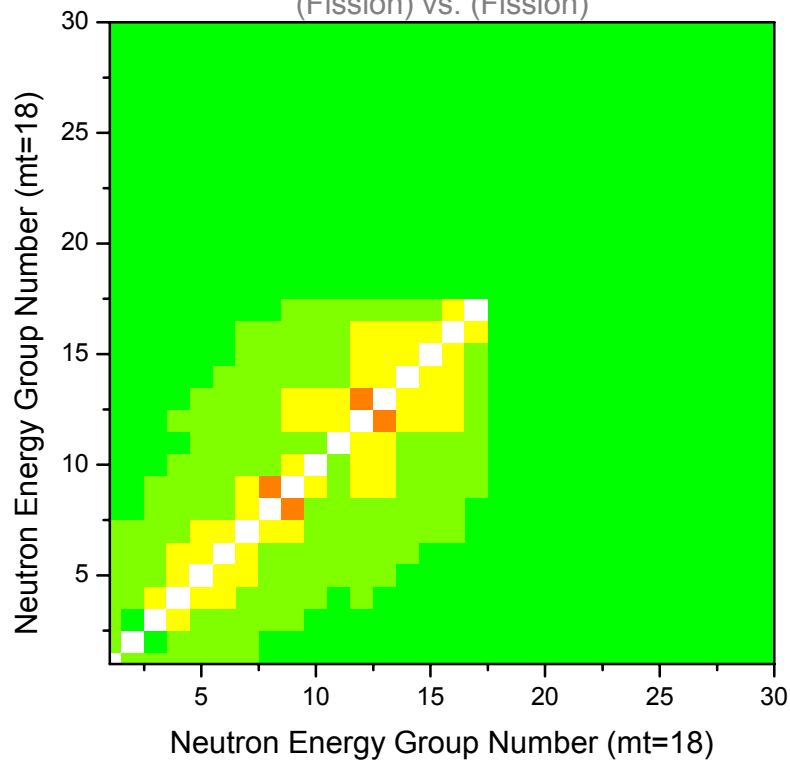
(n,2n) vs. (n,2n)

Correlation Matrices (x1000) for U-235
(n,2n) vs. (n,2n)



