Absorber Material Behavior in Water-Reflected Metal Systems

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Introduction

- Monte Carlo models were used to determine the behavior and performance of neutron absorption materials for use with water-reflected systems
- Why perform this work given the amount of published material concerning absorption materials?
  - Reactor applications vs. experiment and process facilities
  - Single items
  - Large masses (water-reflected critical masses)
  - Single absorber
  - Fast systems

Introduction

- Ways to limit multiplication in water-reflected subcritical systems:
  - Limit the nuclear material (this work assumes that this rule was not followed)
  - Isolate the nuclear material from the water
  - Use neutron absorbers

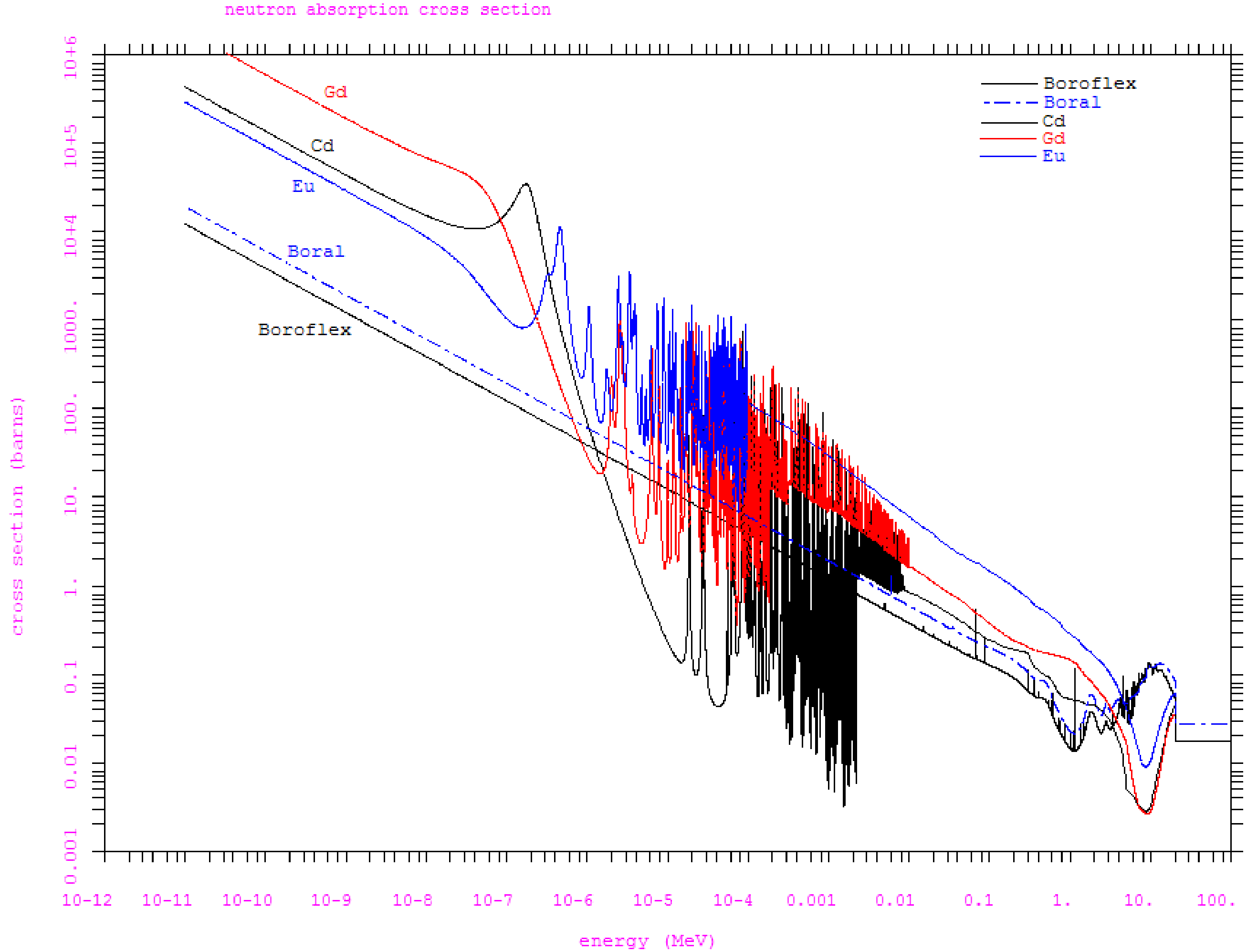
Materials

- HEU: 25 kg sphere, 93.2 wt.% ^{235}U, 18.75 g/cm³
- Plutonium:
  - δ-phase: 8.75 kg sphere, 93.59 wt.% ^{239}Pu, 15.29 g/cm³
