Current Benchmark Evaluation Efforts to Support Integral Nuclear Data

Mini-CSEWG-2015

7 May 2015

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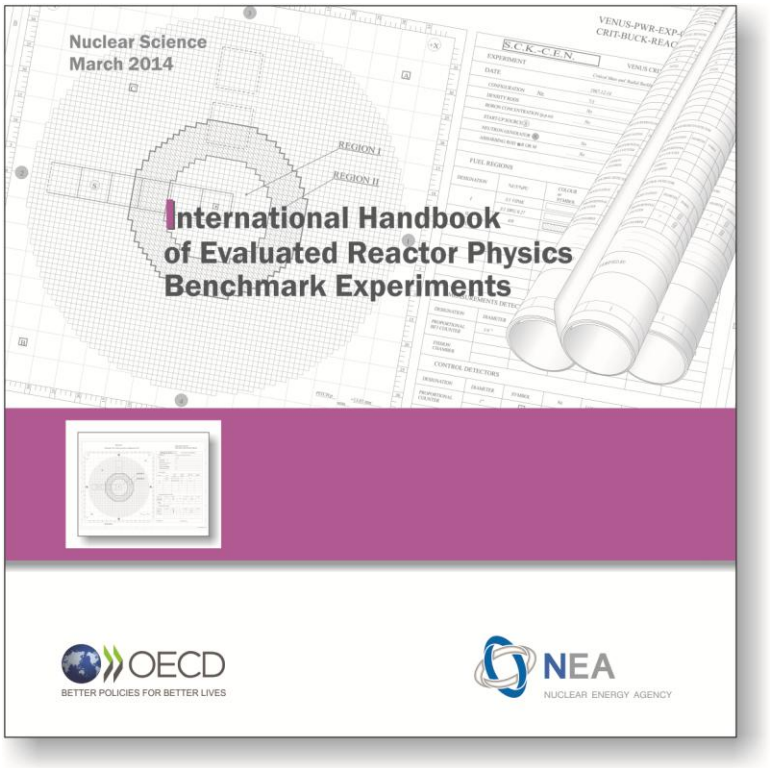
www.inl.gov

Idaho National Laboratory

International Handbook of Evaluated Reactor Physics Benchmark Experiments

March 2015 Edition

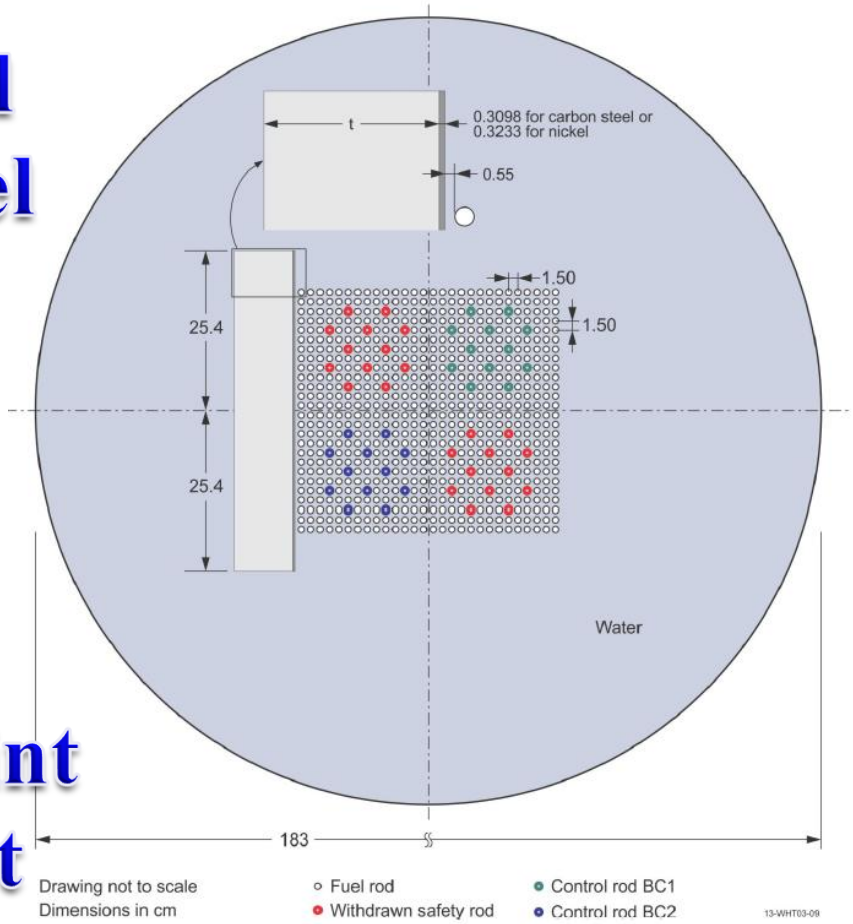
- 20 Contributing Countries
- Data from 143 Experimental Series performed at 50 Reactor Facilities
- Data from 139 are published as approved benchmarks
- Data from 4 are published only in DRAFT form



http://irphep.inl.gov/
http://www.oecd-nea.org/science/wprs/irphe/

IPEN/MB-01 Heavy Metal Reflectors

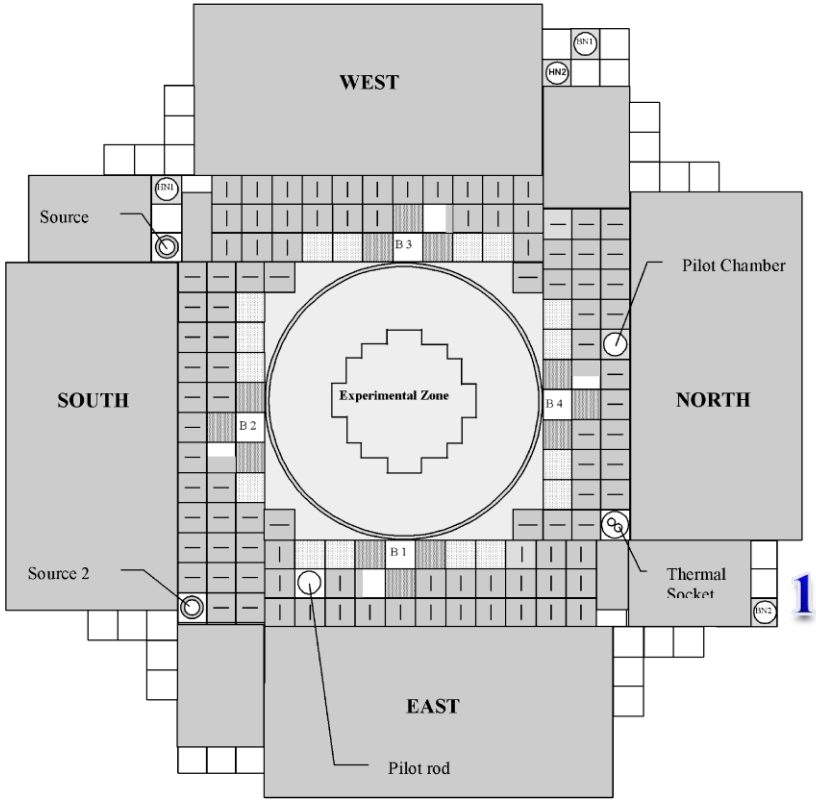
Carbon Steel
Stainless Steel
Nickel

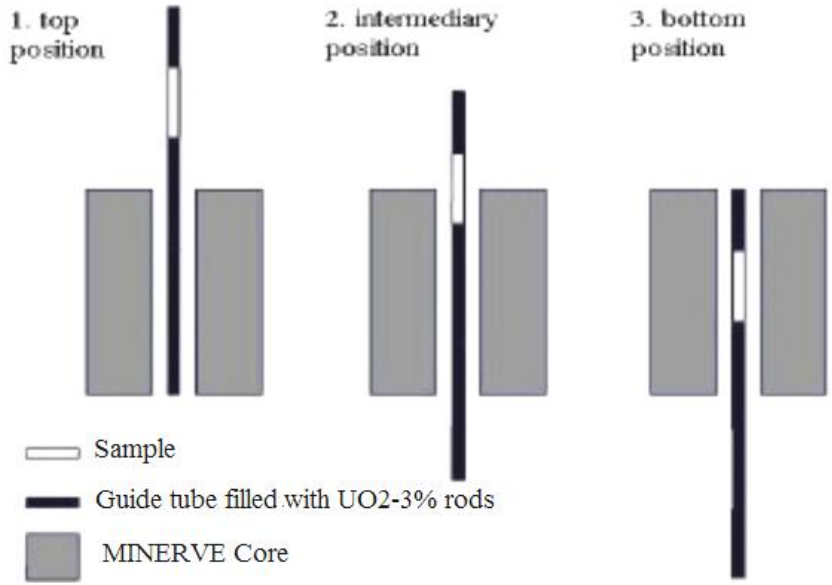


Moderation vs. Scattering

Transition point in MCNP not "perfect"

MINERVE BUC Measurements (DRAFT)