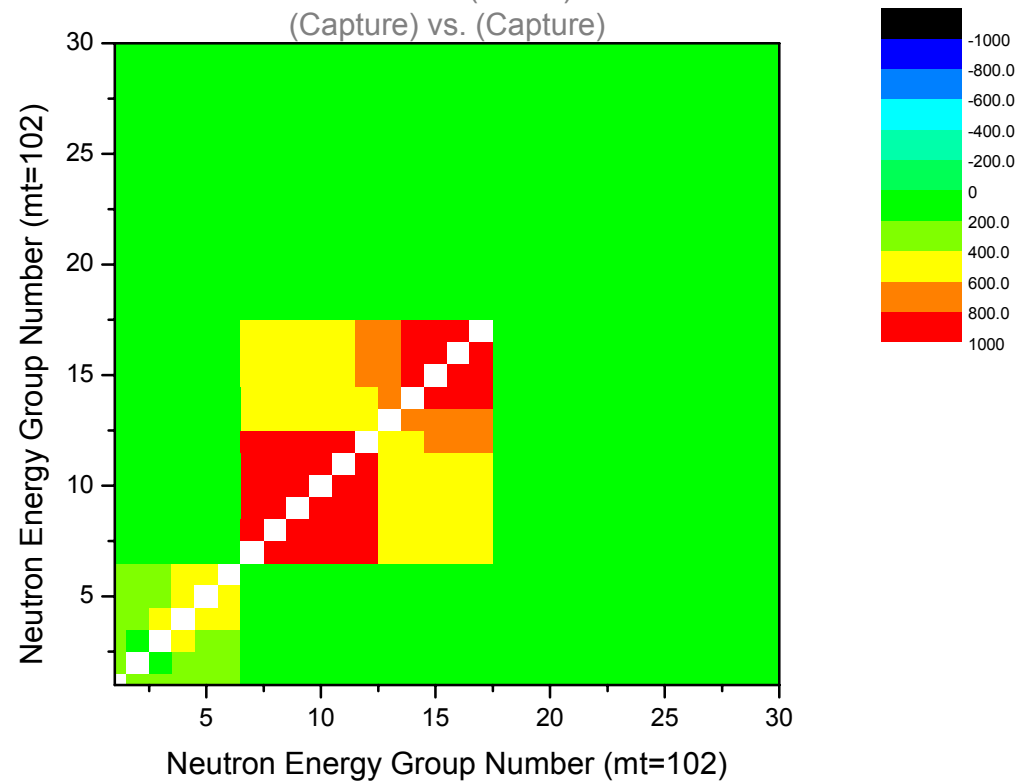
Fission vs. Fission

Correlation Matrices (x1000) for U-235
(Fission) vs. (Fission)

