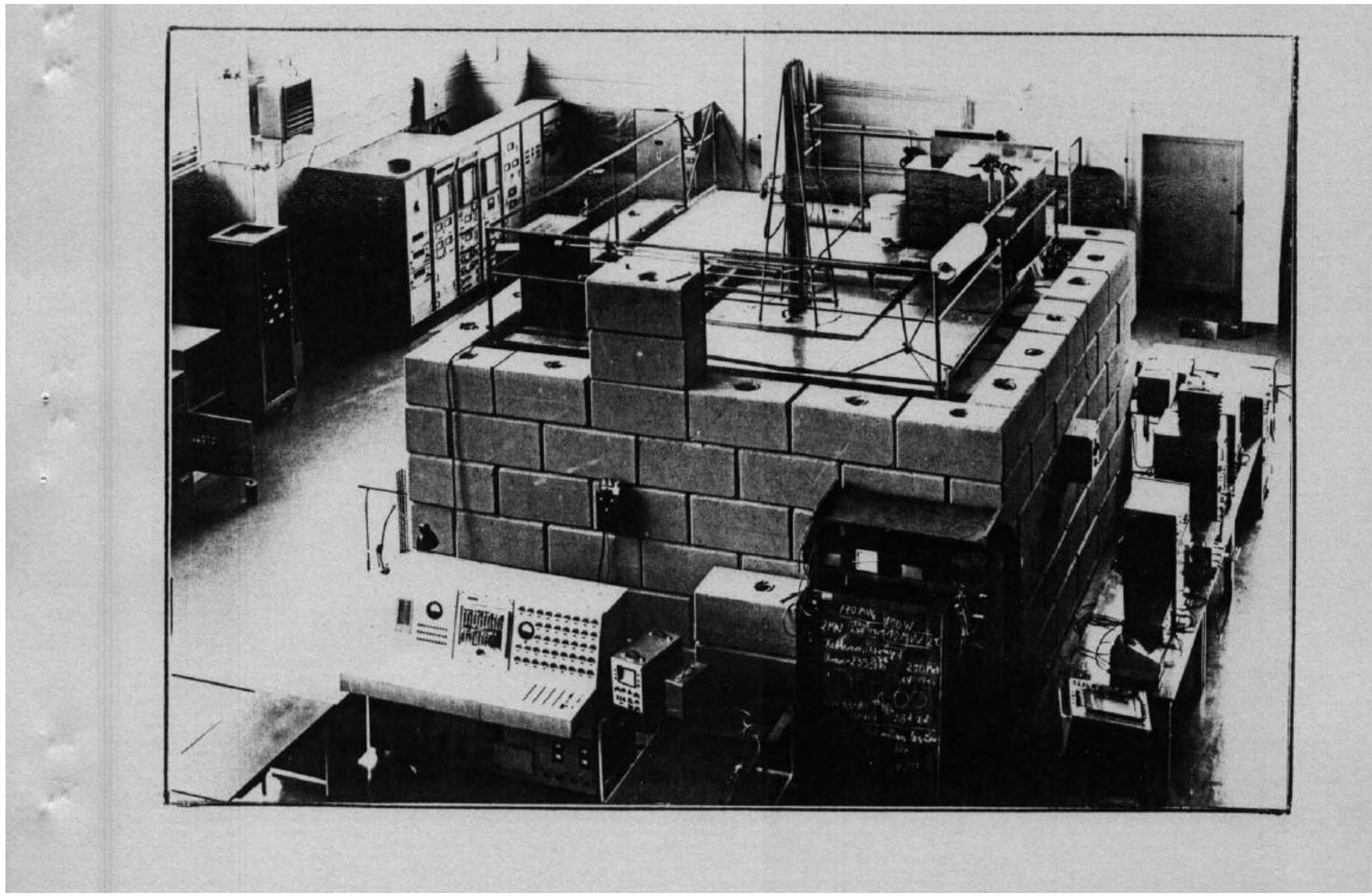
Re-analysis of the RRR/SEG Reactivity Measurements using TRIPOLI-4



Dietze [1]

Andrew Hummel

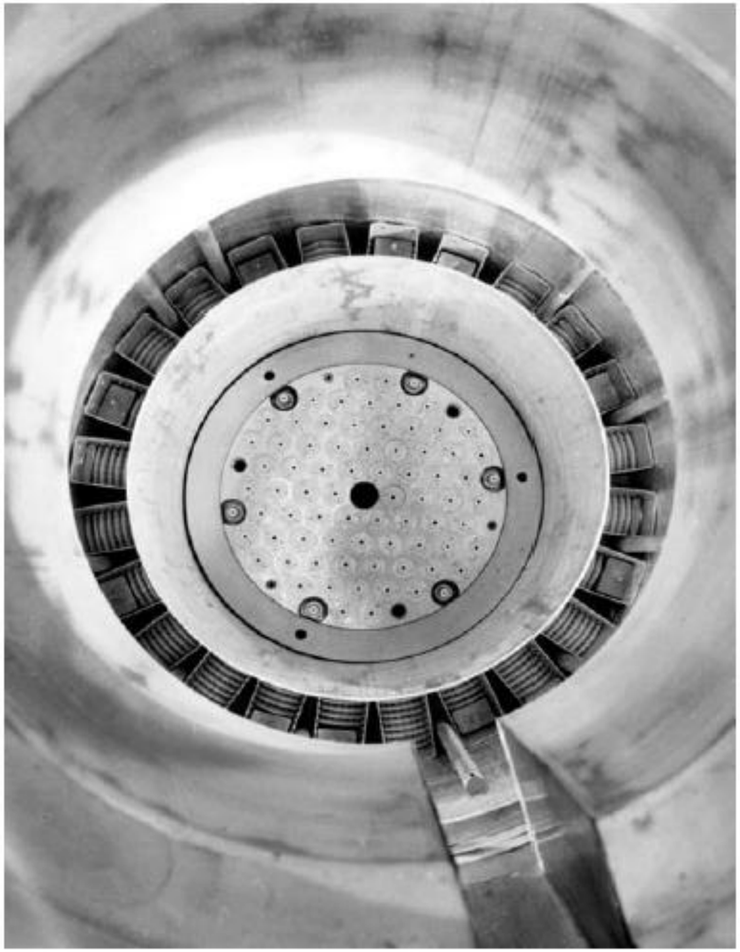
2016 WPEC Meeting [SG39] – Paris, France

RRR/SEG Fast-Thermal Coupled Facility

- Rossendorfer Ringzonen-Reaktor (RRR)
  - Zero power Argonaut type reactor consisting of an annular core
  - Criticality reached December 16, 1962
  - Thermal driver fuel zone:
    - 60 %U_3O_8 / 40% Al (20% U-235)
  - Contained both outer and inner graphite reflectors

- Schnelles Einsatz-Gitter (SEG)
  - Fast insertion lattice deployed in 1972
  - Al or Fe matrix filled with varying pellets (unit cells)
  - 7 primary configurations
  - Initial focus on SEG 4 – 7: Measurements/data on structural materials and fission products

RRR/SEG Fast-Thermal Coupled Facility

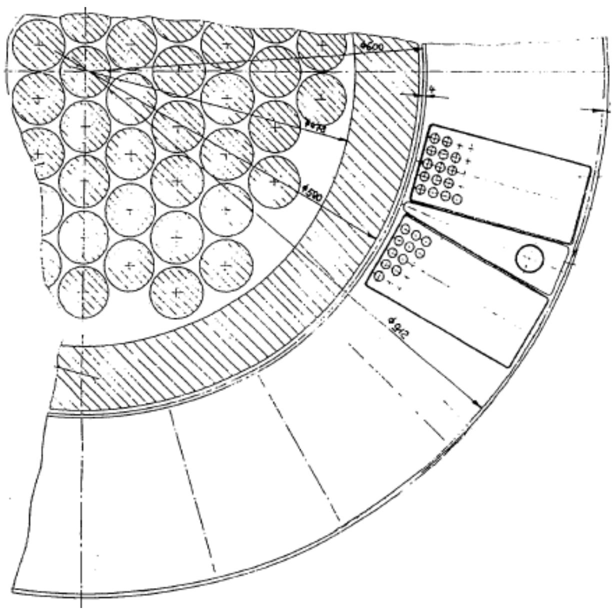


Liewers [2]

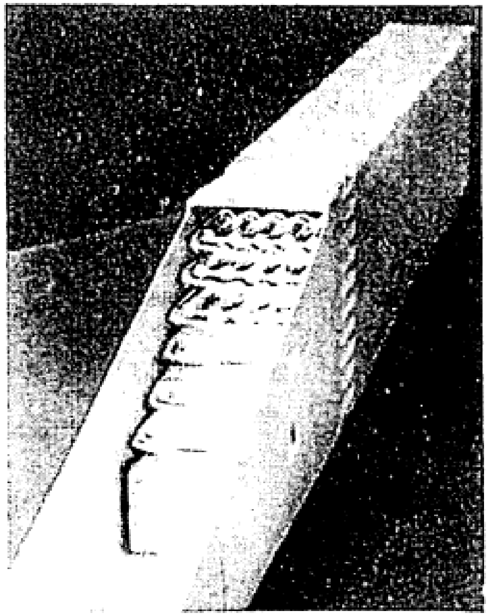
Integral experimental setup used to perform small sample reactivity measurements

RRR/SEG Fast-Thermal Coupled Facility

- Annular driver zone consists of 24 rectangular cassettes with a max of 12 fuel sections of 6 pins in each cassette
  - 24 triangular graphite wedges fill in between; water moderated
- This zone is treated homogenously since the exact number of fuel sections varies (and is unknown); vary the radius to achieve criticality

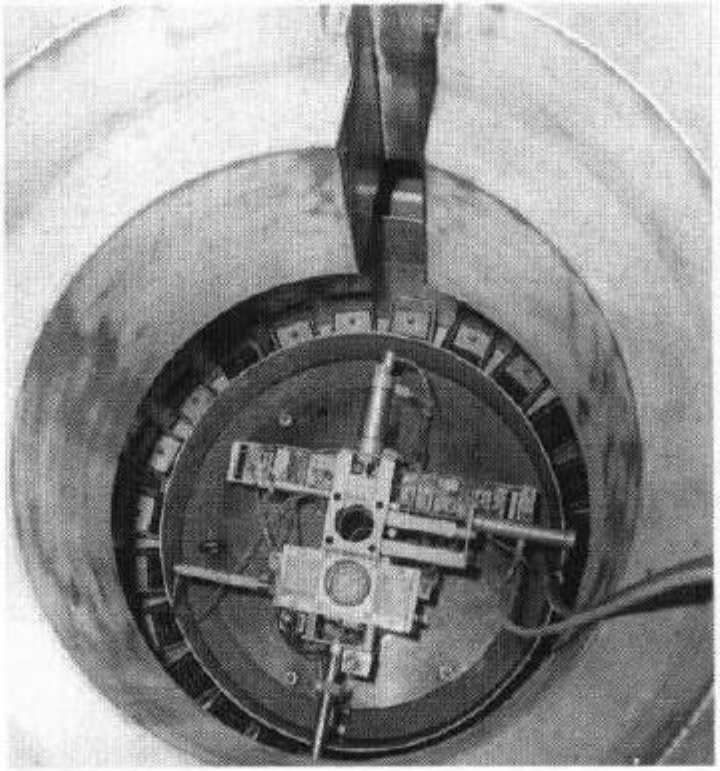


Dietze [3]

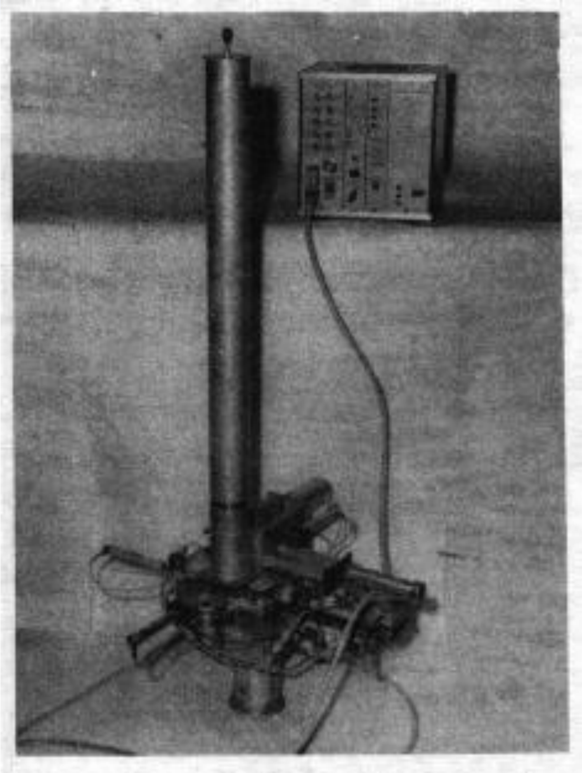


Kampf & Liewers [4]

Pile Oscillator Method for Measurement



Dietze et al [5]



Lehmann et al [6]

- PUWO oscillator (Probe-Untergrund-Wechseloszillator)
- Pneumatically driven with a 20.48 second period, 80cm stroke
- Measured background and reactivity effect simultaneously
- Depends on reactor power, number of measured periods, and reproducibility
  - $\Delta k/k < 10^{-8}$ is achieved after 1000 cycles

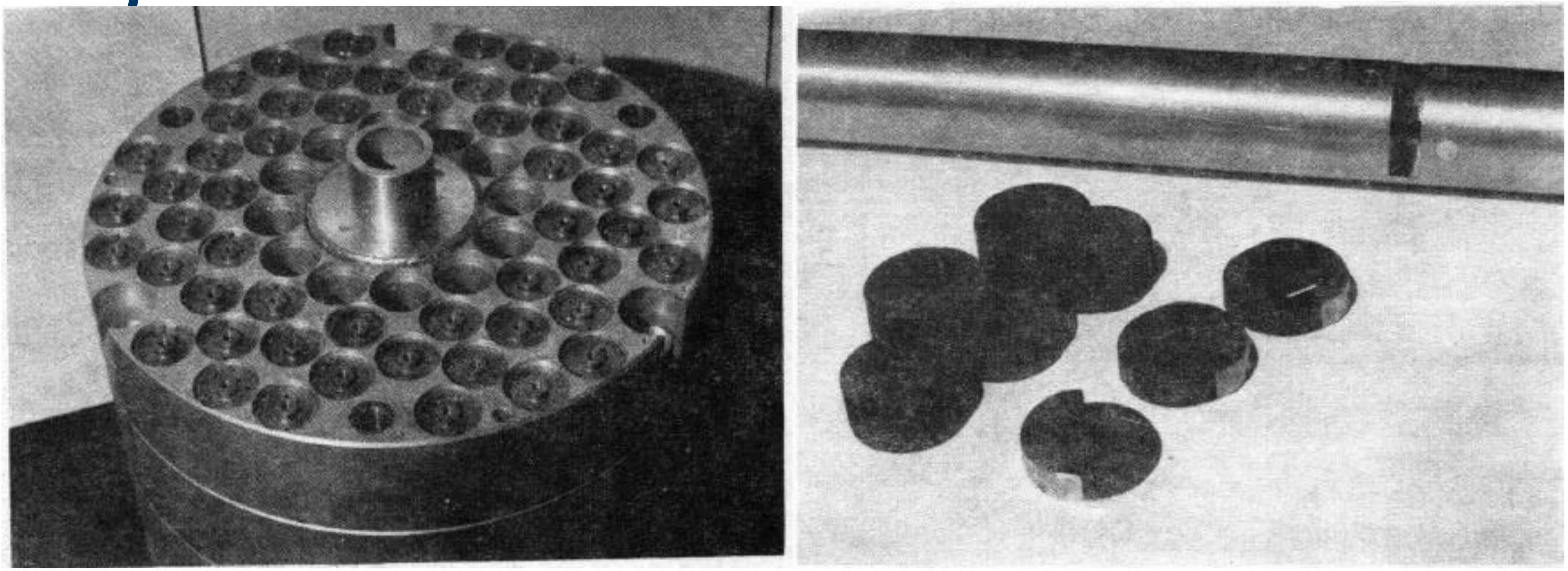
Description of Measurements

- The pile oscillator method was used to measure reactivity effects
  - +/- 0.3 millicents – accuracy of method
  - +/- 0.1 millicents – inherent accuracy due to reactor drift behavior