^{147}Sm, ^{149}Sm, ^{152}Sm, ^{nat}Sm

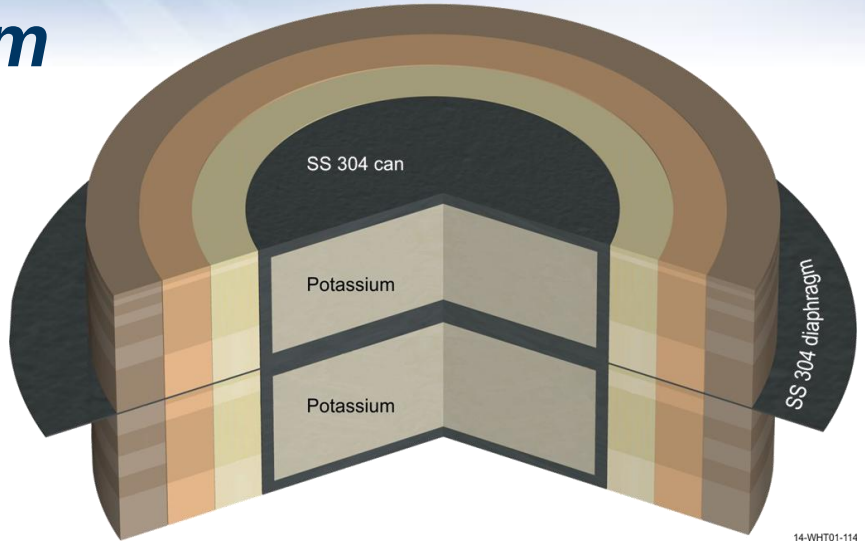
^{143}Nd, ^{145}Nd, ^{nat}Nd

^{153}Eu, ^{155}Gd, ^{103}Rh

^{95}Mo, ^{99}Tc, ^{133}Cs

C/E-1 < 10%

Potassium Fast-Spectrum Validation at ORCEF

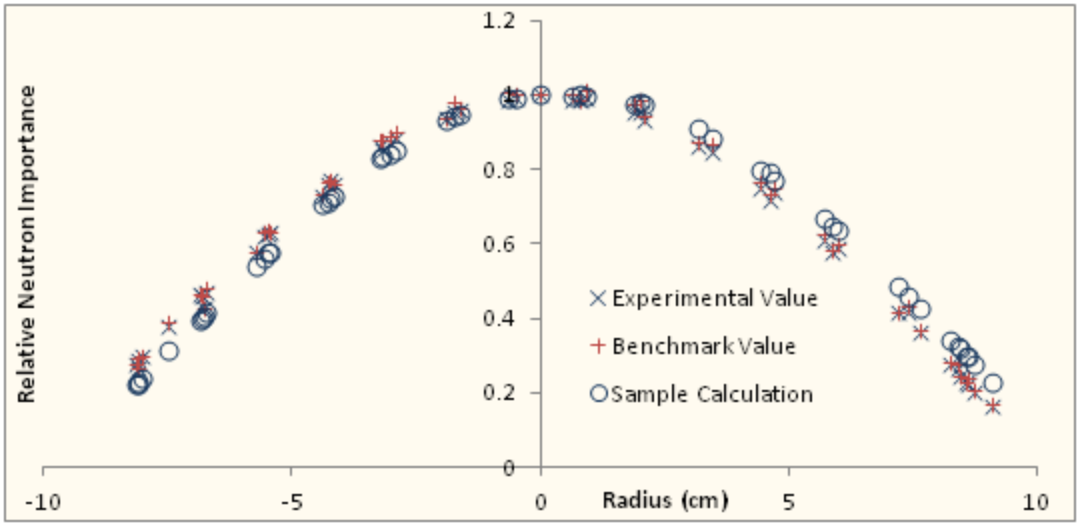


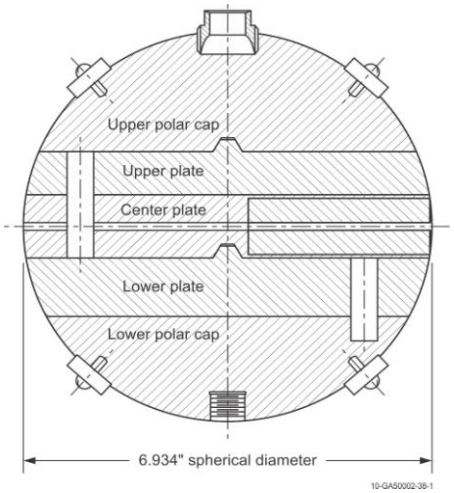
C/E-1 ~ -70%

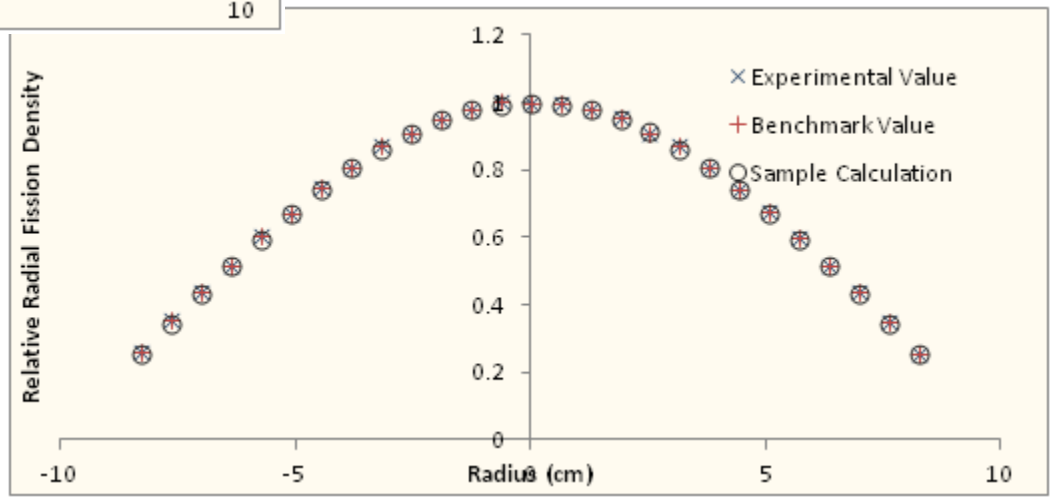
Analysis Code	Neutron Cross Section Library	Calculated ρ(¢) ± σ	Benchmark Experiment ρ(¢) ± σ	$\frac{C-E}{E}$ %
MCNP6	ENDF/B-VII.1	3.8 ± 0.4	11.4 ± 1.2	-67 ± 5
	ENDF/B-VII.0	3.1 ± 0.4		-73 ± 5
	JEFF-3.1	2.3 ± 0.4		-80 ± 4
	JENDL-3.3	2.4 ± 0.4		-79 ± 4

Additional ORSphere Measurements

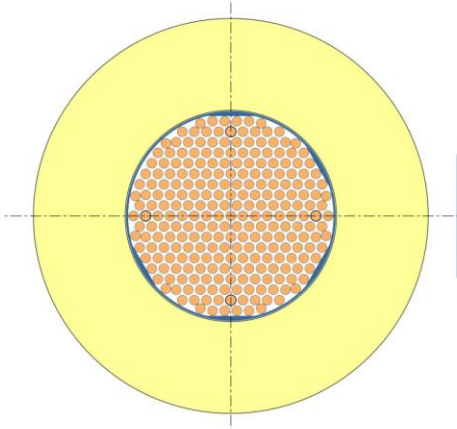
Relative Neutron Importance and Fission Density Distributions

