Re-analysis of the Rossendorfer Ringzonen-Reaktor/Schnelles Einsatz-Gitter Experiments

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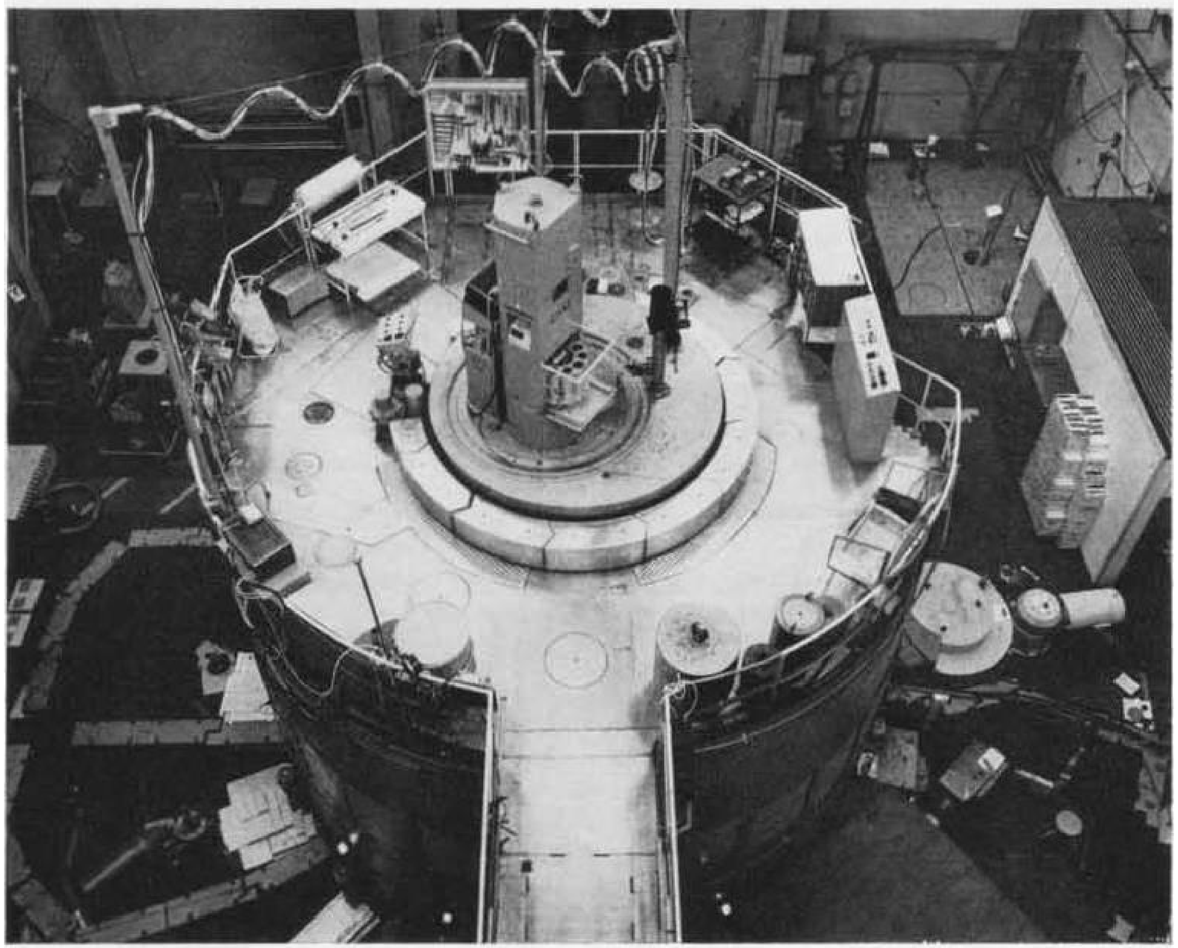
RRR/SEG Fast-Thermal Coupled Facility