- Oscillating Al tube filled with graphite and samples placed in graphite containers
  - Oscillated against dummy graphite containers - "clean experiments"

- Neutron spectrum measurements [5], [10]
  - Boron ionization chamber detected the flux response
  - Proton recoil spec., Li-6 sandwich spec., stilbene scintillation, foil activation, fission reaction rates…….
- Importance function measurements, verification [11]
  - Radioactive neutron sources (Ra-Be, Na-Be, Na-D, Sb-Be)
  - Pure scattering material (H, D, C)
  - Materials with similar behavior (Pb, Al, Bi)

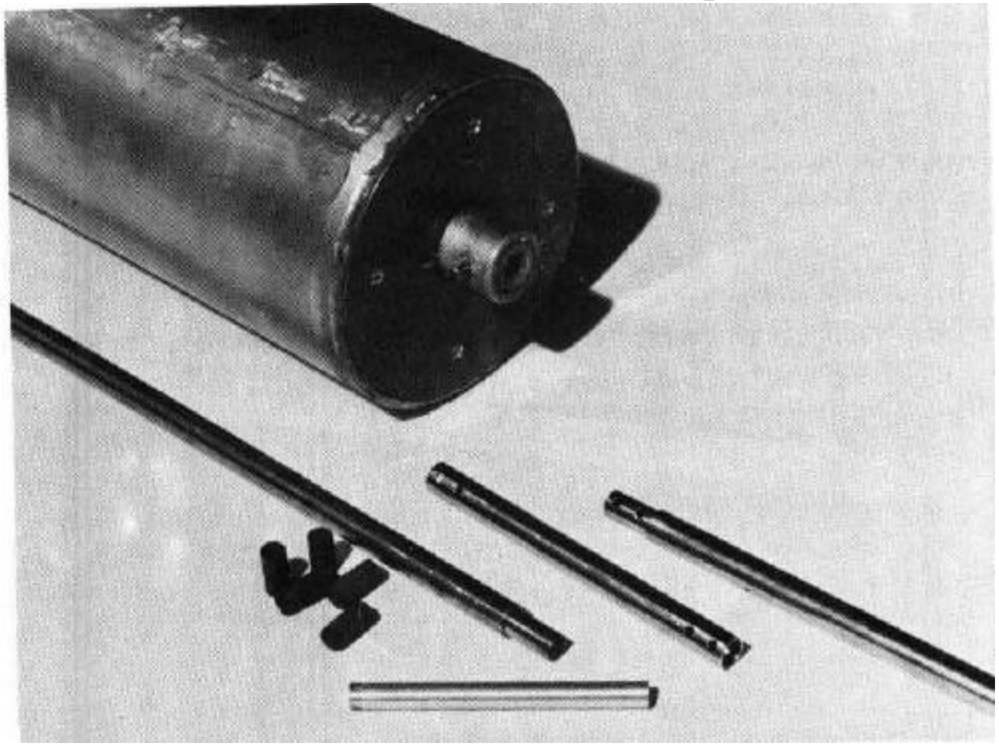
SEG 6 insertion lattice; oscillator tube and small sample disks for EK-45



Lehmann et al [7]

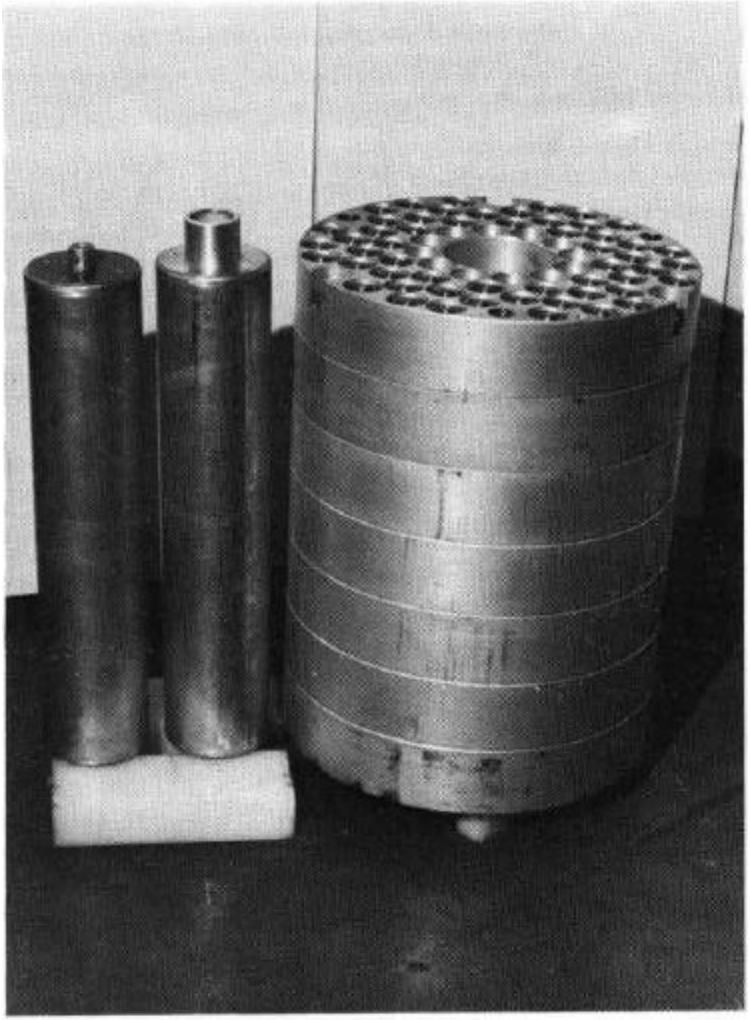
"Reactivity and the total neutron population undergo oscillations with the same frequency as the oscillations of the sample" (Foell – 1972)

SEG 6 aluminum lattice; absorbing insertion zone and wire samples for EK-10



Lehmann et al [7]

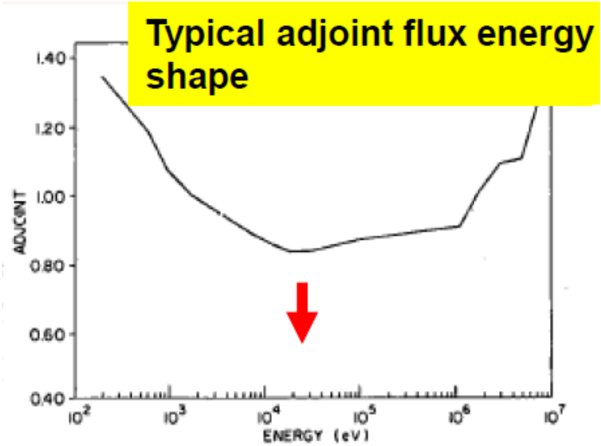
“The sample reactivity is identical with the reactivity difference in the two oscillator positions” (Dietze – 1993)



Lehmann et al [8]

Spectral Characteristics

- Adjoint exhibits a depression around 10 keV with rapid increases to higher and lower energies



- Different pellet arrangements in the SEG lattice lead to both hard and soft neutron spectrums and different adjoint function shapes
  - Obtain separate capture and scattering information

- Measured through pseudo-reactivity worths of different radioactive neutron sources in central channel

SEG Pellet Unit Cells

- SEG 4/5: energy-independent adjoint spectrum (reduce U-238 content)
  - Slowing down effect disappears: i.e. the reactivity change is due only to capture

SEG 4 →

C	Cd	C	Cd	C	Cd	C	Cd	U 36%	Cd	C	Cd	C	Cd	C	Cd	C	Cd

SEG 5 →

C	BG	C	U 36%	C	BG	C

BG=borated graphite

- SEG 6 EK-10/EK-45: monotonously rising adjoint function
  - Hard neutron spectrum with a dominant, negative scattering effect: suitable for inelastic scattering data

SEG 6 → no unit cell (radial arrangement of nat U and 36% U)

- SEG 7A/7B: similar to SEG 4/5 but have softer neutron spectrums (PE)
  - Capture and scattering effects are negative

SEG 7A →

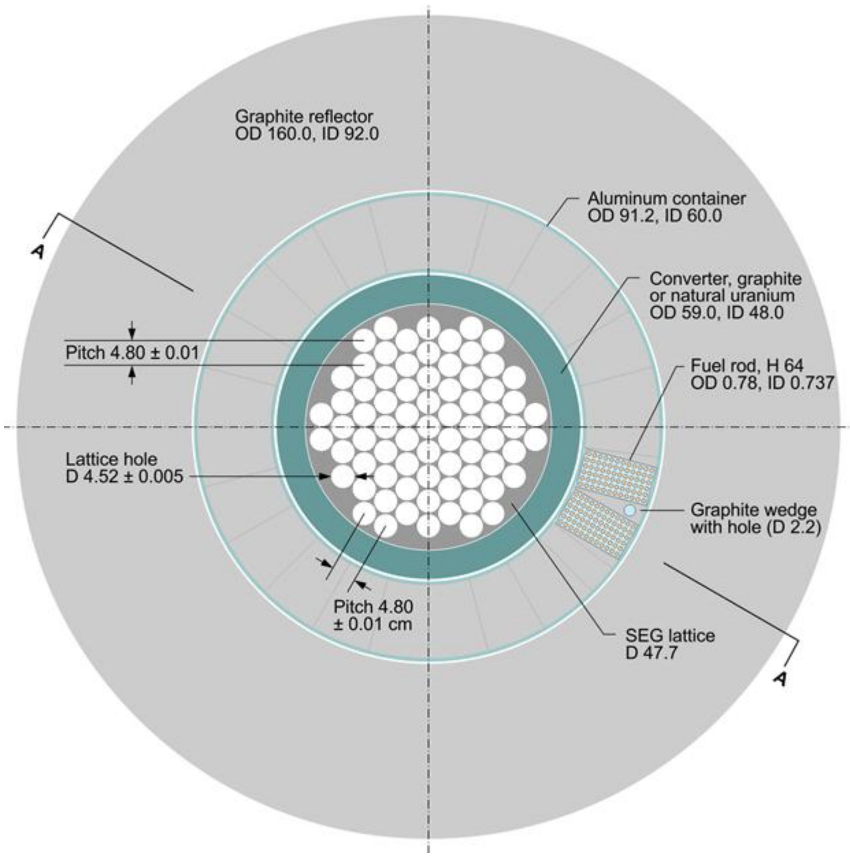
C	BG	PE	U 36%	BG	C	PE	BG

SEG 7B →

BG	PE	C	PE	U 36%	BG	PE	C	PE

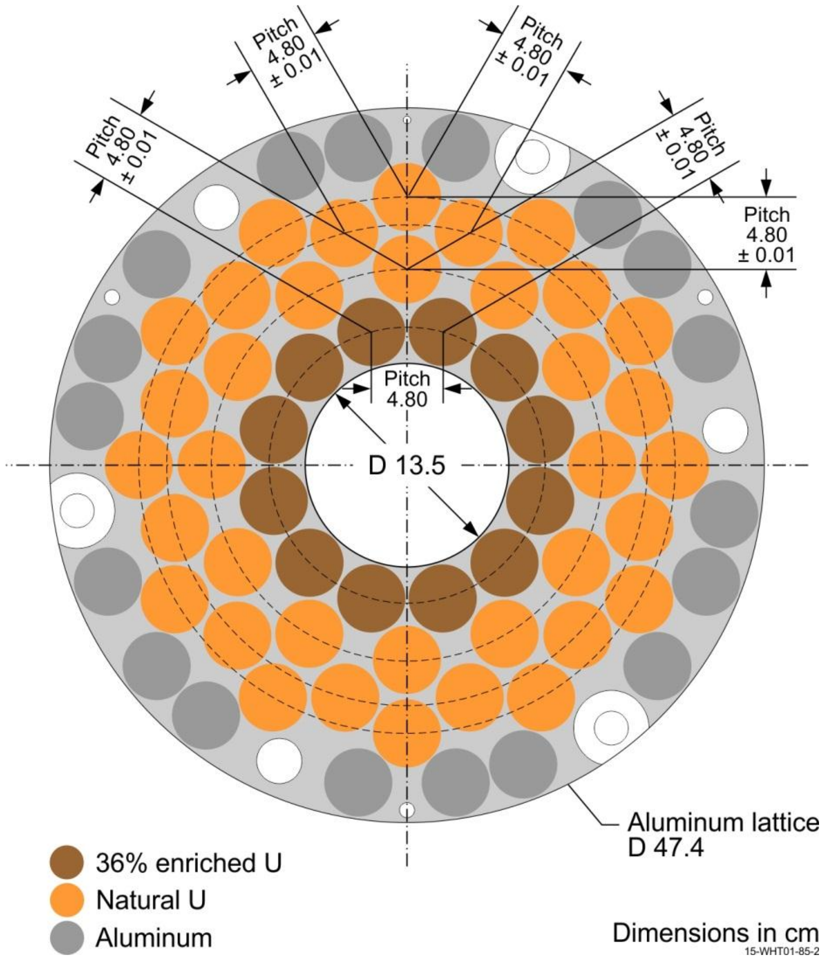
PE=polyethylene

RRR/SEG Fast-Thermal Coupled Facility

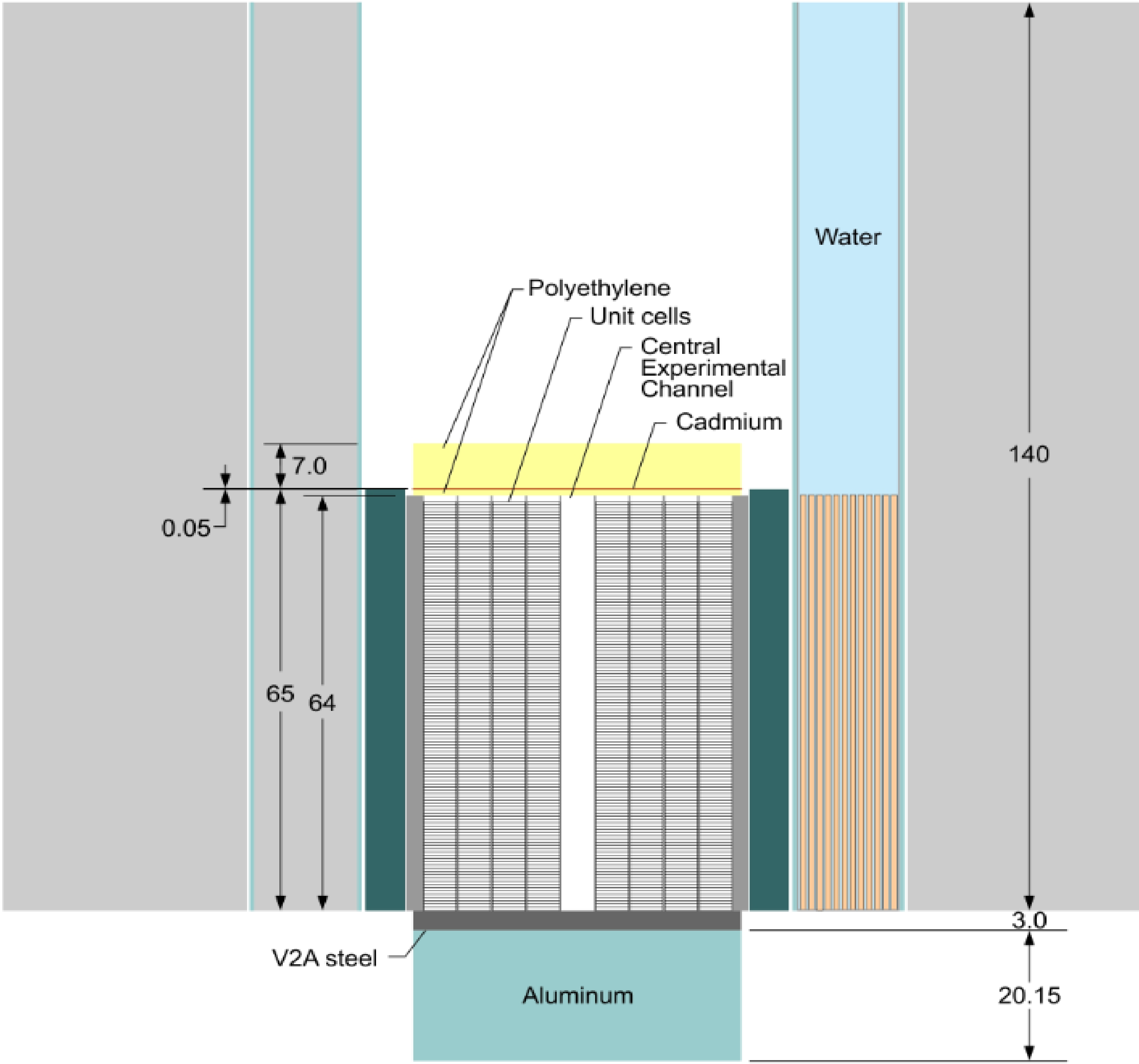


- SEG 4, 5, & 7 lattice
  - 72 holes in a six-angular arrangement
  - Central channel filled with graphite and sample material
  - Pellets grouped in unit cells fill holes
  - Graphite converter surrounded by annular driver fuel

