

# ANL Results of Cross Section Adjustment Including Fission Spectrum and Mubar

G. Aliberti and R.D. McKnight  
Nuclear Engineering Division  
Argonne National Laboratory

## *Introduction*

According to the specifications of the cross section adjustment exercise proposed by the OECD NEA Subgroup 33, sensitivities for selected integral parameters have to be calculated with respect to the prompt fission spectrum ( $\chi_p$ ) and the average cosine of the elastic scattering angle ( $\bar{\mu}_s$ ) in addition to the elastic, inelastic, capture,  $\nu$  and fission reactions.

➤ Procedures have been developed with the deterministic ERANOS code system to calculate the sensitivities of all integral parameters of interest for the Subgroup 33 studies also with respect to fission spectrum and  $\bar{\mu}_s$  that were omitted in the past calculations.

➤ A new cross section adjustment has been performed by taking into account these additional parameters.



## *Methodologies for Sensitivities Analysis*

Two main methodologies to evaluate sensitivities of a parameter  $R$  with respect to  $\sigma$ : 
$$S_j = \frac{\partial R}{R} \bigg/ \frac{\partial \sigma_j}{\sigma_j}$$

↪ The forward (direct) method: the sensitivity coefficients of an integral parameter  $R$  with respect to a cross section  $\sigma$  are determined via a direct perturbation calculation, i.e. as the variation of the integral parameter value due to a constant perturbation of  $\sigma$  for each isotope and energy group.

↪ The adjoint method: the sensitivity coefficients are evaluated without solving the perturbed system equations with the use of adjoint (importance) functions.

↪ Classical Perturbation Theory, where the importance is the adjoint function, is widely used in neutronics to calculate the sensitivities of the **fundamental eigenvalue**.

↪ Generalized Perturbation Theory (GPT) is commonly used for the sensitivity analysis of a wide range of integral parameters that in the most general formulation are bilinear functional of the direct and adjoint fluxes (e.g.,  $\beta_{\text{eff}}$ ,  $\Lambda_{\text{eff}}$ , etc.). The same approach is used if the integral parameter is a functional of the direct flux only (e.g. Rate Ratios, Power, etc.). A generalized importance is calculated for each output parameter of interest by solving an inhomogeneous adjoint neutron transport equation that contains a source term depending on the specific output parameter.



**Classical Perturbation Theory (CPT) for Sensitivity Analysis**

Sensitivity coefficients for the multiplication factor:

$$S_k = \frac{\sigma}{k} \frac{\partial k}{\partial \sigma} = - \frac{k\sigma}{\langle \Phi^*, F\Phi \rangle} \left\langle \Phi^*, \left( \frac{\partial A}{\partial \sigma} - \frac{1}{k} \frac{\partial F}{\partial \sigma} \right) \Phi \right\rangle$$

$\sigma = \chi$  ↓

$$S_{k_\chi} = \frac{\chi}{k} \frac{\partial k}{\partial \chi} = - \frac{\chi}{\langle \Phi^*, F\Phi \rangle} \left\langle \Phi^*, \frac{\partial F}{\partial \chi} \Phi \right\rangle$$

NT

- ⟨a, b⟩ = ∫∫ (ab) dVdE
- A: loss operator (absorption + leakage);
- F: fission production operator;
- k: multiplication factor;
- Φ: direct flux;
- Φ\*: adjoint flux;

**Equivalent Generalized Perturbation Theory (EGPT) for Sensitivity Analysis**

Reactivity coefficients (as coolant void worth) are obtained as the reactivity change of a perturbed system from an unperturbed, reference system:  $\Delta\rho = \rho' - \rho = 1/k - 1/k'$

Thus, for reactivity coefficients the sensitivity coefficients can be obtained by combining the  $k_{\text{eff}}$  sensitivity relative to the two states:

$$S_{\Delta\rho_\chi} = \frac{\chi}{\Delta\rho} \frac{\partial \Delta\rho}{\partial \chi} = \frac{\chi}{\Delta\rho} \left( \frac{1}{k'^2} \frac{\partial k'}{\partial \chi} - \frac{1}{k^2} \frac{\partial k}{\partial \chi} \right) = \frac{1}{\Delta\rho} \left( \frac{S_{k'_\chi}}{k'} - \frac{S_{k_\chi}}{k} \right)$$



## Generalized Perturbation Theory (GPT) for Sensitivity Analysis

For a reaction rate ratio:

$$R = \langle \Sigma_n \Phi \rangle / \langle \Sigma_d \Phi \rangle$$

fission spectrum sensitivities are obtained as:

$$S_R = \frac{\sigma}{R} \frac{dR}{d\sigma} = \frac{\sigma}{R} \left\langle \Gamma^*, \left( \frac{\partial A}{\partial \sigma} - \frac{1}{k} \frac{\partial F}{\partial \sigma} \right) \Phi \right\rangle \quad \xrightarrow{\sigma = \chi} \quad S_{R_\chi} = \frac{\chi}{R} \frac{\partial R}{\partial \chi} = \frac{\chi}{R} \left\langle \Gamma^*, \frac{1}{k} \frac{\partial F}{\partial \chi} \Phi \right\rangle$$

where the cross sections  $\Sigma_n$  and  $\Sigma_d$  can be either microscopic or macroscopic, the rate  $\langle \Sigma \Phi \rangle$  can be either integrated or in a given point and  $\Gamma^*$  is the generalized importance function, which is the solution of the following generalized adjoint equation:

$$\left( A^* - \frac{F^*}{k} \right) \Gamma^* = \frac{\partial R}{\partial \Phi} = \left[ \frac{\Sigma_n}{\langle \Sigma_d \Phi \rangle} - \frac{\Sigma_d \langle \Sigma_n \Phi \rangle}{\langle \Sigma_d \Phi \rangle^2} \right]$$



## *Sensitivity Analysis with Respect to the Average Cosine of the Elastic Scattering Angle*

In  $P_n$  transport approximation, the elastic scattering cross section is typically expanded as a Legendre polynomial of the cosine of scattering angle:

$$\Sigma_s(\mu_s, E) = \sum_{n=0}^{\infty} \frac{2n+1}{2} \Sigma_{s,n}(E) P_n(\mu_s)$$

where  $\mu$  is the cosine of the scattered angle,  $E$  is the energy of the incident neutron and  $\Sigma_{s,n}$  is the  $n$ -th Legendre polynomial coefficient,

$$\Sigma_{s,n}(E) = \int_{-1}^1 d\mu_s P_n(\mu_s) \Sigma_s(\mu_s, E)$$

In  $P_1$  approximation, the series is truncated by the first order term and the  $P_1$  component is represented by the product of the  $P_0$  component and the average cosine of scattering angle,

$$\Sigma_{s,1} = \bar{\mu}_s \Sigma_{s,0}$$



## *Sensitivity Analysis with Respect to the Average Cosine of the Elastic Scattering Angle*

Sensitivity coefficients with respect to  $\bar{\mu}_s$  have been calculated by the direct method rather than the adjoint method as:

$$S_{P(\sigma)} \equiv \frac{\delta P}{P} \bigg/ \frac{\delta \sigma}{\sigma}$$

by varying the cross section  $\sigma$  one by one (i.e., for each isotope and energy group) by a fixed amount and solving the transport equation with perturbed cross section data.

With this direct method, the sensitivity coefficient with respect to  $\bar{\mu}_s$  was determined as the variation of the parameter value due to a constant perturbation of  $\bar{\mu}_s$  of each isotope. Specifically, for each energy group and each isotope, a constant variation of 10% was introduced in the elastic scattering cross sections  $\Sigma_{s,1}^{g \rightarrow g}$  and  $\Sigma_{s,1}^{g \rightarrow g+1}$ , since the down-scattering is limited to one group in the 33-group structure used in this study.



## *Benchmark Results*

- ↪ All investigated assemblies have been recalculated.
- ↪ The adopted mesh grid is consistent with the benchmark specifications.
- ↪ Calculations were performed in  $S_4P_1$  approximation with the BISTRO transport code of ERANOS, using 33-group cross-sections prepared with ECCO based on ENDF/B-VII.0 data.

## Benchmark Results: C/E

	Parameters	ANL S4P1 (ERANOS)	REF <sup>(a)</sup> S4 R. (ERANOS)	REF MC Detailed (Monte Carlo)	Corrective Factors	Experiment	ANL C/E	REF C/E
<b>FLATTOP Pu239</b>	<b>k<sub>eff</sub></b>	1.00093	0.99962	1.00097±18pcm	1.00135±100pcm	1.00000±300pcm	1.0023	1.0010
	<b>F28/F25</b>	0.1698	0.1715	0.1767±0.0013	1.0303±1%	0.1799±1.1%	0.9723	0.9822
	<b>F37/F25</b>	0.8411	0.8452	0.8523±0.0013	1.0084±1%	0.8561±1.4%	0.9907	0.9956
<b>JEZEBEL Pu239</b>	<b>k<sub>eff</sub></b>	1.00538	1.00538	0.99986±9pcm	0.99451±100pcm	1.00000±200pcm	0.9999	0.9999
	<b>F28/F25</b>	0.2010	0.2032	0.2084±0.0009	1.0256±1%	0.2133±1.1%	0.9663	0.9770
	<b>F37/F25</b>	0.9582	0.9620	0.9707±0.0013	1.0090±1%	0.9835±1.4%	0.9831	0.9870
	<b>F49/F25</b>	1.4207	1.4220	1.4248±0.0018	1.0020±1%	1.4609±0.9%	0.9744	0.9753
<b>JEZEBEL Pu240</b>	<b>k<sub>eff</sub></b>	1.00460	1.00459	0.99981±9pcm	0.99527±100pcm	1.00000±200pcm	0.9998	0.9998

<sup>(a)</sup> REF: Values provided with the benchmark specifications



## Benchmark Results: C/E

	Parameters	ANL S4P1 (ERANOS)	REF <sup>(a)</sup> S4 R-Z (ERANOS)	REF MC Detailed (Monte Carlo)	Corrective Factors	Experiment	ANL C/E	REF C/E
<b>ZPR-6/7</b>	<b>k<sub>eff</sub></b>	0.98875	0.98915	1.00094±7pcm	1.01192±100pcm	1.00051±230pcm	1.0000	1.0004
	<b>F49/F25</b>	0.9358	0.9232	0.9093±0.0065	0.9849±1.0%	0.9435±2.1%	0.9769	0.9638
	<b>F28/F25</b>	0.0218	0.0218	0.0224±0.0002	1.0275±1.0%	0.0223±3.0%	1.0064	1.0045
	<b>C28/F25</b>	0.1387	0.1387	0.1336±0.0008	0.9632±1.0%	0.1323±2.4%	1.0099	1.0098
<b>ZPR-6/7 Pu240</b>	<b>k<sub>eff</sub></b>	0.98762	0.98781	1.00017±11pcm	1.01251±100pcm	1.00080±220pcm	0.9992	0.9994
<b>JOYO</b>	<b>k<sub>eff</sub></b>	0.99859	1.00107	0.99851±9pcm	0.99744±100pcm	1.00105±180pcm	0.9950	0.9975
<b>ZPPR-9</b>	<b>k<sub>eff</sub></b>	0.98701	0.98809	1.00028±3pcm	1.01234±100pcm	1.00106±117pcm	0.9981	0.9992
	<b>Void Step3</b>	106 pcm	106 pcm	106±4pcm	1±4pcm	104 pcm ±1.9%	1.0221	1.0192
	<b>Void Step5</b>	141 pcm	141 pcm	109±4pcm	0.7730±4pcm	112 pcm ±1.9%	0.9718	0.9732
	<b>F28/F25</b>	0.01982	0.0198	0.0201±0.55%	1.0152±1.0%	0.0207±2.7%	0.9721	0.9710
	<b>F49/F25</b>	0.9264	0.9141	0.9048±0.37%	0.9898±1.0%	0.9225±2.0%	0.9940	0.9808
	<b>C28/F25</b>	0.1371	0.1371	0.1308±0.33%	0.9540±1.0%	0.1296±1.9%	1.0091	1.0093

<sup>(a)</sup> REF: Values provided with the benchmark specifications



## Benchmark Results: Uncertainties

Parameter Calculated Values and Total Uncertainties Using the COMMARA-2.0\* Covariance Matrix

