WPEC Subgroup 33 Benchmark Results

November 29, 2012
Nuclear Energy Agency
Issy-les-Moulineaux, France

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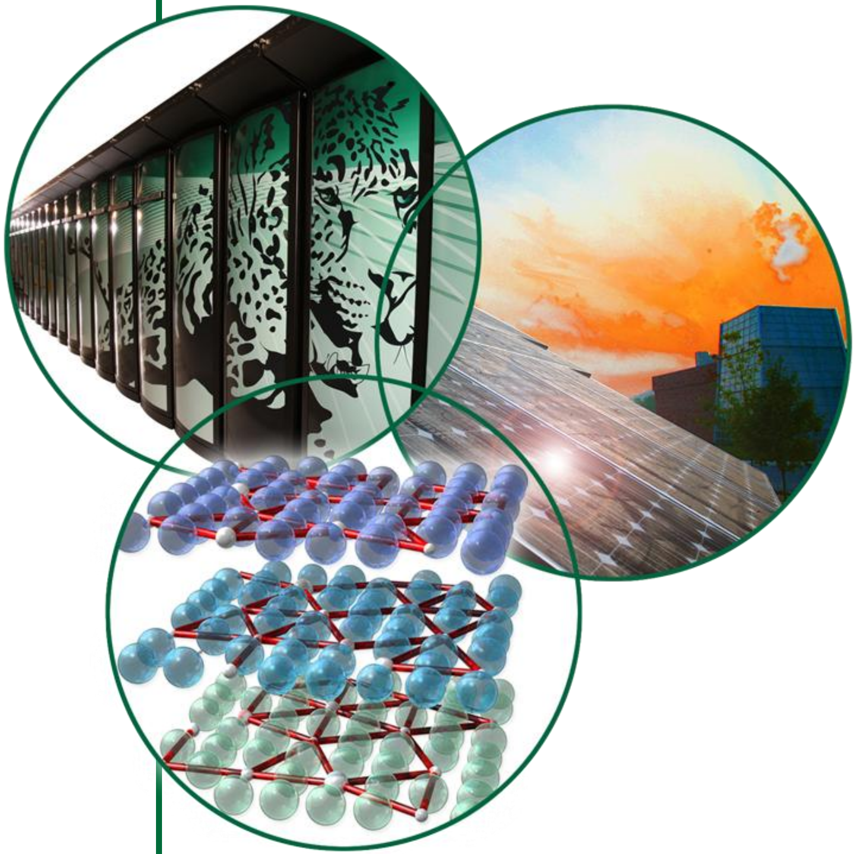

U.S. DEPARTMENT OF ENERGY

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Introduction

- **Sensitivity coefficients were calculated for the eigenvalue and several spectral index responses using the TSUNAMI-1D code, and were used to guide the TSURFER adjustment of cross-section data.**
- **Because TSUNAMI-1D uses the one-dimensional XSDRNPM code to solve the forward, adjoint, and generalized-adjoint transport equations, the scope of this analysis was limited to the one-dimensional benchmark cases (JEZEBEL239, JEZEBEL240, and FLATTOP-PU).**
- **The development of a 2D (R–Z) or 3D generalized perturbation tool would allow TSUNAMI to analyze all cases in this benchmark study.**
- **Additionally, mu-bar sensitivity calculations were not performed because ORNL has no mu-bar covariance data.**

Methodology

- **The Sensitivity Data Files (SDFs) generated from TSUNAMI-1D calculations were passed to the TSURFER code, which used them to guide the cross-section adjustment in this study.**
  - **TSURFER uses a Generalized Linear Least Squares (GLLS) approach to adjust cross-section data and minimize the difference between the experimental and application responses.**

$$\chi^2 = \underbrace{\sum_{\alpha}^{N}\left(\frac{\alpha' - \alpha}{\sigma_\alpha}\right)^2}_{\text{data adjustments in units of variance}} + \underbrace{\sum_{k}^{M}\left(\frac{k' - k}{\sigma_k}\right)^2}_{\text{measurement adjustments in units of variance}} \quad \text{(no correlations)}$$

  - **TSURFER filters the experimental and application cases and identifies outlier cases which are ignored during the data adjustment process. The Delta-Chi-Square filtering method was used in this study.**