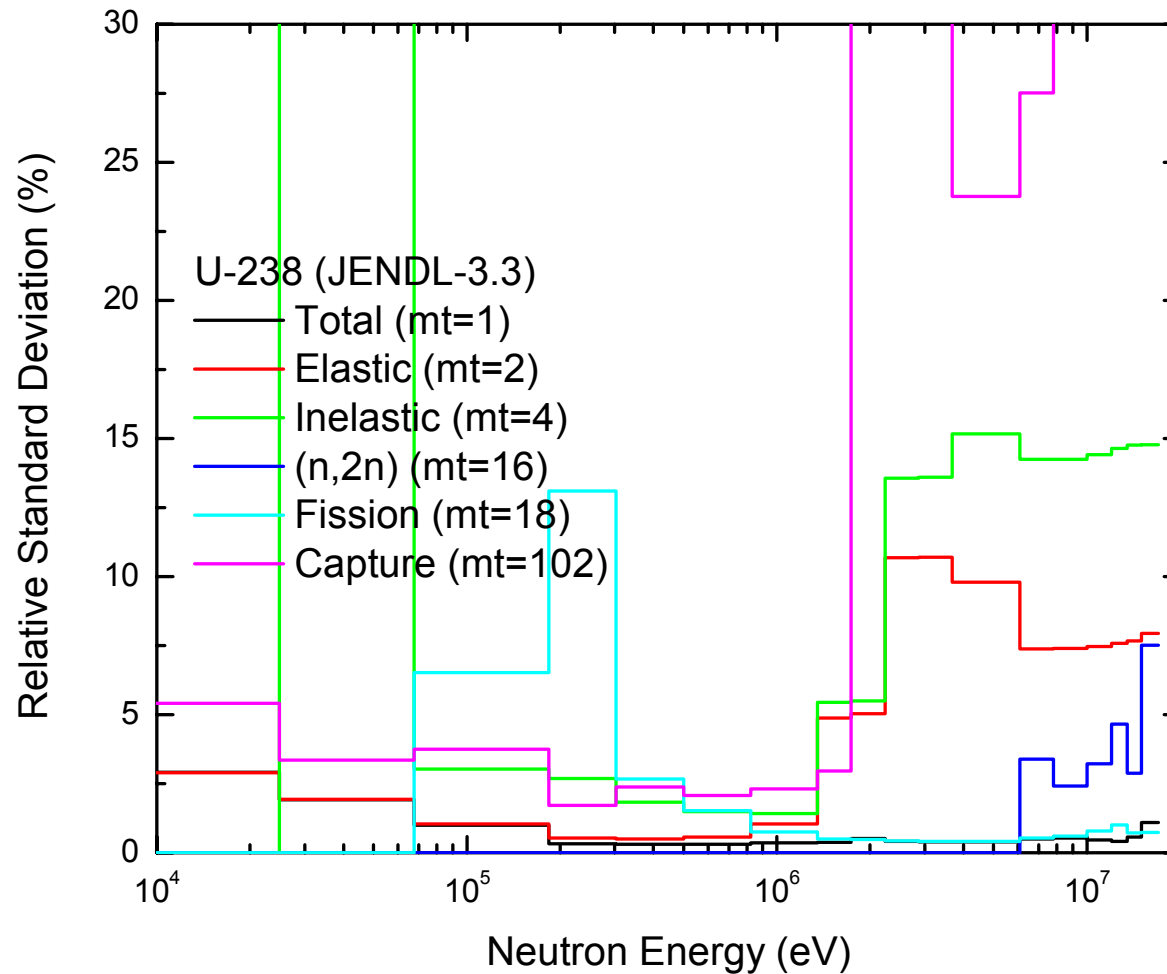


Capture vs. Capture

Correlation Matrices (x1000) for U-235