Parameter		Calculated value	Uncertainties							
			Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
FLATTOP Pu239	k <sub>eff</sub>	1.00093	0.44i	0.79	0.13	0.00	0.29	0.14	0.16	0.76
	F28/F25	0.1698	0.51i	2.40	0.17	0.00	0.66	0.06	1.93	3.11
	F37/F25	0.8411	0.21i	1.82	0.15	0.00	0.42	0.04	0.85	2.04
JEZEBEL Pu239	k <sub>eff</sub>	1.00538	0.42i	0.64	0.08	0.00	0.35	0.11	0.16	0.64
	F28/F25	0.2010	0.90i	3.19	0.10	0.00	0.67	0.00	2.00	3.71
	F37/F25	0.9582	0.59i	2.23	0.08	0.00	0.41	0.00	0.90	2.37
	F49/F25	1.4207	0.13i	0.51	0.02	0.00	0.63	0.00	0.19	0.83
JEZEBEL Pu240	k <sub>eff</sub>	1.00460	0.32i	0.47	0.11	0.00	0.35	0.37	0.21	0.66
ZPR6/7	k <sub>eff</sub>	0.98875	0.26	0.71	0.49	0.07	0.24	0.18	0.19	0.96
	F49/F25	0.9358	0.24	0.46	0.16	0.01	0.59	0.00	0.08	0.81
	F28/F25	0.0218	0.24i	6.10	0.75	0.04	0.67	0.01	1.70	6.40
	C28/F25	0.1387	0.76	0.56	1.21	0.02	0.43	0.00	0.10	1.59
ZPR6/7 Pu240	k <sub>eff</sub>	0.98762	0.27	0.71	0.48	0.07	0.23	0.19	0.18	0.97
JOYO	k <sub>eff</sub>	0.99859	0.36	0.01	0.76	0.19	0.17	0.15	0.05	0.89
ZPPR9	k <sub>eff</sub>	0.98701	0.23	0.98	0.49	0.06	0.24	0.20	0.22	1.18
	Void Step3	106 pcm	2.40	6.62	2.37	4.68	1.47	0.54	0.26	8.92
	Void Step5	141 pcm	2.59	8.57	3.15	4.23	1.99	0.78	0.41	10.62
	F28/F25	0.01982	0.54i	7.62	0.79	0.05	0.67	0.01	1.64	7.85
	F49/F25	0.9264	0.20	0.54	0.17	0.00	0.59	0.00	0.07	0.84
	C28/F25	0.1371	0.65	0.66	1.15	0.00	0.43	0.00	0.09	1.54

\* Chi data only for Pu238, Pu239 and Pu240; Mu-bar data only for Na23 and Fe56



## Benchmark Results: Uncertainties

### Parameter Calculated Values and Total Uncertainties Using the COMMARA-2.0\* Covariance Matrix

Parameter		Calculated value	Uncertainties							Total
			Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	
FBR	$k_{\text{eff}}$	1.05379	0.19	0.80	0.47	0.06	0.22	0.25	0.16	1.02
ABR Metal	$k_{\text{eff}}$	1.00443	0.33	0.79	0.36	0.15	0.26	0.18	0.20	1.01
ABR Oxide	$k_{\text{eff}}$	1.04245	0.22	0.61	0.49	0.09	0.24	0.17	0.18	0.88
ABR Oxide Recycled	$k_{\text{eff}}$	1.01549	0.20	0.78	0.41	0.09	0.25	0.32	0.20	1.02

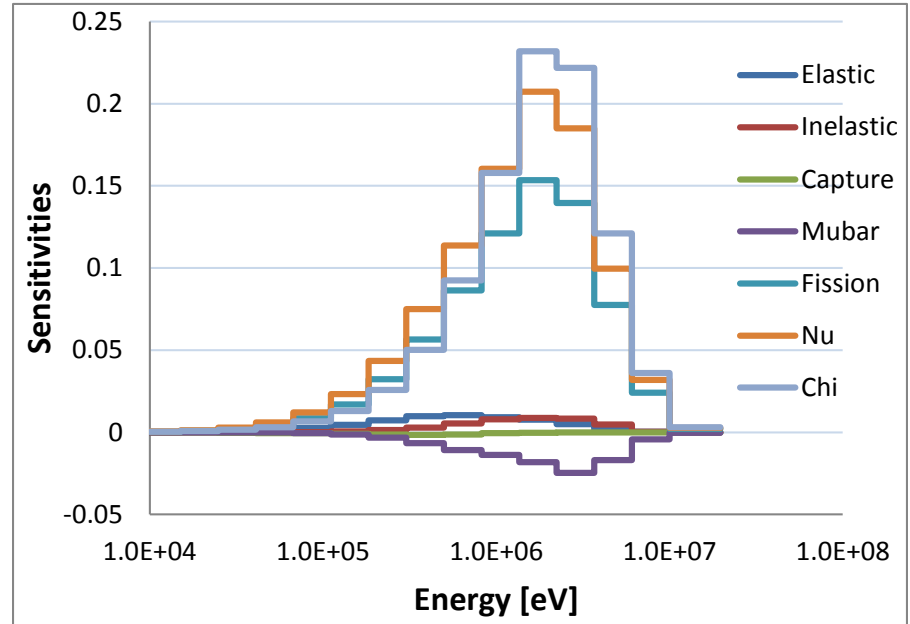
\* Chi data only for Pu238, Pu239 and Pu240; Mu-bar data only for Na23 and Fe56



JEZEBEL Pu239  $k_{eff}$  Sensitivities to Mubar

Gr	eV	Pu239	Pu240	Pu241
1	1.964E+7	-0.00028	-0.00001	- (a)
2	1.000E+7	-0.00424	-0.00021	-0.00001
3	6.065E+6	-0.01690	-0.00081	-0.00005
4	3.679E+6	-0.02460	-0.00119	-0.00008
5	2.231E+6	-0.01814	-0.00095	-0.00007
6	1.353E+6	-0.01372	-0.00074	-0.00005
7	8.209E+5	-0.01079	-0.00051	-0.00003
8	4.979E+5	-0.00668	-0.00031	-0.00002
9	3.020E+5	-0.00324	-0.00014	-0.00001
10	1.832E+5	-0.00129	-0.00006	-
11	1.111E+5	-0.00046	-0.00002	-
12	6.738E+4	-0.00015	-0.00001	-
13	4.087E+4	-0.00004	-	-
14	2.479E+4	-0.00001	-	-
15	1.503E+4	-	-	-
16	9.119E+3	-	-	-
17	5.531E+3	-	-	-
18	3.355E+3	-	-	-
19	2.035E+3	-	-	-
20	1.234E+3	-	-	-
21	7.485E+2	-	-	-
22	4.540E+2	-	-	-
23	3.043E+2	-	-	-
24	1.486E+2	-	-	-
25	9.166E+1	-	-	-
26	6.790E+1	-	-	-
27	4.017E+1	-	-	-
28	2.260E+1	-	-	-
29	1.371E+1	-	-	-
30	8.315E+0	-	-	-
31	4.000E+0	-	-	-
32	5.400E-1	-	-	-
33	1.000E-1	-	-	-
Sum		-0.10056	-0.00497	-0.00035

*Analysis of Mubar Sensitivities and Uncertainties*



**Energy Profile of JEZEBEL Pu239  $k_{eff}$  Sensitivities due to Pu239 Reactions**

(a) Sensitivities  
<0.000005



**Sensitivities Coefficients for JEZEBEL Pu239 Multiplication Factor**

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>Pu239</b>	0.061	0.041	-0.008	-0.101	0.726	0.966	0.966	<b>2.652</b>
<b>Pu240</b>	0.003	0.002	-0.001	-0.005	0.024	0.031	0.031	<b>0.086</b>
<b>Pu241</b>	0.000	0.000	0.000	0.000	0.002	0.003	0.003	<b>0.008</b>
<b>Sum</b>	<b>0.065</b>	<b>0.043</b>	<b>-0.008</b>	<b>-0.106</b>	<b>0.752</b>	<b>1.000</b>	<b>1.000</b>	<b>2.745</b>

**Uncertainties for JEZEBEL Pu239 Multiplication Factor**

**Using Mu-bar 10% Relative Standard Deviations and**

**COMMARA-2.0 for all Other Reactions**

Isotope	Elastic	Inelastic	Capture	Mubar	Fission	Nu	Chi-p	Total
<b>Pu239</b>	0.42i	0.64	0.08	0.40	0.35	0.08	0.16	<b>0.75</b>
<b>Pu240</b>	0.03i	0.04	0.02	0.02	0.04	0.08	0.02	<b>0.10</b>
<b>Pu241</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>Total</b>	<b>0.42i</b>	<b>0.64</b>	<b>0.08</b>	<b>0.40</b>	<b>0.35</b>	<b>0.11</b>	<b>0.16</b>	<b>0.75</b>



Gr.	eV	O16	Na23	Cr52	Fe56	Ni58	U235	U238	Pu239	Pu240	Pu241
1	1.964E+7	-0.00001	- <sup>(a)</sup>	0.00001	-0.00002	0.00001	-	-0.00001	-	-	0.00001
2	1.000E+7	-0.00001	-0.00006	-0.00005	-0.00028	-0.00012	0.00003	-0.00043	-0.00004	0.00001	-0.00002
3	6.065E+6	-0.00039	0.00021	-0.00018	-0.00080	-0.00006	-0.00001	-0.00157	-0.00012	-0.00001	-
4	3.679E+6	-0.00034	-0.00078	-0.00026	-0.00048	-0.00008	-	-0.00248	-0.00020	-0.00004	-
5	2.231E+6	-0.00050	-0.00074	-0.00016	-0.00100	-0.00007	-0.00001	-0.00184	-0.00013	-0.00001	0.00001
6	1.353E+6	-0.00035	-0.00075	-0.00011	-0.00038	-0.00002	0.00003	-0.00128	-0.00010	-0.00003	-
7	8.209E+5	-0.00165	-0.00120	-0.00018	-0.00075	-0.00006	-	-0.00232	-0.00019	-0.00003	-
8	4.979E+5	-0.00084	-0.00016	-0.00008	-0.00016	-0.00002	-	-0.00115	-0.00010	-0.00001	-
9	3.020E+5	0.00024	-0.00016	-0.00006	-0.00016	-0.00003	-0.00001	-0.00111	-0.00009	-0.00002	-0.00001
10	1.832E+5	-0.00005	-0.00007	-0.00005	-0.00005	-0.00002	-	-0.00087	-0.00008	-0.00002	-0.00001
11	1.111E+5	-0.00068	-0.00005	-0.00003	-0.00007	-0.00001	-	-0.00037	-0.00004	-0.00001	-
12	6.738E+4	-0.00006	-0.00003	-0.00001	-0.00007	-0.00001	-	-0.00017	-0.00002	-	-0.00001
13	4.087E+4	-0.00001	-0.00001	-	-0.00005	-	0.00001	0.00017	-	0.00004	-
14	2.479E+4	-0.00004	-0.00002	0.00001	-0.00002	-0.00001	-	-0.00004	-	0.00001	-
15	1.503E+4	-0.00001	-	0.00001	-0.00001	-0.00001	-	0.00024	-0.00001	-	-
16	9.119E+3	-0.00001	-0.00001	-	-0.00001	-	-	-0.00001	-	-	0.00008
17	5.531E+3	-0.00001	-0.00001	-	-	-	0.00001	-0.00001	0.00001	-	-
18	3.355E+3	-	-	-	0.00001	-0.00002	0.00001	0.00001	-	0.00001	-
19	2.035E+3	-	-0.00001	-	-0.00001	-0.00001	0.00012	-0.00001	-	0.00001	0.00001
20	1.234E+3	-	0.00006	-	-	-	-0.00013	-	-	-	-
21	7.485E+2	-	-	-	-	-	-	-	-0.00001	-	-0.00001
22	4.540E+2	0.00001	-0.00054	-	0.00001	-0.00001	0.00001	0.00002	-0.00001	0.00001	0.00002
23	3.043E+2	-0.00001	0.00001	0.00001	-0.00001	-	-	-	0.00001	-	-0.00001
24	1.486E+2	-	0.00001	-0.00001	-	-	0.00001	-	-	-	-
25	9.166E+1	-	0.00002	-	-	0.00001	-0.00001	-	-	0.00001	0.00001
26	6.790E+1	-	-0.00001	-	-	-	-	-0.00001	0.00001	0.00001	-0.00001
27	4.017E+1	-	0.00058	-0.00001	-0.00001	-0.00001	-0.00001	-	0.00003	-0.00032	-
28	2.260E+1	-0.00001	-	-	0.00001	-	-0.00001	-	0.00017	-	0.00001
29	1.371E+1	-	-	-0.00001	-	-	-	-	-0.00001	0.00002	-0.00001
30	8.315E+0	-	-	0.00001	-	-	-0.00001	-	-	-0.00001	0.00004
31	4.000E+0	-	-0.00003	-	-	0.00001	-0.00001	0.00001	0.00001	-	-0.00010
32	5.400E-1	-	-	-	-	0.00001	-	0.00001	0.00001	-0.00001	-
33	1.000E-1	-	-	0.00001	-	-	-	-0.00006	-	-	-
Sum		-0.00476	-0.00373	-0.00116	-0.00431	-0.00055	0.00002	-0.01329	-0.00093	-0.00043	0.00001