  - α-phase: 6 kg sphere, 93.735 wt.% ^{239}Pu, 19.60 g/cm³
- Approximately equal to water-reflected critical masses
- Displacement was provided by polyurethane foam, with a density of 0.021 g/cm³

Neutron Absorber Materials

Material	Natural Abundance (per cent)	Thermal σa (barns)	Thermal Σa (cm-1)	Major Resonances	
				Energy (eV)	σa (barns)
Boron (B)	---	760	107	---	---
Boron-10	20	3840	---	None	
Cadmium (Cd)	---	2520	113	---	---
Cadmium-113	12.2	20,600	---	0.18	7,200
Samarium (Sm)	---	5,600	155	---	---
Samarium-149	13.8	41,000	---	0.096	16,000
Samarium-152	26.6	225	---	8.2	15,000
Europium (Eu)	---	4,300	90	---	---
Europium-151	47.8	7,700	---	0.46	11,000
Europium-153	52.2	450	---	2.46	3,000
Gadolinium (Gd)	---	49,000	1,400	---	---
Gadolinium -155	14.8	61,000	---	2.6	1,400
Gadolinium -157	15.7	255,000	---	17	1,000
Hafnium (Hf)	---	105	4.71	---	---
Hafnium-177	18.6	370	---	2.36	6,000
Hafnium-178	27.3	75	---	7.8	10,000
Hafnium-177	13.6	43	---	5.69	1,100
Hafnium-178	35.1	13	---	74	130