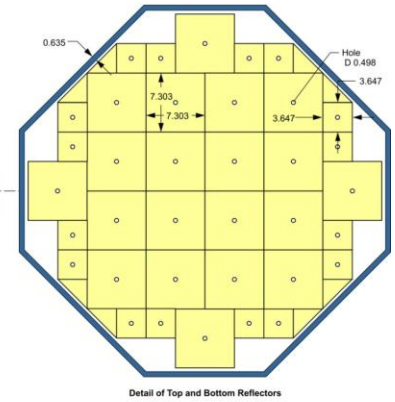




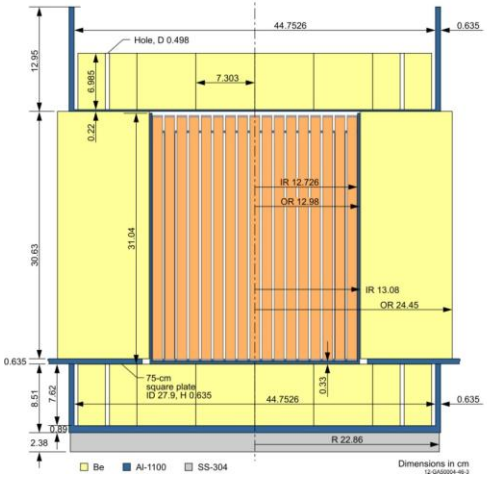


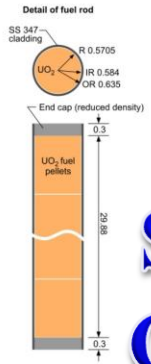
SCCA Reactivity Effects Measurements

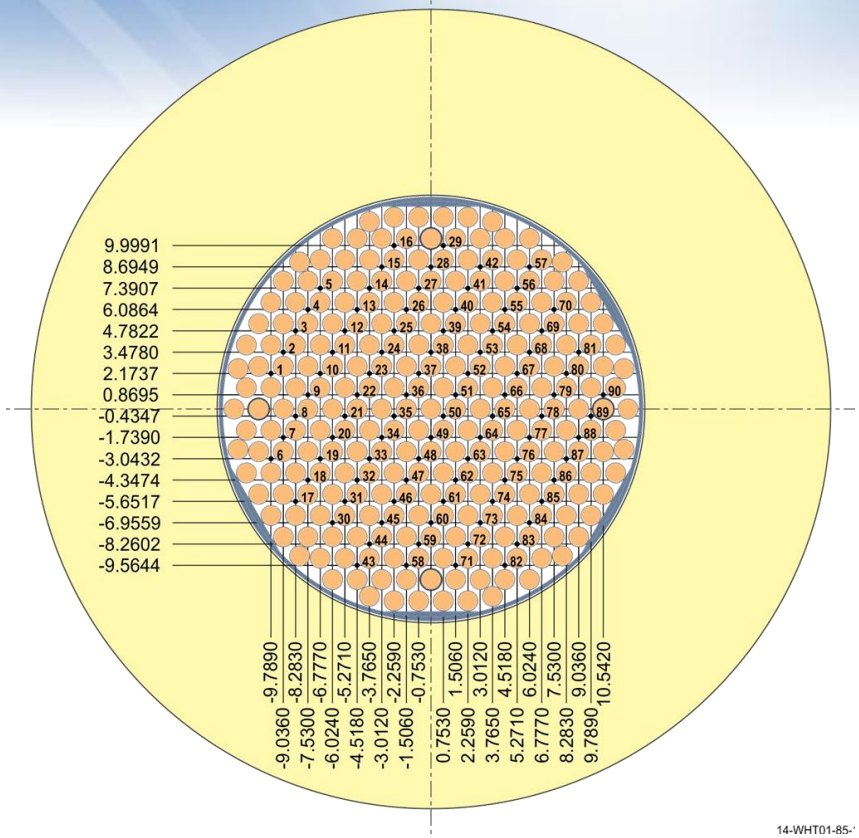




Detail of Top and Bottom Reflectors







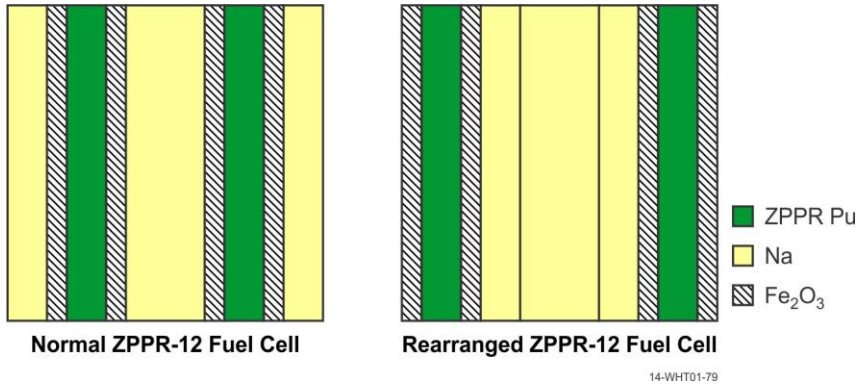
SS347, W, Nb, PE, C rodlets

C/E-1 ~ 30, -30, 100, -10, 2%

Benchmark Uncertainty

~30%

Sodium Streaming Effects in ZPPR-12: Mockup of Clinch River Breeder Reactor



C/E-1…

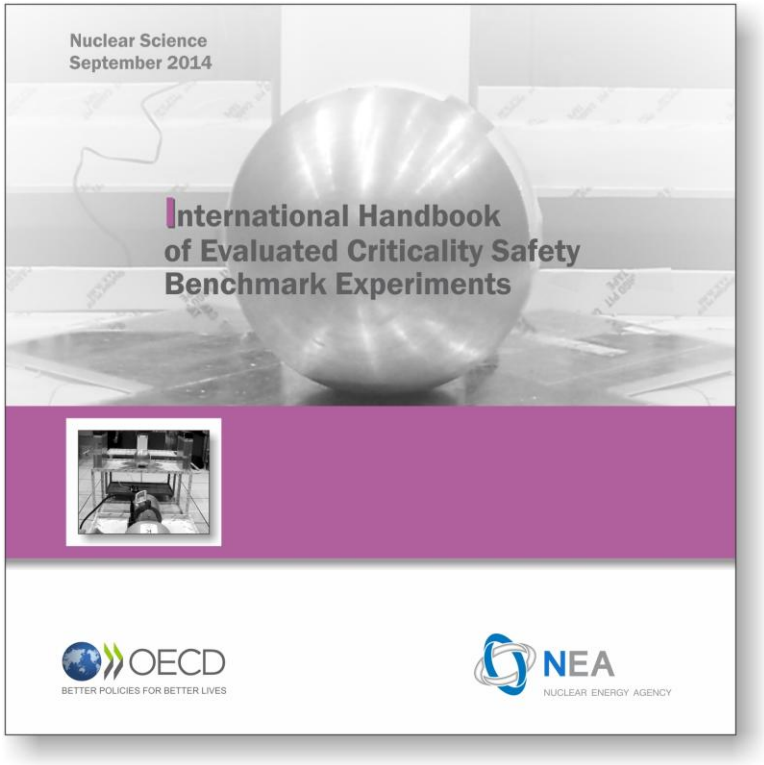
Results range from +125 to -940%

One skeptical result -2400%

International Handbook of Evaluated Criticality Safety Benchmark Experiments

September 2014 Edition

- 20 Contributing Countries
- ~67,000 Pages
- 561 Evaluations
  - 4,839 Critical, Near-Critical, or Subcritical Configurations
  - 24 Criticality Alarm Placement/Shielding Configurations
  - 207 Configurations with Fundamental Physics Measurements
  - 829 Unacceptable Experiment Configurations



http://icsbep.inl.gov/
https://www.oecd-nea.org/science/wpncs/icsbep/

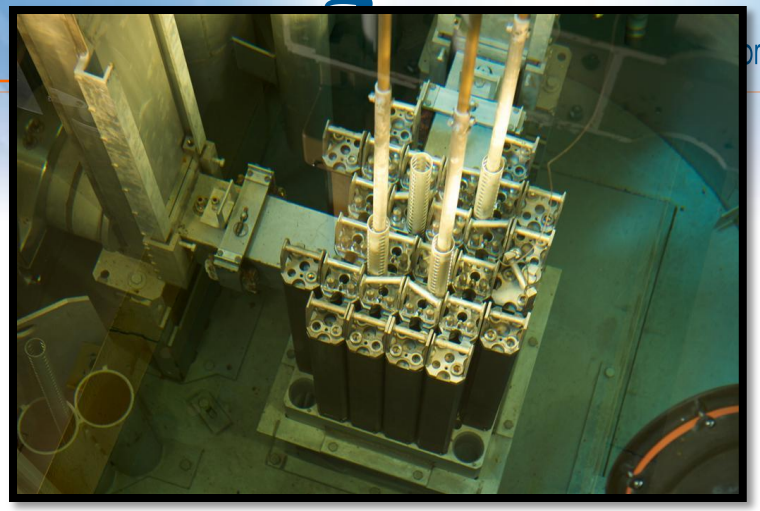
ICSBEP Meeting Next Week (11-12 May 2015)

- SCCA-003
  - Potassium Worth Measurement
- IPEN/MB-01 Reactor
  - Criticality with Mo Rods
- SNL 7uPCX
  - U(6.9%)O_2 Rods in 19 Critical Lattice Configurations
- SILENE Bare Pulse
  - Neutron Activation and TLD Responses
- U(37%)O_2F_2 Sphere
  - IEU-SOL-THERM
- Oralloy Configurations
  - Bare Metal Annuli
  - Complex Metal Annuli
  - Bare Metal Annuli with Graphite Cores

Nuclear Data Points of Interest

- TRIGA Reactors
  - UZrH or UErZrH Fuel
- Fast-Spectra Graphite
  - HEU-MET-FAST-071
- Thermal-Spectra Graphite
  - HTTR
  - HTR-PROTEUS

Neutron Radiography (NRAD) Reactor



Small Uncertainties

Summary of Experimental Uncertainties*

Parameter\Number of fuel elements	56	60	62	64
Mass of ^{235}U in fuel	18	18	18	18
^{234}U content in fuel	29	31	27	30
^{236}U content in fuel	43	46	49	48
Hydrogen-to-zirconium ratio in fuel	19	18	19	18
Erbium content in fuel	50	49	49	50
Manganese content in steel clad	71	68	65	70
Nickel content in steel clad	17	14	20	12
Impurities in steel clad	36	35	36	42
Impurities in boron carbide absorber	19	10	10	10
Graphite reflector block density	14	12	14	11
Graphite reflector block dimensions	14	14	19	15
Water saturation of graphite blocks	19	Negligible	Negligible	17
Assembly pitch in grid plate	16	18	15	17
Diameter of assembly holes in grid	13	14	12	13
Impurities in tank water	26	10	10	10
Placement of beam lines	11	14	12	Negligible
Total experimental uncertainties	122 (0.163 $)	116 (0.155 $)	116 (0.155 $)	120 (0.160 $)

*In pcm.