RRR/SEG Fast-Thermal Coupled Facility



- SEG 6 lattice
  - Radial arrangement of 4 rings each having 12 channels
  - Inner ring: 36% enriched U
  - Outer 3 rings: natural U
  - Inner absorption zone: B_4C
  - Experimental channel is either 5.0 or 1.2 cm in diameter
  - Natural U converter surrounded by annular driver fuel



Section A-A

Dimensions in cm

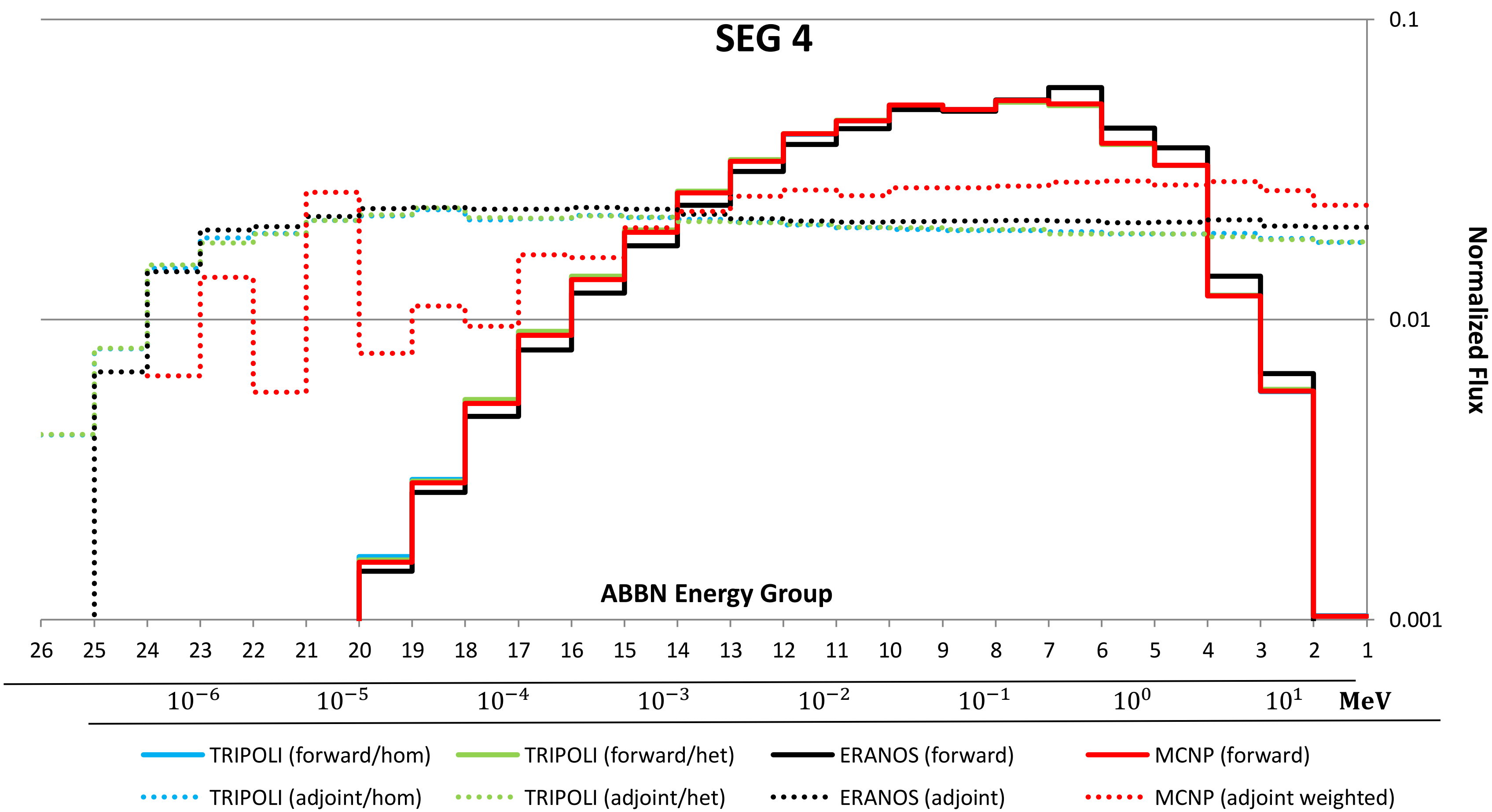
TRIPOLI-4 Continuous Energy MC code

- Capable of exact perturbation theory
  - Perform forward calculation with ***perturbed cross-sections*** to obtain flux
    - Collision sites saved; parameters stored (i.e. location, energy, direction, neutron weight, cross-sections)
  - Obtain the adjoint flux via the Iterated-Fission-Probability method with ***reference, unpertubed cross-sections***
    - Previous collision sites used as external source; parameters again stored
  - Use quantities to perform continuous integration to determine reactivity effect

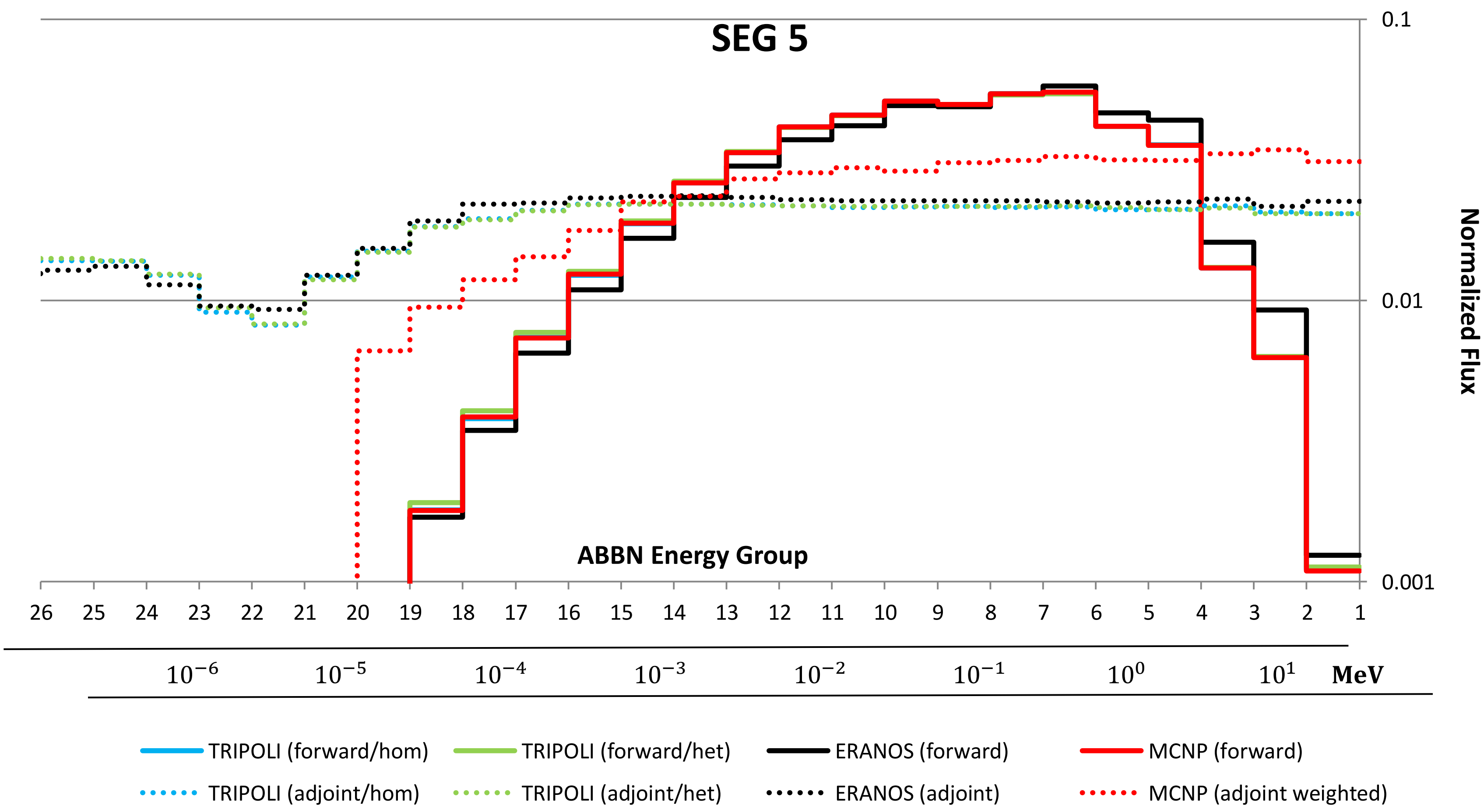
$$\Delta\rho = -\frac{\left\langle \phi^{\dagger}_{ref}, \left(\Delta M - \frac{\Delta P}{k_{ref}}\right)\phi_{pert}\right\rangle}{\left\langle \phi^{\dagger}_{ref}, P_{pert}\phi_{pert}\right\rangle}$$

	SEG 4	SEG 5	SEG 6_45	SEG 7A	SEG 7B
	k_{eff}				
MCNP6 ENDF/B-7.0	1.00058	0.99954	1.00040	1.00001	1.00060
ENDF/B-7.1	0.99943	0.99867	0.99961	0.99918	0.99982
TRIPOLI4 ENDF/B-7.1 (homogeneous)	0.99989	0.99920	1.00036	0.99979	1.00024
TRIPOLI4 ENDF/B-7.1 (heterogeneous)	0.99848	1.00034	0.99905	0.99952	1.00105
	$0.00001 < 1\sigma < 0.00004$				
Δ ENDF/B-7.1 (homogeneous)	**46 pcm**	**53 pcm**	**75 pcm**	**61 pcm**	**42 pcm**
Homogeneous Critical Radius (cm)	7.82	7.45	9.17	8.50	7.98
Heterogeneous Critical # Fuel Plates	141	~ 138	~ 158	150	~ 145