- 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

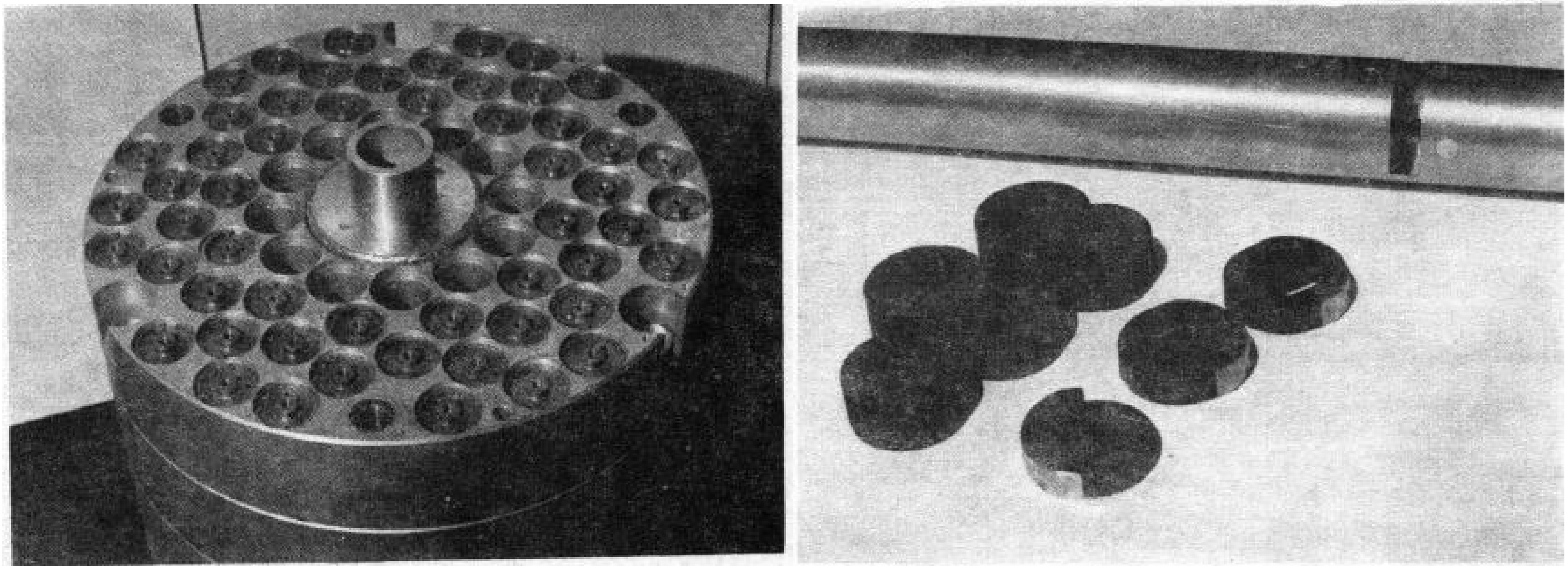
- Schnelles Einsatz-Gitter (SEG)
  - Fast insertion lattice deployed in 1972
  - Al or Fe matrix filled with varying pellets (unit cells)
  - 7 primary configurations
  - Initial focus on SEG 4 – 7: Measurements/data on structural materials and fission products

RRR/SEG Fast-Thermal Coupled Facility



Heironymus [1]

RRR/SEG Fast-Thermal Coupled Facility



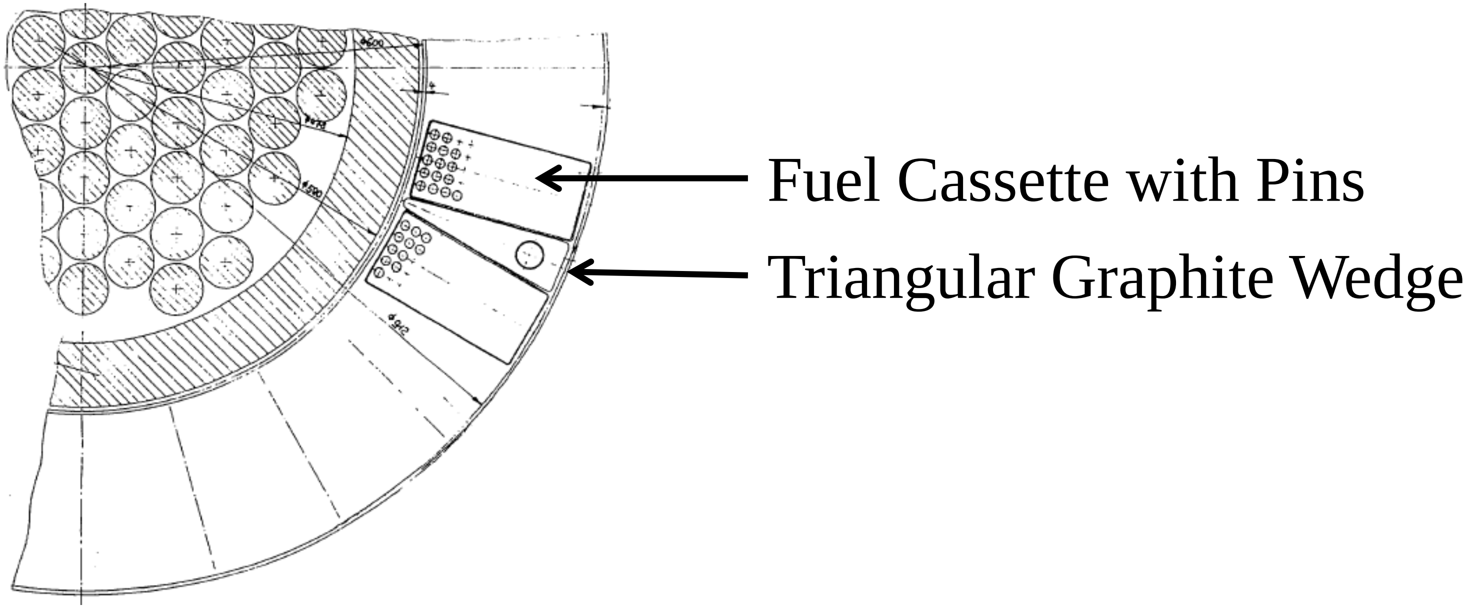
Lehmann et al [2]