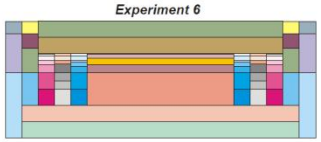
Neutron Radiography (NRAD) Reactor

- Calculated k_{eff} ~1.4% (1.75 $, 9σ) greater than benchmark k_{eff}
- Similar problems with other HEU and LEU TRIGA reactors including Slovenia TRIGA reactor benchmark
- Slovenian's believe due to ^{91}Zr and thermal scattering data for ZrH
  - "Higher elastic scattering resonance integral increases thermal neutron flux by improving neutron thermalization"
- Minimal to no impact on control rod worth calculations

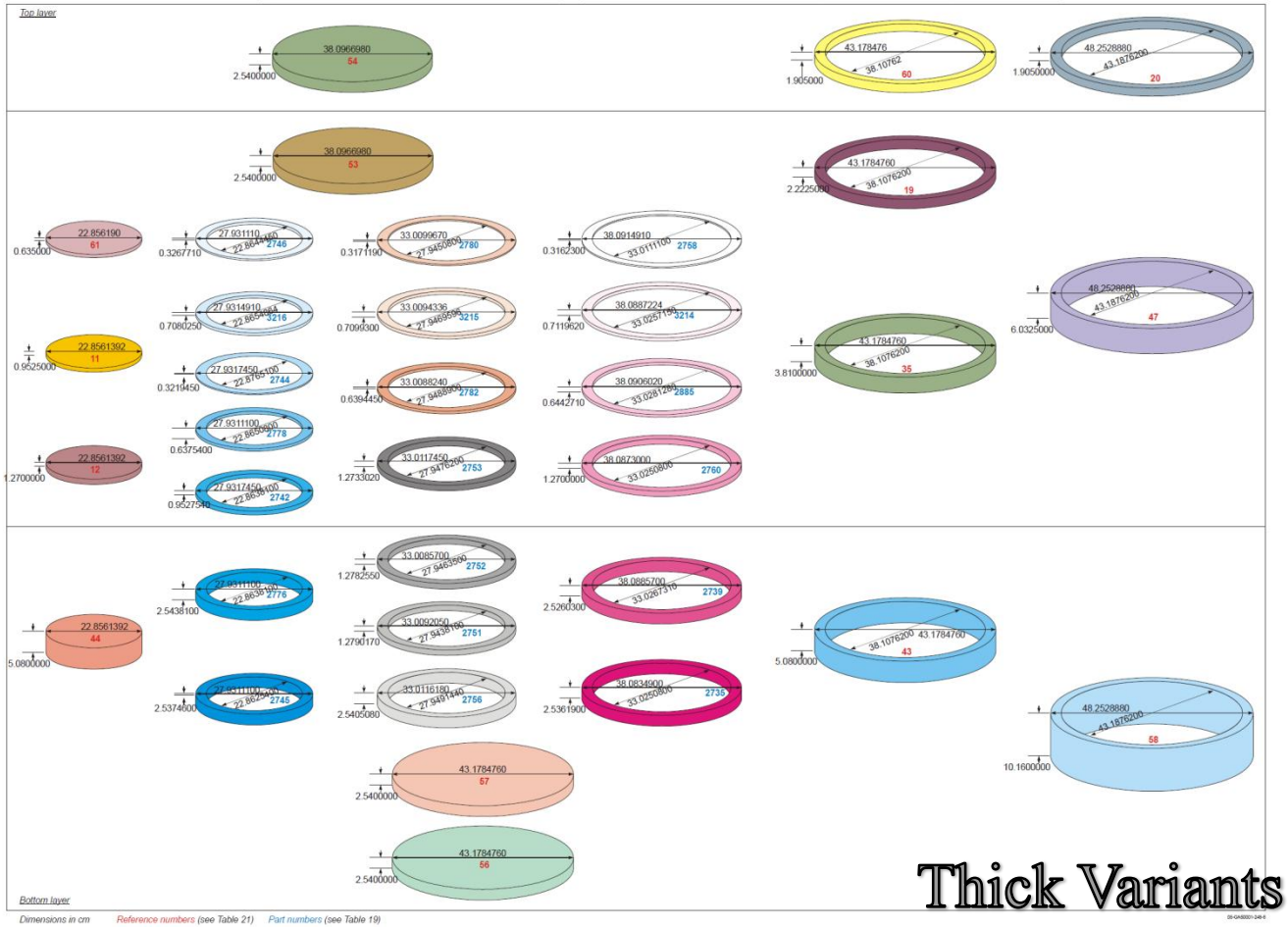
Comparison of Benchmark Experiment (k_E) and Calculated (k_C) Eigenvalues Using MCNP5 with ENDF/B-VII.0 Nuclear Data

Number of Fuel Elements	Calculated	Benchmark	$\frac{k_C - k_E}{k_E}$ (%)
	$k_C \pm \sigma$	$k_E \pm \sigma$	
56	1.01412 ± 0.00007	1.0012 ± 0.0015	1.29
60	1.01413 ± 0.00007	1.0012 ± 0.0015	1.29
62	1.01459 ± 0.00007	1.0011 ± 0.0015	1.35
64	1.01479 ± 0.00007	1.0012 ± 0.0015	1.36

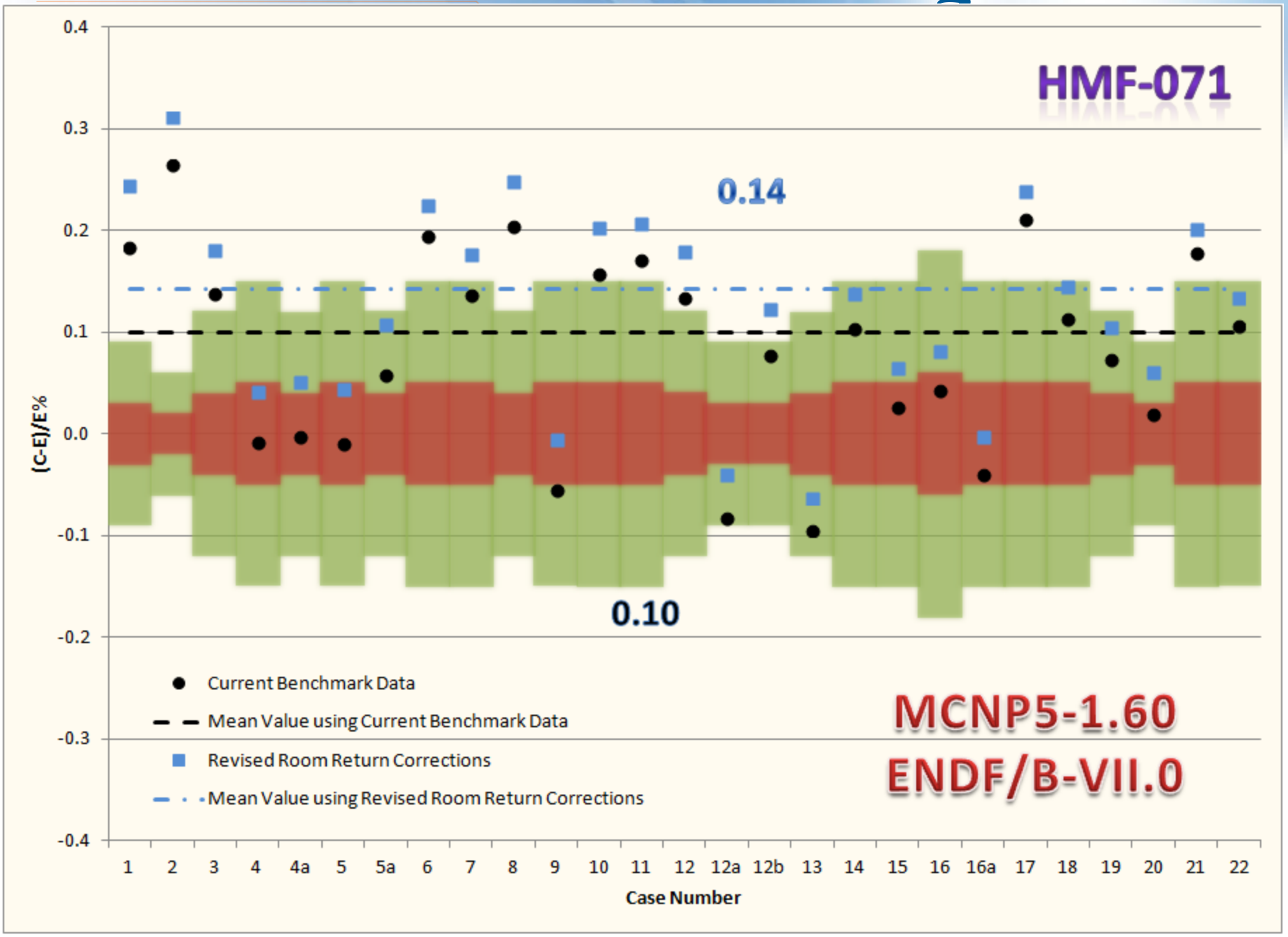
Thin Graphite Reflected (1” and 2”) (HEU-MET-FAST-071) revised