## Analysis of Mubar Sensitivities and Uncertainties

<sup>(a)</sup> Sensitivities  
<0.000005

**Sensitivities Coefficients for ZPPR-9 Multiplication Factor**

<b>Isotope</b>	<b>Elastic</b>	<b>Inelastic</b>	<b>Capture</b>	<b>Mu-bar</b>	<b>Fission</b>	<b>Nu</b>	<b>Chi-p</b>	<b>Sum</b>
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	-0.014	0.000	-0.002	-0.005	0.000	0.000	0.000	<b>-0.022</b>
<b>Na23</b>	0.004	-0.008	-0.002	-0.004	0.000	0.000	0.000	<b>-0.010</b>
<b>Cr52</b>	0.002	-0.004	-0.002	-0.001	0.000	0.000	0.000	<b>-0.005</b>
<b>Fe56</b>	0.011	-0.018	-0.012	-0.004	0.000	0.000	0.000	<b>-0.023</b>
<b>Ni58</b>	0.002	-0.001	-0.004	-0.001	0.000	0.000	0.000	<b>-0.004</b>
<b>U235</b>	0.000	0.000	-0.001	0.000	0.010	0.015	0.015	<b>0.038</b>
<b>U238</b>	0.027	-0.060	-0.268	-0.013	0.091	0.147	0.145	<b>0.068</b>
<b>Pu239</b>	0.002	-0.004	-0.062	-0.001	0.581	0.801	0.802	<b>2.119</b>
<b>Pu240</b>	0.000	0.000	-0.008	0.000	0.015	0.022	0.022	<b>0.051</b>
<b>Pu241</b>	0.000	0.000	-0.001	0.000	0.010	0.014	0.014	<b>0.038</b>
<b>Sum</b>	<b>0.035</b>	<b>-0.096</b>	<b>-0.363</b>	<b>-0.029</b>	<b>0.708</b>	<b>0.998</b>	<b>0.998</b>	<b>2.251</b>



**Uncertainties for ZPPR-9 Multiplication Factor. Mu-bar Data from COMMARA-2.0 for Fe56 and Na23;**

**Mu-bar 10% Relative Standard Deviations for Other Isotopes**

<b>Isotope</b>	<b>Elastic</b>	<b>Inelastic</b>	<b>Capture</b>	<b>Mubar</b>	<b>Fission</b>	<b>Nu</b>	<b>Chi-p</b>	<b>Total</b>
<b>O16</b>	0.03	0.00	0.11	0.02	0.00	0.00	0.00	0.12
<b>Na23</b>	0.02	0.08	0.00	0.06	0.00	0.00	0.00	0.10
<b>Cr52</b>	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.03
<b>Fe56</b>	0.06	0.11	0.09	0.02	0.00	0.00	0.00	0.16
<b>Ni58</b>	0.01	0.01	0.03	0.00	0.00	0.00	0.00	0.03
<b>U235</b>	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02
<b>U238</b>	0.22	0.96	0.37	0.05	0.05	0.17	0.00	1.07
<b>Pu239</b>	0.03	0.08	0.29	0.00	0.23	0.07	0.22	0.44
<b>Pu240</b>	0.00	0.01	0.05	0.00	0.04	0.07	0.02	0.09
<b>Pu241</b>	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01
<b>Total</b>	0.23	0.98	0.49	0.08	0.24	0.20	0.22	1.18



## *Cross Section Adjustment*

### **Computational Methods and Data**

- Generalized least square fitting code GMADJ of ANL has been used
  - Cross section data: ENDF/B-VII.0
  - Covariance data: 33-group COMMARA-2.0 –  $\chi_p$  only for Pu239 and Pu240; Mubar only for Na23 and Fe56.
  - 20 experiments were used
    - 33-group sensitivity coefficients calculated with ERANOS (transport theory) based on ENDF/B-VII.0 data
    - Calculated values provided by INL
  - 1266 group constants were considered
    - Isotopes: U235, U238, Pu239, Pu240, Pu241, Fe56, Cr52, Ni58, O16, Na23, B10
    - Reactions: capture ((n, $\alpha$ ) for B-10), fission, prompt fission spectrum, total nu, elastic scattering, inelastic scattering and mubar



Adjustment without Experiment Correlations

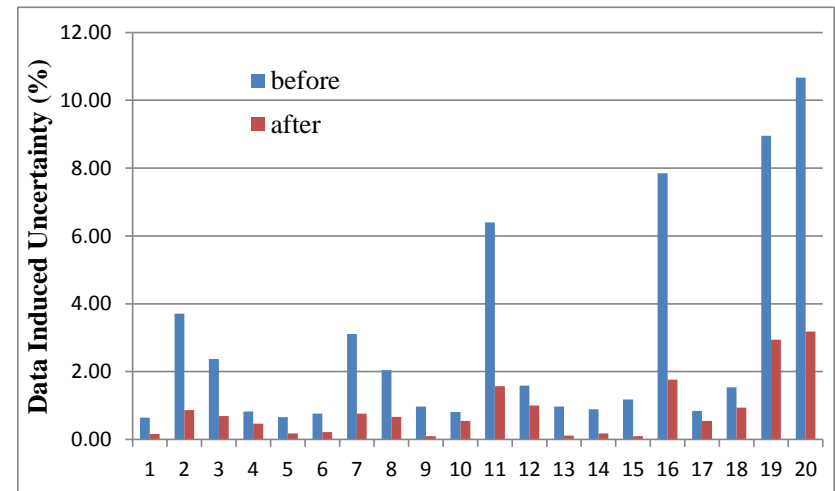
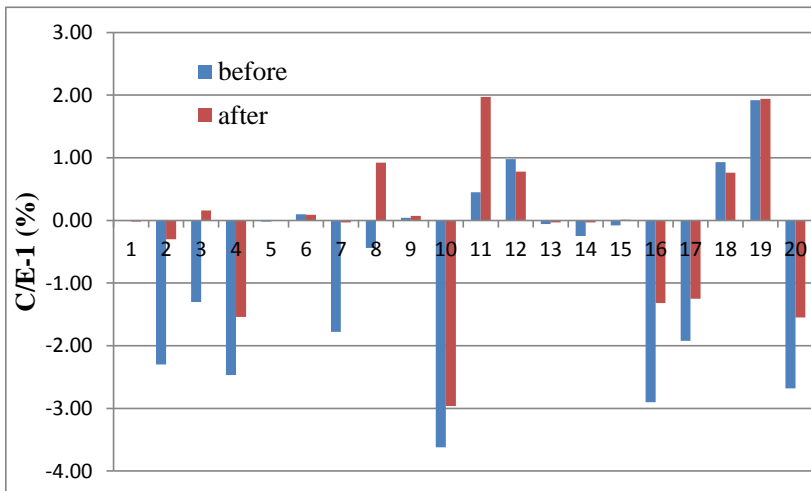
Reactor	Parameter	C/E-1 (%)		Data Uncertainty (%)		Experiment Uncertainty (%)
		before	after	before	after	
JEZEBEL Pu239	$k_{\text{eff}}$	-0.01	-0.02	0.64	0.16	0.20
	F28/F25	-2.30	-0.30	3.71	0.87	1.18
	F37/F25	-1.30	0.16	2.37	0.69	1.41
	F49/F25	-2.47	-1.54	0.83	0.47	0.91
JEZEBEL Pu240	$k_{\text{eff}}$	-0.02	0.00	0.66	0.18	0.20
FLATTOP Pu239	$k_{\text{eff}}$	0.10	0.09	0.76	0.22	0.30
	F28/F25	-1.78	-0.03	3.11	0.76	1.33
	F37/F25	-0.44	0.92	2.04	0.67	1.41
ZPR6/7	$k_{\text{eff}}$	0.04	0.07	0.97	0.10	0.23
	F49/F25	-3.62	-2.96	0.81	0.55	2.22
	F28/F25	0.45	1.97	6.40	1.57	3.13
	C28/F25	0.98	0.78	1.59	1.00	2.47
ZPR6/7 Pu240	$k_{\text{eff}}$	-0.06	-0.03	0.97	0.11	0.22
JOYO	$k_{\text{eff}}$	-0.25	-0.03	0.89	0.18	0.18
ZPPR9	$k_{\text{eff}}$	-0.08	0.01	1.18	0.10	0.12
	F28/F25	-2.90	-1.32	7.85	1.76	2.76
	F49/F25	-1.92	-1.25	0.84	0.55	2.03
	C28/F25	0.93	0.76	1.54	0.94	1.93
	Void Step3	1.92	1.94	8.95	2.94	4.22
	Void Step5	-2.68	-1.55	10.67	3.18	4.13



## Adjustment without Experiment Correlations

- C/E values are improved for 15 cases among 20 experiments
  - Non-negligible deterioration for 2 cases
- Estimated parameter uncertainty due to data uncertainties is reduced significantly for all 20 cases

		before	after
C/E	RMS error (%)	2.73	1.33
	Outside of $1\sigma_e$	5	2
	Outside of $2\sigma_e$	1	0
RMS of data induced uncertainty (%)		17.11	1.47



Adjustment with Experiment Correlations

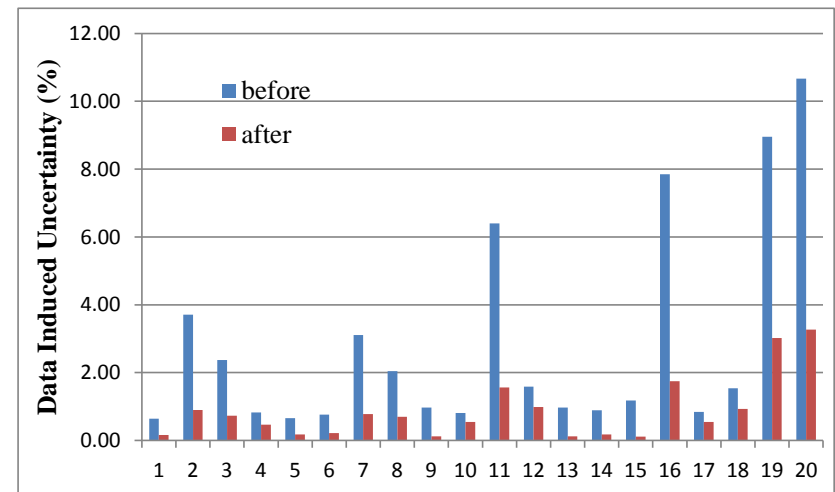
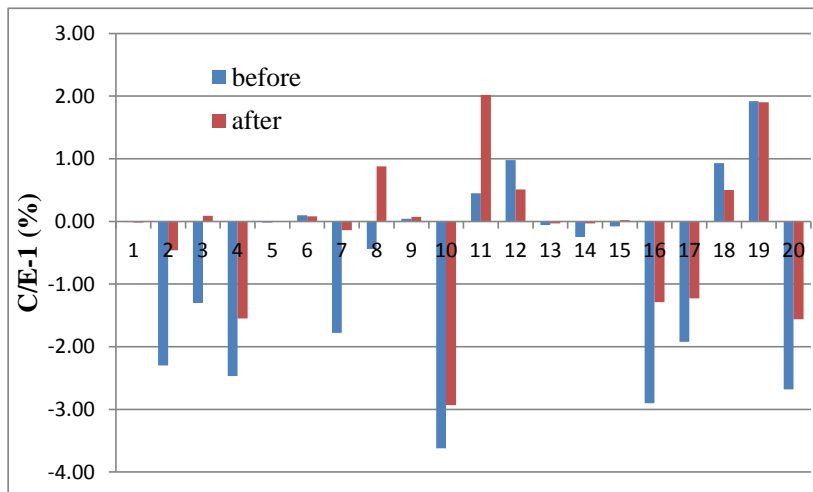
Reactor	Parameter	C/E -1 (%)		Data Uncertainty (%)		Experiment Uncertainty (%)
		before	after	before	after	
JEZEBEL Pu239	$k_{\text{eff}}$	-0.01	-0.02	0.64	0.16	0.20
	F28/F25	-2.30	-0.46	3.71	0.90	1.18
	F37/F25	-1.30	0.09	2.37	0.73	1.41
	F49/F25	-2.47	-1.55	0.83	0.47	0.91
JEZEBEL Pu240	$k_{\text{eff}}$	-0.02	0.00	0.66	0.18	0.20
FLATTOP Pu239	$k_{\text{eff}}$	0.10	0.08	0.76	0.22	0.30
	F28/F25	-1.78	-0.14	3.11	0.78	1.33
	F37/F25	-0.44	0.88	2.04	0.70	1.41
ZPR6/7	$k_{\text{eff}}$	0.04	0.07	0.97	0.12	0.23
	F49/F25	-3.62	-2.93	0.81	0.55	2.22
	F28/F25	0.45	2.02	6.40	1.56	3.13
	C28/F25	0.98	0.51	1.59	0.99	2.47
ZPR6/7 Pu240	$k_{\text{eff}}$	-0.06	-0.03	0.97	0.12	0.22
JOYO	$k_{\text{eff}}$	-0.25	-0.03	0.89	0.18	0.18
ZPPR9	$k_{\text{eff}}$	-0.08	0.02	1.18	0.11	0.12
	F28/F25	-2.90	-1.29	7.85	1.75	2.76
	F49/F25	-1.92	-1.23	0.84	0.55	2.03
	C28/F25	0.93	0.50	1.54	0.93	1.93
	Void Step3	1.92	1.90	8.95	3.02	4.22
	Void Step5	-2.68	-1.56	10.67	3.27	4.13



## Adjustment with Experiment Correlations

- No noticeable difference from adjustment without experiment correlations
- C/E values are improved for 16 cases among 20 experiments
- Estimated parameter uncertainty due to data uncertainties is reduced significantly for all 20 cases

		before	after
C/E	RMS error (%)	2.73	1.29
	Outside of $1\sigma_e$	5	2
	Outside of $2\sigma_e$	1	0
RMS of data induced uncertainty (%)		17.11	1.53



## Conclusions

- ↪ Sensitivities to the average cosine of the elastic scattering angle and to prompt fission spectrum have been obtained for all integral parameters selected for the Subgroup 33 cross section adjustment exercise.
- ↪ Results showed that in the case of small size systems with large leakage effects, such as JEZEBEL Pu239, the sensitivities due to  $\bar{\mu}_s$  are not negligible and could play an important role in uncertainty estimations or other applications.
- ↪ Cross section adjustment was performed with the ANL Generalized Least Squares (GLS) fitting code GMADJ. After adjustment: the C/E improved for all 20 experiments except f37/f25 of FLATTOP Pu239 and f28/f25 of ZPR-6/7; the data induced uncertainties improved significantly for all 20 experiments. Considering the experiment correlations, no noticeable difference was found with respect to the results from adjustment without experiment correlations.