(Capture) vs. (Capture)



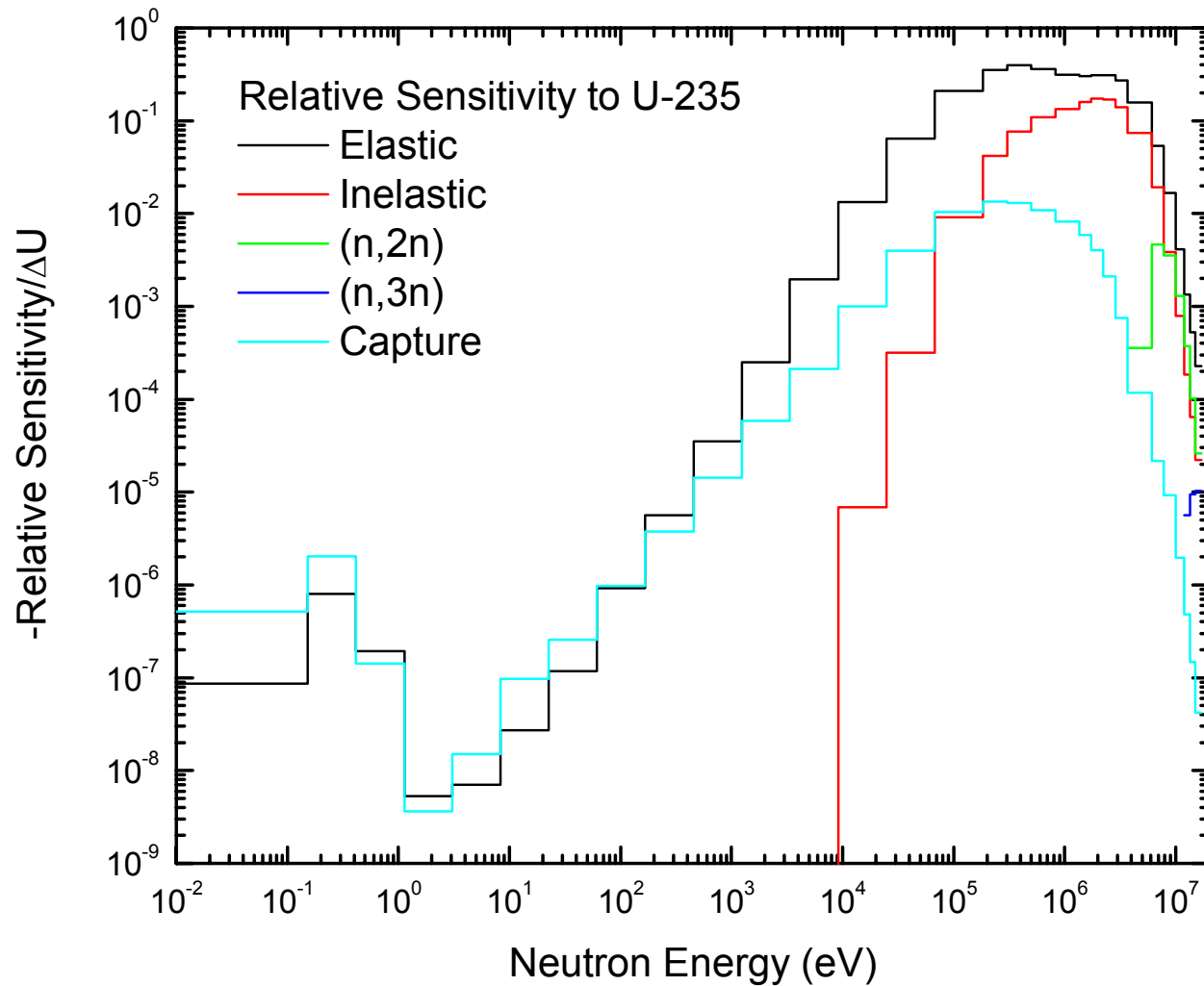
❖ Relative uncertainty of U-238 cross sections