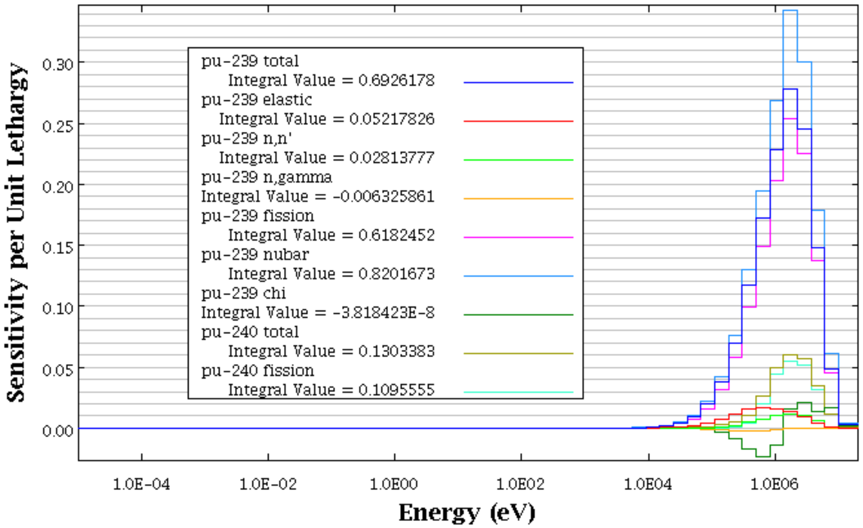
- **All calculations used ORNL ENDF/B-VII 238-group cross-section data and ENDF/B-V 44-group covariance data. The ANGELO code was used to collapse the 44-group data into the SG33 33-group structure.**

Sensitivity Coefficient Results

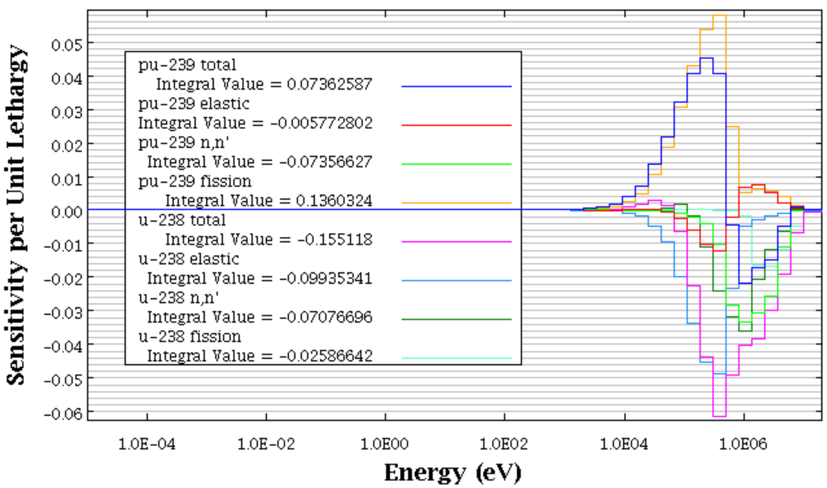
Experimental Responses of Interest

Experiment	Responses
Jezebel-Pu239	k_{eff}
	F28/F25
	F49/F25
	F37/F25
Jezebel-Pu240	k_{eff}
Flattop	k_{eff}
	F28/F25
	F37/F25

- k_{eff} = System Eigenvalue
- F25 = U-235 Fission Reaction Rate
- F28 = U-238 Fission Reaction Rate
- F37 = Np-237 Fission Reaction Rate
- F49 = Pu-239 Fission Reaction Rate



Sample Jezebel-Pu240 k_{eff} sensitivities



Sample Flattop F37/F25 sensitivities

Sensitivity Coefficient Validation

- **Direct perturbation (DP) calculations were used to verify the k_{eff} and GPT nuclide total sensitivity coefficients.**

Jezebel-Pu240 k_{eff} Sensitivity Verification Results

Nuclide	DP Sensitivity	Tsunami-1D Sensitivity	Difference
Pu-239	6.932E-01	6.926E-01	-0.08%
Pu-240	1.315E-01	1.303E-01	-0.91%
Pu-241	2.576E-02	2.586E-02	0.38%
Pu-242	2.250E-03	2.230E-03	-0.90%
Ga	3.367E-03	3.364E-03	-0.11%