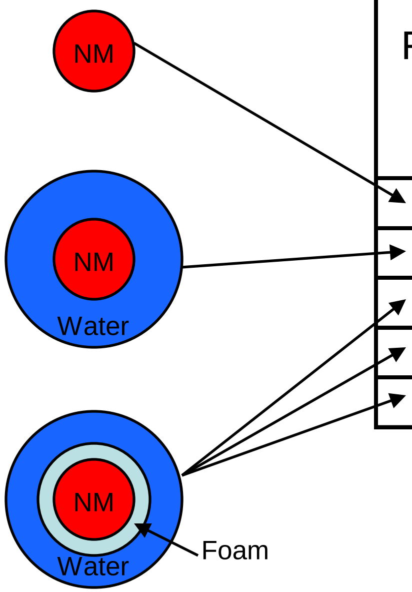
Neutron Absorber Materials



Method

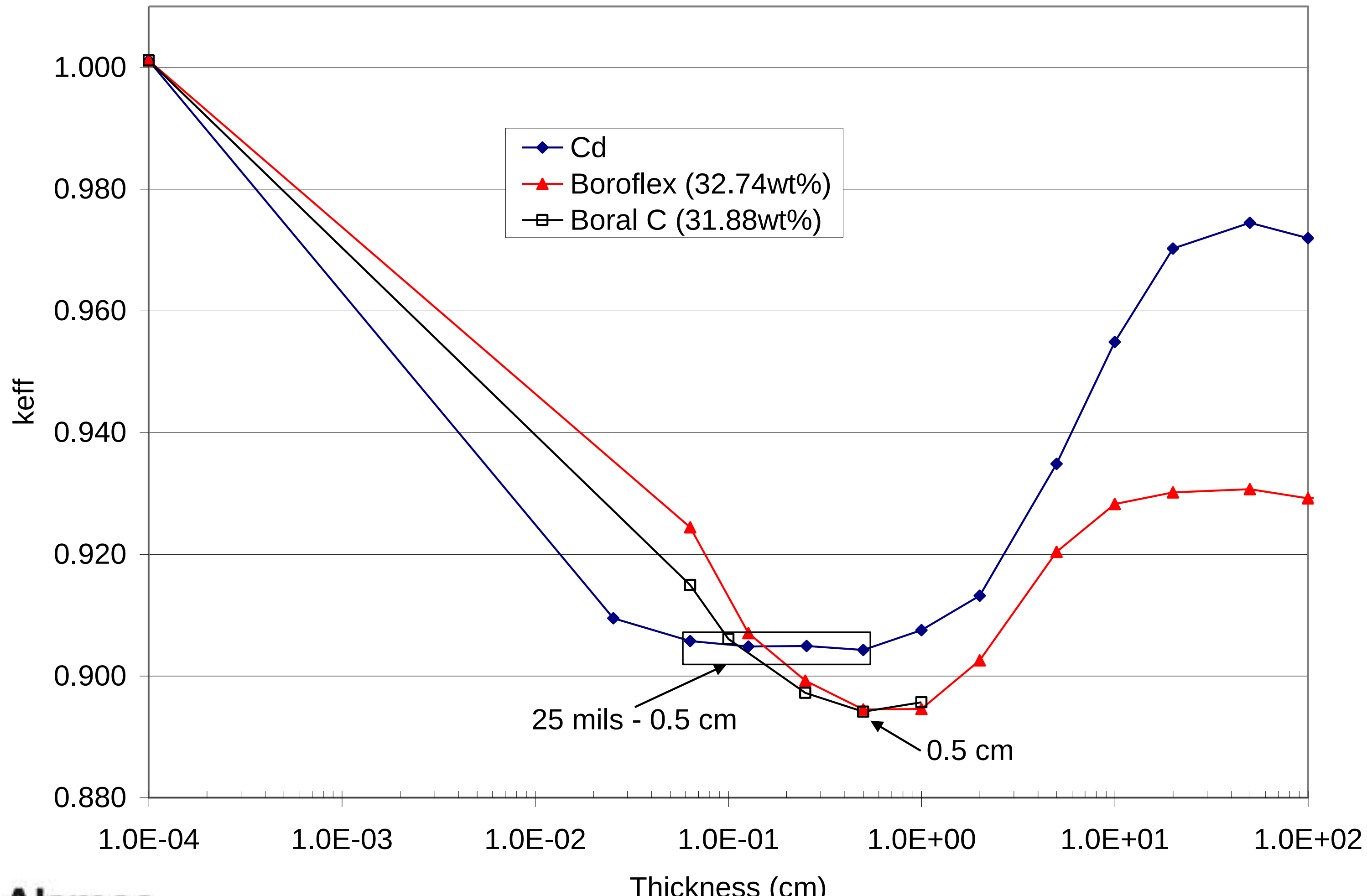
- Models used MCNP5 with ENDF/B VI.8 cross-sections
- KCODE calculations:
  - 1000 neutrons/cycle
  - 1050 cycles (first 50 skipped)
  - 1σ standard deviation in the keff values: 0.00050-0.00080
- Some assumptions used:
  - All geometry consisted of perfect spheres
  - All materials homogeneously distributed
  - 100 cm of water for infinite water