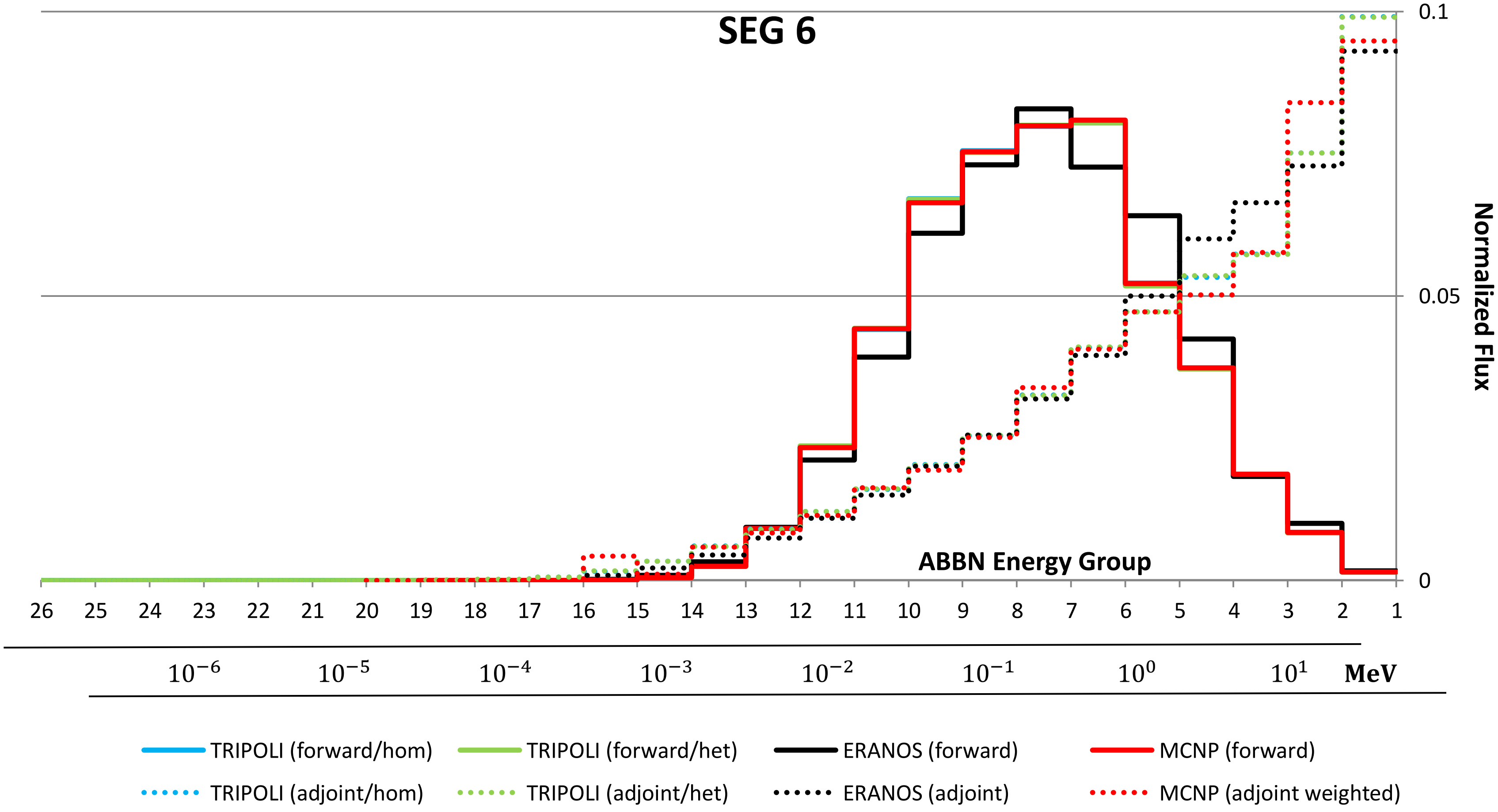
Forward and Adjoint Flux Spectrums



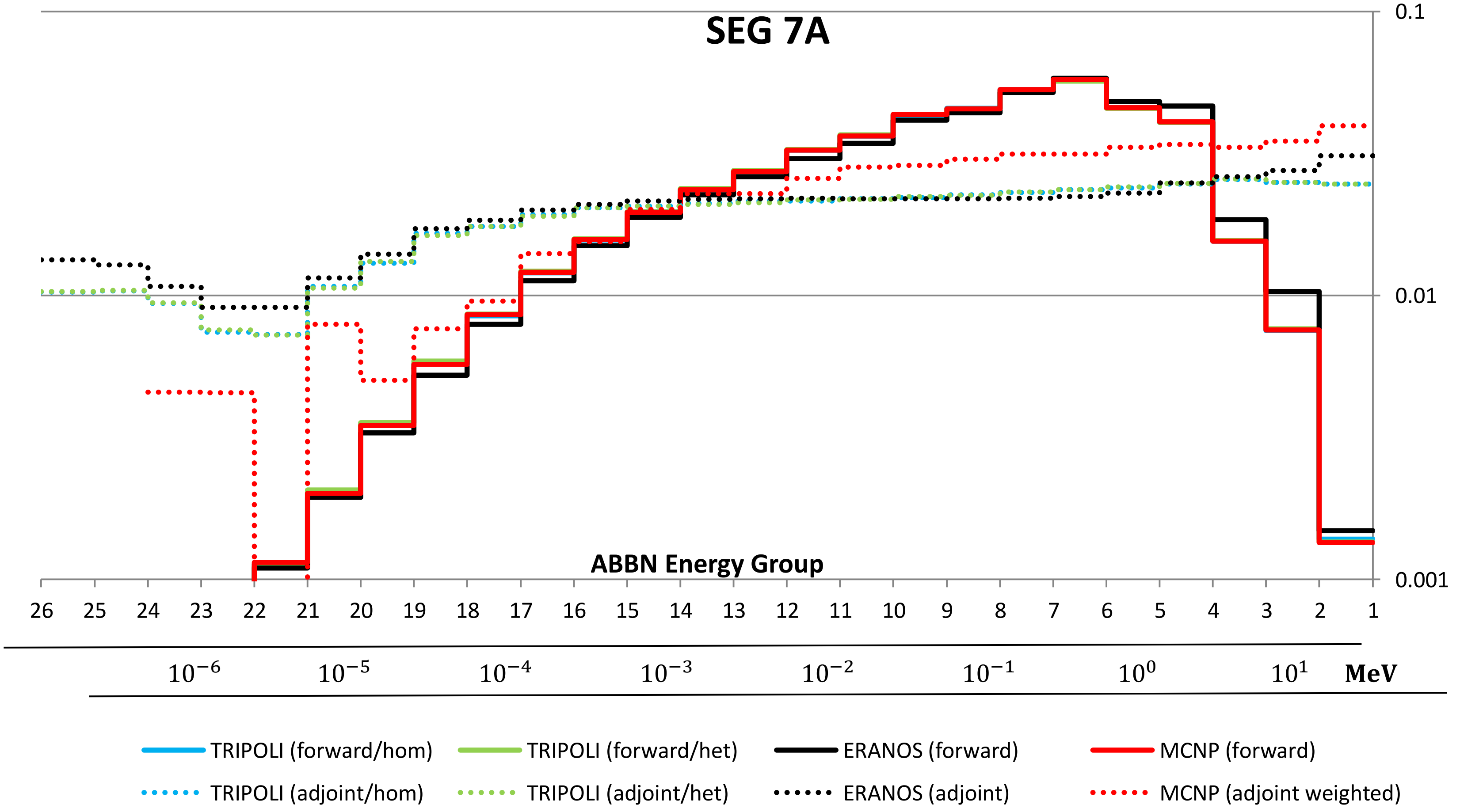
Forward and Adjoint Flux Spectrums



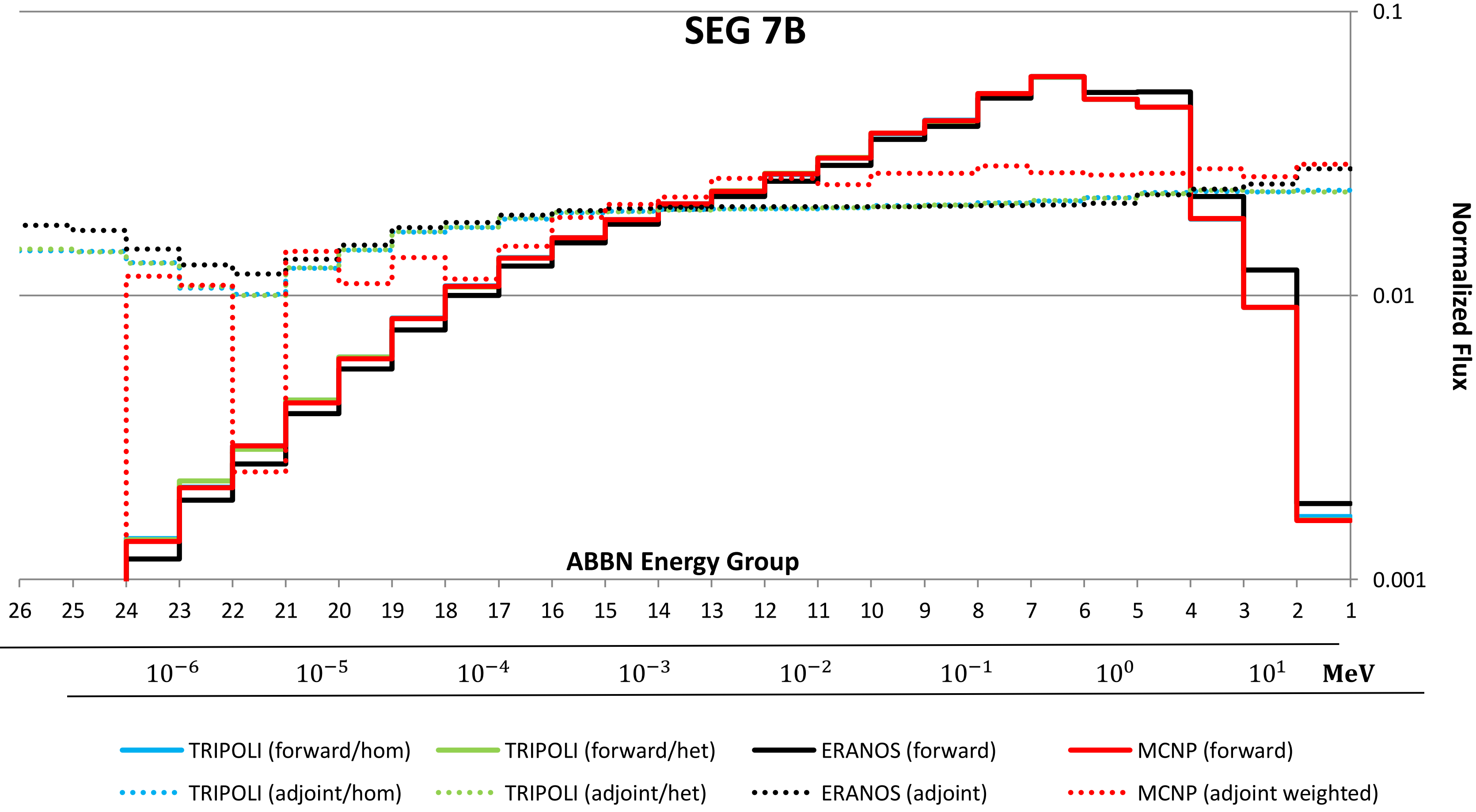
Forward and Adjoint Flux Spectrums



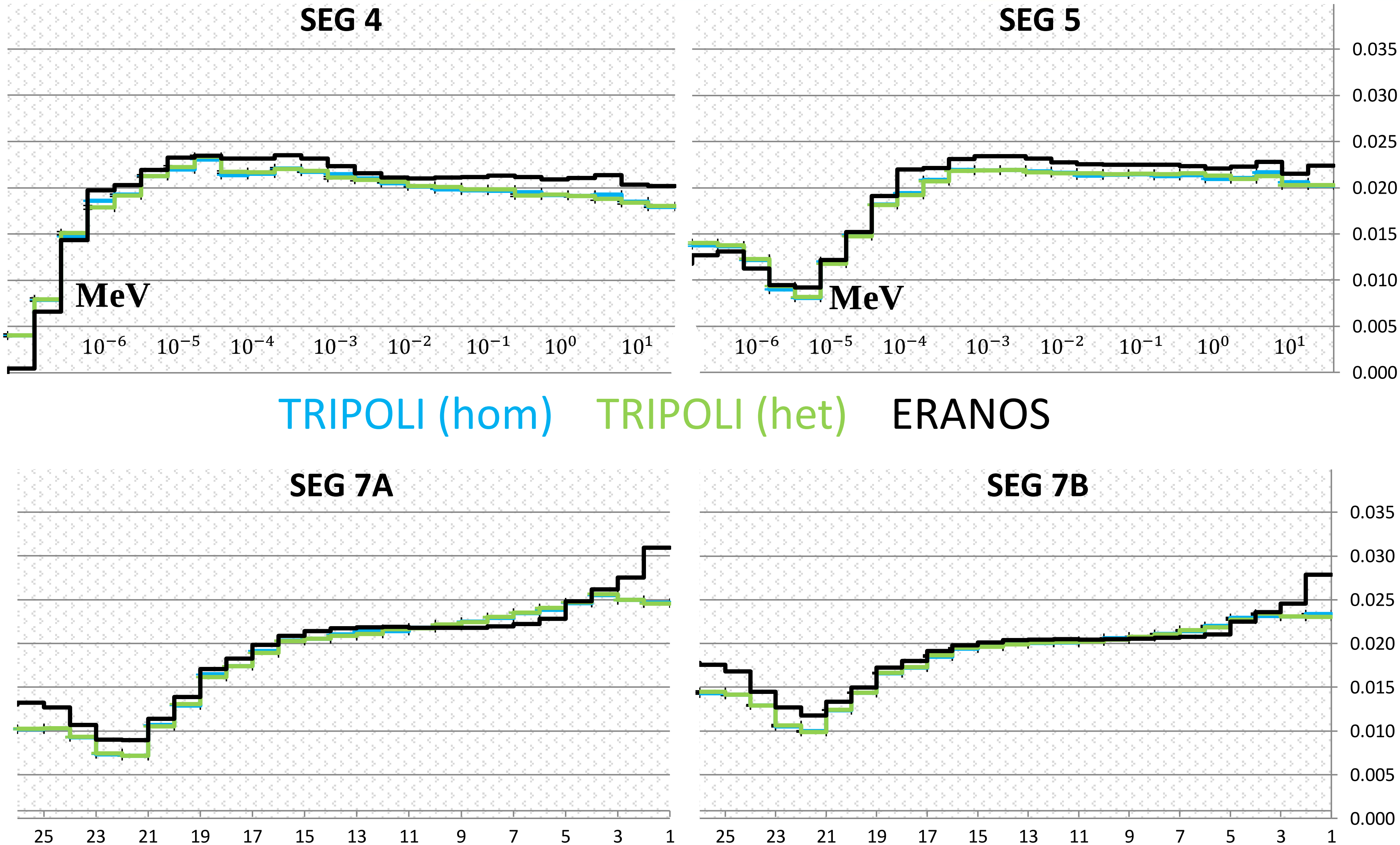
Forward and Adjoint Flux Spectrums



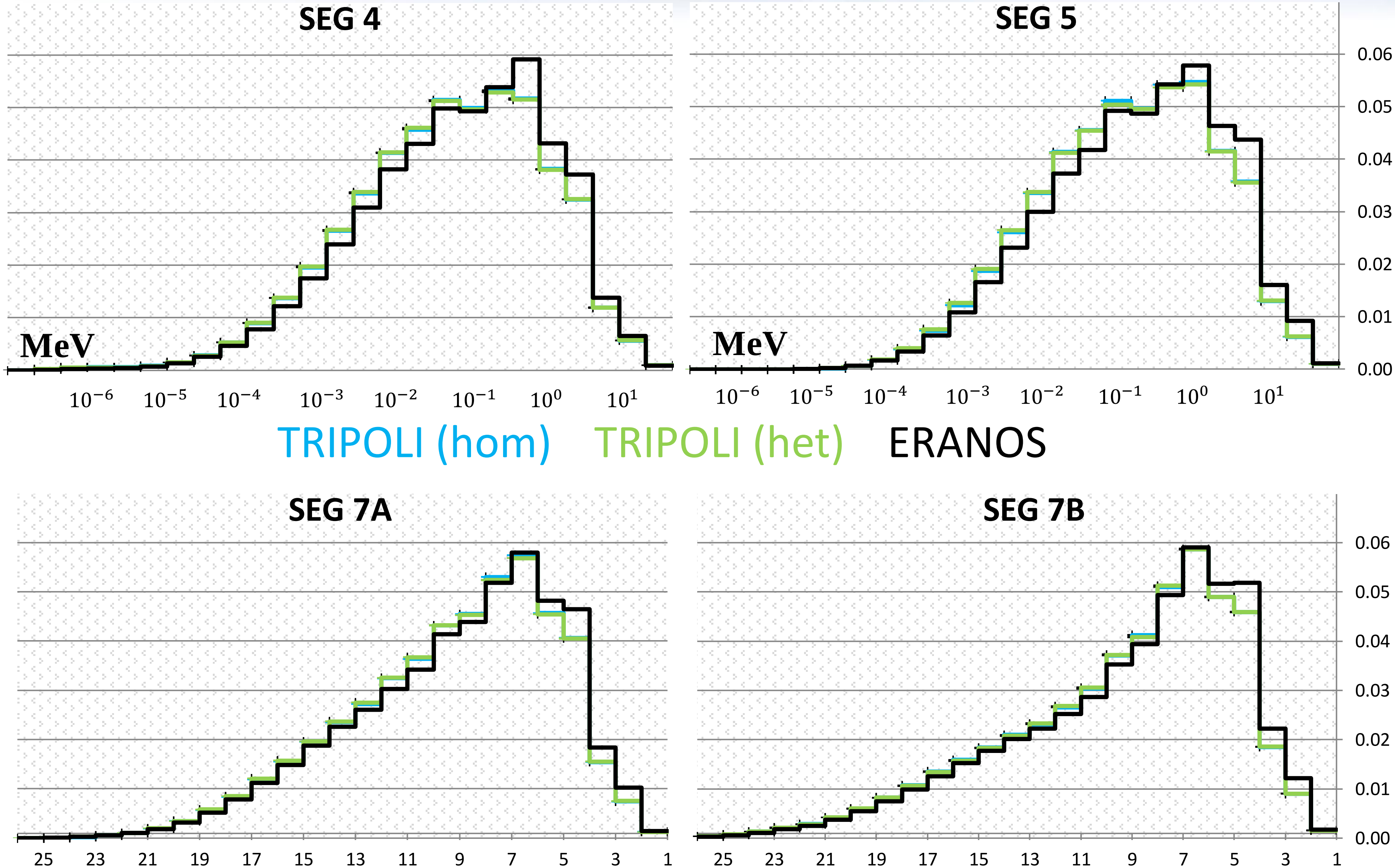
Forward and Adjoint Flux Spectrums



Adjoint Discrepancies (linear plot)



Forward Discrepancies (linear plot)



SEG4 CRWs; Normalized to B10

$$\frac{C}{E} = \frac{C_i * E_{ref} * A_{ref}}{E_i * C_{ref} * A_i}$$

Sample Material	ID-No.	CRW exp. (millicent/g)	C/E-values 70g JNC route JENDL-3.2	C/E-values 70g JNC route JEF-2.2	C/E-values 33g ECCO/ERANOS JEF-2.2	Total C/E Error (%)	C/E-values 1968g TRIPOLI JEFF-3.2	Calc. C/E Error (%)
B-10	105	- 1326 ± 20	1.000	1.000	1.000	2	1.000	0.6
U-235	925	+ 31.2 ± 2.0	0.950	0.980	0.965	10	**0.741**	0.6
U-238	928	- 7.2 ± 0.5	**1.260**	**1.242**	1.056	10	**1.174**	4.0
Ta	731	- 37.0 ± 2.0	0.922	0.884	**0.851**	8	0.956	2.3
Mo	42	- 6.2 ± 0.5	**1.208**	1.153	0.906	12	1.135	3.9
Nb	413	- 8.5 ± 0.5	1.039	1.049	0.889	10	0.966	1.2
Mn	25	- 8.3 ± 0.6	**0.826**	**1.214**	0.957	11	**1.170**	2.6
Fe	26	- 0.52 ± 0.07	**1.340**	**1.388**	1.086	12	**0.774**	6.1
Cr	24	- 0.50 ± 0.03	**1.167**	**1.291**	1.076	10	**0.733**	5.2
Ni	28	- 1.00 ± 0.08	1.067	1.104	1.091	11	1.007	2.2
Cd	48	- 7.5 ± 0.5	**1.296**	**1.502**	1.046	10	1.138	2.5
Cu	29	- 4.2 ± 0.3	1.030	1.093	0.878	11	0.854	3.1
Zr	40	- 0.90 ± 0.08	**1.192**	1.051	0.911	12	0.884	3.4
W	74	- 15.0 ± 1.0	**0.823**	0.876	0.896	10	1.029	5.0
Mo-95	425	- 18.0 ± 1.0	1.121	**1.151**	0.913	10	1.068	5.2
Mo-97	427	- 11.0 ± 0.5	1.106	**1.142**	0.952	9	1.024	1.3
Mo-98	428	- 5.3 ± 0.4	0.856	0.891	**0.773**	12	**0.693**	2.4
Mo-100	420	- 3.5 ± 0.3	0.995	0.966	**0.803**	13	0.906	2.8
Rh-103	453	- 35.0 ± 3.0	1.096	1.132	1.056	12	1.077	2.3
Pd-105	465	- 30.5 ± 5.0	1.031	1.013	0.882	19	0.942	0.9
Ag-109	479	- 65.0 ± 5.0	**0.777**	0.846	**0.809**	12	1.027	4.8
Cs-133	553	- 22.0 ± 2.0	1.000	0.985	1.038	13	1.138	2.9
Sm-149	629	- 105 ± 5.0	1.057	1.137	1.094	9	1.098	1.3
Eu-153	633	- 93.0 ± 5.0	1.009	0.992	1.108	10	1.014	1.0