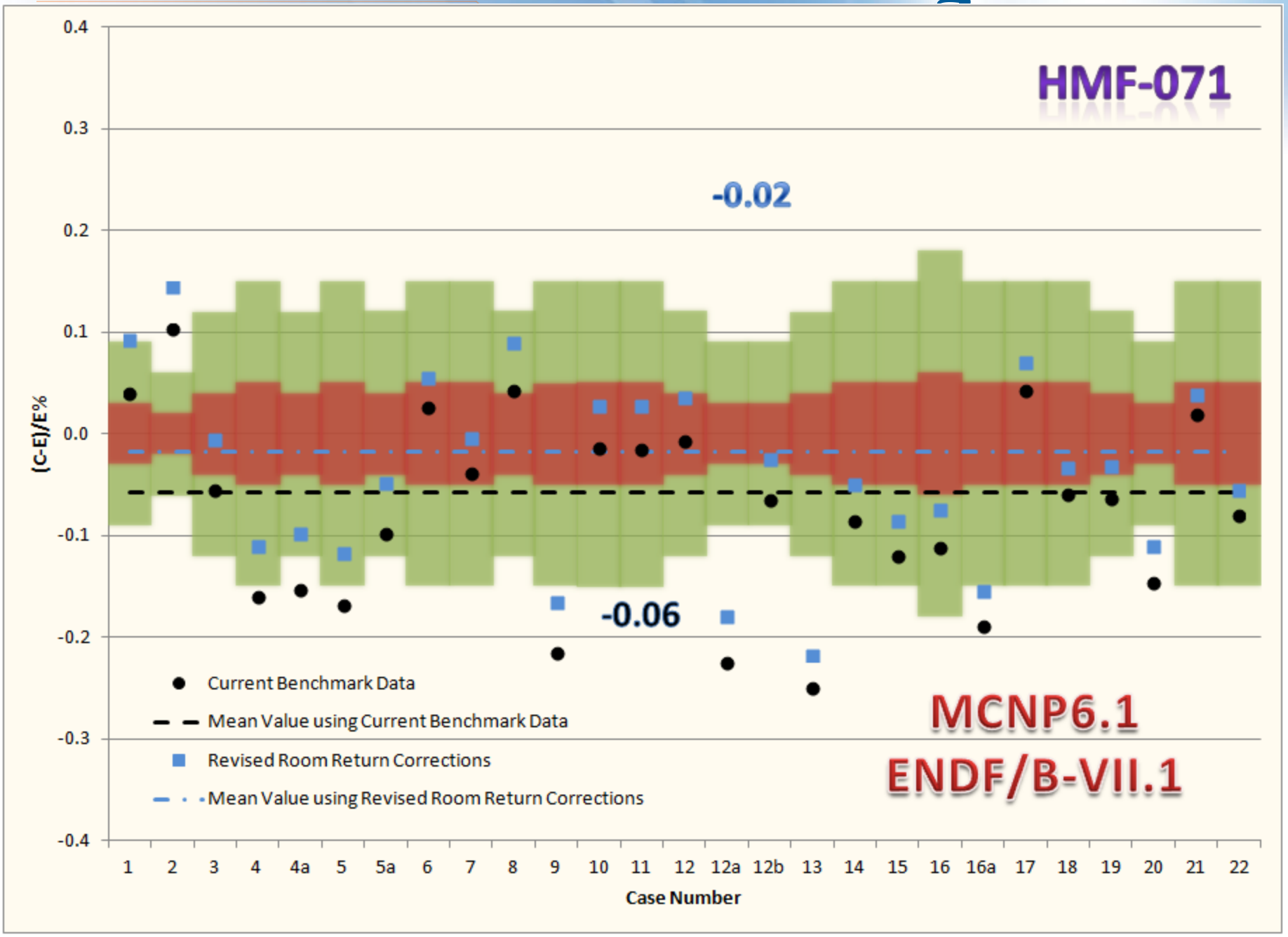


Region (nominal)	Height (cm)	Average Gap (cm)
Fuel height, 22.86 cm ID, 27.94 cm OD region	8.037322	0.00150368
Fuel height, 27.94 cm ID, 33.02 cm OD region	8.049260	0.00194818
Fuel height, 33.02 cm ID, 38.10 cm OD region	8.050022	0.00906780
Graphite stack, 43.18 cm OD, 38.10 cm ID	18.177256	0.02658618
Graphite stack, 48.26 cm OD, 43.18 cm ID	18.186654	0.0445770
Graphite core	7.957312	0.00660400

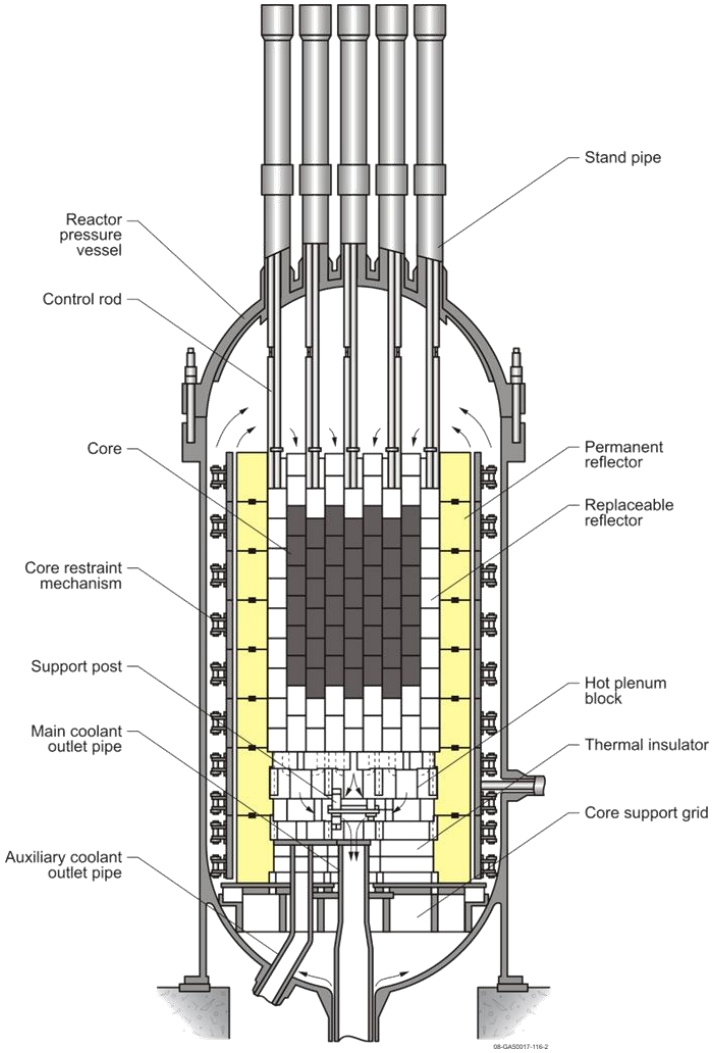


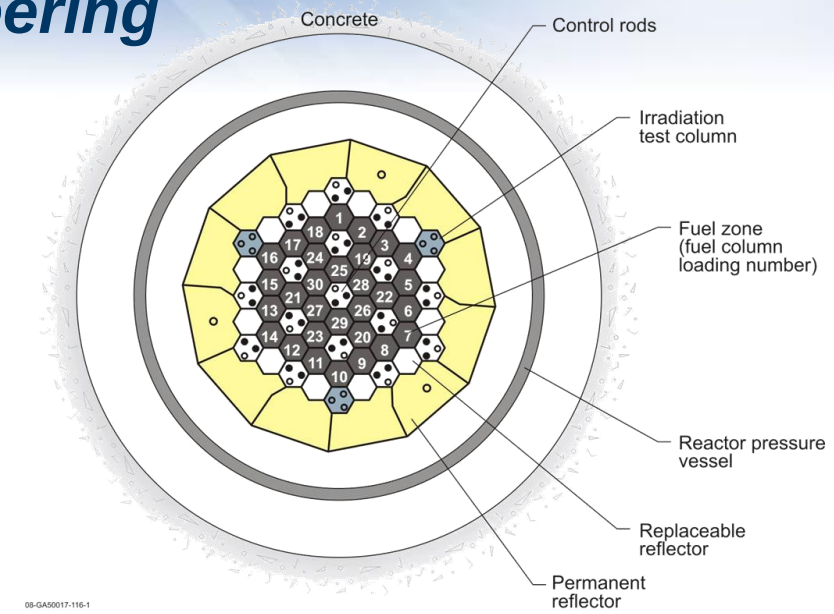
Thick Variants To Be Investigated

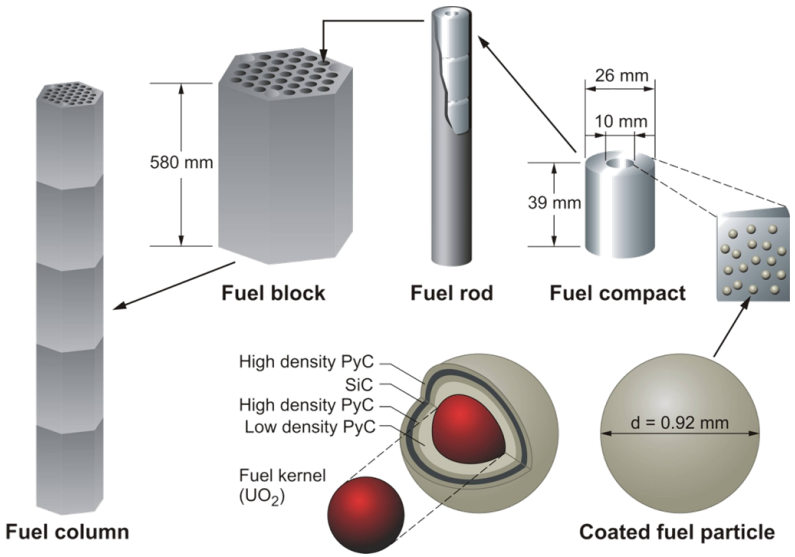

HMF-071
0.14
0.10
MCNP5-1.60
ENDF/B-VII.0
Current Benchmark Data
Mean Value using Current Benchmark Data
Revised Room Return Corrections
Mean Value using Revised Room Return Corrections
(C-E)/E%
Case Number
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
1
2
3
4
4a
5
5a
6
7
8
9
10
11
12
12a
12b
13
14
15
16
16a
17
18
19
20
21
22