Results

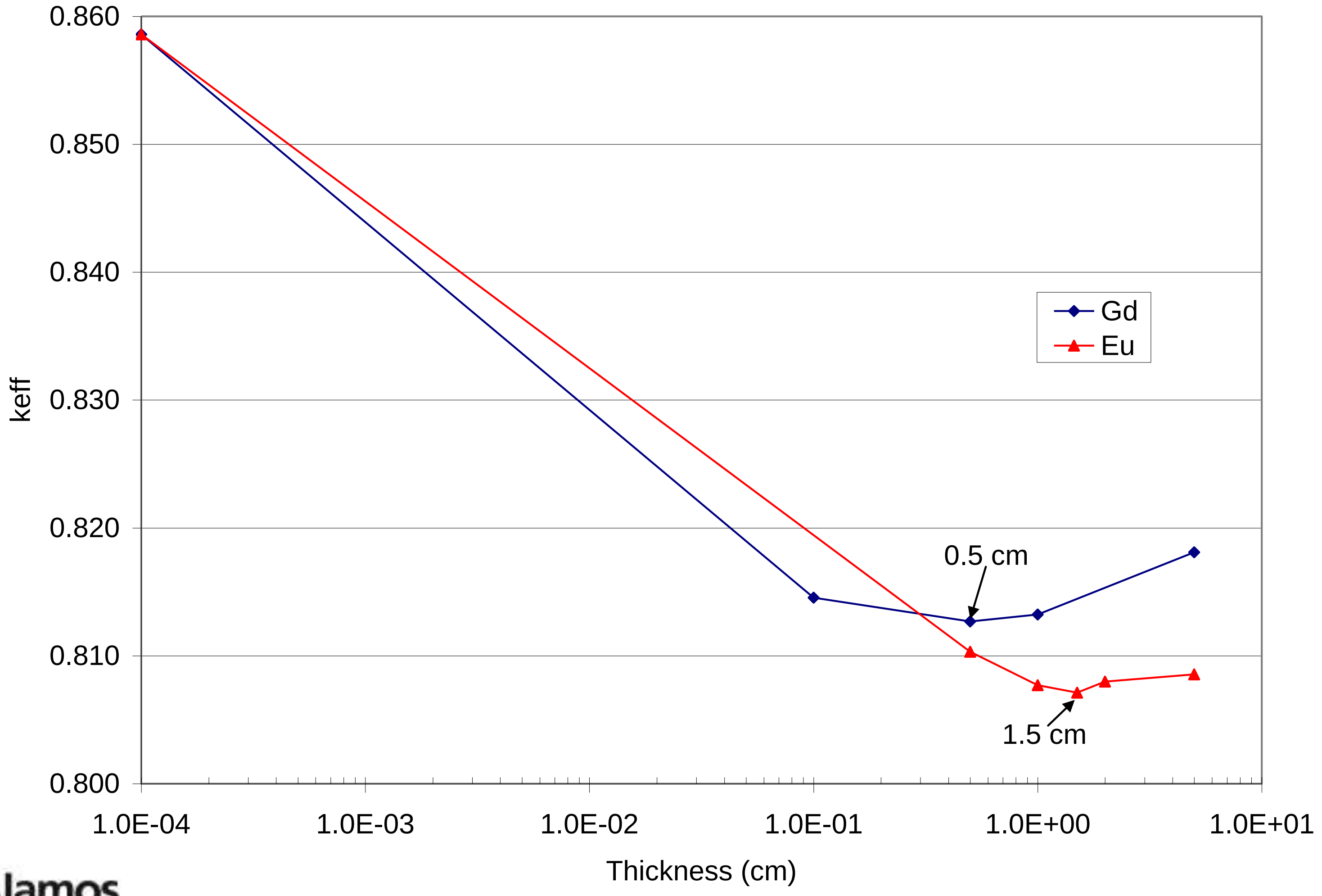


Foam thickness (in)	Water-Reflected keff		
	HEU	d-Pu	a-Pu
0 (no water)	0.7984	0.8098	0.8420
0	1.0011	0.9984	1.0025
1	0.9460	0.9410	0.9488
2	0.9140	0.9095	0.9205
5	0.8586	0.8578	0.8783

Results


Cd
Boroflex (32.74wt%)
Boral C (31.88wt%)
keff
1.000
0.980
0.960
0.940
0.920
0.900
0.880
25 mils - 0.5 cm
0.5 cm
1.0E-04
1.0E-03
1.0E-02
1.0E-01
1.0E+00
1.0E+01
1.0E+02
Thickness (cm)