$k_{\text{eff}}$ 

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Na23</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Cr52</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Fe56</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Ni58</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>U235</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>U238</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Pu239</b>	0.061	0.041	-0.008	-0.101	0.726	0.966	0.966	<b>2.652</b>
<b>Pu240</b>	0.003	0.002	-0.001	-0.005	0.024	0.031	0.031	<b>0.086</b>
<b>Pu241</b>	0.000	0.000	0.000	0.000	0.002	0.003	0.003	<b>0.008</b>
<b>Sum</b>	<b>0.065</b>	<b>0.043</b>	<b>-0.008</b>	<b>-0.106</b>	<b>0.752</b>	<b>1.000</b>	<b>1.000</b>	<b>2.745</b>

## F7F5

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Na23</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Cr52</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Fe56</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Ni58</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>U235</b>	0.000	0.000	0.000	0.000	-1.000	0.000	0.000	<b>-1.000</b>
<b>U238</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Pu239</b>	-0.046	-0.106	0.009	-0.005	0.041	0.004	0.005	<b>-0.097</b>
<b>Pu240</b>	-0.003	-0.004	0.001	0.000	-0.001	0.000	-0.001	<b>-0.009</b>
<b>Pu241</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Sum</b>	<b>-0.049</b>	<b>-0.110</b>	<b>0.010</b>	<b>-0.005</b>	<b>-0.960</b>	<b>0.005</b>	<b>0.005</b>	<b>-1.106</b>



**F8F5**

<b>Isotope</b>	<b>Elastic</b>	<b>Inelastic</b>	<b>Capture</b>	<b>Mu-bar</b>	<b>Fission</b>	<b>Nu</b>	<b>Chi-p</b>	<b>Sum</b>
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Na23</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Cr52</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Fe56</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Ni58</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>U235</b>	0.000	0.000	0.000	0.000	-1.000	0.000	0.000	<b>-1.000</b>
<b>U238</b>	0.000	0.000	0.000	0.000	1.000	0.000	0.000	<b>1.000</b>
<b>Pu239</b>	-0.067	-0.170	0.011	-0.016	0.062	0.006	0.008	<b>-0.164</b>
<b>Pu240</b>	-0.004	-0.009	0.001	-0.001	-0.001	0.000	-0.002	<b>-0.015</b>
<b>Pu241</b>	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	<b>-0.001</b>
<b>Sum</b>	<b>-0.071</b>	<b>-0.179</b>	<b>0.012</b>	<b>-0.016</b>	<b>0.062</b>	<b>0.007</b>	<b>0.007</b>	<b>-0.180</b>

**F9F5**

<b>Isotope</b>	<b>Elastic</b>	<b>Inelastic</b>	<b>Capture</b>	<b>Mu-bar</b>	<b>Fission</b>	<b>Nu</b>	<b>Chi-p</b>	<b>Sum</b>
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Na23</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Cr52</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Fe56</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Ni58</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>U235</b>	0.000	0.000	0.000	0.000	-1.000	0.000	0.000	<b>-1.000</b>
<b>U238</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Pu239</b>	-0.011	-0.023	0.003	-0.001	1.010	0.001	0.001	<b>0.979</b>
<b>Pu240</b>	-0.001	-0.001	0.000	0.000	0.000	0.000	0.000	<b>-0.002</b>
<b>Pu241</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Sum</b>	<b>-0.012</b>	<b>-0.024</b>	<b>0.003</b>	<b>-0.001</b>	<b>0.010</b>	<b>0.001</b>	<b>0.001</b>	<b>-0.022</b>



$k_{\text{eff}}$

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Na23</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Cr52</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Fe56</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Ni58</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>U235</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>U238</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Pu239</b>	0.050	0.029	-0.007	-0.083	0.617	0.820	0.821	<b>2.249</b>
<b>Pu240</b>	0.015	0.008	-0.003	-0.023	0.109	0.146	0.146	<b>0.399</b>
<b>Pu241</b>	0.002	0.002	-0.001	-0.004	0.023	0.031	0.031	<b>0.084</b>
<b>Sum</b>	<b>0.068</b>	<b>0.039</b>	<b>-0.010</b>	<b>-0.109</b>	<b>0.750</b>	<b>0.998</b>	<b>0.998</b>	<b>2.733</b>



$k_{\text{eff}}$ 

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Na23</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Cr52</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Fe56</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Ni58</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>U235</b>	0.001	0.000	-0.001	-0.001	0.008	0.011	0.011	<b>0.030</b>
<b>U238</b>	0.135	0.074	-0.042	-0.108	0.062	0.083	0.082	<b>0.286</b>
<b>Pu239</b>	0.021	0.015	-0.013	-0.041	0.629	0.877	0.878	<b>2.366</b>
<b>Pu240</b>	0.001	0.001	-0.001	-0.002	0.019	0.026	0.026	<b>0.070</b>
<b>Pu241</b>	0.000	0.000	0.000	0.000	0.002	0.003	0.003	<b>0.007</b>
<b>Sum</b>	<b>0.158</b>	<b>0.090</b>	<b>-0.057</b>	<b>-0.153</b>	<b>0.720</b>	<b>1.000</b>	<b>1.000</b>	<b>2.758</b>

## F7F5

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Na23</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Cr52</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Fe56</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Ni58</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>U235</b>	-0.001	0.000	0.001	0.000	-1.003	-0.006	-0.006	<b>-1.015</b>
<b>U238</b>	-0.095	-0.063	0.038	0.023	-0.024	-0.036	-0.036	<b>-0.192</b>
<b>Pu239</b>	-0.008	-0.075	0.017	-0.034	0.154	0.065	0.066	<b>0.184</b>
<b>Pu240</b>	-0.001	-0.003	0.001	-0.002	0.002	0.002	0.001	<b>0.001</b>
<b>Pu241</b>	0.000	0.000	0.000	0.000	0.001	0.000	0.000	<b>0.001</b>
<b>Sum</b>	<b>-0.104</b>	<b>-0.142</b>	<b>0.057</b>	<b>-0.012</b>	<b>-0.871</b>	<b>0.026</b>	<b>0.026</b>	<b>-1.022</b>



**F8F5**

<b>Isotope</b>	<b>Elastic</b>	<b>Inelastic</b>	<b>Capture</b>	<b>Mu-bar</b>	<b>Fission</b>	<b>Nu</b>	<b>Chi-p</b>	<b>Sum</b>
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Na23</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Cr52</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Fe56</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Ni58</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>U235</b>	-0.001	0.000	0.001	0.000	-1.004	-0.007	-0.007	<b>-1.020</b>
<b>U238</b>	-0.126	-0.071	0.043	0.043	0.967	-0.049	-0.049	<b>0.756</b>
<b>Pu239</b>	-0.018	-0.119	0.020	-0.057	0.209	0.088	0.090	<b>0.213</b>
<b>Pu240</b>	-0.001	-0.006	0.001	-0.003	0.003	0.003	0.001	<b>-0.002</b>
<b>Pu241</b>	0.000	0.000	0.000	0.000	0.001	0.000	0.000	<b>0.001</b>
<b>Sum</b>	<b>-0.147</b>	<b>-0.198</b>	<b>0.064</b>	<b>-0.017</b>	<b>0.176</b>	<b>0.035</b>	<b>0.035</b>	<b>-0.051</b>



$k_{\text{eff}}$ 

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.001	0.000	0.000	0.000	<b>0.001</b>
<b>O16</b>	0.071	0.000	-0.002	-0.011	0.000	0.000	0.000	<b>0.058</b>
<b>Na23</b>	0.041	0.002	-0.001	-0.013	0.000	0.000	0.000	<b>0.029</b>
<b>Cr52</b>	0.012	-0.001	-0.002	-0.003	0.000	0.000	0.000	<b>0.007</b>
<b>Fe56</b>	0.038	-0.001	-0.007	-0.011	0.000	0.000	0.000	<b>0.019</b>
<b>Ni58</b>	0.009	0.000	-0.005	-0.001	0.000	0.000	0.000	<b>0.003</b>
<b>U235</b>	0.005	0.001	-0.045	-0.003	0.277	0.456	0.456	<b>1.147</b>
<b>U238</b>	0.055	0.006	-0.128	-0.029	0.059	0.091	0.091	<b>0.146</b>
<b>Pu239</b>	0.003	0.001	-0.026	-0.002	0.272	0.403	0.403	<b>1.054</b>
<b>Pu240</b>	0.001	0.000	-0.007	0.000	0.021	0.031	0.031	<b>0.077</b>
<b>Pu241</b>	0.000	0.000	-0.001	0.001	0.012	0.017	0.017	<b>0.047</b>
<b>Sum</b>	<b>0.235</b>	<b>0.008</b>	<b>-0.224</b>	<b>-0.069</b>	<b>0.641</b>	<b>0.998</b>	<b>0.998</b>	<b>2.588</b>



$k_{\text{eff}}$ 

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	-0.002	0.000	-0.002	-0.003	0.000	0.000	0.000	<b>-0.008</b>
<b>Na23</b>	0.011	-0.008	-0.002	-0.005	0.000	0.000	0.000	<b>-0.004</b>
<b>Cr52</b>	0.003	-0.003	-0.002	-0.001	0.000	0.000	0.000	<b>-0.004</b>
<b>Fe56</b>	0.019	-0.018	-0.014	-0.005	0.000	0.000	0.000	<b>-0.018</b>
<b>Ni58</b>	0.004	-0.001	-0.004	-0.001	0.000	0.000	0.000	<b>-0.002</b>
<b>U235</b>	0.000	0.000	-0.001	-0.001	0.009	0.013	0.013	<b>0.033</b>
<b>U238</b>	0.045	-0.042	-0.246	-0.020	0.080	0.127	0.126	<b>0.070</b>
<b>Pu239</b>	0.003	-0.003	-0.069	-0.002	0.584	0.817	0.818	<b>2.148</b>
<b>Pu240</b>	0.000	0.000	-0.009	0.000	0.016	0.022	0.022	<b>0.051</b>
<b>Pu241</b>	0.000	0.000	-0.001	0.000	0.014	0.019	0.019	<b>0.051</b>
<b>Sum</b>	<b>0.083</b>	<b>-0.076</b>	<b>-0.351</b>	<b>-0.039</b>	<b>0.702</b>	<b>0.999</b>	<b>0.999</b>	<b>2.317</b>

**F8F5**

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	-0.169	-0.002	-0.003	0.001	0.000	0.000	0.000	<b>-0.172</b>
<b>Na23</b>	-0.088	-0.076	0.002	0.000	0.000	0.000	0.000	<b>-0.162</b>
<b>Cr52</b>	-0.014	-0.034	0.003	0.000	0.000	0.000	0.000	<b>-0.045</b>
<b>Fe56</b>	-0.056	-0.183	0.019	-0.003	0.000	0.000	0.000	<b>-0.223</b>
<b>Ni58</b>	-0.012	-0.010	0.002	0.001	0.000	0.000	0.000	<b>-0.019</b>
<b>U235</b>	0.000	-0.001	0.002	0.001	-0.997	-0.002	-0.002	<b>-1.000</b>
<b>U238</b>	-0.063	-0.323	0.355	0.010	0.970	-0.007	-0.015	<b>0.926</b>
<b>Pu239</b>	-0.005	-0.025	0.106	0.002	0.298	0.013	0.022	<b>0.411</b>
<b>Pu240</b>	-0.001	-0.004	0.014	0.001	0.004	0.001	0.000	<b>0.015</b>
<b>Pu241</b>	0.000	0.000	0.001	0.000	0.006	-0.001	-0.002	<b>0.003</b>
<b>Sum</b>	<b>-0.407</b>	<b>-0.658</b>	<b>0.502</b>	<b>0.012</b>	<b>0.280</b>	<b>0.003</b>	<b>0.003</b>	<b>-0.265</b>