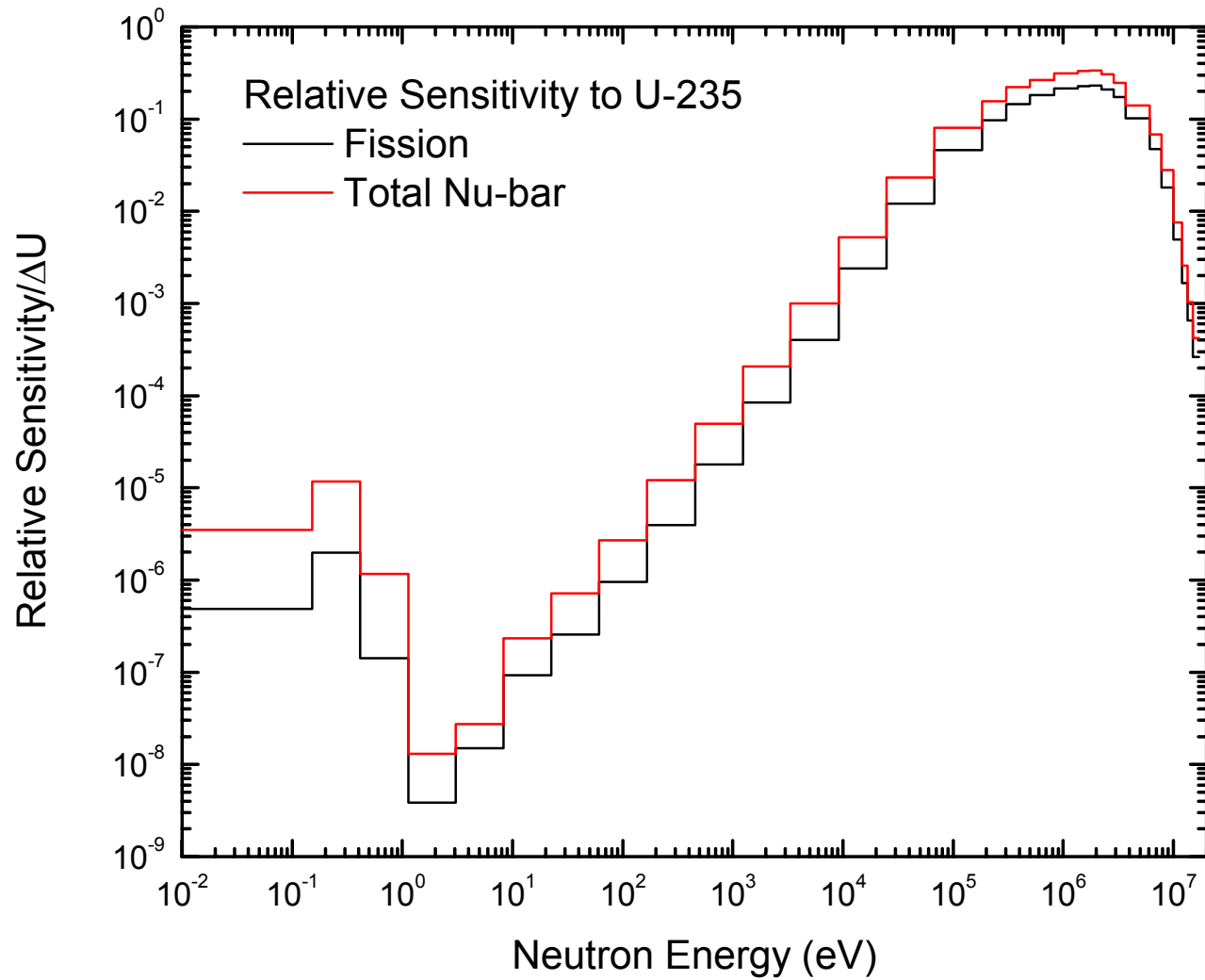


❖ The uncertainties of U-238 data (%)
 (from ANL covariance matrix analyses)

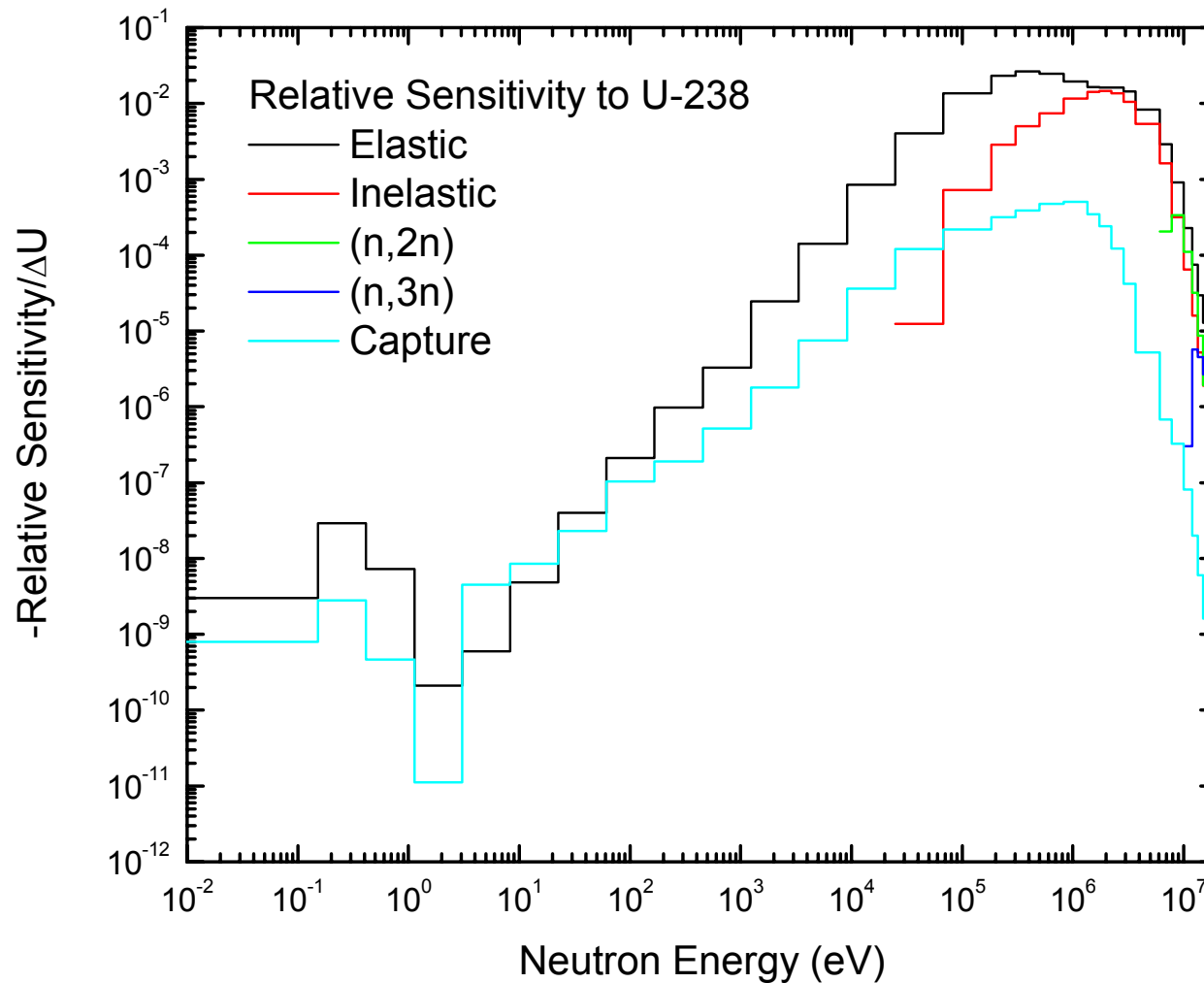
Energy	ν	σ_f	σ_{inel}	σ_{el}	σ_{capt}	$\Sigma_{n,2n}$
0.10 eV	2	20		1	1	
0.54 eV	2	20		1	1	
4.00 eV	2	20		5	3	
22.6 eV	2	20		5	3	
454 eV	2	20		5	3	
2.03 keV	2	20		5	3	
9.12 keV	2	20		5	3	
24.8 keV	2	20		5	5	
67.4 keV	2	20	15	5	5	
183 keV	2	20	10	5	5	
498 keV	2	5	10	5	5	
1.35 MeV	2	5	10	5	5	
2.23 MeV	2	5	10	5	5	
6.07 MeV	2	5	15	5	10	
19.6 MeV	3	5	20	5	30	30
55.2 MeV	2	10	20	10	20	100
150 MeV	3	10	30	15	30	100