Flattop F37/F25 Sensitivity Verification Results

Nuclide	DP Sensitivity	Tsunami-1D Sensitivity	Difference (%)
Pu-239	6.783E-02	7.235E-02	6.65%
Pu-240	-1.410E-03	-2.293E-03	62.59%
Pu-241	1.735E-04	2.063E-04	18.94%
Ga	-1.526E-03	-1.581E-03	3.58%
U-234	-1.652E-05	-1.408E-05	-14.80%
U-235	-3.4871E-03	-3.6803E-03	5.54%
U-238	-1.5245E-01	-1.5424E-01	1.17%

- **In general the TSUNAMI-1D sensitivity coefficients were found to agree well with the reference sensitivity coefficients, although some differences were observed for the smaller sensitivity coefficients.**

TSURFER Data Adjustment Results

Initial, Experimental, and Adjusted Response Values

Experiment	Response	Calc. Value	Exp. Value	Adj. Value
Jezebel-Pu239	k_{eff}	1.0000	1.0000	0.9996
	F28/F25	0.2086	0.2133	0.2134
	F49/F25	1.4243	1.4609	1.4403
	F37/F25	0.9714	0.9835	0.9779
Jezebel-Pu240	k_{eff}	1.0008	1.0000	1.0004
Flattop	k_{eff}	1.0026	1.0000	1.0000
	F28/F25	0.1746	0.1799	0.1787
	F37/F25	0.8477	0.8561	0.8544

Initial and Adjusted C/E Values

Experiment	Response	Initial C/E	Adjusted C/E
Jezebel-Pu239	k_{eff}	1.0000	0.9996
	F28/F25	0.9782	1.0004
	F49/F25	0.9749	0.9859
	F37/F25	0.9877	0.9943
Jezebel-Pu240	k_{eff}	1.0008	1.0004
Flattop	k_{eff}	1.0026	1.0000
	F28/F25	0.9706	0.9932
	F37/F25	0.9902	0.9980
Average C/E		0.9881	0.9965

- **The TSURFER data adjustment produced an adjusted set of nuclear data that improved the accuracy of nearly all of the response parameters.**

Effect of the Nuclear Data Adjustment on the Response Uncertainties

- **The GLLS data adjustment process significantly reduced the amount of uncertainty in the calculated responses.**

Exp.	Resp.	Exp. Unc.	Calc. Unc.	Adj. Unc.	Unc. Reduct.
Jezebel-Pu239	k_{eff}	0.20%	1.19%	0.17%	85.27%
	F28/F25	1.10%	3.31%	0.82%	75.16%
	F49/F25	0.90%	0.81%	0.51%	36.77%
	F37/F25	1.40%	7.20%	1.00%	86.12%
Jezebel-Pu240	k_{eff}	0.20%	0.98%	0.17%	82.64%
Flattop	k_{eff}	0.30%	1.13%	0.28%	75.09%
	F28/F25	1.10%	2.62%	0.73%	71.97%
	F37/F25	1.40%	7.08%	0.99%	85.97%

Correlation Matrix Comparison

- **The data adjustment was successful in reducing the amount of shared uncertainty between the calculated responses.**