**C8F5**

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	0.197	0.000	0.000	0.001	0.000	0.000	0.000	<b>0.199</b>
<b>Na23</b>	0.115	0.007	-0.002	0.002	0.000	0.000	0.000	<b>0.121</b>
<b>Cr52</b>	0.009	0.002	-0.002	0.001	0.000	0.000	0.000	<b>0.009</b>
<b>Fe56</b>	0.063	0.011	-0.011	0.002	0.000	0.000	0.000	<b>0.065</b>
<b>Ni58</b>	0.017	0.001	-0.001	0.000	0.000	0.000	0.000	<b>0.017</b>
<b>U235</b>	0.000	0.000	-0.001	0.001	-1.002	0.001	0.001	<b>-1.002</b>
<b>U238</b>	0.031	0.050	0.809	-0.001	0.003	0.002	0.002	<b>0.896</b>
<b>Pu239</b>	0.003	0.006	-0.086	0.000	-0.146	-0.003	-0.004	<b>-0.229</b>
<b>Pu240</b>	0.001	0.001	-0.011	0.000	-0.001	0.000	0.000	<b>-0.010</b>
<b>Pu241</b>	0.000	0.000	-0.001	0.001	-0.004	0.000	0.000	<b>-0.003</b>
<b>Sum</b>	<b>0.436</b>	<b>0.077</b>	<b>0.694</b>	<b>0.006</b>	<b>-1.150</b>	<b>-0.001</b>	<b>-0.001</b>	<b>0.062</b>

**F9F5**

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	-0.067	0.000	0.000	0.000	0.000	0.000	0.000	<b>-0.068</b>
<b>Na23</b>	-0.029	-0.006	0.001	-0.001	0.000	0.000	0.000	<b>-0.035</b>
<b>Cr52</b>	-0.003	-0.001	0.001	0.000	0.000	0.000	0.000	<b>-0.004</b>
<b>Fe56</b>	-0.013	-0.009	0.003	-0.001	0.000	0.000	0.000	<b>-0.019</b>
<b>Ni58</b>	-0.004	0.000	0.001	0.000	0.000	0.000	0.000	<b>-0.003</b>
<b>U235</b>	0.000	0.000	0.000	0.000	-0.999	0.000	0.000	<b>-1.000</b>
<b>U238</b>	-0.013	-0.037	0.069	0.001	-0.002	-0.001	-0.001	<b>0.015</b>
<b>Pu239</b>	-0.001	-0.004	0.020	0.000	1.048	0.002	0.002	<b>1.068</b>
<b>Pu240</b>	0.000	0.000	0.003	0.000	0.000	0.000	0.000	<b>0.003</b>
<b>Pu241</b>	0.000	0.000	0.000	0.000	0.001	0.000	0.000	<b>0.001</b>
<b>Sum</b>	<b>-0.131</b>	<b>-0.058</b>	<b>0.097</b>	<b>-0.001</b>	<b>0.049</b>	<b>0.000</b>	<b>0.000</b>	<b>-0.044</b>



$k_{\text{eff}}$

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	-0.002	0.000	-0.002	-0.004	0.000	0.000	0.000	<b>-0.008</b>
<b>Na23</b>	0.011	-0.008	-0.002	-0.005	0.000	0.000	0.000	<b>-0.004</b>
<b>Cr52</b>	0.004	-0.003	-0.002	-0.001	0.000	0.000	0.000	<b>-0.003</b>
<b>Fe56</b>	0.019	-0.018	-0.013	-0.005	0.000	0.000	0.000	<b>-0.018</b>
<b>Ni58</b>	0.004	-0.001	-0.004	0.000	0.000	0.000	0.000	<b>-0.002</b>
<b>U235</b>	0.000	0.000	-0.001	0.000	0.009	0.013	0.012	<b>0.032</b>
<b>U238</b>	0.047	-0.043	-0.240	-0.020	0.079	0.127	0.126	<b>0.076</b>
<b>Pu239</b>	0.003	-0.003	-0.066	-0.001	0.571	0.798	0.799	<b>2.100</b>
<b>Pu240</b>	0.000	-0.001	-0.012	0.000	0.022	0.031	0.031	<b>0.071</b>
<b>Pu241</b>	0.000	0.000	-0.001	0.000	0.022	0.030	0.030	<b>0.081</b>
<b>Sum</b>	<b>0.086</b>	<b>-0.076</b>	<b>-0.345</b>	<b>-0.037</b>	<b>0.702</b>	<b>0.998</b>	<b>0.998</b>	<b>2.326</b>



$k_{\text{eff}}$ 

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	-0.014	0.000	-0.002	-0.005	0.000	0.000	0.000	<b>-0.022</b>
<b>Na23</b>	0.004	-0.008	-0.002	-0.004	0.000	0.000	0.000	<b>-0.010</b>
<b>Cr52</b>	0.002	-0.004	-0.002	-0.001	0.000	0.000	0.000	<b>-0.005</b>
<b>Fe56</b>	0.011	-0.018	-0.012	-0.004	0.000	0.000	0.000	<b>-0.023</b>
<b>Ni58</b>	0.002	-0.001	-0.004	-0.001	0.000	0.000	0.000	<b>-0.004</b>
<b>U235</b>	0.000	0.000	-0.001	0.000	0.010	0.015	0.015	<b>0.038</b>
<b>U238</b>	0.027	-0.060	-0.268	-0.013	0.091	0.147	0.145	<b>0.068</b>
<b>Pu239</b>	0.002	-0.004	-0.062	-0.001	0.581	0.801	0.802	<b>2.119</b>
<b>Pu240</b>	0.000	0.000	-0.008	0.000	0.015	0.022	0.022	<b>0.051</b>
<b>Pu241</b>	0.000	0.000	-0.001	0.000	0.010	0.014	0.014	<b>0.038</b>
<b>Sum</b>	<b>0.035</b>	<b>-0.096</b>	<b>-0.363</b>	<b>-0.029</b>	<b>0.708</b>	<b>0.998</b>	<b>0.998</b>	<b>2.251</b>

**F8F5**

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	-0.141	-0.002	-0.003	0.006	0.000	0.000	0.000	<b>-0.140</b>
<b>Na23</b>	-0.066	-0.064	0.002	0.002	0.000	0.000	0.000	<b>-0.126</b>
<b>Cr52</b>	-0.012	-0.033	0.003	0.001	0.000	0.000	0.000	<b>-0.041</b>
<b>Fe56</b>	-0.042	-0.151	0.016	0.003	0.000	0.000	0.000	<b>-0.174</b>
<b>Ni58</b>	-0.009	-0.010	0.002	0.003	0.000	0.000	0.000	<b>-0.014</b>
<b>U235</b>	0.000	-0.001	0.002	0.000	-0.994	0.000	0.000	<b>-0.992</b>
<b>U238</b>	-0.045	-0.407	0.413	0.005	0.969	0.004	-0.004	<b>0.936</b>
<b>Pu239</b>	-0.003	-0.021	0.098	0.001	0.270	-0.003	0.007	<b>0.348</b>
<b>Pu240</b>	-0.001	-0.003	0.013	0.001	0.002	-0.001	-0.002	<b>0.009</b>
<b>Pu241</b>	0.000	0.000	0.001	-0.002	0.005	0.000	0.000	<b>0.004</b>
<b>Sum</b>	<b>-0.318</b>	<b>-0.693</b>	<b>0.548</b>	<b>0.020</b>	<b>0.254</b>	<b>0.000</b>	<b>0.000</b>	<b>-0.189</b>



**C8F5**

<b>Isotope</b>	<b>Elastic</b>	<b>Inelastic</b>	<b>Capture</b>	<b>Mu-bar</b>	<b>Fission</b>	<b>Nu</b>	<b>Chi-p</b>	<b>Sum</b>
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	0.185	0.000	0.000	-0.001	0.000	0.000	0.000	<b>0.185</b>
<b>Na23</b>	0.100	0.006	-0.002	0.000	0.000	0.000	0.000	<b>0.104</b>
<b>Cr52</b>	0.008	0.002	-0.002	0.000	0.000	0.000	0.000	<b>0.008</b>
<b>Fe56</b>	0.052	0.009	-0.010	0.000	0.000	0.000	0.000	<b>0.051</b>
<b>Ni58</b>	0.016	0.000	-0.001	0.000	0.000	0.000	0.000	<b>0.015</b>
<b>U235</b>	0.000	0.000	-0.002	0.000	-1.004	0.000	0.000	<b>-1.005</b>
<b>U238</b>	0.030	0.062	0.778	0.000	0.001	-0.001	-0.001	<b>0.868</b>
<b>Pu239</b>	0.003	0.005	-0.079	0.000	-0.131	0.001	0.000	<b>-0.200</b>
<b>Pu240</b>	0.000	0.000	-0.010	0.000	0.000	0.000	0.000	<b>-0.008</b>
<b>Pu241</b>	0.000	0.000	-0.001	0.001	-0.003	0.000	0.000	<b>-0.003</b>
<b>Sum</b>	<b>0.395</b>	<b>0.084</b>	<b>0.673</b>	<b>0.001</b>	<b>-1.137</b>	<b>0.000</b>	<b>0.000</b>	<b>0.015</b>

**F9F5**

<b>Isotope</b>	<b>Elastic</b>	<b>Inelastic</b>	<b>Capture</b>	<b>Mu-bar</b>	<b>Fission</b>	<b>Nu</b>	<b>Chi-p</b>	<b>Sum</b>
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	-0.061	0.000	0.000	0.001	0.000	0.000	0.000	<b>-0.061</b>
<b>Na23</b>	-0.023	-0.005	0.000	0.000	0.000	0.000	0.000	<b>-0.028</b>
<b>Cr52</b>	-0.003	-0.001	0.001	0.000	0.000	0.000	0.000	<b>-0.004</b>
<b>Fe56</b>	-0.010	-0.007	0.003	0.000	0.000	0.000	0.000	<b>-0.014</b>
<b>Ni58</b>	-0.003	0.000	0.001	0.000	0.000	0.000	0.000	<b>-0.003</b>
<b>U235</b>	0.000	0.000	0.000	0.000	-0.999	0.000	0.000	<b>-0.999</b>
<b>U238</b>	-0.011	-0.045	0.080	0.001	-0.001	0.001	0.000	<b>0.024</b>
<b>Pu239</b>	-0.001	-0.003	0.018	0.000	1.042	0.000	0.000	<b>1.055</b>
<b>Pu240</b>	0.000	0.000	0.002	0.000	0.000	0.000	0.000	<b>0.002</b>
<b>Pu241</b>	0.000	0.000	0.000	0.000	0.001	0.000	0.000	<b>0.001</b>
<b>Sum</b>	<b>-0.113</b>	<b>-0.062</b>	<b>0.105</b>	<b>0.002</b>	<b>0.043</b>	<b>0.000</b>	<b>0.000</b>	<b>-0.026</b>



**VOID STEP3**

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	-0.550	-0.003	-0.011	1.145	0.000	0.000	0.000	<b>0.581</b>
<b>Na23</b>	0.282	0.356	0.077	-0.103	0.000	0.000	0.000	<b>0.611</b>
<b>Cr52</b>	-0.022	-0.022	0.011	0.433	0.000	0.000	0.000	<b>0.400</b>
<b>Fe56</b>	-0.110	-0.106	0.061	0.228	0.000	0.000	0.000	<b>0.074</b>
<b>Ni58</b>	-0.034	-0.006	-0.007	0.476	0.000	0.000	0.000	<b>0.430</b>
<b>U235</b>	0.000	-0.001	0.007	0.277	-0.016	-0.027	-0.027	<b>0.213</b>
<b>U238</b>	-0.086	-0.438	0.695	-0.020	0.096	0.268	0.263	<b>0.778</b>
<b>Pu239</b>	-0.005	-0.026	0.458	0.200	-0.822	-1.240	-1.233	<b>-2.668</b>
<b>Pu240</b>	-0.001	-0.003	0.054	0.167	0.010	0.021	0.021	<b>0.270</b>
<b>Pu241</b>	0.000	-0.001	0.003	0.542	-0.015	-0.024	-0.024	<b>0.482</b>
<b>Sum</b>	<b>-0.526</b>	<b>-0.250</b>	<b>1.349</b>	<b>3.346</b>	<b>-0.747</b>	<b>-1.001</b>	<b>-0.999</b>	<b>1.171</b>