SEG5 CRWs; Normalized to B10

$$\frac{C}{E} = \frac{C_i * E_{ref} * A_{ref}}{E_i * C_{ref} * A_i}$$

Sample Material	ID-No.	CRW exp. (millicent/g)	C/E-values 70g JNC route JENDL-3.2	C/E-values 70g JNC route JEF-2.2	C/E-values 33g ECCO/ERANOS JEF-2.2	Total C/E Error (%)	C/E-values 1968g TRIPOLI JEFF-3.2	Calc. C/E Error (%)	C/E-values 1968g TRIPOLI ENDF-7.1	Calc. C/E Error (%)
B-10 ss	105	- 1230 ± 20	1.000	1.000	1.000	2	1.000	0.4	1.000	0.3
Ta	731	- 31.5 ± 1.0	0.956	0.933	0.956	7	0.932	0.8	0.999	0.8
U-235	925	+ 31.2 ± 2.0	1.138	1.124	1.084	10	**1.179**	0.3	**1.176**	0.3
Mo	42	- 7.4 ± 0.5	1.031	0.984	0.964	10	1.056	2.2	1.108	2.3
Mn	25	- 12.0 ± 0.5	**0.658**	0.942	0.952	7	0.904	1.3	1.002	2.1
Cd	48	- 10.0 ± 0.5	1.070	**1.214**	**1.215**	9	1.102	2.4	**1.173**	2.6
Nb	413	- 10.0 ± 0.6	1.072	1.048	1.022	9	**1.148**	0.8	**1.155**	0.8
Cu	29	- 4.5 ± 0.5	1.174	**1.214**	1.119	14	0.997	1.9	1.179	1.8
Zr	40	- 1.05 ± 0.1	**1.302**	1.085	1.032	13	**1.210**	2.1	**1.334**	1.8
W	74	- 10.0 ± 0.5	0.918	1.019	1.085	8	1.002	2.7	-	-
Fe	26	- 0.7 ± 0.06	**1.342**	**1.232**	1.084	11	1.062	3.1	**1.246**	2.8
Cr	24	- 0.8 ± 0.06	1.037	1.095	1.032	10	**0.840**	2.4	**0.828**	2.3
Ni	28	- 1.3 ± 0.1	**1.237**	**1.185**	1.073	10	**1.380**	5.7	**1.213**	1.0
Co	279	- 20.0 ± 1.5	1.032	1.076	0.992	10	**1.165**	2.6	**1.252**	2.7
B-10 fp	105	- 1174 ± 20	1.000	1.000	1.000	2	1.000	0.4	1.000	0.3
Mo-95	425	- 14.5 ± 1.0	**1.185**	**1.194**	1.133	10	1.148	2.9	**1.256**	3.0
Mo-97	427	- 14.0 ± 1.0	0.980	0.994	0.954	10	0.950	0.8	0.962	0.8
Mo-98	428	- 5.0 ± 0.6	1.035	1.039	1.061	15	0.961	1.7	1.027	1.9
Mo-100	420	- 4.1 ± 0.5	0.996	0.923	0.888	16	0.983	2.2	0.951	2.0
Rh-103	453	- 27.0 ± 1.0	0.899	0.914	0.901	7	0.888	0.8	**0.847**	0.7
Pd-105	465	- 30.2 ± 1.0	1.117	1.077	1.064	7	1.058	0.5	1.057	0.5
Ag-109	479	- 31.5 ± 1.5	0.886	0.926	0.929	8	0.937	1.2	0.888	1.5
Cs-133	553	- 19.5 ± 2.0	0.909	0.912	0.926	13	0.942	1.1	0.896	1.1
Nd-143	603	- 16.0 ± 1.0	0.882	0.897	0.896	9	0.865	1.3	**0.776**	1.3
Nd-145	605	- 18.0 ± 1.0	1.020	1.018	1.066	9	0.972	0.9	0.930	1.2
Sm-149	629	- 83 ± 5	1.023	1.121	**1.191**	9	1.105	1.9	1.097	2.3
Eu-153	633	- 75 ± 5	1.059	1.068	1.091	10	1.040	0.4	-	-

SEG6_EK45 CRWs; normalized to H1

$$\frac{C}{E} = \frac{C_i * E_{ref} * A_{ref}}{E_i * C_{ref} * A_i}$$

Sample Material	ID-No.	CRW exp. (millcent/g)	C/E-values 70g JNC route JENDL-3.2	C/E-values 70g JNC route JEF-2.2	Total C/E Error (%)	C/E-values 1968g TRIPOLI JEFF-3.2	Calc. C/E Error (%)	C/E-values 1968g TRIPOLI ENDF-7.1	Calc. C/E Error (%)
H	1	- 1099 ± 10	1.000	1.000	5	1.000	0.2	1.000	0.2
C	6	- 7.35 ± 0.06	0.918	0.959	8	1.041	0.2	1.053	0.2
B-10	105	- 95.9 ± 6.0	**0.823**	**0.821**	12	**0.771**	0.2	**0.771**	0.2
Mo	42	- 1.70 ± 0.04	0.935	0.898	7	0.960	0.3	1.000	0.3
Fe	26	- 1.22 ± 0.04	0.925	0.952	7	0.923	0.3	0.948	0.3
Cr	24	- 1.21 ± 0.04	0.887	0.977	7	1.014	0.4	1.046	0.4
Ni	28	- 1.55 ± 0.05	0.986	1.096	9	0.984	0.4	0.996	0.4
Al	13	- 2.00 ± 0.06	1.109	**1.202**	8	**1.152**	0.3	**1.148**	0.3
Zr	40	- 1.01 ± 0.03	0.918	**0.859**	8	1.003	0.3	0.949	0.3
Ti	22	- 1.93 ± 0.05	0.911	0.881	8			-	-
Cd	48	- 1.89 ± 0.05	**0.802**	1.026	7	0.993	0.3	1.004	0.3
Pb	82	- 0.32 ± 0.02	1.166	0.883	12	0.882	0.4	0.902	0.4
Bi	839	- 0.30 ± 0.02	0.911	0.986	12	0.933	0.4	0.949	0.4
Mg	12	- 3.01 ± 0.08	1.082	1.014	13	**1.181**	0.3	1.169	0.3
Be	4	- 14.04 ± 0.10	**1.186**	**1.138**	7	1.090	0.2	1.113	0.2
W	74	- 1.34 ± 0.03	0.926	0.912	9	0.914	0.3	-	-
Cu	29	- 1.45 ± 0.02	1.046	1.063	8	1.007	0.3	1.032	0.3
Au	79	-1.63 ± 0.07		0.919	9	0.895	0.3	-	-
Mn	25	- 1.53 ± 0.03	0.896	1.045	8	1.087	0.5	**1.214**	0.4
Ta	731	- 2.15 ± 0.02	**0.874**	**0.834**	7	**0.771**	0.3	**0.878**	0.3
V	23	- 1.91 ± 0.05	0.934	1.034	9	0.974	0.5	1.006	0.4
Si	14	- 1.82 ± 0.09	0.893	1.049	11	1.007	0.3	1.067	0.3
Nb	413	- 1.96 ± 0.04	0.943	0.900	8	0.886	0.3	0.910	0.3
Co	279	- 1.25 ± 0.02	1.119	**1.184**	8	**1.219**	0.4	**1.262**	0.3
U-235	925	+ 10.9 ± 0.07	0.898	0.907	7	0.963	0.2	0.975	0.2
U-238	928	- 0.703 ± 0.04	0.906	0.881	12	0.989	0.3	0.999	0.3
Th	902	- 1.35 ± 0.04	**0.858**	**0.832**	9	0.867	0.3	0.892	0.3

$$\frac{C}{E} = \frac{C_i * E_{ref} * A_{ref}}{E_i * C_{ref} * A_i}$$

SEG6_EK45 CRWs; normalized to C

Sample Material	ID-No.	CRW exp. (millcent/g)	C/E-values 33g ECCO/ERANOS JEF-2.2	Total C/E Error (%)	C/E-values 1968g TRIPOLI JEFF-3.2	Calc. C/E Error (%)	C/E-values 1968g TRIPOLI ENDF-7.1	Calc. C/E Error (%)
H	1.0	- 1099 ± 10	1.071	5	0.960	0.2	0.950	0.7
C	6.0	- 7.35 ± 0.06	1.000	8	1.000	0.2	1.000	31.7
B-10	105.0	- 95.9 ± 6.0	0.896	12	**0.741**	0.2	**0.732**	0.3
Mo	42.0	- 1.70 ± 0.04	0.913	7	0.922	0.3	0.950	2.3
Fe	26.0	- 1.22 ± 0.04	0.916	7	0.886	0.3	0.900	2.8
Cr	24.0	- 1.21 ± 0.04	0.915	7	0.974	0.4	0.993	2.3
Ni	28.0	- 1.55 ± 0.05	1.133	9	0.945	0.4	0.946	1.0
Al	13.0	- 2.00 ± 0.06	1.032	8	1.106	0.3	1.091	2.2
Zr	40.0	- 1.01 ± 0.03	**0.860**	8	0.963	0.3	0.902	1.8
Ti	22.0	- 1.93 ± 0.05	0.921	8	-	-	-	-
Cd	48.0	- 1.89 ± 0.05	1.105	7	0.954	0.3	0.953	2.6
Pb	82.0	- 0.32 ± 0.02	0.913	12	0.848	0.4	0.857	4.5
Bi	839.0	- 0.30 ± 0.02	1.016	12	0.896	0.4	0.901	3.6
Mg	12.0	- 3.01 ± 0.08	1.094	13	1.134	0.3	1.110	23.4
Be	4.0	- 14.04 ± 0.10	**1.323**	7	1.047	0.2	1.057	1.0
W	74.0	- 1.34 ± 0.03	0.942	9	0.878	0.3	-	-
Cu	29.0	- 1.45 ± 0.02	1.095	8	0.968	0.3	0.980	1.8
Au	79.0	-1.63 ± 0.07	0.963	9	**0.860**	0.2	-	-
Mn	25.0	- 1.53 ± 0.03	1.076	8	1.044	0.5	**1.153**	2.1
Ta	731.0	- 2.15 ± 0.02	0.895	7	**0.740**	0.3	**0.834**	0.8
V	23.0	- 1.91 ± 0.05	1.016	9	0.935	0.5	0.955	1.7
Si	14.0	- 1.82 ± 0.09	**1.207**	11	0.968	0.3	1.013	4.6
Nb	413.0	- 1.96 ± 0.04	0.955	8	**0.851**	0.3	**0.865**	0.8
Co	279.0	- 1.25 ± 0.02	**1.241**	8	**1.171**	0.4	**1.199**	2.7
U-235	925.0	+ 10.9 ± 0.07	0.978	7	0.925	0.2	0.926	0.3
U-238	928.0	- 0.703 ± 0.04	0.923	12	0.950	0.3	0.949	2.1
Th	902.0	- 1.35 ± 0.04	0.865	9	**0.833**	0.3	**0.847**	1.5

SEG7A CRWs; normalized to B10

Sample Material	ID-No.	CRW exp. (millicent/g)	C/E-values 70g JNC route JENDL-3.2	C/E-values 70g JNC route JEF-2.2	C/E-values 33g ECCO/ERANOS JEF-2.2	Total C/E Error (%)	C/E-values 1968g TRIPOLI JEFF-3.2	Calc. C/E Error (%)	C/E-values 1968g TRIPOLI ENDF-7.1	Calc. C/E Error (%)	C/E-values 26g TRIPOLI JEFF-3.2	C/E-values CE TRIPOLI JEFF-3.2
B-10	105	- 850 ± 10	1.000	1.000	1.000	2	1.000	0.3	1.000	0.4	1.000	1.000
C	6	- 1.9 ± 0.05	1.035	1.041	1.091	6	**1.119**	0.4	**1.128**	0.6	**1.122**	3.092
U-235	925	+ 28.0 ± 3.0	1.149	1.144	1.150	13	1.142	0.4	1.137	0.5	1.149	1.118
Ta	731	- 26.0 ± 1.0	**0.868**	**0.867**	0.928	7	0.899	0.9	0.935	1.2	0.886	0.887
Cd	48				**1.304**	15	-	-				
Mo-95	425	- 16.8 ± 2.5	0.940	1.050	0.960	**18**	1.006	2.7	0.968	2.9	0.984	0.614
Mo-97	427	- 8.0 ± 0.6	0.956	0.982	0.961	11	0.993	0.9	1.010	1.1	0.982	0.972
Mo-98	428	- 2.7 ± 1.0	1.133	1.164	1.141	**40**	1.222	1.7	1.192	1.9	1.173	1.580
Mo-100	420	- 8.1 ± 1.0	**0.300**	**0.286**	**0.471**	13	**0.306**	1.7	**0.281**	1.8	**0.300**	0.859
Rh-103	453	- 15.0 ± 2.0	1.168	**1.230**	1.118	16	1.141	1.2	1.092	1.3	1.110	1.053
Ag-109	479	- 36.0 ± 1.5	**0.820**	0.901	0.894	7	**0.853**	1.9	**0.838**	2.3	**0.835**	0.881
Sm-149	629	- 70.0 ± 3.0	**1.751**	**1.337**	**1.498**	7	**1.357**	1.6	**1.299**	1.8	**1.346**	1.214

$$\frac{C}{E} = \frac{C_i * E_{ref} * A_{ref}}{E_i * C_{ref} * A_i}$$

SEG5 Scattering to Total Reactivity Ratios

Sample Material	Scat./ Tot. (%) JNC route 70=>18g JENDL-3.2	Scat./ Tot. (%) JNC route 70=>18g JEF-2.2	Scat./ Tot. (%) JNC route 70g JENDL-3.2	Scat./Tot. (%) Europ. scheme 1968,172,33=>33g JEF-2.2	Elas./Tot. (%) TRIPOLI 1968g JEF-3.2	Calc. Error (%)	Inel./Tot. (%) TRIPOLI 1968g JEF-3.2	Calc. Error (%)	Scat./Tot. (%) TRIPOLI 1968g JEF-3.2
B-10 ss	+0.10	+0.08	+0.01	-0.012	-0.025	2.6	-0.001	8.6	-0.026
Ta	+0.45		+0.26	-0.02	-0.343	21.5	-0.169	1.0	-0.512
U-235	-0.17	-0.19	-0.12	+0.008	-0.007	33.6	-0.098	0.4	-0.104
Mo	+2.5	+2.9	+1.5	+0.12	1.332	18.6	1.202	2.2	2.533
Mn	+9.3	+4.5	+3.9	+0.12	4.912	22.0	-0.554	1.4	4.358
Cd	+1.2		+0.76	-0.14	1.065	9.4	0.942	2.4	2.007
Nb	+1.6		+0.97	-0.05	0.059	59.3	-0.897	0.8	-0.837
Cu	+5.4	+4.8	+1.5	-0.61	7.342	4.5	1.240	1.9	8.582
Zr	+7.5	+9.1	+4.8	-0.27	8.390	5.8	2.860	2.1	11.250
W	+3.8		+1.2	+0.10	2.309	33.7	0.647	2.8	2.956
Fe	+19.6	+20.8	+9.7	-8.0	3.401	24.1	6.569	3.2	9.971
Cr	+12.8	+14.4	+2.7	-12.3	4.165	18.5	4.743	2.6	8.909
Ni	+11.2	+11.9	-4.5	-11.1	4.296	17.4	1.511	5.8	5.807
Co	+1.5		+2.9	+0.21	3.043	43.4	-0.271	2.6	2.773
Mo-95	+1.1		+0.75	+0.64	0.957	27.2	-0.624	2.9	0.333
Mo-97	+1.3		+0.77	-0.12	0.058	44.6	-1.114	0.8	-1.056
Mo-98	+6.3		+2.5	+0.01	-2.954	6.8	-1.851	1.7	-4.804
Mo-100	+3.4		+2.9	-0.12	5.606	9.8	-2.635	2.2	2.971
Rh-103	+0.6		+0.38	-0.07	-0.161	14.6	-0.460	0.8	-0.622
Pd-105	+0.4		+0.28	-0.07	0.081	10.9	-0.438	0.5	-0.357
Ag-109	+0.5		+0.31	-0.03	0.020	133.0	-0.361	1.2	-0.341
Cs-133	+0.6		+0.43	-0.03	0.505	16.0	-0.284	1.2	0.221
Nd-143	+1.0		+0.55	+0.99	-0.204	161.8	-0.240	1.3	-0.444
Nd-145	+2.0		+0.44	+0.81	-1.544	15.9	-0.387	1.0	-1.932
Sm-149	+0.2		+0.09	+0.02	0.055	54.4	-0.090	1.9	-0.035
Eu-153	+0.2		+0.10	-0.01	-0.037	15.3	-0.101	0.5	-0.138