HMF-071
-0.02
-0.06
MCNP6.1
ENDF/B-VII.1
Current Benchmark Data
Mean Value using Current Benchmark Data
Revised Room Return Corrections
Mean Value using Revised Room Return Corrections
(C-E)/E%
Case Number
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
1
2
3
4
4a
5
5a
6
7
8
9
10
11
12
12a
12b
13
14
15
16
16a
17
18
19
20
21
22

High Temperature Engineering Test Reactor (HTTR)







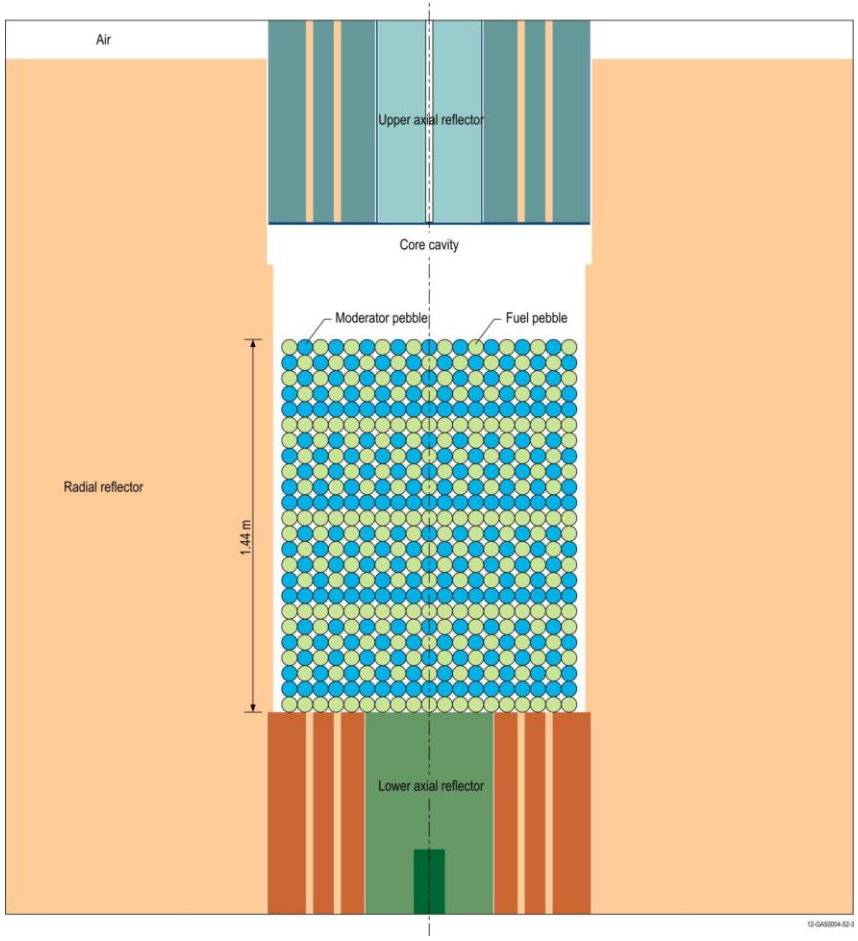
HTTR k_{eff}'s

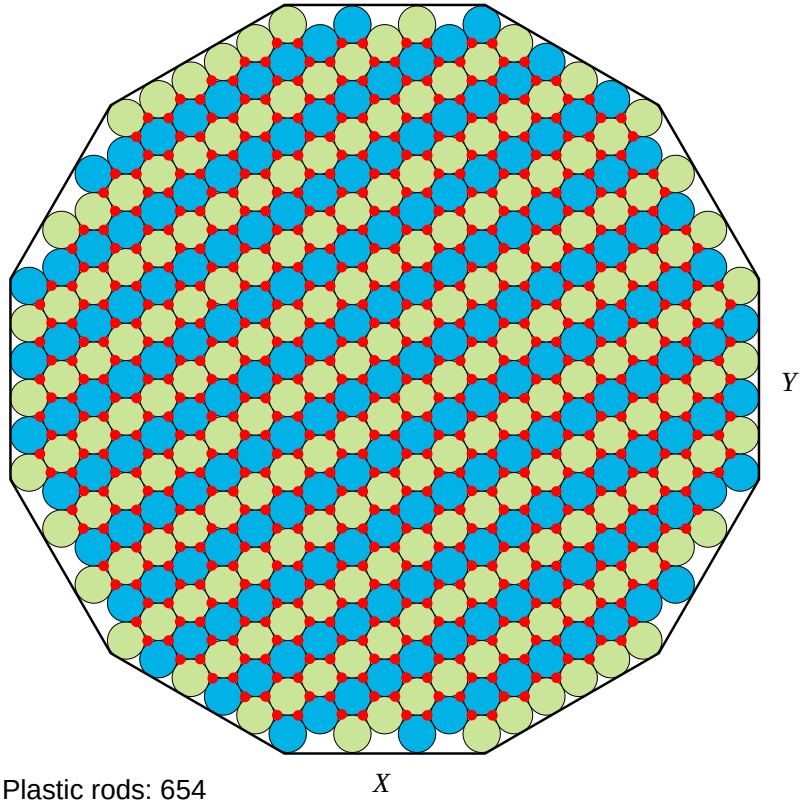
High Bias but Large EBC Uncertainty

Case Number	Nuclear Data Library	Benchmark Experiment Eigenvalue			Calculated Eigenvalue	$\frac{k_C - k_E}{k_E}$ (%)
		k_E	-1σ	$+1\sigma$	$k_C \pm 1\sigma$	
1	ENDF/B-VI.8	1.0048	−0.0103	+0.0100	1.0267 ± 0.0001	2.17
	ENDF/B-VII.0				1.0276 ± 0.0001	2.27
	ENDF/B-VII.1				1.0143 ± 0.0001	0.94
	JEFF-3.1				1.0280 ± 0.0001	2.31
	JENDL-3.3				1.0222 ± 0.0001	1.73
2	ENDF/B-VI.8	1.0040	−0.0100	+0.0092	1.0289 ± 0.0001	2.48
	ENDF/B-VII.0				1.0297 ± 0.0001	2.55
	ENDF/B-VII.1				1.0173 ± 0.0001	1.32
	JEFF-3.1				1.0301 ± 0.0001	2.60
	JENDL-3.3				1.0241 ± 0.0001	1.99
3	ENDF/B-VI.8	1.0035	−0.0078	+0.0084	1.0243 ± 0.0001	2.07
	ENDF/B-VII.0				1.0249 ± 0.0001	2.13
	ENDF/B-VII.1				1.0141 ± 0.0001	1.06
	JEFF-3.1				1.0257 ± 0.0001	2.21
	JENDL-3.3				1.0198 ± 0.0001	1.62
4	ENDF/B-VI.8	1.0032	−0.0080	+0.0074	1.0284 ± 0.0001	2.52
	ENDF/B-VII.0				1.0287 ± 0.0001	2.54
	ENDF/B-VII.1				1.0191 ± 0.0001	1.59
	JEFF-3.1				1.0298 ± 0.0001	2.65
	JENDL-3.3				1.0239 ± 0.0001	2.07
5	ENDF/B-VI.8	1.0029	−0.0068	+0.0075	1.0211 ± 0.0001	1.82
	ENDF/B-VII.0				1.0218 ± 0.0001	1.88
	ENDF/B-VII.1				1.0117 ± 0.0001	0.87
	JEFF-3.1				1.0224 ± 0.0001	1.94
	JENDL-3.3				1.0167 ± 0.0001	1.37
6	ENDF/B-VI.8	1.0025	−0.0060	+0.0071	1.0222 ± 0.0001	1.96
	ENDF/B-VII.0				1.0229 ± 0.0001	2.03
	ENDF/B-VII.1				1.0141 ± 0.0001	1.15
	JEFF-3.1				1.0236 ± 0.0001	2.10
	JENDL-3.3				1.0178 ± 0.0001	1.53
6sub	ENDF/B-VI.8	0.6876	−0.0104	+0.0104	0.7025 ± 0.0001	2.17
	ENDF/B-VII.0				0.6999 ± 0.0001	1.78
	ENDF/B-VII.1				0.7001 ± 0.0001	1.82
	JEFF-3.1				0.7036 ± 0.0001	2.33
	JENDL-3.3				0.6979 ± 0.0001	1.50
7	ENDF/B-VII.0	1.0019	−0.0057	+0.0068	1.0195 ± 0.0001	1.75
8	ENDF/B-VII.0	1.0024	−0.0057	+0.0067	1.0201 ± 0.0001	1.77

*Calculations performed using MCNP5-1.51 except for ENDF/B-VII.1, which used MCNP6.1.