SEG 6 insertion lattice and small sample disks

Integral experimental setup used to perform small sample reactivity measurements

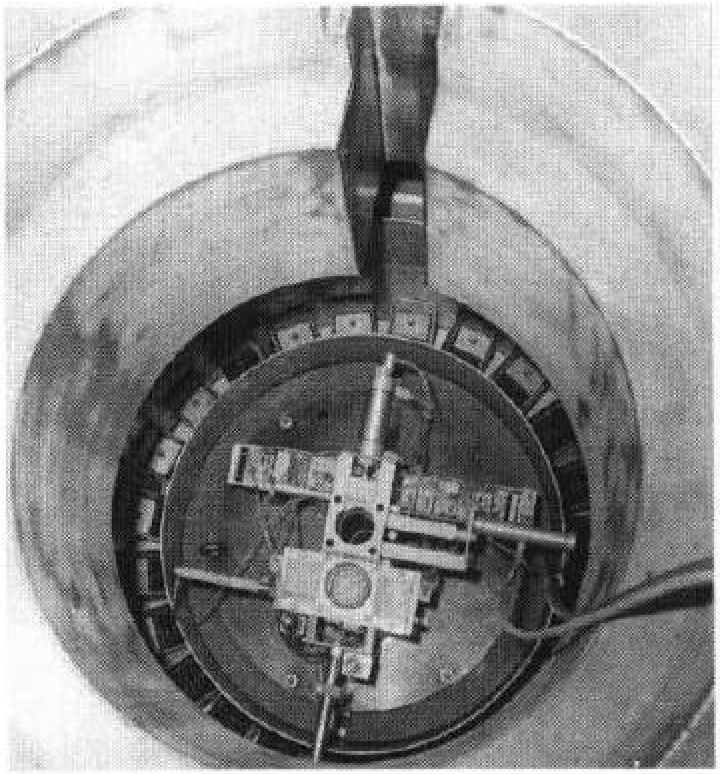
RRR/SEG Fast-Thermal Coupled Facility

- 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]

Pile Oscillator Method for Measurement



Dietze et al [4]

- Pneumatically driven with a 20.48 second period, 80cm stroke
- Depends on reactor power, number of measured periods, and reproducibility
- Measured background and reactivity effect simultaneously
  - PUWO oscillator

Description of Measurements

- The pile oscillator method was used to measure reactivity effects
  - +/- 0.3 millicents (~0.00219 pcm) – accuracy of method
  - +/- 0.1 millicents (~0.00073 pcm) – 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"

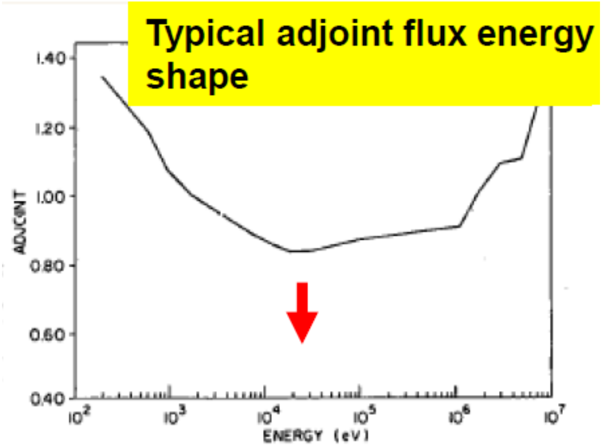
- Boron ionization chamber detected the flux response

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

- *"The sample reactivity is identical with the reactivity difference in the two oscillator positions" (Dietze – 1993)*

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

Salvatores [6]