**VOID STEP5**

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>O16</b>	-0.607	-0.004	-0.015	0.527	0.000	0.000	0.000	<b>-0.099</b>
<b>Na23</b>	0.115	0.451	0.102	0.055	0.000	0.000	0.000	<b>0.722</b>
<b>Cr52</b>	-0.009	-0.030	0.015	0.406	0.000	0.000	0.000	<b>0.383</b>
<b>Fe56</b>	-0.081	-0.139	0.081	0.008	0.000	0.000	0.000	<b>-0.131</b>
<b>Ni58</b>	-0.034	-0.009	-0.009	0.632	0.000	0.000	0.000	<b>0.580</b>
<b>U235</b>	0.000	-0.001	0.009	0.428	-0.013	-0.027	-0.027	<b>0.371</b>
<b>U238</b>	0.017	-0.548	0.912	0.395	0.194	0.429	0.422	<b>1.820</b>
<b>Pu239</b>	-0.002	-0.033	0.609	0.581	-0.881	-1.418	-1.409	<b>-2.553</b>
<b>Pu240</b>	0.000	-0.004	0.072	0.570	0.024	0.041	0.041	<b>0.745</b>
<b>Pu241</b>	0.000	-0.001	0.004	0.365	-0.017	-0.028	-0.028	<b>0.295</b>
<b>Sum</b>	<b>-0.601</b>	<b>-0.317</b>	<b>1.780</b>	<b>3.967</b>	<b>-0.693</b>	<b>-1.003</b>	<b>-1.001</b>	<b>2.132</b>



$k_{\text{eff}}$ 

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	-0.003	0.000	0.000	0.000	0.000	<b>-0.003</b>
<b>O16</b>	-0.026	0.000	-0.003	-0.004	0.000	0.000	0.000	<b>-0.033</b>
<b>Na23</b>	-0.001	-0.008	-0.002	-0.004	0.000	0.000	0.000	<b>-0.015</b>
<b>Cr52</b>	0.002	-0.004	-0.002	-0.001	0.000	0.000	0.000	<b>-0.005</b>
<b>Fe56</b>	0.008	-0.016	-0.012	-0.004	0.000	0.000	0.000	<b>-0.023</b>
<b>Ni58</b>	0.003	-0.003	-0.011	-0.001	0.000	0.000	0.000	<b>-0.012</b>
<b>U235</b>	0.000	0.000	-0.001	0.000	0.008	0.012	0.012	<b>0.032</b>
<b>U238</b>	0.019	-0.049	-0.229	-0.010	0.069	0.116	0.115	<b>0.030</b>
<b>Pu239</b>	0.001	-0.003	-0.050	-0.001	0.450	0.632	0.634	<b>1.664</b>
<b>Pu240</b>	0.001	-0.001	-0.024	0.000	0.043	0.064	0.064	<b>0.146</b>
<b>Pu241</b>	0.000	-0.001	-0.008	0.000	0.118	0.163	0.163	<b>0.435</b>
<b>Sum</b>	<b>0.007</b>	<b>-0.085</b>	<b>-0.344</b>	<b>-0.025</b>	<b>0.688</b>	<b>0.988</b>	<b>0.988</b>	<b>2.216</b>



$k_{\text{eff}}$ 

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	-0.001	0.000	-0.015	0.000	0.000	0.000	0.000	<b>-0.016</b>
<b>O16</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>Na23</b>	0.004	-0.007	-0.002	-0.008	0.000	0.000	0.000	<b>-0.013</b>
<b>Cr52</b>	0.010	-0.003	-0.002	-0.003	0.000	0.000	0.000	<b>0.002</b>
<b>Fe56</b>	0.035	-0.022	-0.018	-0.014	0.000	0.000	0.000	<b>-0.020</b>
<b>Ni58</b>	0.001	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>U235</b>	0.000	0.000	-0.001	0.000	0.005	0.007	0.007	<b>0.018</b>
<b>U238</b>	0.023	-0.050	-0.179	-0.012	0.078	0.126	0.125	<b>0.111</b>
<b>Pu239</b>	0.003	-0.004	-0.043	-0.002	0.604	0.837	0.838	<b>2.232</b>
<b>Pu240</b>	0.000	0.000	-0.006	0.000	0.015	0.022	0.022	<b>0.053</b>
<b>Pu241</b>	0.000	0.000	0.000	0.000	0.006	0.008	0.008	<b>0.022</b>
<b>Sum</b>	<b>0.075</b>	<b>-0.087</b>	<b>-0.265</b>	<b>-0.040</b>	<b>0.707</b>	<b>0.999</b>	<b>0.999</b>	<b>2.389</b>



$k_{\text{eff}}$ 

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	-0.008	0.000	0.000	0.000	0.000	<b>-0.009</b>
<b>O16</b>	-0.019	0.000	-0.002	-0.003	0.000	0.000	0.000	<b>-0.024</b>
<b>Na23</b>	0.005	-0.008	-0.002	-0.006	0.000	0.000	0.000	<b>-0.011</b>
<b>Cr52</b>	0.006	-0.003	-0.003	-0.002	0.000	0.000	0.000	<b>-0.001</b>
<b>Fe56</b>	0.026	-0.022	-0.022	-0.010	0.000	0.000	0.000	<b>-0.028</b>
<b>Ni58</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>U235</b>	0.000	0.000	-0.001	0.000	0.004	0.006	0.005	<b>0.014</b>
<b>U238</b>	0.015	-0.036	-0.208	-0.007	0.060	0.100	0.099	<b>0.023</b>
<b>Pu239</b>	0.002	-0.003	-0.071	-0.001	0.598	0.847	0.848	<b>2.220</b>
<b>Pu240</b>	0.000	-0.001	-0.012	0.000	0.020	0.029	0.029	<b>0.065</b>
<b>Pu241</b>	0.000	0.000	-0.001	0.000	0.013	0.018	0.017	<b>0.047</b>
<b>Sum</b>	<b>0.036</b>	<b>-0.074</b>	<b>-0.331</b>	<b>-0.028</b>	<b>0.694</b>	<b>0.999</b>	<b>0.999</b>	<b>2.295</b>



$k_{\text{eff}}$

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Sum
<b>B10</b>	0.000	0.000	-0.008	0.000	0.000	0.000	0.000	<b>-0.009</b>
<b>O16</b>	-0.030	0.000	-0.002	-0.003	0.000	0.000	0.000	<b>-0.035</b>
<b>Na23</b>	-0.002	-0.011	-0.002	-0.005	0.000	0.000	0.000	<b>-0.020</b>
<b>Cr52</b>	0.005	-0.004	-0.002	-0.002	0.000	0.000	0.000	<b>-0.003</b>
<b>Fe56</b>	0.020	-0.031	-0.019	-0.010	0.000	0.000	0.000	<b>-0.040</b>
<b>Ni58</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>U235</b>	0.000	0.000	0.000	0.000	0.004	0.005	0.005	<b>0.014</b>
<b>U238</b>	0.011	-0.045	-0.164	-0.006	0.055	0.091	0.091	<b>0.034</b>
<b>Pu239</b>	0.001	-0.003	-0.043	-0.001	0.439	0.600	0.602	<b>1.596</b>
<b>Pu240</b>	0.001	-0.003	-0.033	-0.001	0.069	0.100	0.099	<b>0.233</b>
<b>Pu241</b>	0.000	-0.001	-0.005	0.000	0.082	0.110	0.110	<b>0.296</b>
<b>Sum</b>	<b>0.007</b>	<b>-0.098</b>	<b>-0.279</b>	<b>-0.027</b>	<b>0.649</b>	<b>0.907</b>	<b>0.907</b>	<b>2.066</b>



$k_{\text{eff}}$

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Na23</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Cr52</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Fe56</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Ni58</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>U235</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>U238</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Pu239</b>	0.42i	0.64	0.08	0.00	0.35	0.08	0.16	<b>0.63</b>
<b>Pu240</b>	0.03i	0.04	0.02	0.00	0.04	0.08	0.02	<b>0.10</b>
<b>Pu241</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Total</b>	<b>0.42i</b>	<b>0.64</b>	<b>0.08</b>	<b>0.00</b>	<b>0.35</b>	<b>0.11</b>	<b>0.16</b>	<b>0.64</b>

**F7F5**

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Na23</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Cr52</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Fe56</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Ni58</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>U235</b>	0.00	0.00	0.00	0.00	0.41	0.00	0.00	<b>0.41</b>
<b>U238</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Pu239</b>	0.59i	2.23	0.08	0.00	0.04	0.00	0.89	<b>2.33</b>
<b>Pu240</b>	0.03i	0.12	0.00	0.00	0.00	0.00	0.17	<b>0.20</b>
<b>Pu241</b>	0.00	0.01	0.00	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>Total</b>	<b>0.59i</b>	<b>2.23</b>	<b>0.08</b>	<b>0.00</b>	<b>0.41</b>	<b>0.00</b>	<b>0.90</b>	<b>2.37</b>



**F8F5**

<b>Isotope</b>	<b>Elastic</b>	<b>Inelastic</b>	<b>Capture</b>	<b>Mu-bar</b>	<b>Fission</b>	<b>Nu</b>	<b>Chi-p</b>	<b>Total</b>
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Na23</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Cr52</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Fe56</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Ni58</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>U235</b>	0.00	0.00	0.00	0.00	0.41	0.00	0.00	<b>0.41</b>
<b>U238</b>	0.00	0.00	0.00	0.00	0.52	0.00	0.00	<b>0.52</b>
<b>Pu239</b>	0.90i	3.18	0.10	0.00	0.06	0.00	1.97	<b>3.63</b>
<b>Pu240</b>	0.06i	0.23	0.00	0.00	0.01	0.00	0.31	<b>0.39</b>
<b>Pu241</b>	0.00	0.01	0.00	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>Total</b>	<b>0.90i</b>	<b>3.19</b>	<b>0.10</b>	<b>0.00</b>	<b>0.67</b>	<b>0.00</b>	<b>2.00</b>	<b>3.71</b>

**F9F5**

<b>Isotope</b>	<b>Elastic</b>	<b>Inelastic</b>	<b>Capture</b>	<b>Mu-bar</b>	<b>Fission</b>	<b>Nu</b>	<b>Chi-p</b>	<b>Total</b>
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Na23</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Cr52</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Fe56</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Ni58</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>U235</b>	0.00	0.00	0.00	0.00	0.41	0.00	0.00	<b>0.41</b>
<b>U238</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Pu239</b>	0.13i	0.51	0.02	0.00	0.48	0.00	0.19	<b>0.72</b>
<b>Pu240</b>	0.01i	0.02	0.00	0.00	0.00	0.00	0.04	<b>0.04</b>
<b>Pu241</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Total</b>	<b>0.13i</b>	<b>0.51</b>	<b>0.02</b>	<b>0.00</b>	<b>0.63</b>	<b>0.00</b>	<b>0.19</b>	<b>0.83</b>



$k_{\text{eff}}$

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Na23</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Cr52</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Fe56</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Ni58</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>U235</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>U238</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Pu239</b>	0.30i	0.44	0.07	0.00	0.29	0.07	0.17	<b>0.48</b>
<b>Pu240</b>	0.11i	0.16	0.09	0.00	0.20	0.36	0.12	<b>0.45</b>
<b>Pu241</b>	0.01	0.04	0.03	0.00	0.02	0.01	0.00	<b>0.05</b>
<b>Total</b>	<b>0.32i</b>	<b>0.47</b>	<b>0.11</b>	<b>0.00</b>	<b>0.35</b>	<b>0.37</b>	<b>0.21</b>	<b>0.66</b>



**$k_{\text{eff}}$**

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Na23</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Cr52</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Fe56</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Ni58</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>U235</b>	0.00	0.00	0.01	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>U238</b>	0.41i	0.75	0.05	0.00	0.03	0.10	0.00	<b>0.64</b>
<b>Pu239</b>	0.16i	0.23	0.12	0.00	0.29	0.07	0.16	<b>0.39</b>
<b>Pu240</b>	0.01i	0.01	0.02	0.00	0.04	0.07	0.02	<b>0.08</b>
<b>Pu241</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Total</b>	<b>0.44i</b>	<b>0.79</b>	<b>0.13</b>	<b>0.00</b>	<b>0.29</b>	<b>0.14</b>	<b>0.16</b>	<b>0.76</b>