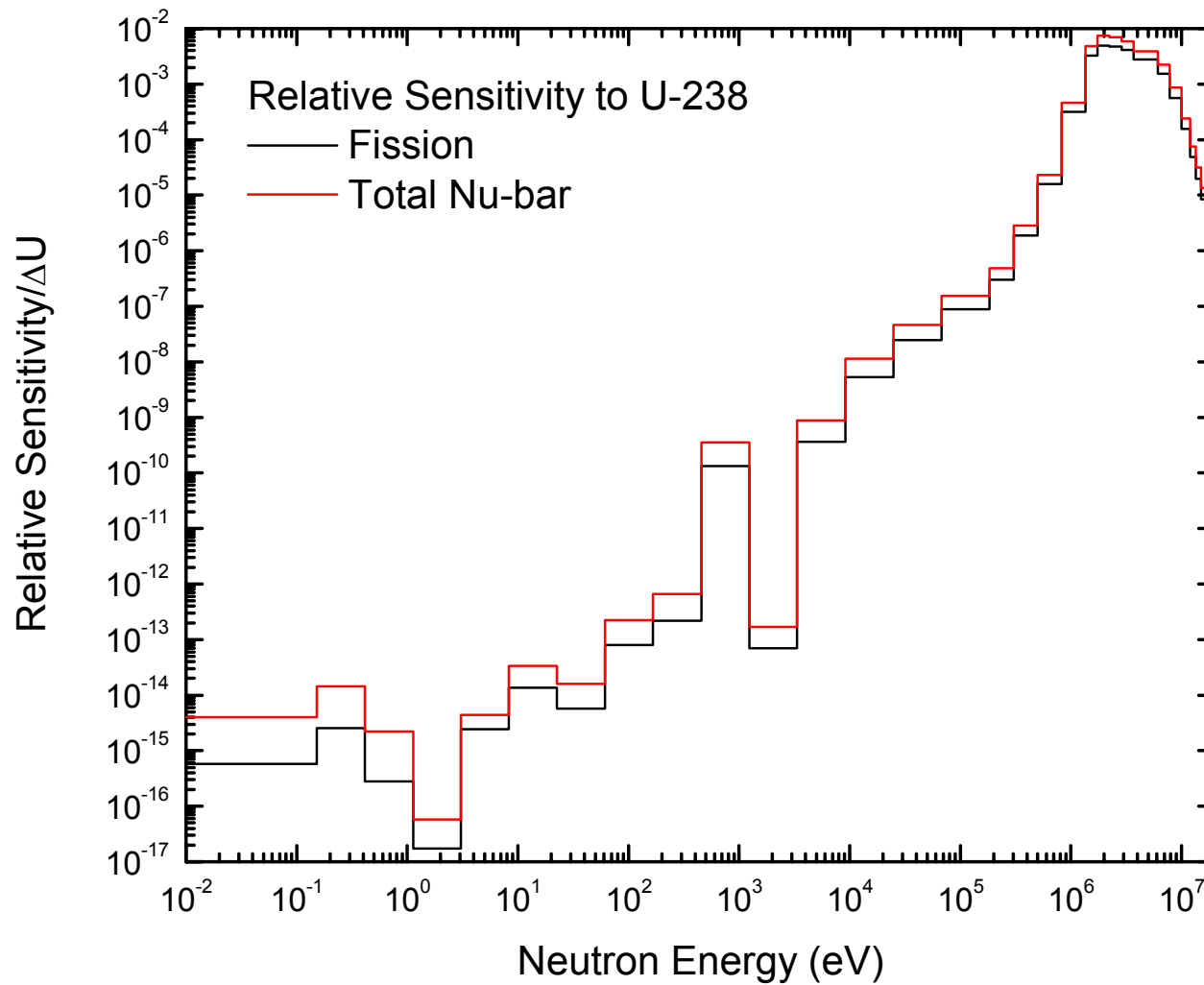
❖ Relative sensitivity of U-235 cross sections for GODIVA