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 →

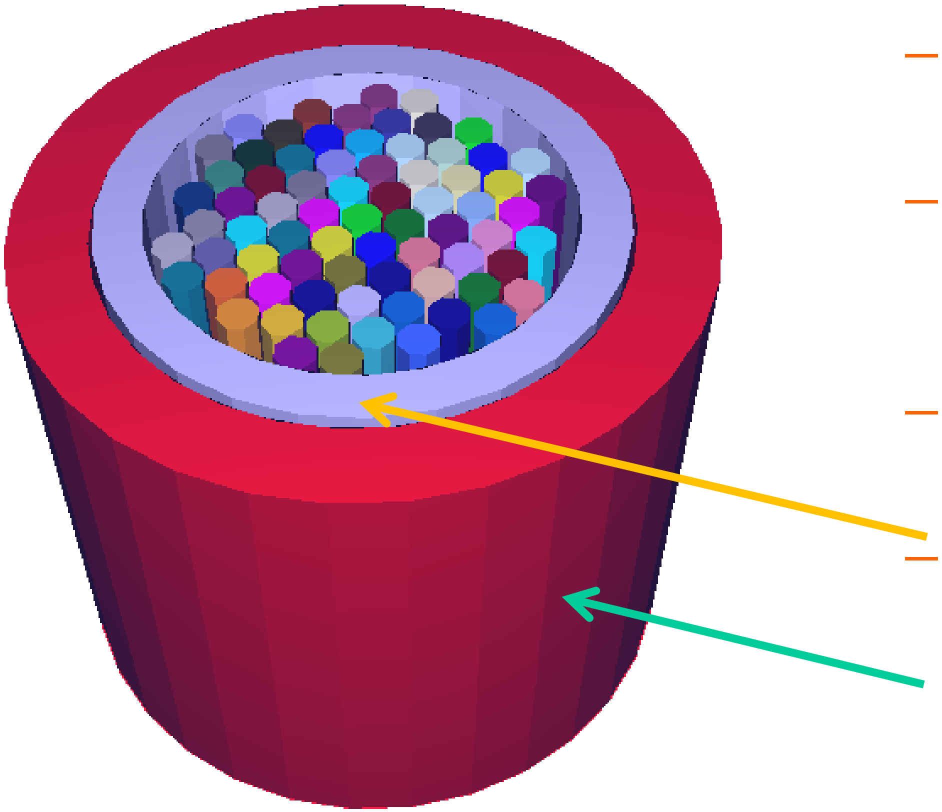
C	BG	PE	U 36%	BG	C	PE	BG

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

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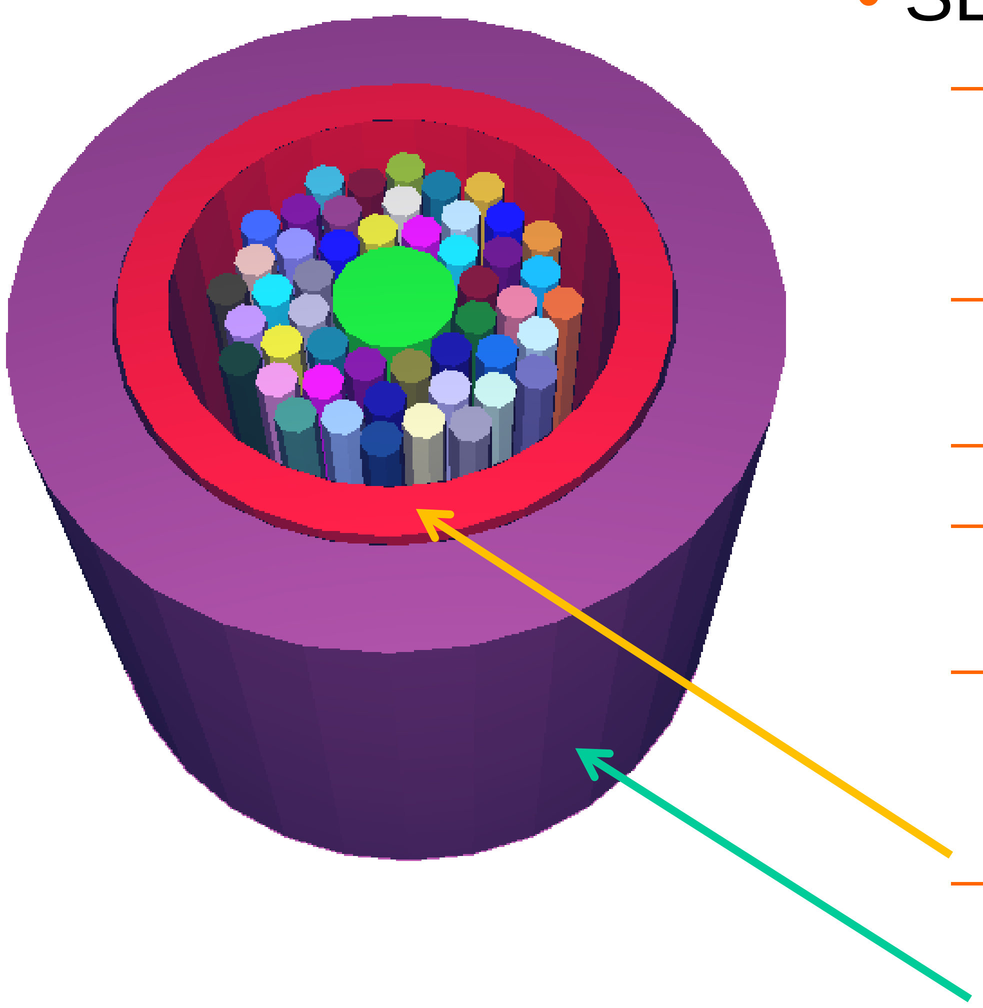