HTR-PROTEUS





- Plastic rods: 654
- Fuel pebbles: 184
- Moderator pebbles: 177
- Total pebbles: 361

11-GA50002-72-7

HTR-PROTEUS Calculations

Idaho National Laboratory

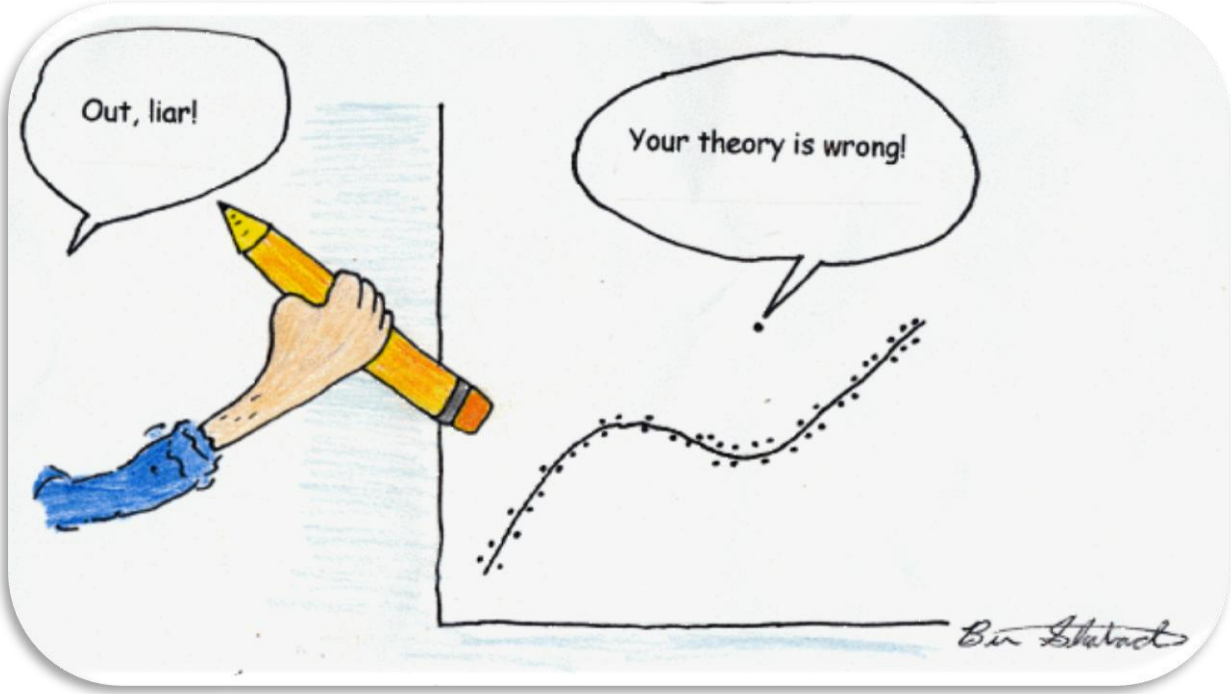
Core Number	Benchmark Eigenvalue $k_B \pm 1\sigma$	Calculated Eigenvalue $k_C \pm 1\sigma$	$\frac{k_C - k_B}{k_B}$ (%)
1	1.0048 ± 0.0030	1.0106 ± 0.0001	0.58
1A	1.0034 ± 0.0031	1.0095 ± 0.0001	0.60
2	1.0029 ± 0.0033	1.0104 ± 0.0001	0.75
3	0.9999 ± 0.0033	1.0089 ± 0.0001	0.90
4	1.0039 ± 0.0036	1.0174 ± 0.0001	1.34
5	1.0024 ± 0.0030	1.0071 ± 0.0001	0.47
6	1.0014 ± 0.0041	1.0065 ± 0.0001	0.51
7	1.0017 ± 0.0034	1.0086 ± 0.0001	0.69
8	1.0030 ± 0.0030	1.0081 ± 0.0001	0.51
9	1.0029 ± 0.0036	1.0058 ± 0.0001	0.38
10	1.0020 ± 0.0037	1.0067 ± 0.0001	0.54

*Calculations were performed with MCNP5 and ENDF/B-VII.0.

Core Number	Benchmark Eigenvalue $k_B \pm 1\sigma$	Calculated Eigenvalue $k_C \pm 1\sigma$	$\frac{k_C - k_B}{k_B}$ (%)
1	1.0048 ± 0.0030	0.9989 ± 0.0001	−0.58
1A	1.0034 ± 0.0031	0.9970 ± 0.0001	−0.64
2	1.0029 ± 0.0033	0.9969 ± 0.0001	−0.60
3	0.9999 ± 0.0033	0.9978 ± 0.0001	−0.21
4	1.0039 ± 0.0036	1.0026 ± 0.0001	−0.13
5	1.0024 ± 0.0030	0.9931 ± 0.0001	−0.93
6	1.0014 ± 0.0041	0.9977 ± 0.0001	−0.37
7	1.0017 ± 0.0034	0.9984 ± 0.0001	−0.33
8	1.0030 ± 0.0030	0.9950 ± 0.0001	−0.80
9	1.0029 ± 0.0036	0.9910 ± 0.0001	−1.19
10	1.0020 ± 0.0037	0.9949 ± 0.0001	−0.71

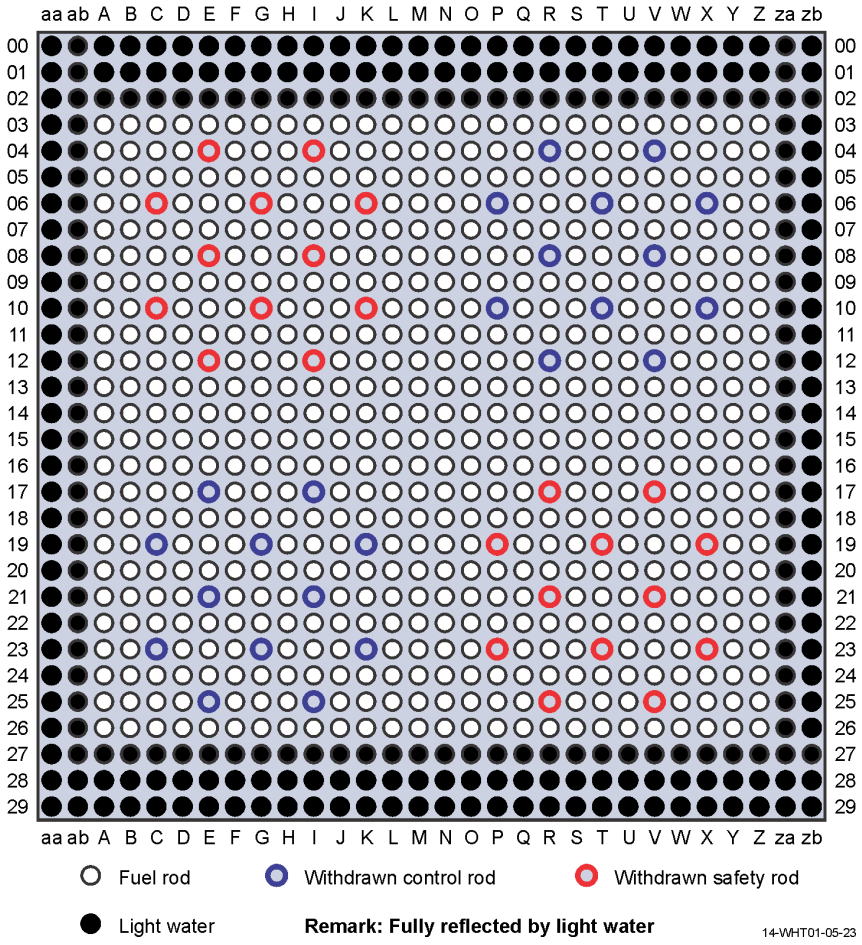
*Calculations were performed with MCNP6.1 and ENDF/B-VII.1.