Initial Application Response Correlation Matrix

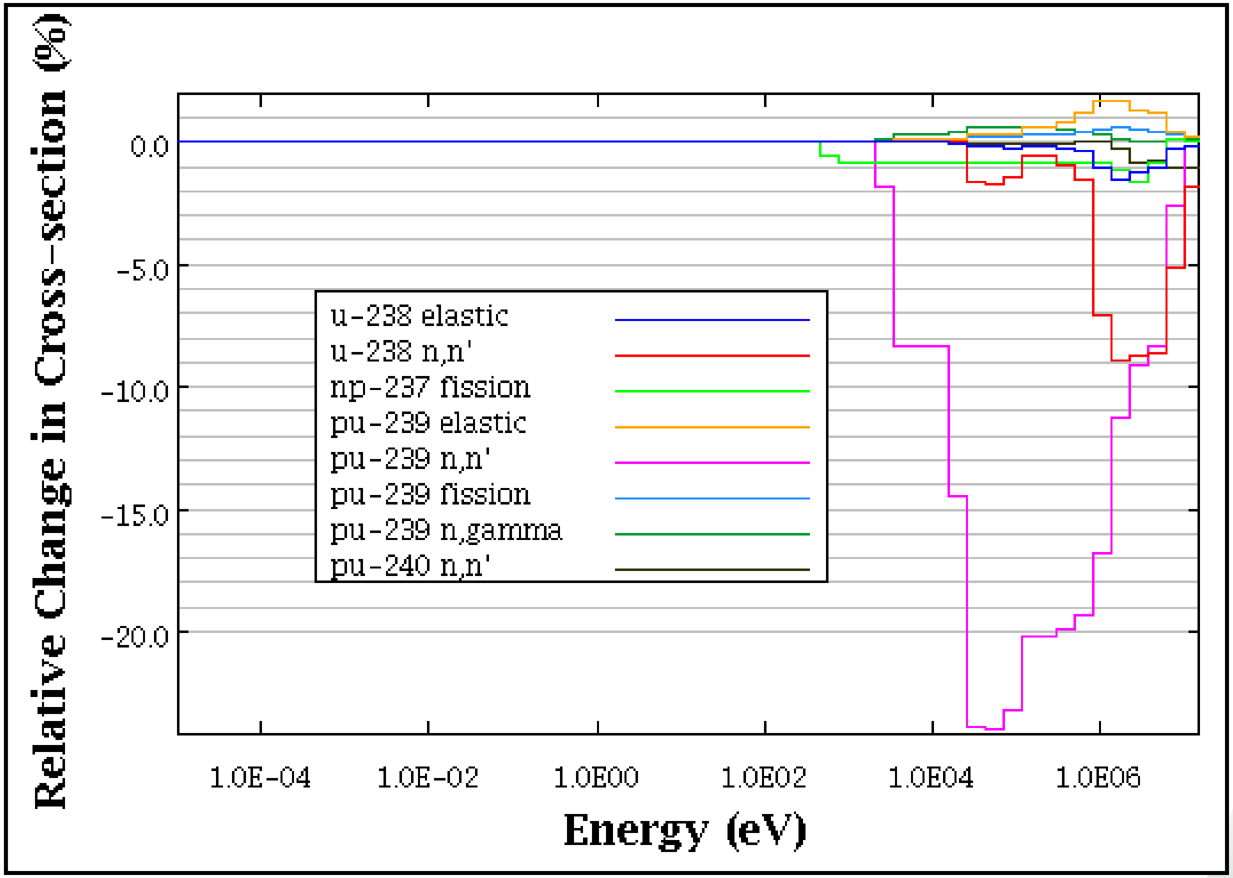
	Model	Response	1	2	3	4	5	6	7	8
1	JEZEBEL239	keff	1000	-730	-294	-234	954	524	-628	-170
2	JEZEBEL239	F28/F25	-730	1000	646	301	-641	-258	922	230
3	JEZEBEL239	F49/F25	-294	646	1000	223	-235	-26	620	184
4	JEZEBEL239	F37/F25	-234	301	223	1000	-206	-87	275	991
5	JEZEBEL240	keff	954	-641	-235	-206	1000	519	-546	-149
6	FLATTOP-PU	keff	524	-258	-26	-87	519	1000	-508	-142
7	FLATTOP-PU	F28/F25	-628	922	620	275	-546	-508	1000	251
8	FLATTOP-PU	F37/F25	-170	230	184	991	-149	-142	251	1000