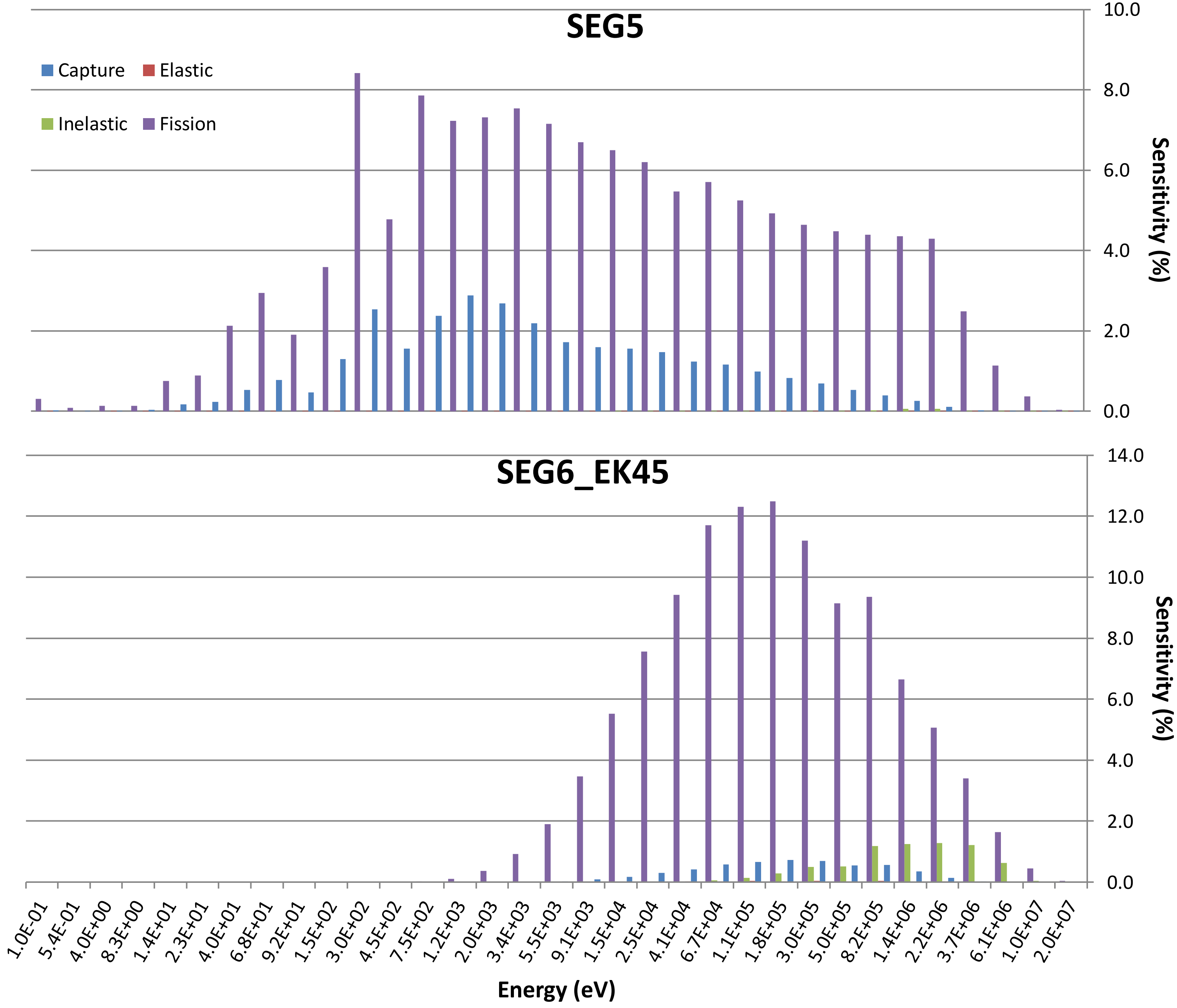
SEG6_EK45 reactivity contributions

Sample Material	JNC route with JENDL-3.2				ECCO/ERANOS with JEF-2.2				TRIPOLI with JEFF-3.2 (1968g)			
	Capture (%)	El. Scatt. (%)	Inel. Scatt. (%)	Fission (%)	Capture (%)	El. Scatt. (%)	Inel. Scatt. (%)	Fission (%)	Capture (%)	El. Scatt. (%)	Inel. Scatt. (%)	Fission (%)
H	0.004	100.0	0.0		0.	100	0.		0.04	99.92	0.04	
C	0.46	98.4	1.2		0.4	98.6	1.0		0.36	98.46	1.19	
B-10	89.6	9.8	0.6		90.4	9.4	0.2		87.96	11.80	0.24	
Mo	25.6	11.5	62.7		23.2	12.8	64.0		23.72	12.93	63.28	
Fe	9.0	25.5	65.5		6.1	25.9	68.0		7.13	32.19	60.66	
Cr	6.5	35.5	58.1		5.7	33.2	61.1		5.12	43.92	63.15	
Ni	32.7	37.7	30.1		35.9	39.6	24.5		30.30	36.14	33.55	
Al	3.5	68.6	28.0		3.8	68.0	28.2		3.72	64.83	31.45	
Zr	10.0	23.9	66.0		7.6	28.5	63.9		8.62	29.17	62.09	
Ti	6.5	45.3	48.2		6.3	51.4	42.3					
Cd	39.5	6.9	53.3		32.8	7.6	59.6		32.33	6.61	61.04	
Pb	2.7	11.8	84.2		3.8	20.2	76.0		3.10	17.30	79.22	
Bi	4.2	14.7	79.7		4.6	20.1	75.3		2.57	19.56	77.33	
Mg	3.4	73.3	23.4		2.3	76.7	21.0		3.34	75.73	20.93	
Be	6.4	79.9	13.7		6.1	82.1	11.8		6.37	96.74	0.35	
W	24.8	3.6	70.7		26.7	5.2	68.1		23.92	4.46	71.37	
Cu	18.6	21.7	59.8		18.2	26.6	55.2		16.42	26.22	57.35	
Au					43.3	3.7	53.0		39.64	3.51	56.78	
Mn	6.8	32.2	61.0		8.9	30.5	60.6		5.46	27.54	66.97	
Ta	50.0	2.3	47.4		49.7	2.8	47.5		42.64	3.16	54.04	
V	5.0	45.7	49.4		3.4	43.5	53.1		3.90	49.04	47.05	
Si	6.1	68.4	25.7		6.0	74.0	20.0		5.66	71.67	22.67	
Nb	28.3	12.1	59.6		28.4	57.7	13.9		27.30	13.14	59.51	
Co	9.5	28.9	61.7		8.1	31.5	60.4		7.65	32.58	59.75	
U-235	6.8	0.3	6.0	113.2	6.5	0.3	6.1	112.9	5.34	0.31	7.05	112.73
U-238	57.7	5.4	115.7	81.0	62.8	5.0	113.8	81.6	48.12	7.14	108.64	64.37
Th-232	38.6	3.1	65.5	8.7	48.5	2.7	56.6	7.8	38.84	3.36	64.47	6.96

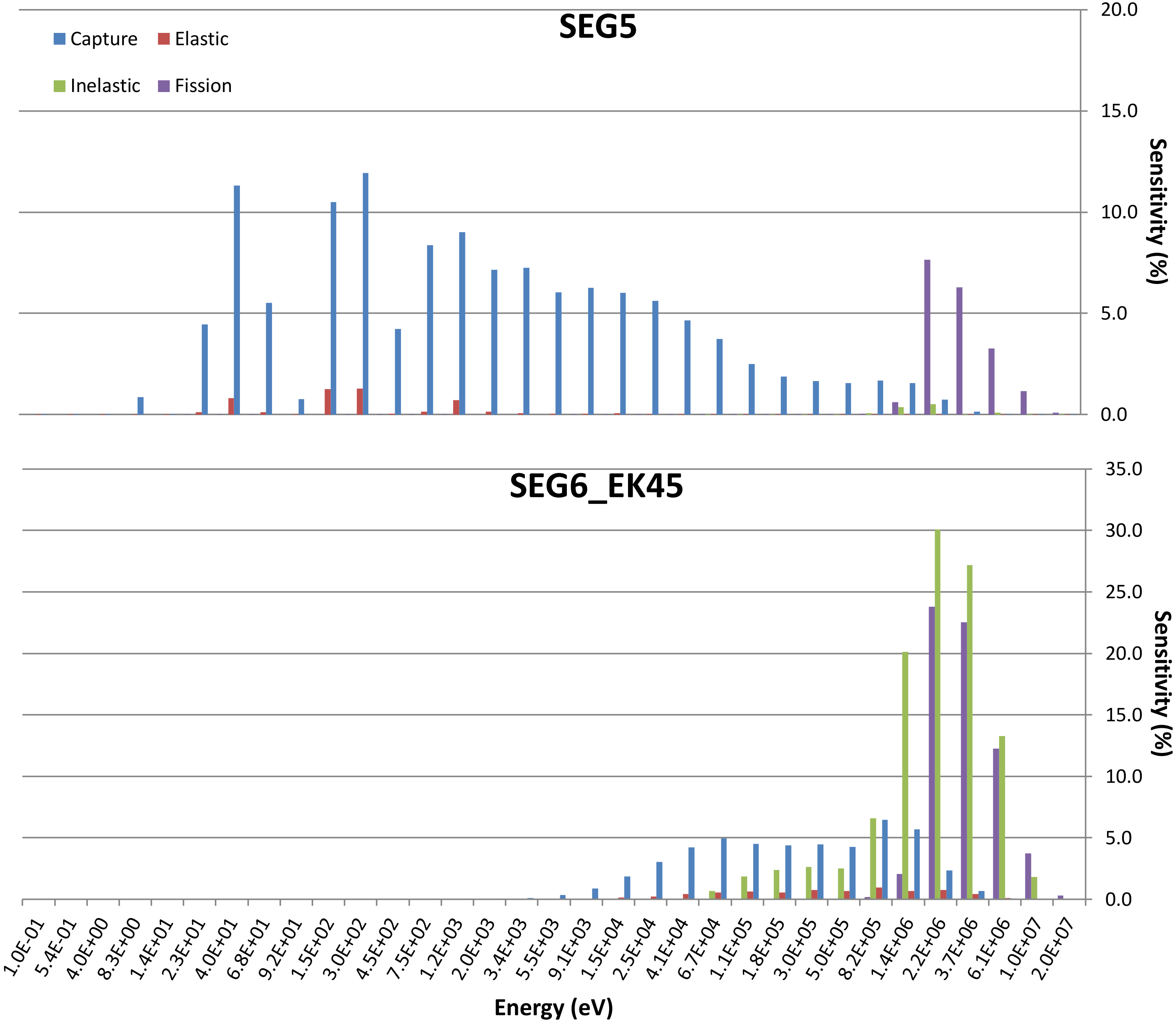
SEG7A Scattering to Total Reactivity Ratios

Sample Material	ID-No.	Elas./Tot. (%) TRIPOLI 1968g JEF-3.2	Calc. Error (%)	Inel./Tot. (%) TRIPOLI 1968g JEF-3.2	Calc. Error (%)	Scat./Tot. (%) TRIPOLI 1968g JEF-3.2	Elas./Tot. (%) TRIPOLI 26g JEF-3.2	Calc. Error (%)	Inel./Tot. (%) TRIPOLI 26g JEF-3.2	Calc. Error (%)	Scat./Tot. (%) TRIPOLI 26g JEF-3.2	Elas./Tot. (%) TRIPOLI CE JEF-3.2	Calc. Error (%)	Inel./Tot. (%) TRIPOLI CE JEF-3.2	Calc. Error (%)	Scat./Tot. (%) TRIPOLI CE JEF-3.2
B-10	105	0.229	3.5	0.003	6.8	0.23	0.225	1.0	0.003	1.8	0.228	1.297	49.5	0.008	99.0	1.305
C	6	98.780	6.5	0.275	21.8	99.06	98.655	1.2	0.322	4.4	98.978	99.322	270.9	0.027	3641.2	99.349
U-235	925	-0.059	55.9	-0.456	1.5	-0.51	-0.034	4.6	-0.445	1.3	-0.479	0.081	3736.8	-0.674	65.8	-0.593
Ta	731	1.078	30.0	0.810	3.3	1.89	0.145	12.9	0.804	3.3	0.949	12.135	92.1	1.143	51.4	13.278
Cd	48	2.811	43.9	3.027	9.4	5.84	0.375	10.7	2.845	10.3	3.221	-62.130	193.8	3.290	170.4	-58.840
Mo-95	425	5.559	48.3	1.451	10.6	7.01	0.472	12.1	1.611	8.7	2.082	8.928	607.9	1.311	131.9	10.239
Mo-97	427	1.278	33.7	4.025	3.3	5.30	0.568	3.9	3.995	3.2	4.563	11.613	235.8	4.868	59.9	16.481
Mo-98	428	13.607	32.0	6.560	8.1	20.17	7.657	22.1	6.956	6.4	14.613	67.130	74.9	5.987	53.2	73.118
Mo-100	420	-1.492	324.1	10.932	7.5	9.44	1.837	6.2	10.117	5.7	11.954	75.073	102.6	1.373	116.6	76.447
Rh-103	453	1.157	29.3	0.942	7.0	2.10	0.200	4.4	0.820	8.0	1.020	15.894	76.2	0.769	67.0	16.662
Ag-109	479	-0.167	353.9	0.818	7.6	0.65	0.115	9.3	0.713	7.5	0.828	6.263	117.9	0.678	63.1	6.940
Sm-149	629	-1.032	24.8	0.267	5.0	-0.76	0.044	6.7	0.259	5.3	0.303	6.833	117.8	0.358	69.0	7.192