**F7F5**

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Na23</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Cr52</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Fe56</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Ni58</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>U235</b>	0.00	0.00	0.01	0.00	0.41	0.00	0.00	<b>0.41</b>
<b>U238</b>	0.22i	0.57	0.05	0.00	0.01	0.04	0.00	<b>0.53</b>
<b>Pu239</b>	0.08	1.73	0.14	0.00	0.07	0.01	0.84	<b>1.93</b>
<b>Pu240</b>	0.01	0.09	0.00	0.00	0.01	0.01	0.15	<b>0.18</b>
<b>Pu241</b>	0.00	0.01	0.00	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>Total</b>	<b>0.21i</b>	<b>1.82</b>	<b>0.15</b>	<b>0.00</b>	<b>0.42</b>	<b>0.04</b>	<b>0.85</b>	<b>2.04</b>



**F8F5**

<b>Isotope</b>	<b>Elastic</b>	<b>Inelastic</b>	<b>Capture</b>	<b>Mu-bar</b>	<b>Fission</b>	<b>Nu</b>	<b>Chi-p</b>	<b>Total</b>
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Na23</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Cr52</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Fe56</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Ni58</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>U235</b>	0.00	0.00	0.01	0.00	0.41	0.00	0.00	<b>0.41</b>
<b>U238</b>	0.35i	0.67	0.06	0.00	0.50	0.06	0.00	<b>0.76</b>
<b>Pu239</b>	0.37i	2.30	0.16	0.00	0.10	0.01	1.91	<b>2.97</b>
<b>Pu240</b>	0.03i	0.18	0.01	0.00	0.01	0.01	0.29	<b>0.34</b>
<b>Pu241</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>Total</b>	<b>0.51i</b>	<b>2.40</b>	<b>0.17</b>	<b>0.00</b>	<b>0.66</b>	<b>0.06</b>	<b>1.93</b>	<b>3.11</b>



$k_{\text{eff}}$ 

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.13	0.00	0.10	0.00	0.00	0.00	0.00	<b>0.16</b>
<b>Na23</b>	0.17	0.02	0.00	0.19	0.00	0.00	0.00	<b>0.25</b>
<b>Cr52</b>	0.08	0.01	0.01	0.00	0.00	0.00	0.00	<b>0.09</b>
<b>Fe56</b>	0.23	0.02	0.06	0.04	0.00	0.00	0.00	<b>0.24</b>
<b>Ni58</b>	0.03	0.00	0.04	0.00	0.00	0.00	0.00	<b>0.05</b>
<b>U235</b>	0.06	0.01	0.71	0.00	0.11	0.05	0.00	<b>0.72</b>
<b>U238</b>	0.13	0.04i	0.17	0.00	0.03	0.11	0.00	<b>0.24</b>
<b>Pu239</b>	0.00	0.02	0.15	0.00	0.11	0.03	0.05	<b>0.19</b>
<b>Pu240</b>	0.00	0.00	0.04	0.00	0.05	0.09	0.01	<b>0.11</b>
<b>Pu241</b>	0.00	0.00	0.01	0.00	0.01	0.00	0.00	<b>0.02</b>
<b>Total</b>	<b>0.36</b>	<b>0.01</b>	<b>0.76</b>	<b>0.19</b>	<b>0.17</b>	<b>0.15</b>	<b>0.05</b>	<b>0.89</b>



$k_{\text{eff}}$ 

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.01	0.00	0.11	0.00	0.00	0.00	0.00	<b>0.11</b>
<b>Na23</b>	0.04	0.07	0.00	0.07	0.00	0.00	0.00	<b>0.11</b>
<b>Cr52</b>	0.02	0.02	0.02	0.00	0.00	0.00	0.00	<b>0.04</b>
<b>Fe56</b>	0.10	0.11	0.10	0.02	0.00	0.00	0.00	<b>0.18</b>
<b>Ni58</b>	0.01	0.01	0.03	0.00	0.00	0.00	0.00	<b>0.03</b>
<b>U235</b>	0.00	0.00	0.02	0.00	0.00	0.00	0.00	<b>0.02</b>
<b>U238</b>	0.23	0.69	0.34	0.00	0.04	0.15	0.00	<b>0.82</b>
<b>Pu239</b>	0.03	0.06	0.31	0.00	0.23	0.07	0.18	<b>0.44</b>
<b>Pu240</b>	0.00	0.01	0.05	0.00	0.04	0.07	0.02	<b>0.09</b>
<b>Pu241</b>	0.00	0.00	0.01	0.00	0.01	0.00	0.00	<b>0.02</b>
<b>Total</b>	<b>0.26</b>	<b>0.71</b>	<b>0.49</b>	<b>0.07</b>	<b>0.24</b>	<b>0.18</b>	<b>0.19</b>	<b>0.96</b>

## F8F5

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.33	0.02	0.13	0.00	0.00	0.00	0.00	<b>0.35</b>
<b>Na23</b>	0.41	0.59	0.00	0.03	0.00	0.00	0.00	<b>0.72</b>
<b>Cr52</b>	0.07	0.20	0.03	0.00	0.00	0.00	0.00	<b>0.21</b>
<b>Fe56</b>	0.17	1.04	0.15	0.03	0.00	0.00	0.00	<b>1.06</b>
<b>Ni58</b>	0.03	0.11	0.03	0.00	0.00	0.00	0.00	<b>0.12</b>
<b>U235</b>	0.00	0.00	0.03	0.00	0.41	0.00	0.00	<b>0.41</b>
<b>U238</b>	0.60i	5.95	0.51	0.00	0.51	0.01	0.00	<b>5.97</b>
<b>Pu239</b>	0.06i	0.47	0.50	0.00	0.13	0.00	1.69	<b>1.82</b>
<b>Pu240</b>	0.01i	0.10	0.07	0.00	0.02	0.00	0.22	<b>0.25</b>
<b>Pu241</b>	0.00	0.01	0.01	0.00	0.00	0.00	0.00	<b>0.02</b>
<b>Total</b>	<b>0.24i</b>	<b>6.10</b>	<b>0.75</b>	<b>0.04</b>	<b>0.67</b>	<b>0.01</b>	<b>1.70</b>	<b>6.40</b>



**C8F5**

<b>Isotope</b>	<b>Elastic</b>	<b>Inelastic</b>	<b>Capture</b>	<b>Mu-bar</b>	<b>Fission</b>	<b>Nu</b>	<b>Chi-p</b>	<b>Total</b>
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.39	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.39</b>
<b>Na23</b>	0.52	0.09	0.00	0.02	0.00	0.00	0.00	<b>0.53</b>
<b>Cr52</b>	0.06	0.01	0.01	0.00	0.00	0.00	0.00	<b>0.06</b>
<b>Fe56</b>	0.38	0.08	0.08	0.01	0.00	0.00	0.00	<b>0.40</b>
<b>Ni58</b>	0.04	0.01	0.01	0.00	0.00	0.00	0.00	<b>0.04</b>
<b>U235</b>	0.00	0.00	0.01i	0.00	0.41	0.00	0.00	<b>0.41</b>
<b>U238</b>	0.04i	0.52	1.18	0.00	0.00	0.00	0.00	<b>1.28</b>
<b>Pu239</b>	0.03i	0.18	0.27	0.00	0.11	0.00	0.10	<b>0.35</b>
<b>Pu240</b>	0.00	0.02	0.06	0.00	0.01	0.00	0.02	<b>0.06</b>
<b>Pu241</b>	0.00	0.01	0.01	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>Total</b>	<b>0.76</b>	<b>0.56</b>	<b>1.21</b>	<b>0.02</b>	<b>0.43</b>	<b>0.00</b>	<b>0.10</b>	<b>1.59</b>

**F9F5**

<b>Isotope</b>	<b>Elastic</b>	<b>Inelastic</b>	<b>Capture</b>	<b>Mu-bar</b>	<b>Fission</b>	<b>Nu</b>	<b>Chi-p</b>	<b>Total</b>
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.13	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.13</b>
<b>Na23</b>	0.16	0.09	0.00	0.01	0.00	0.00	0.00	<b>0.19</b>
<b>Cr52</b>	0.03	0.01	0.00	0.00	0.00	0.00	0.00	<b>0.03</b>
<b>Fe56</b>	0.12	0.07	0.02	0.00	0.00	0.00	0.00	<b>0.14</b>
<b>Ni58</b>	0.02	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.02</b>
<b>U235</b>	0.00	0.00	0.01	0.00	0.41	0.00	0.00	<b>0.41</b>
<b>U238</b>	0.04i	0.44	0.11	0.00	0.00	0.00	0.00	<b>0.45</b>
<b>Pu239</b>	0.02i	0.10	0.12	0.00	0.42	0.00	0.08	<b>0.45</b>
<b>Pu240</b>	0.00	0.01	0.01	0.00	0.00	0.00	0.01	<b>0.02</b>
<b>Pu241</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>Total</b>	<b>0.24</b>	<b>0.46</b>	<b>0.16</b>	<b>0.01</b>	<b>0.59</b>	<b>0.00</b>	<b>0.08</b>	<b>0.81</b>



$k_{\text{eff}}$

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.00	0.00	0.11	0.00	0.00	0.00	0.00	<b>0.11</b>
<b>Na23</b>	0.04	0.07	0.00	0.07	0.00	0.00	0.00	<b>0.11</b>
<b>Cr52</b>	0.02	0.02	0.02	0.00	0.00	0.00	0.00	<b>0.04</b>
<b>Fe56</b>	0.10	0.11	0.10	0.02	0.00	0.00	0.00	<b>0.19</b>
<b>Ni58</b>	0.01	0.01	0.03	0.00	0.00	0.00	0.00	<b>0.03</b>
<b>U235</b>	0.00	0.00	0.02	0.00	0.00	0.00	0.00	<b>0.02</b>
<b>U238</b>	0.24	0.69	0.33	0.00	0.04	0.15	0.00	<b>0.82</b>
<b>Pu239</b>	0.03	0.06	0.30	0.00	0.22	0.07	0.18	<b>0.43</b>
<b>Pu240</b>	0.01	0.02	0.07	0.00	0.05	0.09	0.03	<b>0.13</b>
<b>Pu241</b>	0.00	0.00	0.02	0.00	0.01	0.01	0.00	<b>0.02</b>
<b>Total</b>	<b>0.27</b>	<b>0.71</b>	<b>0.48</b>	<b>0.07</b>	<b>0.23</b>	<b>0.19</b>	<b>0.18</b>	<b>0.97</b>



$k_{\text{eff}}$ 

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.03	0.00	0.11	0.00	0.00	0.00	0.00	<b>0.11</b>
<b>Na23</b>	0.02	0.08	0.00	0.06	0.00	0.00	0.00	<b>0.10</b>
<b>Cr52</b>	0.02	0.02	0.02	0.00	0.00	0.00	0.00	<b>0.03</b>
<b>Fe56</b>	0.06	0.11	0.09	0.02	0.00	0.00	0.00	<b>0.16</b>
<b>Ni58</b>	0.01	0.01	0.03	0.00	0.00	0.00	0.00	<b>0.03</b>
<b>U235</b>	0.00	0.00	0.02	0.00	0.00	0.00	0.00	<b>0.02</b>
<b>U238</b>	0.22	0.96	0.37	0.00	0.05	0.17	0.00	<b>1.07</b>
<b>Pu239</b>	0.03	0.08	0.29	0.00	0.23	0.07	0.22	<b>0.44</b>
<b>Pu240</b>	0.00	0.01	0.05	0.00	0.04	0.07	0.02	<b>0.09</b>
<b>Pu241</b>	0.00	0.00	0.01	0.00	0.01	0.00	0.00	<b>0.01</b>
<b>Total</b>	<b>0.23</b>	<b>0.98</b>	<b>0.49</b>	<b>0.06</b>	<b>0.24</b>	<b>0.20</b>	<b>0.22</b>	<b>1.18</b>

## F8F5

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.27	0.02	0.13	0.00	0.00	0.00	0.00	<b>0.30</b>
<b>Na23</b>	0.32	0.49	0.00	0.04	0.00	0.00	0.00	<b>0.58</b>
<b>Cr52</b>	0.05	0.19	0.02	0.00	0.00	0.00	0.00	<b>0.20</b>
<b>Fe56</b>	0.03	0.84	0.13	0.03	0.00	0.00	0.00	<b>0.85</b>
<b>Ni58</b>	0.02	0.10	0.03	0.00	0.00	0.00	0.00	<b>0.11</b>
<b>U235</b>	0.00	0.00	0.03	0.00	0.41	0.00	0.00	<b>0.41</b>
<b>U238</b>	0.68i	7.55	0.60	0.00	0.51	0.01	0.00	<b>7.56</b>
<b>Pu239</b>	0.05i	0.40	0.47	0.00	0.13	0.00	1.63	<b>1.74</b>
<b>Pu240</b>	0.01i	0.09	0.06	0.00	0.01	0.00	0.20	<b>0.23</b>
<b>Pu241</b>	0.00	0.01	0.01	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>Total</b>	<b>0.54i</b>	<b>7.62</b>	<b>0.79</b>	<b>0.05</b>	<b>0.67</b>	<b>0.01</b>	<b>1.64</b>	<b>7.85</b>