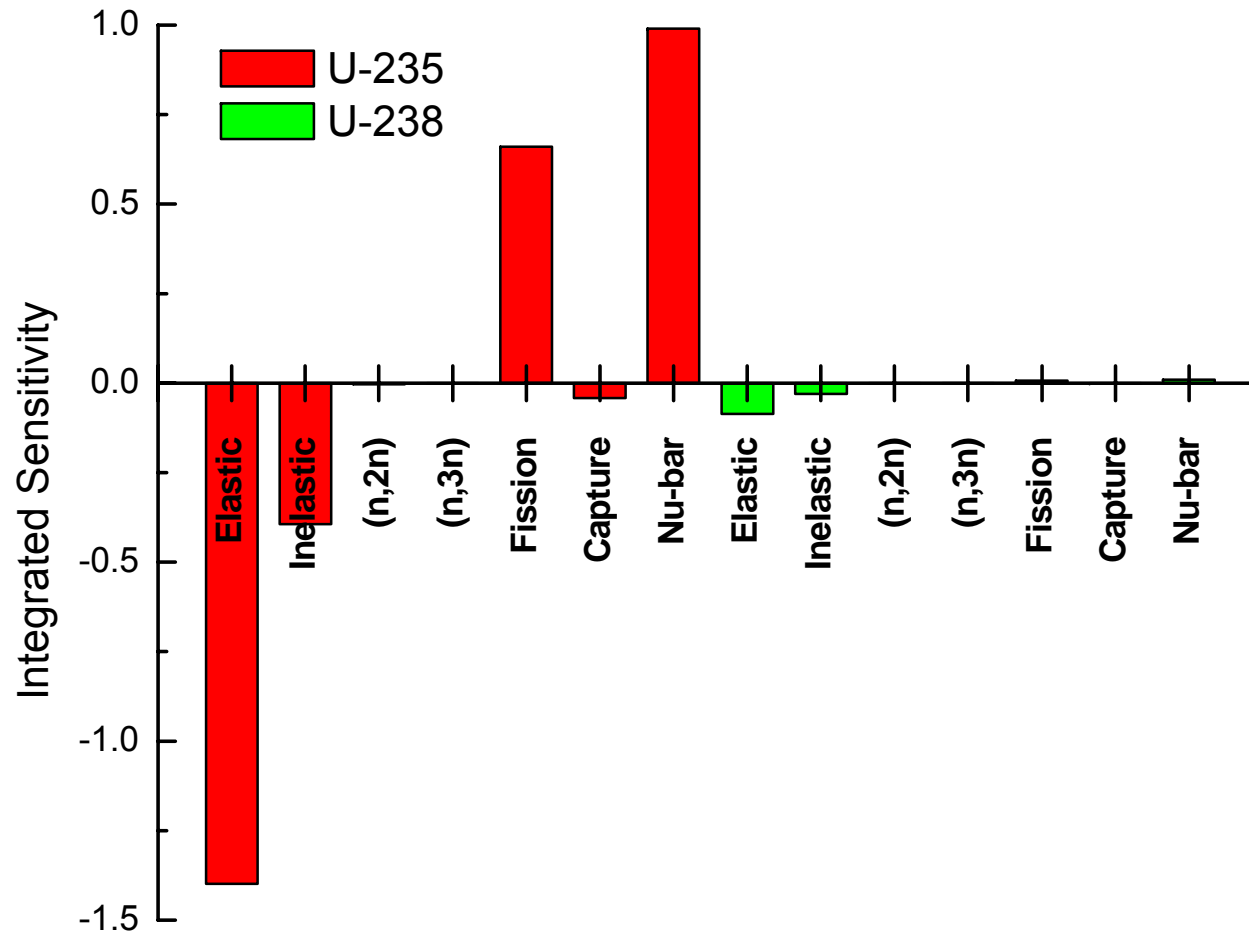


❖ Relative sensitivity of U-238 cross sections for GODIVA





❖ Integral sensitivity of U-235 and U-238 cross sections for GODIVA



❖ Relative uncertainty of k-eff. to U-235 and U-238 cross sections for GODIVA

	U-235							U-238						
	Elas.	Inel.	(n,2n)	(n,3n)	Fiss.	Capt.	Nu-bar	Elas.	Inel.	(n,2n)	(n,3n)	Fiss.	Capt.	Nu-bar
Elas.	1.6E-03	-1.4E-03	-1.9E-08		1.5E-06	-2.6E-06						1.0E-08		
Inel.	-1.4E-03	1.5E-03												
(n,2n)	-1.9E-08		2.0E-08											
(n,3n)														
Fiss.	1.5E-06				2.9E-06			9.5E-09				4.1E-08		
Capt.	-2.6E-06					2.6E-06								
Nu-bar							2.2E-06							
Elas.					9.5E-09			2.5E-06	-2.3E-06	-1.3E-11		2.0E-10	7.9E-11	
Inel.								-2.3E-06	2.3E-06					
(n,2n)								-1.3E-11		1.4E-11				
(n,3n)														
Fiss.	1.0E-08				4.1E-08			2.0E-10				4.3E-10	1.5E-20	
Capt.								7.9E-11				1.5E-20	1.5E-09	
Nu-bar														3.3E-09

$$k_{\text{eff.}} = 1.00448$$

Relative Standard Deviation = 1.2828%

4. Results and summary

Benchmark Cores	k_{eff}	Uncertainty (%)	Used Covariance Data (JENDL-3.3)
GODIVA	1.00448	1.283	U-235, U-238
VNIIEF's CTF	0.99886	1.858	U-235, U-238
Pu-239 JEZEBEL	0.99559	0.546	Pu-239, Pu-240, Pu-241
Pu-240 JEZEBEL	0.99886	0.534	Pu-239, Pu-240, Pu-241
U-233 JEZEBEL	1.00509	1.065	U-233, U-235, U-238

-
- ✓ Uncertainties in nuclear data play an important role in determining the uncertainties in integral parameters for nuclear analyses.
 - ✓ The error estimation for calculated quantities relies on **nuclear data uncertainty information available in basic nuclear data libraries** such as ENDF/B, JENDL, JEFF files.
 - ✓ Available covariance data in ENDF are very limited.