Adjusted Application Response Correlation Matrix

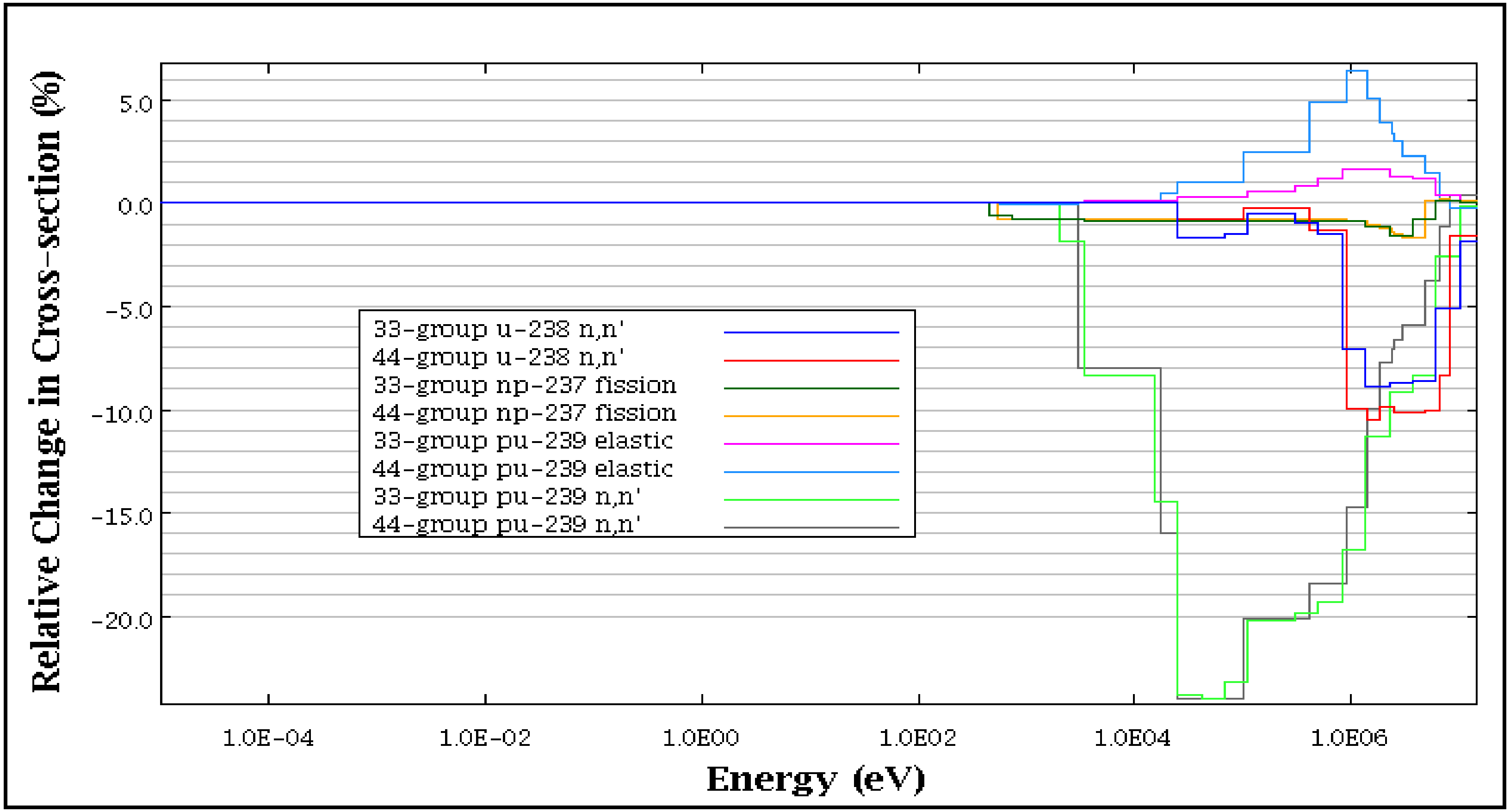
	Model	Response	1	2	3	4	5	6	7	8
1	JEZEBEL239	keff	1000	-169	6	-65	286	41	29	44
2	JEZEBEL239	F28/F25	-169	1000	321	280	7	154	825	142
3	JEZEBEL239	F49/F25	6	321	1000	192	7	73	311	168
4	JEZEBEL239	F37/F25	-65	280	192	1000	-5	95	178	923
5	JEZEBEL240	keff	286	7	7	-5	1000	24	54	20
6	FLATTOP-PU	keff	41	154	73	95	24	1000	-209	-103
7	FLATTOP-PU	F28/F25	29	825	311	178	54	-209	1000	256
8	FLATTOP-PU	F37/F25	44	142	168	923	20	-103	256	1000

TSURFER Data Adjustment Results

- **The largest cross-section adjustments were observed for the Pu-239 and U-238 inelastic reactions.**
- **The predicted adjustments for the fission and absorption reactions were relatively small compared to other adjustments.**