**C8F5**

<b>Isotope</b>	<b>Elastic</b>	<b>Inelastic</b>	<b>Capture</b>	<b>Mu-bar</b>	<b>Fission</b>	<b>Nu</b>	<b>Chi-p</b>	<b>Total</b>
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.37	0.00	0.01	0.00	0.00	0.00	0.00	<b>0.37</b>
<b>Na23</b>	0.44	0.07	0.00	0.00	0.00	0.00	0.00	<b>0.45</b>
<b>Cr52</b>	0.05	0.01	0.01	0.00	0.00	0.00	0.00	<b>0.05</b>
<b>Fe56</b>	0.31	0.06	0.07	0.00	0.00	0.00	0.00	<b>0.32</b>
<b>Ni58</b>	0.04	0.01	0.01	0.00	0.00	0.00	0.00	<b>0.04</b>
<b>U235</b>	0.00	0.00	0.01i	0.00	0.42	0.00	0.00	<b>0.42</b>
<b>U238</b>	0.05i	0.63	1.12	0.00	0.00	0.00	0.00	<b>1.29</b>
<b>Pu239</b>	0.02i	0.15	0.25	0.00	0.10	0.00	0.09	<b>0.32</b>
<b>Pu240</b>	0.00	0.02	0.05	0.00	0.01	0.00	0.01	<b>0.06</b>
<b>Pu241</b>	0.00	0.01	0.01	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>Total</b>	<b>0.65</b>	<b>0.66</b>	<b>1.15</b>	<b>0.00</b>	<b>0.43</b>	<b>0.00</b>	<b>0.09</b>	<b>1.54</b>

**F9F5**

<b>Isotope</b>	<b>Elastic</b>	<b>Inelastic</b>	<b>Capture</b>	<b>Mu-bar</b>	<b>Fission</b>	<b>Nu</b>	<b>Chi-p</b>	<b>Total</b>
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.12	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.12</b>
<b>Na23</b>	0.13	0.07	0.00	0.00	0.00	0.00	0.00	<b>0.15</b>
<b>Cr52</b>	0.03	0.01	0.00	0.00	0.00	0.00	0.00	<b>0.03</b>
<b>Fe56</b>	0.09	0.05	0.02	0.00	0.00	0.00	0.00	<b>0.11</b>
<b>Ni58</b>	0.01	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>U235</b>	0.00	0.00	0.01	0.00	0.41	0.00	0.00	<b>0.41</b>
<b>U238</b>	0.05i	0.52	0.13	0.00	0.00	0.00	0.00	<b>0.53</b>
<b>Pu239</b>	0.01i	0.09	0.11	0.00	0.42	0.00	0.07	<b>0.45</b>
<b>Pu240</b>	0.00	0.01	0.01	0.00	0.00	0.00	0.01	<b>0.02</b>
<b>Pu241</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Total</b>	<b>0.20</b>	<b>0.54</b>	<b>0.17</b>	<b>0.00</b>	<b>0.59</b>	<b>0.00</b>	<b>0.07</b>	<b>0.84</b>



**VOID STEP3**

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	1.08	0.02	0.56	0.00	0.00	0.00	0.00	<b>1.21</b>
<b>Na23</b>	2.14	3.23	0.08	1.24	0.00	0.00	0.00	<b>4.07</b>
<b>Cr52</b>	0.13	0.12	0.05	0.00	0.00	0.00	0.00	<b>0.19</b>
<b>Fe56</b>	0.69	0.51	0.69	4.51	0.00	0.00	0.00	<b>4.65</b>
<b>Ni58</b>	0.10	0.06	0.11	0.00	0.00	0.00	0.00	<b>0.16</b>
<b>U235</b>	0.00	0.01	0.04	0.00	0.03	0.02	0.00	<b>0.05</b>
<b>U238</b>	0.68i	5.71	2.13	0.00	0.06	0.31	0.00	<b>6.06</b>
<b>Pu239</b>	0.03i	0.67	0.44	0.00	1.46	0.42	0.25	<b>1.74</b>
<b>Pu240</b>	0.01	0.08	0.27	0.00	0.11	0.12	0.09	<b>0.34</b>
<b>Pu241</b>	0.00	0.02	0.04	0.00	0.04	0.01	0.00	<b>0.06</b>
<b>Total</b>	<b>2.40</b>	<b>6.62</b>	<b>2.37</b>	<b>4.68</b>	<b>1.47</b>	<b>0.54</b>	<b>0.26</b>	<b>8.92</b>

**VOID STEP5**

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	1.20	0.03	0.76	0.00	0.00	0.00	0.00	<b>1.42</b>
<b>Na23</b>	1.95	4.16	0.11	2.84	0.00	0.00	0.00	<b>5.40</b>
<b>Cr52</b>	0.06	0.17	0.07	0.00	0.00	0.00	0.00	<b>0.19</b>
<b>Fe56</b>	0.57	0.69	0.92	3.13	0.00	0.00	0.00	<b>3.38</b>
<b>Ni58</b>	0.09	0.08	0.16	0.00	0.00	0.00	0.00	<b>0.20</b>
<b>U235</b>	0.00	0.01	0.05	0.00	0.04	0.02	0.00	<b>0.07</b>
<b>U238</b>	1.07	7.41	2.83	0.00	0.11	0.49	0.00	<b>8.02</b>
<b>Pu239</b>	0.13	0.83	0.59	0.00	1.98	0.57	0.38	<b>2.34</b>
<b>Pu240</b>	0.02	0.10	0.35	0.00	0.16	0.20	0.14	<b>0.47</b>
<b>Pu241</b>	0.00	0.03	0.05	0.00	0.06	0.02	0.00	<b>0.08</b>
<b>Total</b>	<b>2.59</b>	<b>8.57</b>	<b>3.15</b>	<b>4.23</b>	<b>1.99</b>	<b>0.78</b>	<b>0.41</b>	<b>10.62</b>



$k_{\text{eff}}$ 

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>O16</b>	0.05	0.00	0.13	0.00	0.00	0.00	0.00	<b>0.14</b>
<b>Na23</b>	0.02	0.08	0.00	0.06	0.00	0.00	0.00	<b>0.10</b>
<b>Cr52</b>	0.01	0.02	0.02	0.00	0.00	0.00	0.00	<b>0.03</b>
<b>Fe56</b>	0.04	0.10	0.09	0.02	0.00	0.00	0.00	<b>0.14</b>
<b>Ni58</b>	0.01	0.03	0.08	0.00	0.00	0.00	0.00	<b>0.09</b>
<b>U235</b>	0.00	0.00	0.02	0.00	0.00	0.00	0.00	<b>0.02</b>
<b>U238</b>	0.17	0.78	0.32	0.00	0.04	0.14	0.00	<b>0.87</b>
<b>Pu239</b>	0.02	0.07	0.24	0.00	0.18	0.06	0.15	<b>0.35</b>
<b>Pu240</b>	0.01	0.04	0.13	0.00	0.10	0.19	0.06	<b>0.27</b>
<b>Pu241</b>	0.00	0.02	0.10	0.00	0.08	0.04	0.00	<b>0.14</b>
<b>Total</b>	<b>0.19</b>	<b>0.80</b>	<b>0.47</b>	<b>0.06</b>	<b>0.22</b>	<b>0.25</b>	<b>0.16</b>	<b>1.02</b>



$k_{\text{eff}}$ 

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.01	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>O16</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>Na23</b>	0.02	0.07	0.00	0.12	0.00	0.00	0.00	<b>0.14</b>
<b>Cr52</b>	0.08	0.02	0.02	0.00	0.00	0.00	0.00	<b>0.08</b>
<b>Fe56</b>	0.25	0.17	0.15	0.08	0.00	0.00	0.00	<b>0.35</b>
<b>Ni58</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>U235</b>	0.00	0.00	0.01	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>U238</b>	0.18	0.76	0.22	0.00	0.04	0.15	0.00	<b>0.83</b>
<b>Pu239</b>	0.04	0.10	0.24	0.00	0.25	0.08	0.20	<b>0.42</b>
<b>Pu240</b>	0.01	0.01	0.03	0.00	0.04	0.07	0.02	<b>0.09</b>
<b>Pu241</b>	0.00	0.00	0.01	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>Total</b>	<b>0.33</b>	<b>0.79</b>	<b>0.36</b>	<b>0.15</b>	<b>0.26</b>	<b>0.18</b>	<b>0.20</b>	<b>1.01</b>



$k_{\text{eff}}$ 

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.01	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>O16</b>	0.04	0.00	0.11	0.00	0.00	0.00	0.00	<b>0.11</b>
<b>Na23</b>	0.02	0.08	0.00	0.08	0.00	0.00	0.00	<b>0.11</b>
<b>Cr52</b>	0.04	0.02	0.02	0.00	0.00	0.00	0.00	<b>0.05</b>
<b>Fe56</b>	0.17	0.15	0.17	0.05	0.00	0.00	0.00	<b>0.29</b>
<b>Ni58</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>U235</b>	0.00	0.00	0.01	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>U238</b>	0.12	0.58	0.29	0.00	0.03	0.12	0.00	<b>0.67</b>
<b>Pu239</b>	0.03	0.08	0.33	0.00	0.24	0.08	0.17	<b>0.45</b>
<b>Pu240</b>	0.01	0.02	0.06	0.00	0.05	0.09	0.02	<b>0.12</b>
<b>Pu241</b>	0.00	0.00	0.01	0.00	0.01	0.00	0.00	<b>0.01</b>
<b>Total</b>	<b>0.22</b>	<b>0.61</b>	<b>0.49</b>	<b>0.09</b>	<b>0.24</b>	<b>0.17</b>	<b>0.18</b>	<b>0.88</b>



$k_{\text{eff}}$

Isotope	Elastic	Inelastic	Capture	Mu-bar	Fission	Nu	Chi-p	Total
<b>B10</b>	0.00	0.00	0.01	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>O16</b>	0.06	0.00	0.11	0.00	0.00	0.00	0.00	<b>0.12</b>
<b>Na23</b>	0.02	0.12	0.00	0.07	0.00	0.00	0.00	<b>0.14</b>
<b>Cr52</b>	0.04	0.03	0.02	0.00	0.00	0.00	0.00	<b>0.05</b>
<b>Fe56</b>	0.14	0.22	0.15	0.05	0.00	0.00	0.00	<b>0.30</b>
<b>Ni58</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<b>0.00</b>
<b>U235</b>	0.00	0.00	0.01	0.00	0.00	0.00	0.00	<b>0.01</b>
<b>U238</b>	0.11	0.73	0.23	0.00	0.03	0.11	0.00	<b>0.78</b>
<b>Pu239</b>	0.02	0.08	0.21	0.00	0.17	0.05	0.16	<b>0.33</b>
<b>Pu240</b>	0.02	0.08	0.18	0.00	0.17	0.30	0.12	<b>0.42</b>
<b>Pu241</b>	0.00	0.02	0.06	0.00	0.06	0.03	0.00	<b>0.09</b>
<b>Total</b>	<b>0.20</b>	<b>0.78</b>	<b>0.41</b>	<b>0.09</b>	<b>0.25</b>	<b>0.32</b>	<b>0.20</b>	<b>1.02</b>



## *Methodologies for Sensitivities Analysis*

By definition, a sensitivity coefficient  $S$  denotes the relative variation of an integral parameter  $R$  due to the relative variation of a cross section  $\sigma$ :

$$S_j = \frac{\partial R}{R} \bigg/ \frac{\partial \sigma_j}{\sigma_j} \quad j = \text{isotope, reaction, energy group}$$

Using a covariance matrix,  $D$ , the uncertainty on the parameter  $R$  is evaluated as:

$$\Delta R^2 = S_R^+ D S_R$$



## *Methodologies for Sensitivity Analyses*

### Forward (direct) method

Advantages: Is preferable when there are few input parameters (cross sections) that can vary and many integral parameters of interest.

Is advisable when the code in use has poor capabilities to solve adjoint neutron equations (see e.g., the “stochastic” probabilistic method with Monte Carlo codes).

If the code in use has capabilities to evaluate the integral parameter of interest and to perturb a single cross section, the forward method can be used for the sensitivity analysis without the need of further developments.

Confidence of the obtained results (sensitivities by adjoint method are often validated by direct perturbation calculations).

Disadvantages: The main drawbacks are the large number of direct calculations and demanding computational resources. However, the powerful machines available nowadays significantly reduced this penalty.



## *Methodologies for Sensitivity Analyses*

### Adjoint method

Advantages: The adjoint method is preferable when there are a limited number of integral parameters and a very large number of input parameters that can vary (i.e., cross sections).

... is more “elegant” than the forward method!

Disadvantages: Procedures have to be developed and sometimes the code itself has to be modified for the solution of the adjoint importance equations every time sensitivities are required for a new integral parameter or with respect to new reaction cross sections.