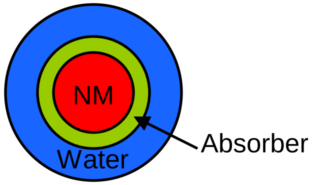
Results



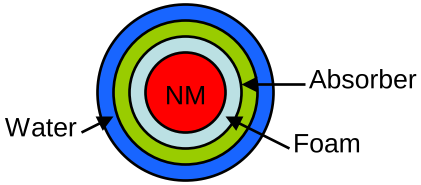
0.860
0.850
0.840
0.830
0.820
0.810
0.800
keff
Gd
Eu
0.5 cm
1.5 cm
1.0E-04
1.0E-03
1.0E-02
1.0E-01
1.0E+00
1.0E+01
Thickness (cm)

		water-reflected keff					
		HEU		d-Pu		a-Pu	
material	boron wt%	C1: abs around bare	C2: abs around 5" foam	C1: abs around bare	C2: abs around 5" foam	C1: abs around bare	C2: abs around 5" foam
-	-	1.0011	0.8586	0.9984	0.8578	1.0025	0.8783
Cd	-	0.9048	0.8154	0.9152	0.8231	0.9352	0.8528
CdO	-	0.9175	0.8159	-	-	-	-
Boroflex	32.74%	0.8945	0.8126	0.9051	0.8217	0.9265	0.8534
	20.00%	0.9002	0.8145	-	-	-	-
	10.00%	0.9091	0.8158	-	-	-	-
	5.00%	0.9220	0.8171	0.9293	0.8265	0.9471	0.8550
Enriched Boroflex	5% B, 99%B10	0.8975	0.8124	-	-	-	-
Boral C	31.88%	0.8941	0.8115	0.9040	0.8218	0.9258	0.8525
	20.00%	0.8960	0.8144	-	-	-	-
	10.00%	0.9037	0.8149	-	-	-	-
	5.00%	0.9139	0.8161	0.9215	0.8253	0.9388	0.8537
Enriched Boral C	5% B, 99%B10	0.8904	0.8127	-	-	-	-
B2O3	40% at.	0.9006	0.8137	-	-	-	-
Gd	-	0.8919	0.8127	0.8999	0.8219	0.9216	0.8521
Gd2O3	-	0.9013	0.8136	-	-	-	-
Eu	-	0.8551	0.8071	0.8664	0.8177	0.8928	0.8495
Eu2O3	-	0.8792	0.8096	-	-	-	-
Sm	-	0.8861	0.8117	0.8989	0.8199	0.9204	0.8521
Sm2O3	-	0.8996	0.8133	-	-	-	-
Hf	-	0.9016	0.8145	0.9115	0.8224	0.9309	0.8538
Dy	-	0.8861	0.8117	0.8951	0.8205	0.9175	0.8514

C1



C2



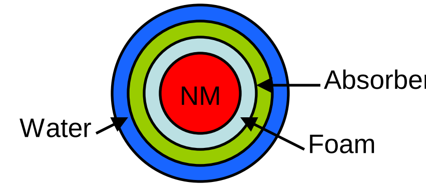
Results

Configuration	Absorber Material	Percent of HEU fissions caused by:		
		Thermal <0.625 eV	Intermediate 0.625 eV - 100 keV	Fast >100 keV
Nuclear Material in air	-	0.00%	4.89%	95.11%
Water reflector	-	15.25%	16.04%	68.71%
5" foam + water	-	12.09%	6.66%	81.25%
C1: Abs + water	Cd	0.01%	16.39%	83.60%
	Boroflex	0.03%	13.25%	86.71%
	Gd	0.03%	13.19%	86.78%
	Eu	0.00%	7.74%	92.26%
C2: 5" foam, abs, water	Cd	0.02%	7.23%	92.75%
	Boroflex	0.02%	6.63%	93.36%
	Gd	0.03%	6.71%	93.26%
	Eu	0.00%	5.53%	94.47%