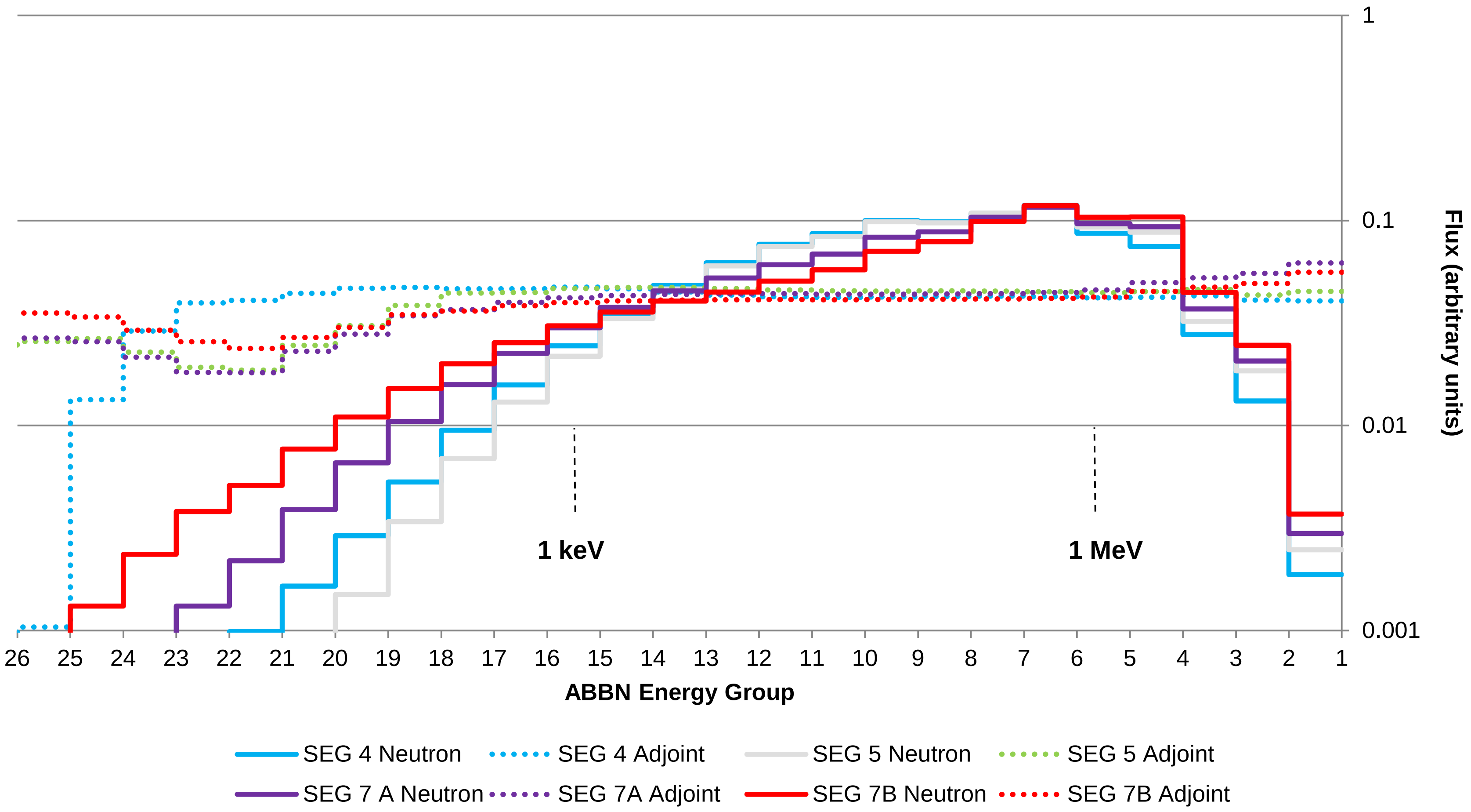
- SEG 6 lattice
  - Radial arrangement of 4 rings each having 12 channels
  - Inner ring: 36% enriched U
  - Outer 3 rings: natural U
  - Inner absorption zone: B_4C
  - Experimental channel is either 5.0 or 1.2 cm in diameter
  - Natural U converter surrounded by annular driver fuel

RRR/SEG Critical Configurations

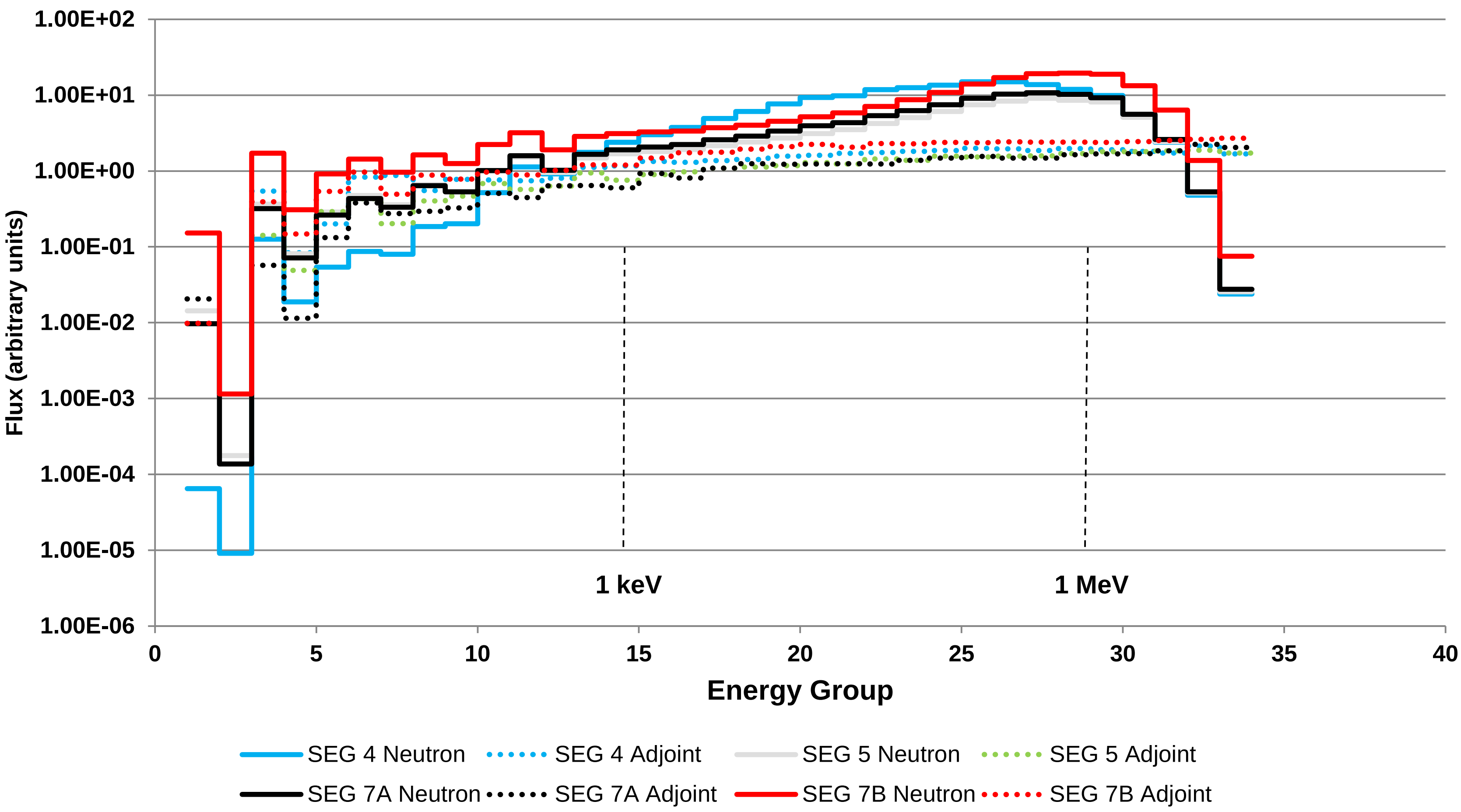
- With the SEG lattice inserted, criticality is achieved by varying the radius of the annular homogenized driver (r_d)
  - Results obtained using MCNP6.1 and ENDF/B-VII.I cross section library