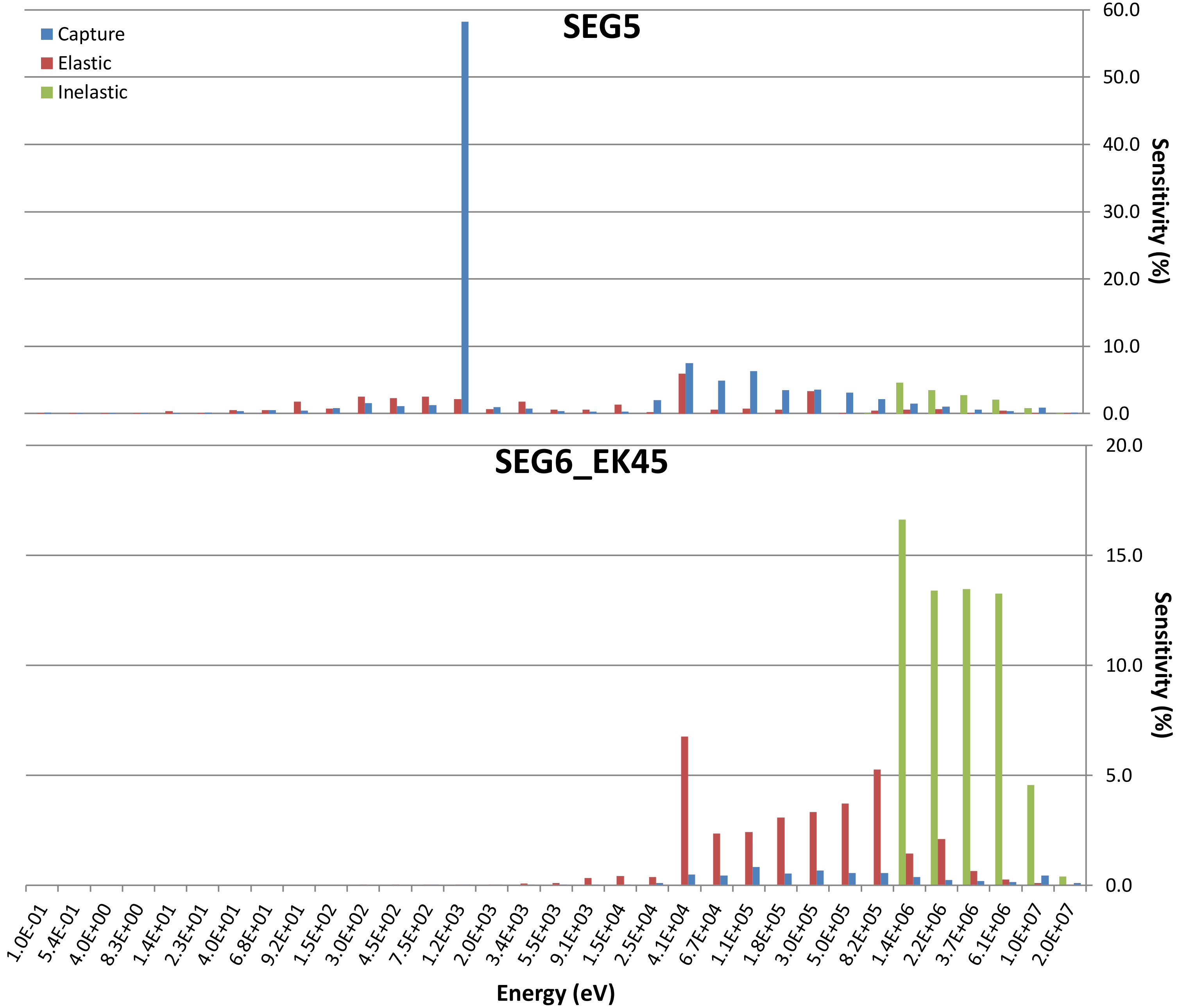
U-235 Sensitivities (JEFF-3.2/TRIPOLI)



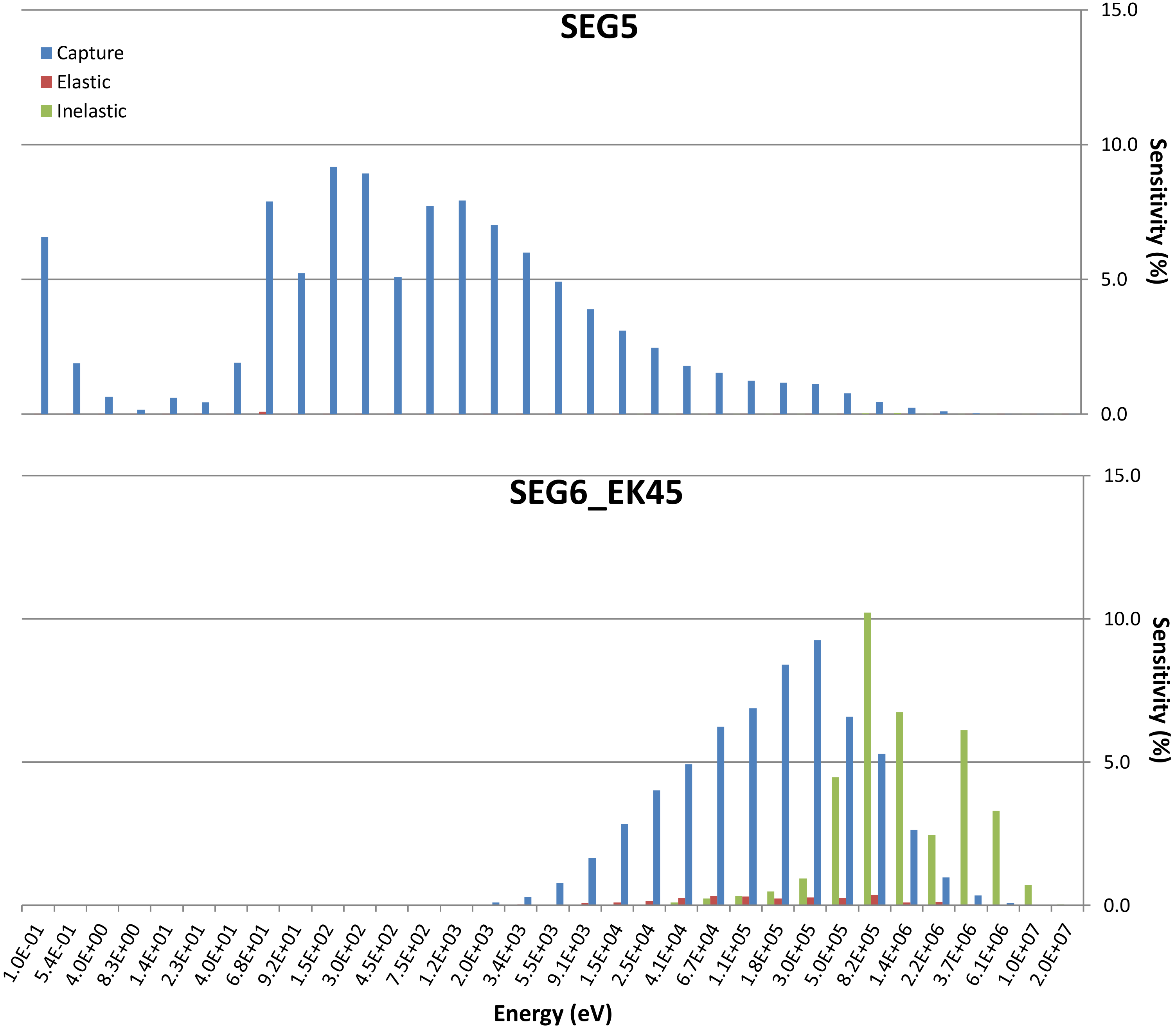
U-238 Sensitivities (JEFF-3.2/TRIPOLI)



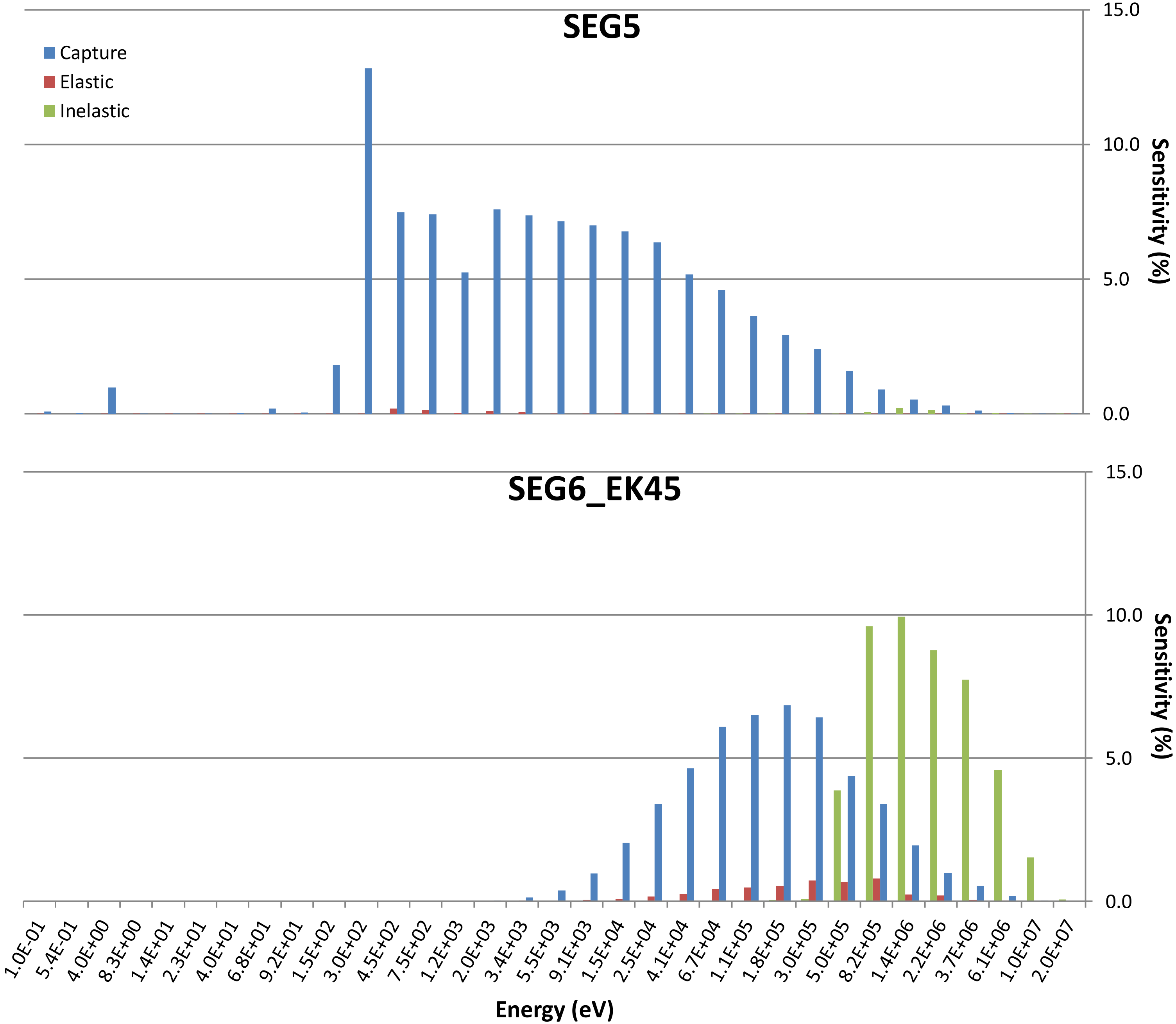
Fe-56 Sensitivities (JEFF-3.2/TRIPOLI)



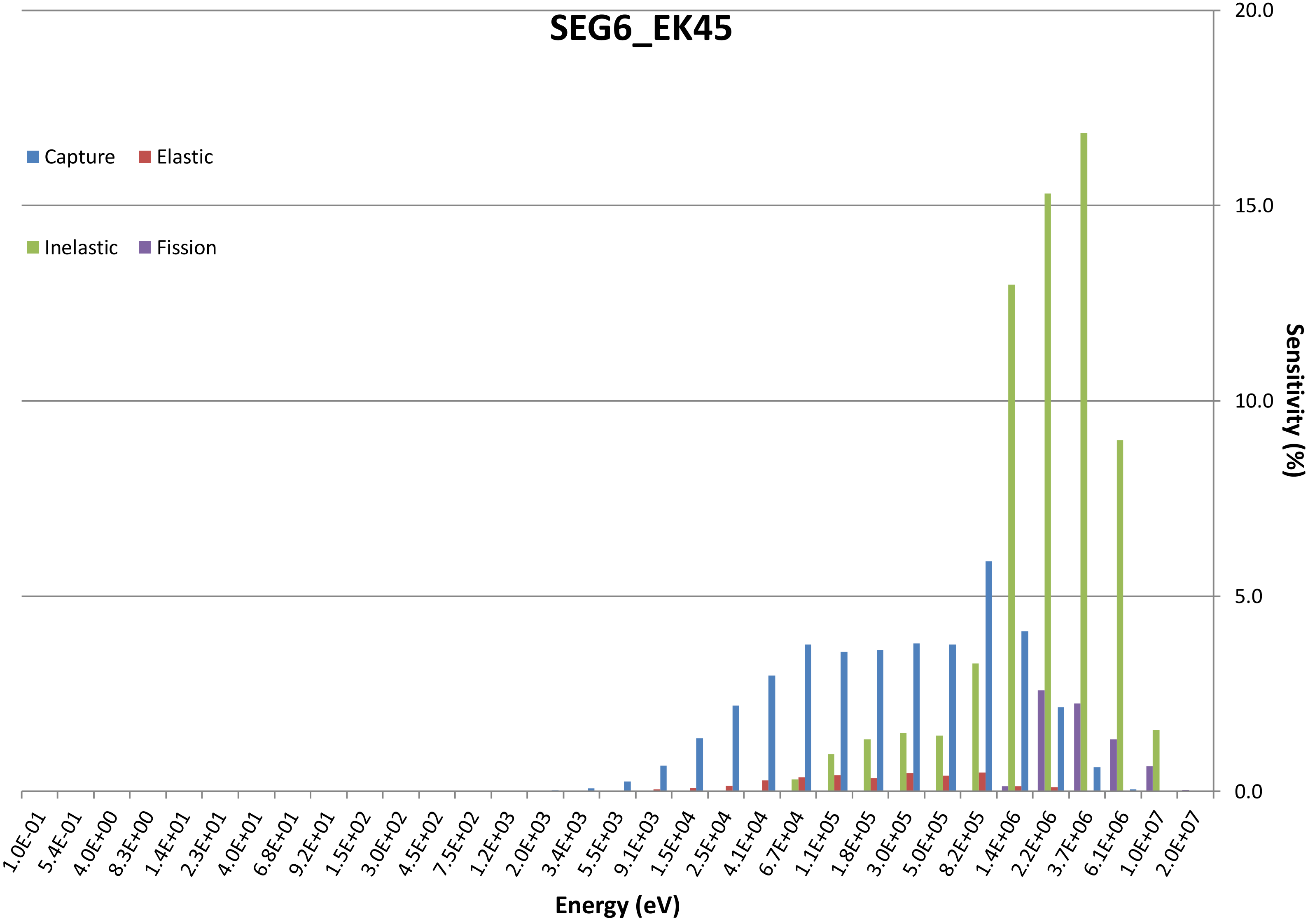
Sm-149 Sensitivities (JEFF-3.2/TRIPOLI)



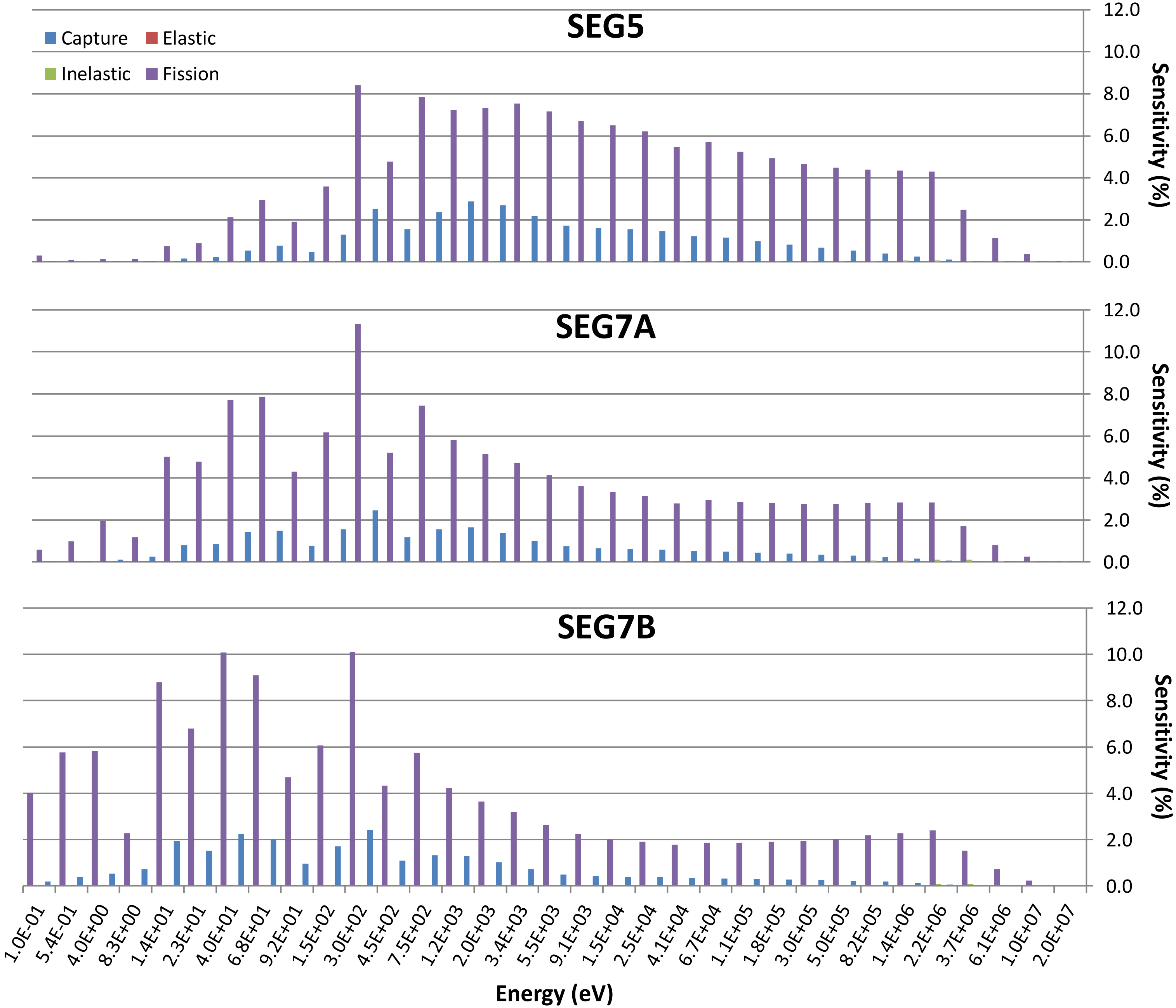
Rh-103 Sensitivities (JEFF-3.2/TRIPOLI)