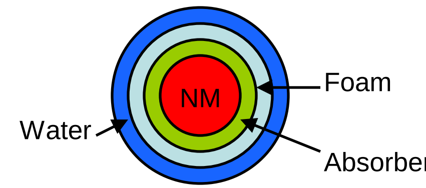
Results

		water-reflected keff	
		HEU	
material	boron wt%	C3: abs around 2"	C4: 2" foam around abs
-	-	0.9140	0.9140
Cd	-	0.8375	0.8402
Boroflex	32.74%	0.8332	0.8486
	5.00%	0.8452	0.8631
	25%, 96% B-10	0.8260	0.8405
Boral C	31.88%	0.8309	0.8468
	5.00%	0.8419	0.8552
Gd	-	0.8324	0.8434
Eu	-	0.8191	0.8339
Sm	-	0.8290	0.8426
Hf	-	0.8357	0.8529
Dy	-	0.8294	0.8396
Neutron Putty	9.37%	0.8280	0.8820
	25%, 96% B-10	0.8190	0.8443

C3



C4



lowest keff	
2nd lowest keff	
3rd lowest keff	

Conclusions

- Optimal absorber thicknesses:
  - Cd: 25 mils – 0.5 cm
  - Boroflex, boral, Gd: 0.5 cm
  - Eu: 1.5 cm
- Absorber material performance:
  - Eu performed best
  - Most materials similar when placed around foam (C2)
- Neutron spectra:
  - Systems are still fast when reflected by infinite water
  - Absorber materials remove most thermal neutrons but do not remove intermediate neutrons
  - Foam removes some of the intermediate neutrons
- Absorber and foam placement:
  - Metal absorbers performed similar when placed inside or outside foam
  - Boron absorbers performed much better when placed outside the foam

Future Work

- Perform calculations with multiple items:
  - 2-4 units
  - Each with own absorber material, displacement material, or both
- Perform subcritical measurements:
  - Use commercially available absorber materials
  - Determine practicality/cost
  - Validate performance of optimal materials

Extra slides

Boron absorber compositions

	Boroflex	Boral
Al	-	59.26
B	32.74	31.88
C	21.13	8.86
H	2.65	-
Cr	0.03	-
Fe	0.05	0.05
Mg	-	0.01
Na	-	0.02
O	21.01	-
Si	22.39	0.06

Results

		water-reflected keff		
		d-Pu		
material	boron wt%	C1: abs around bare	C3: abs around 2" foam	C4: 2" foam around abs
-	-	0.99841	0.90951	0.90951
Cd	-	0.91524	0.84372	0.84722
Boroflex	32.74%	0.90513	0.83844	0.85806
	5.00%	0.92926	0.84967	0.87165
	25%, 96% B-10	0.89167	0.83347	0.85194
Boral C	31.88%	0.90398	0.83790	0.85773
	5.00%	0.92152	0.84651	0.86360
Gd	-	0.89989	0.83865	0.85194
Eu	-	0.86637	0.82862	0.84615
Sm	-	0.89886	0.83720	0.85456
Hf	-	0.91149	0.84245	0.86348
Dy	-	0.89506	0.83647	0.84932
Neutron Putty	9.37%	0.91276	0.83754	0.89277
	25%, 96% B-10	0.87108	0.82789	0.85183

lowest keff	(purple)
2nd lowest keff	(green)
3rd lowest keff	(orange)

Results

		water-reflected keff		
		a-Pu		
material	boron wt%	C1: abs around bare	C3: abs around 2" foam	C4: 2" foam around abs
-	-	1.00250	0.92047	0.92047
Cd	-	0.93519	0.86821	0.87199
Boroflex	32.74%	0.92654	0.86591	0.88424
	5.00%	0.94705	0.87401	0.89372
	25%, 96% B-10	0.91398	0.86131	0.88035
Boral C	31.88%	0.92575	0.86623	0.88429
	5.00%	0.93882	0.87129	0.88835
Gd	-	0.92156	0.86561	0.87913
Eu	-	0.89278	0.85727	0.87472
Sm	-	0.92040	0.86455	0.88246
Hf	-	0.93092	0.86871	0.88880
Dy	-	0.91751	0.86370	0.87676
Neutron Putty	9.37%	0.94259	0.86165	0.91688
	25%, 96% B-10	0.90441	0.85677	0.88154

lowest keff	
2nd lowest keff	
3rd lowest keff	