SEG 4:	$k_{eff} = 1.00029$,	0.00003 ,	$r_d = 10.00\ cm$
SEG 5:	$k_{eff} = 1.00026$,	0.00003 ,	$r_d = 9.10\ cm$
SEG 6 EK-10:	$k_{eff} = 1.00015$,	0.00003 ,	$r_d = 11.20\ cm$
SEG 6 EK-45:	$k_{eff} = 1.00020$,	0.00003 ,	$r_d = 11.20\ cm$
SEG 7A:	$k_{eff} = 0.99956$,	0.00003 ,	$r_d = 10.55\ cm$
SEG 7B:	$k_{eff} = 1.00050$,	0.00003 ,	$r_d = 8.75\ cm$

Experimental Flux and Adjoint Spectrums



MCNP6.1 Calculated Flux and Adjoint Spectrums



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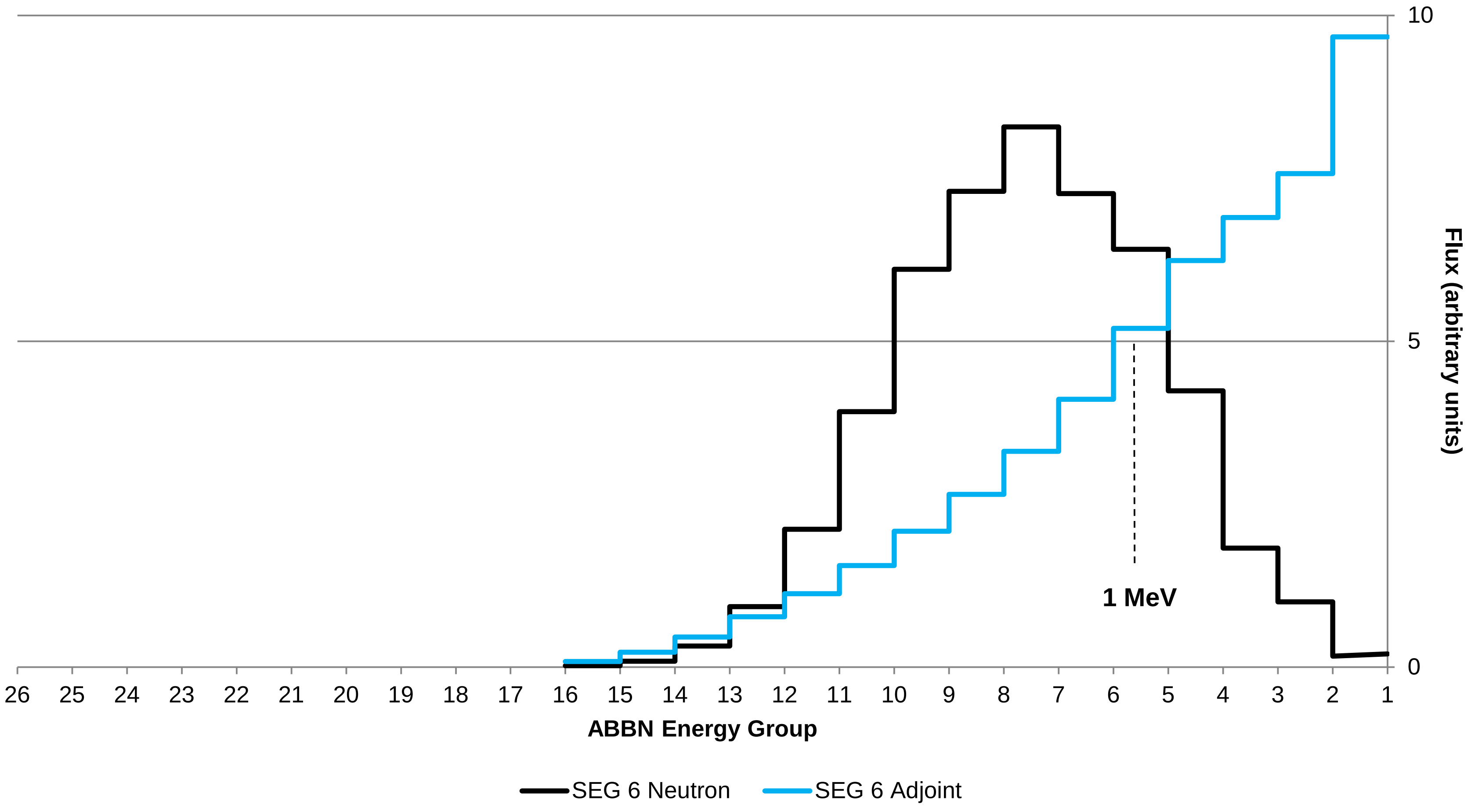