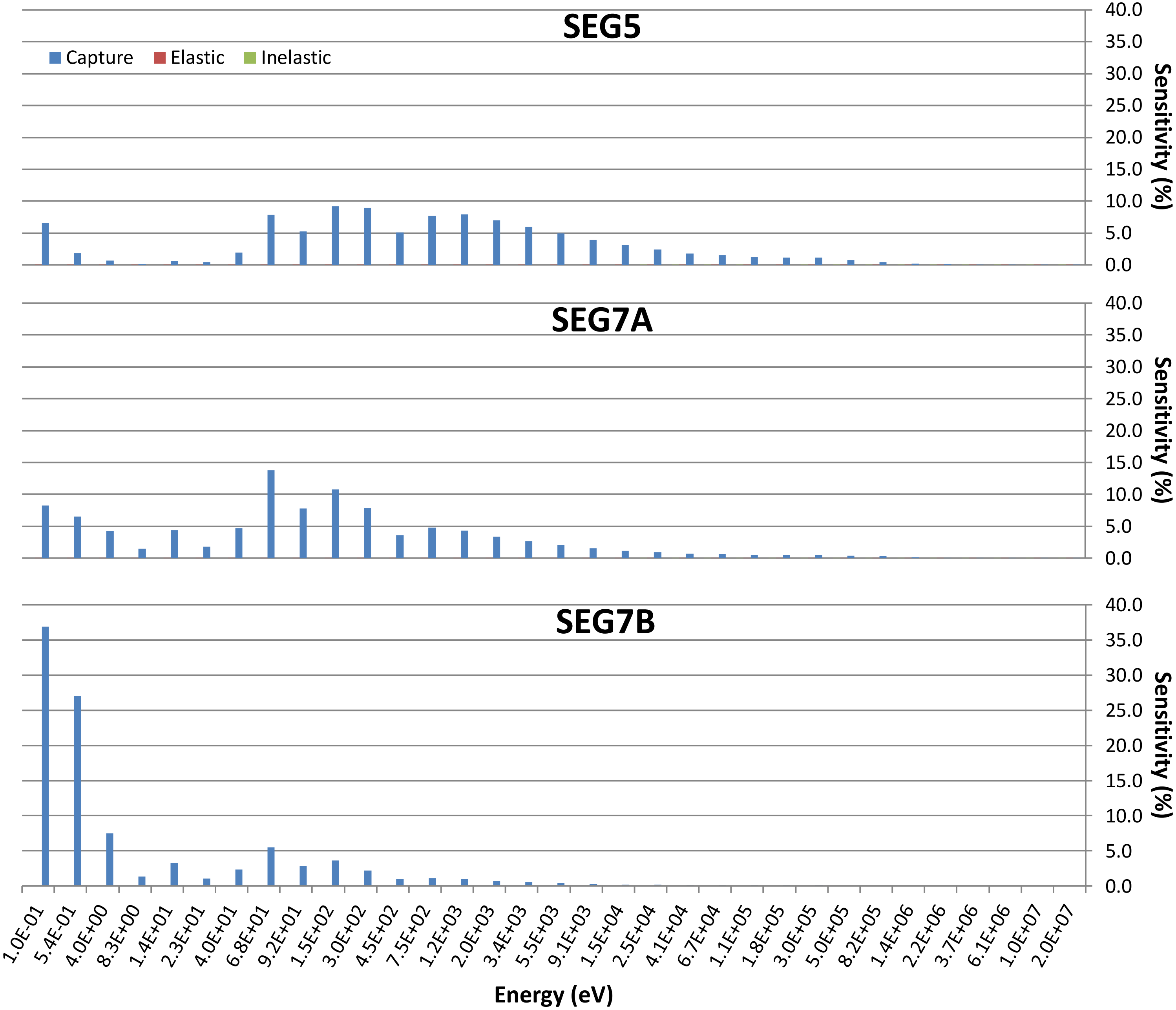
Th-232 Sensitivities (JEFF-3.2/TRIPOLI)



U-235 Sensitivities (JEFF-3.2/TRIPOLI)



Sm-149 Sensitivities (JEFF-3.2/TRIPOLI)



Conclusions and Ongoing Work

- It is important to keep in mind that this analysis using the IFP method in TRIPOLI is new and relatively untested;
  - Very much a ***'first of a kind'*** analysis

- Accurate geometric models were developed in TRIPOLI

  < 100 pcm difference with MCNP for critical configurations

- Forward and adjoint fluxes compare very well between homogeneous and heterogeneous configurations in TRIPOLI
  - Differences exist with ERANOS calculations; most likely due to the older JEF-2.2 cross-section libraries

- Central Reactivity Worths and C/E values are comparable with previous work

Conclusions and Ongoing Work

- Compile results for SEG 6_EK10 and SEG 7B – in progress
  - No previous analysis of 7B measurements
- Examine additional data libraries in TRIPOLI (ENDF-7.0, JENDL?)
- Use ERANOS-2.4 for cross-comparison and ***examine sensitivity coefficients*** – in progress
- Possibly examine SEG3 & STEK experiments
- Finally….propose cross-section recommendations once all TRIPOLI & ERANOS calculations are complete

Acknowledgments

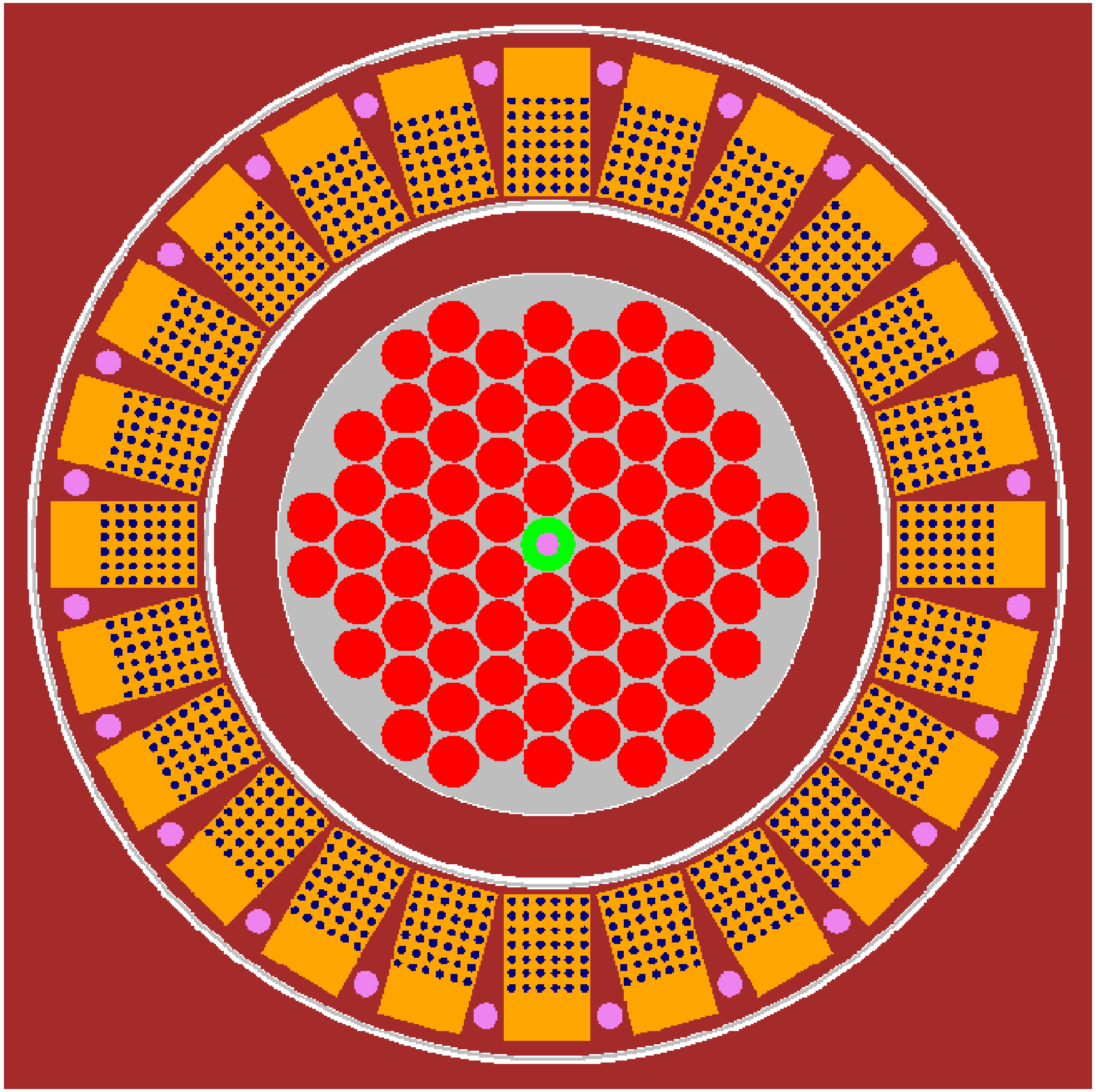
- Pierre Leconte
- Gerald Rimpault
- Giuseppe (Pino) Palmiotti
- Massimo (Max) Salvatores
- John D. Bess

References

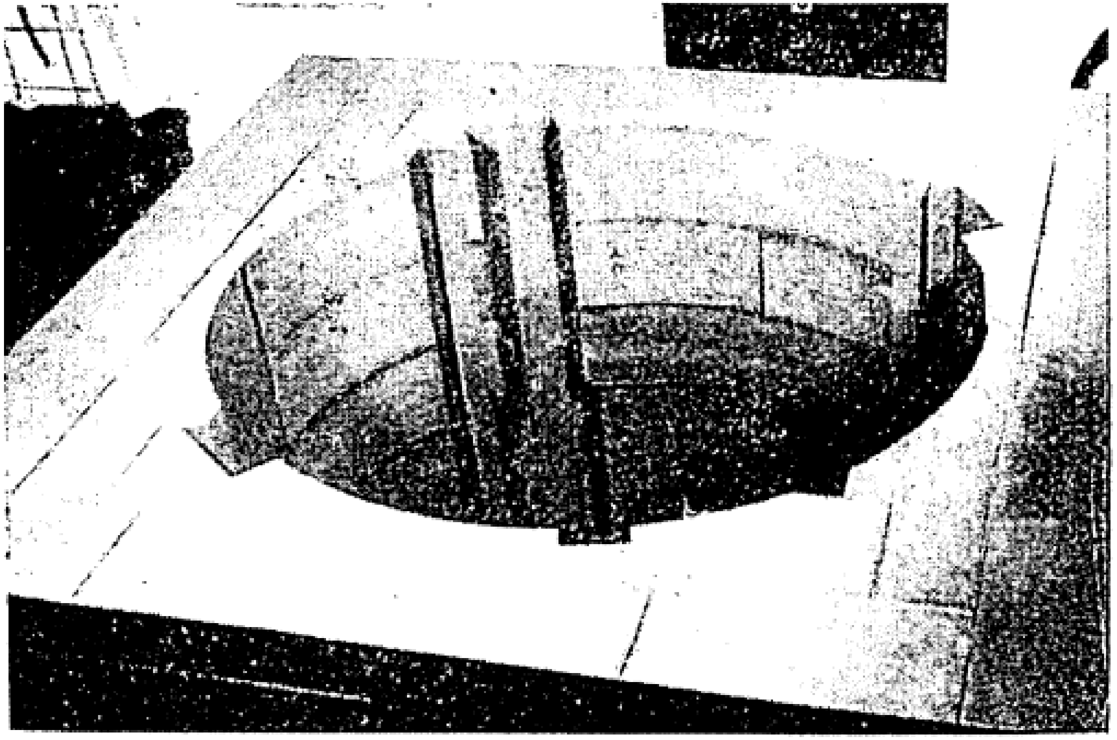
1. Dietze K., "Integral Test of FPND by Reactivity Measurements in Reactor Configurations with Specially Designed Adjoint Spectra" FZR Preprint 92 – 02, May 1992 (NEA-NSC-DOC-92-9).
2. Liewers P, "Reaktorphysikalische Forschungen in der DDR" Sitzungsberichte der Leibniz-Sozietat, 89(2007), 39-54.
3. Dietze K. "The Rossendorf RRR/SEG – Facility," LEPH-93-230, CEA Cadarache 1993.
4. Kampf T., Liewers P., "Der Rossendorfer Ringzonenreaktor (RRR) – ein Instrument fur reaktorphysikalishce Untersuchungen," Kernenergie 6 Jahrgang, P. 300 – 305, Heft 7 1963.
5. Dietze K., Faehrmann K., Huettel G., Hansen W., Kumpf H., Lehmann E., "Neutron Absoption Data Analysisby Means of Integral Experiments in Fast Critical Facilities," Kerntechnik 53/2, p. 143 – 149, 1988 (K-1988).
6. Lehmann E., Dietze K., Fahrmann K-H., Huttel G., Kumpf H., "Ergebnisse von Probenreaktivitatsmessungen von Konstruktionsmaterialien und Spalt-produktnukliden in den schnellen kritischen Anordnungen SEG-IV und SEG-V," ISSN 0138-2950, November 1988 (ZfK-656).
7. Lehmann E., Hansen W., Huettel G., Kumpf H., Richter D., "Investigations in a Fast Reactor Assembly with a Strongly Energy-Independent Adjoint Function," ISSN 0138-2950, December 1990 (ZfK – 729).
8. Lehmann E., Huttel G. Krause H., Kumpf H., "A Fast Critical Reactor Assembly with Strong Energy Dependence of Adjoint Flux," Kernenergie 34/1 p. 9-12, 1991 (Ke34-1p9-1991).
9. Huttel G., Krause H., "Ein pneumatishes Steuerungssystem fur schnelle vertikale Rechteckbewegungen groBerer Lasten," Kernenergie 18, Jahrgang, Heft 11/1975.
10. Rowlands J. L., Smith R. W., Stevenson J. M., Taylor W. H., "Convergence of Integral and Differential Cross-Section Data for Structural Materials," United Kingdom Atomic Energy Authority, Nuclear Data for Science and Technology, 85-97, 1983.
11. Albert D., Fahrmann K., Lehmann E., Seifert E., "Investigation of a moderated Sb-Be photoneutron source and its applicationto the determination of the neutron importance function," Nuclear Instruments and Methods in Physics Research, Vol. 185, Issues 1-3, p. 387-392, June 1981.
12. Dietze K., Kumpf H., "Eine Analyse der Kerndaten von Spaltprodukten durch Reaktivitaetsmessungen in schnellen Reaktorkonfigurationen mit enerie-unabhaengiger Einflussfunftion, Kernenergie 34, 1, p.1, 1991 (Ke34-1-1991).
13. Dietze K., "Zur Normierung und Genauigkeit von integralen Experimenten im SEG, Report RPV – 1/89 Research Center Rossendor (1989).

Total C/E error estimated with partial errors

- Primary
  - Statistical error in the measurement of both the sample and reference materials
- Secondary
  - Extrapolation error to infinitely dilute CRW values of both the sample and reference materials
  - Error associated with the derived experimental CRW value from the molecular sample used
  - Cross-section uncertainty of reference material
  - Additional uncertainties in compositions and moisture
- More info, see references [12], [13] – both in German



Outer Reflector



Kampf & Liewers [4]

Pneumatic Oscillator