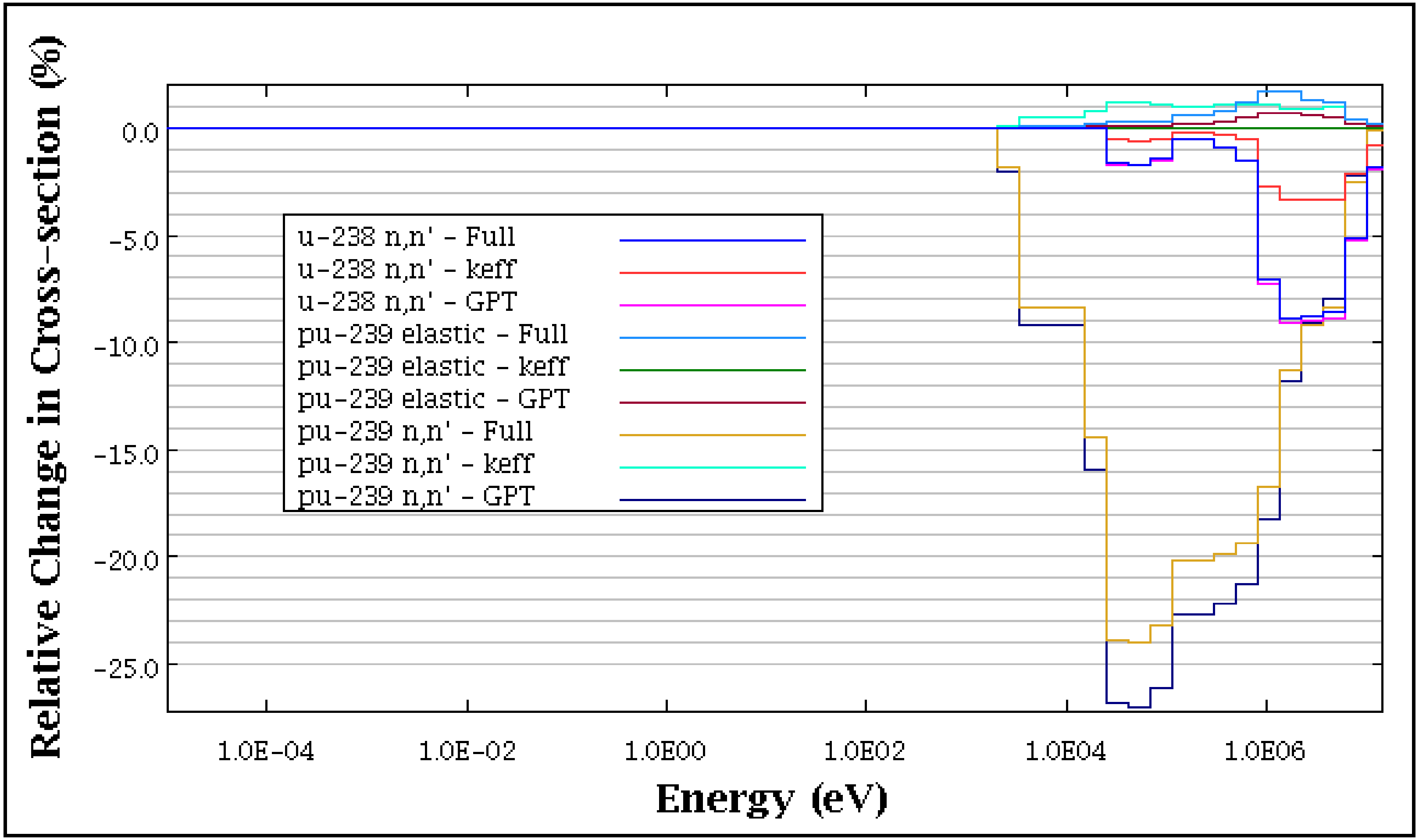


33-group VS 44-group Data Adjustments



- **The 33-group and 44-group adjustments agree on general trends for the cross-section adjustments, but disagree significantly on the magnitude of some adjustments.**

The Importance of the GPT Analysis



- **The TSURFER cross-section adjustments are strongly influenced by k_{eff} and GPT responses.**

Conclusions

- The TSUNAMI methodology for nuclear data adjustment has been applied to several problems within the scope of the WPEC Subgroup 33 mission. The TSUNAMI-1D code calculated sensitivity coefficients for the test problems, and these sensitivity coefficients were used by the TSURFER code to adjust the nuclear data to minimize the difference between the calculated and experimental responses of interest.
- The ^{239}Pu and ^{238}U inelastic cross sections were affected the most by this adjustment.
- Future work includes developing a generalized perturbation capability in TSUNAMI-3D and expanding the scope of this study to span many other systems, including several challenge problems with C/E values that are not close to unity.

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