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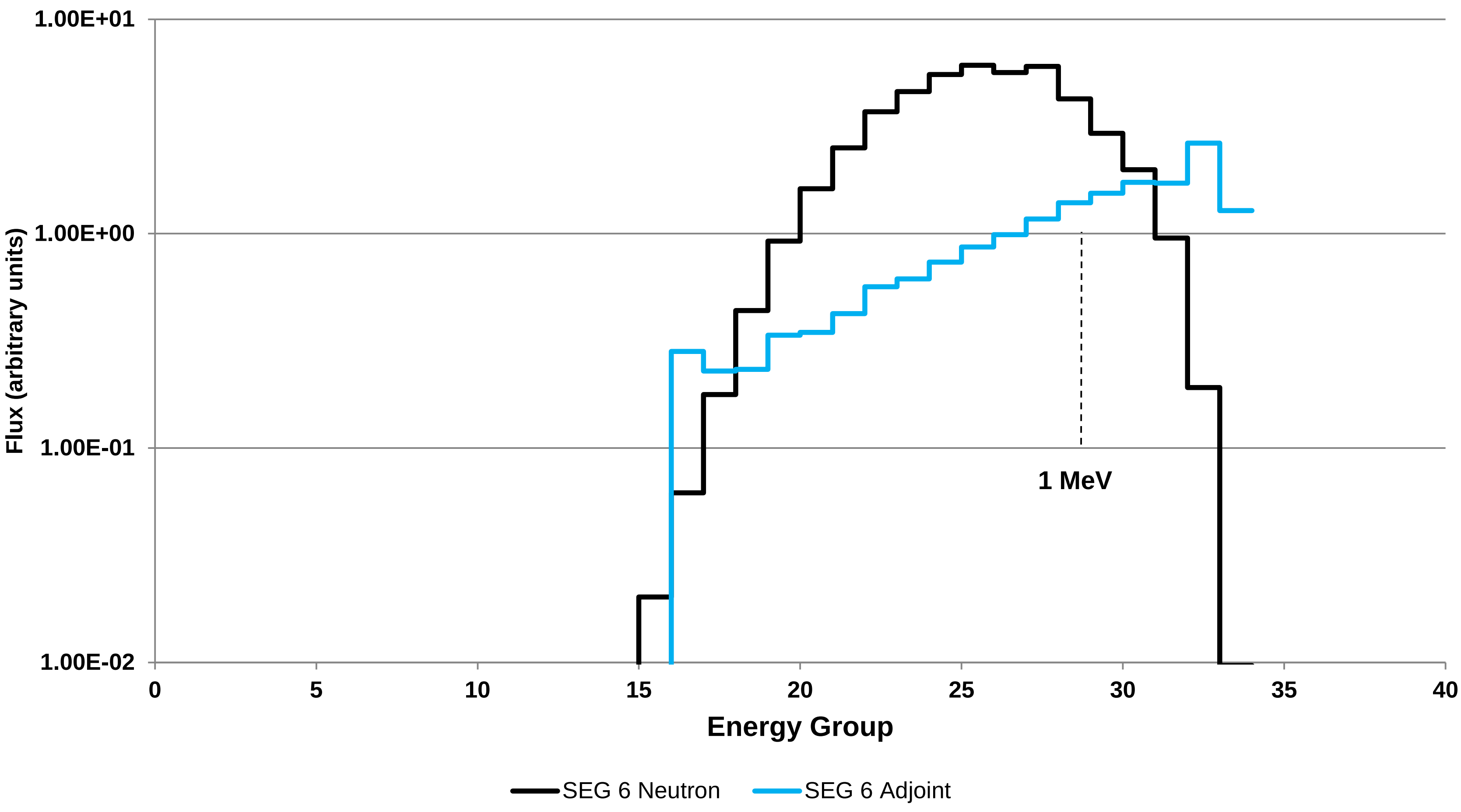

Sample Materials/Measurements of Interest

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	SEG 4	SEG 5	SEG 7A	SEG 7B
Material	Central Reactivity Worth (pcm)			
B_4C (81% B-10)	-2.604 ± 0.0074	-2.7328 ± 0.0052	-1.4570 ± 0.0029	-1.9548 ± 0.0036
B_4C (natural)	-	-	-4.0297	-2.6875 ± 0.0036
U_3O_8 (90% U-235)	0.1406 ± 0.0022	0.1604 ± 0.0022	0.1409 ± 0.0022	0.2165 ± 0.0022
U (89.5% enr.)	-	0.4983 ± 0.0044	-	-
U (36% enr.)	-	3.3915	-	-
U (nat)	-	-0.2517 ± 0.0044	-0.1292 ± 0.0037	-0.1803 ± 0.0036
Mo-95	-0.3966 ± 0.0185	-0.4232 ± 0.0096	-0.0184 ± 0.0022	-0.0232 ± 0.0022
Mo-97	-0.3804 ± 0.0096	-0.4342 ± 0.0096	-0.0162 ± 0.0022	-0.0203 ± 0.0022
Mo-98	-0.1354 ± 0.0148	-0.1192 ± 0.0096	-0.0051 ± 0.0022	-0.0101 ± 0.0022
Mo-100	-0.0770 ± 0.0059	-0.0839 ± 0.0066	-0.0264 ± 0.0022	-0.021 ± 0.0022
Rh-103	-0.3678	-0.3717 ± 0.0029	-0.1908 ± 0.0022	-0.2766 ± 0.0029
Pd-105	-0.6112 ± 0.0074	-0.6484 ± 0.0052	-	-
Cs-133	-0.4211 ± 0.0148	-0.4203 ± 0.0037	-	-
Ag-109	-0.6135 ± 0.0118	-0.4740 ± 0.0044	-0.0499 ± 0.0022	-0.0898 ± 0.0022
Sm-149	-2.3532 ± 0.037	-2.1175 ± 0.0103	-0.1108 ± 0.0022	-0.1948 ± 0.0029
Eu-153	-2.2540 ± 0.0318	-2.0093 ± 0.0155	-	-
Ta	-	-4.7494	-0.6878 ± 0.0037	-2.1923 ± 0.0036
Nb	-	-1.4161 ± 0.0052	-	-0.8102 ± 0.0029
Co	-	-0.4055 ± 0.0044	-	-
Cd	-	-1.7635 ± 0.0052	-	-1.8426 ± 0.0036
Fe	-	-0.2105 ± 0.0044	-	-0.2266 ± 0.0029
Ni	-	-0.4968 ± 0.0037	-	-
Mo	-	-0.6094 ± 0.0037	-	-0.4663 ± 0.0036
Mn	-	-0.3827 ± 0.0029	-	-
Au	-	-0.7220 ± 0.0029	-	-
Cu	-	-0.5483	-	-
Zr	-	-0.1450 ± 0.0044	-	-
W	-	-1.5250 ± 0.0044	-	-
C	-	-	-0.1395 ± 0.0029	-0.1187 ± 0.0029

	SEG 6 (EK-10)	SEG 6 (EK-45)
Material	Central Reactivity Worth (pcm/gram)	
B_4C (81% B-10)	-0.4120 ± 0.0075	-0.4644
B_4C (90% B-10)	-	-
B_4C (natural)	-0.1258 ± 0.0045	-0.1236 ± 0.0030
B-10	-0.6374	
U_3O_8 (90% U-235)	-	0.0360
U-235	-	0.0816
U-238	-	0.0053
Mo	-0.01146	-0.01273
Fe	-0.00899	-0.00914
Cr	0	-0.00906
Ni	-0.01138	-0.01161
Al	-0.01565	-0.01498
Zr	-0.00742	-0.00756
Ti	-0.01213	-0.01446
Cd	-0.01281	-0.01416
Pb	-0.00202	-0.0024
Bi	-0.00217	-0.00225
Mg	-0.02269	-0.02254
Be	-0.10112	-0.10516
W	-0.00944	-0.01004
Cu	-0.01049	-0.01086
Rh	-0.0215	-
Mn	-	-0.01146
Ta	-	-0.0161
V	-	-0.01431
Si	-	-0.01363
Nb	-	-1.46804
Co	-	-0.00936
H-10	-7.9318	-8.2315
Polyethelene	-1.1834 ± 0.0037	-1.2284
Polyethelene (D)	-0.3970 ± 0.0075	0.3970 ± 0.0112
H_2O	-0.9587 ± 0.0037	-0.9617 ± 0.0037
D_2O	-0.2959 ± 0.0030	-0.3003 ± 0.0037
C	-0.0528 ± 0.0004	-0.0551 ± 0.0004

SEG 6 sample masses only found for B_4C, U_3O_8, C, and PE samples

Current Status and Future Work

- Sample reactivity effects were not observable using MCNP6.1
  - Larger samples
  - Sensitivity coefficients
- Continue analysis using TRIPOLI - capable of exact perturbation calculations
  - Develop accurate geometric models
  - Verify adjoint shapes
  - Calculate and compare central reactivity worths
- Compile experimental results for absorption and scattering measurements
- Sensitivity/uncertainty analysis

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