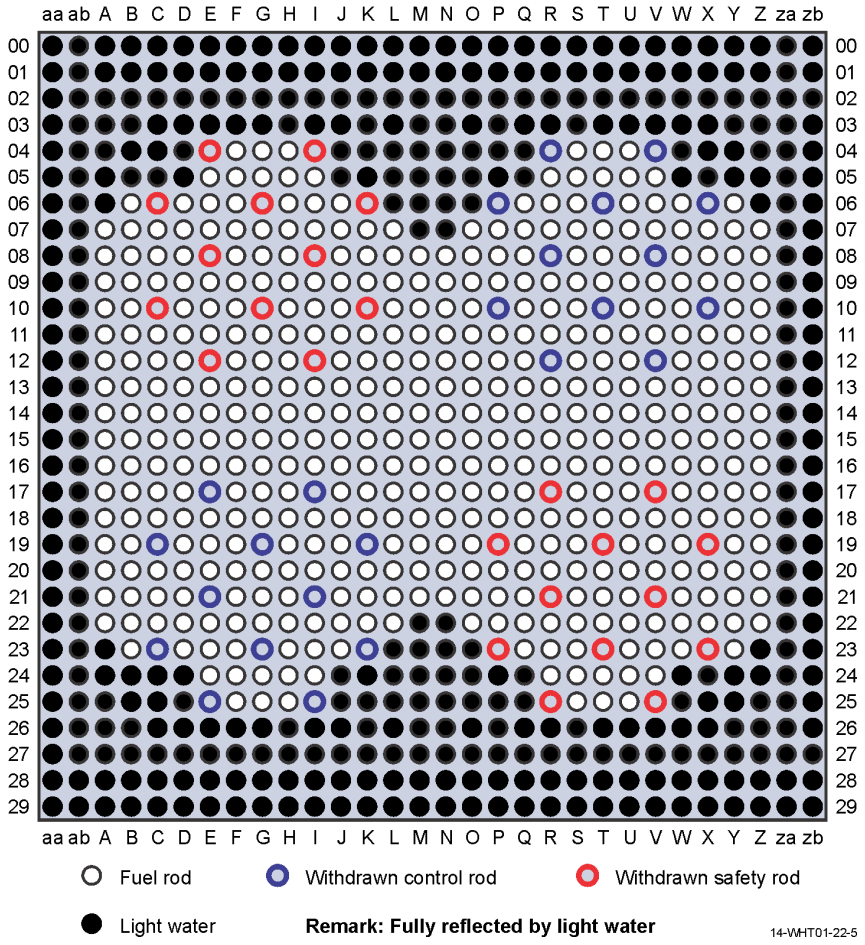
Questions?



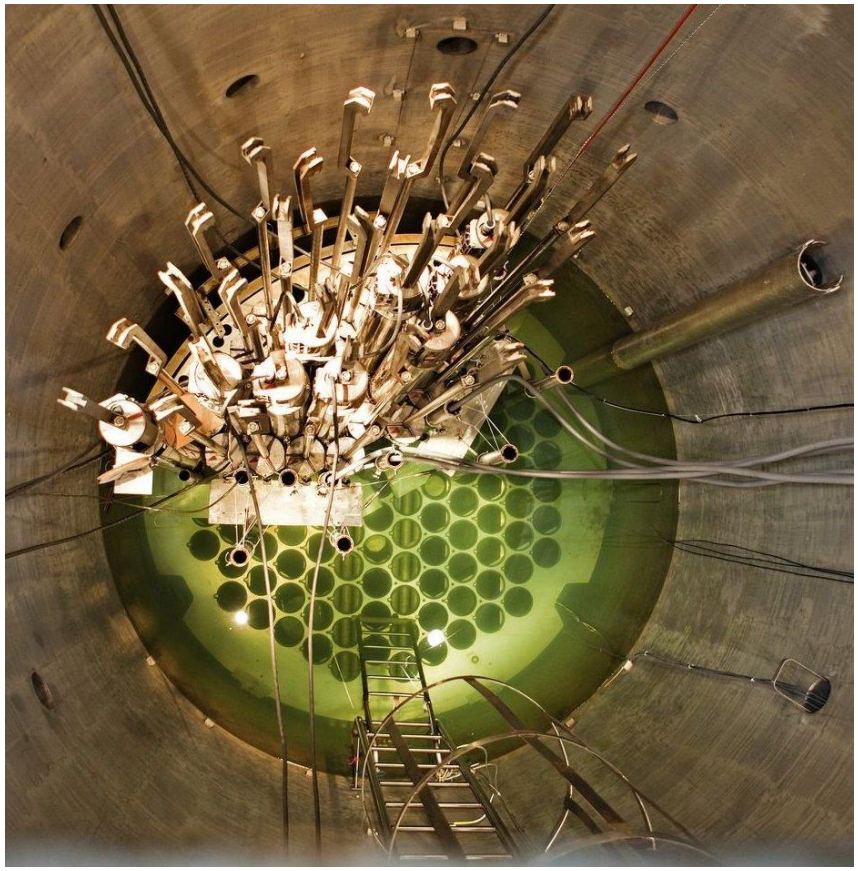
EXTRA SLIDES

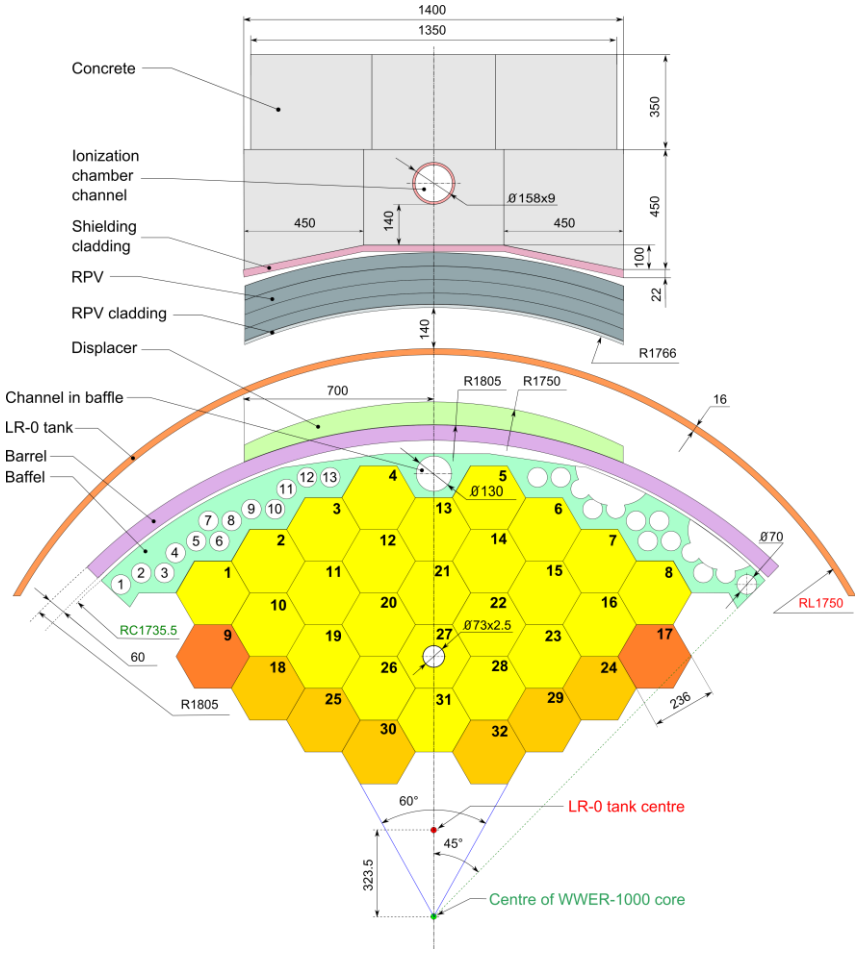
IPEN/MB-01 Subcritical Configurations





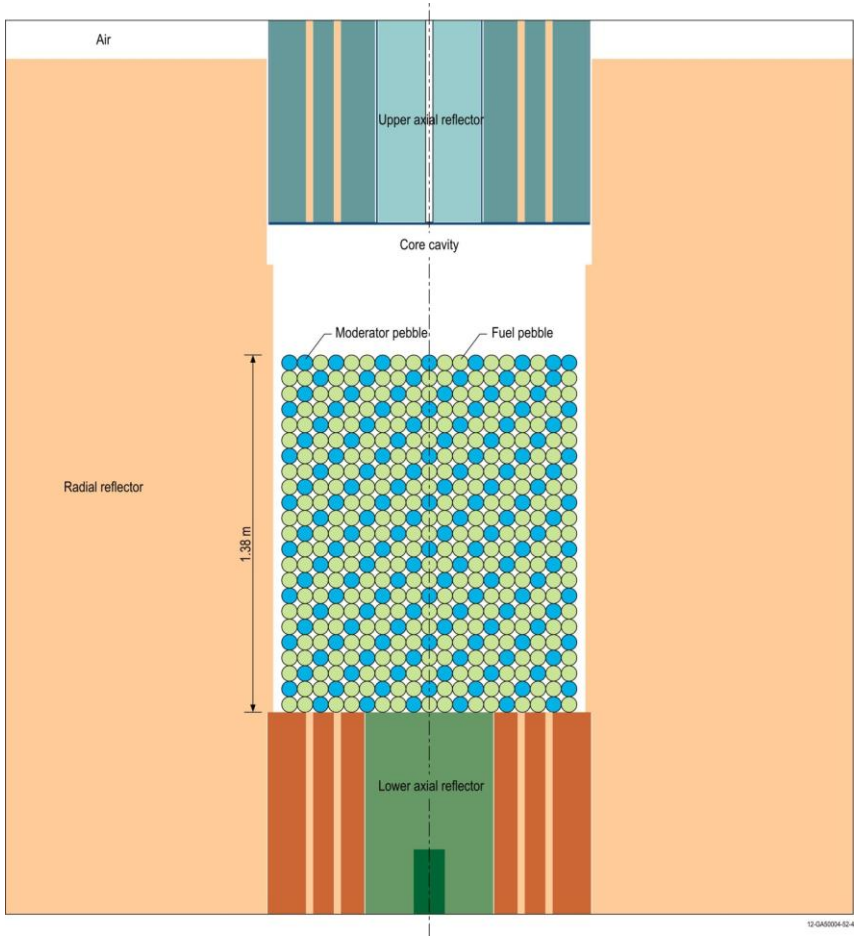
LR(0) VVER-1000 Mockup

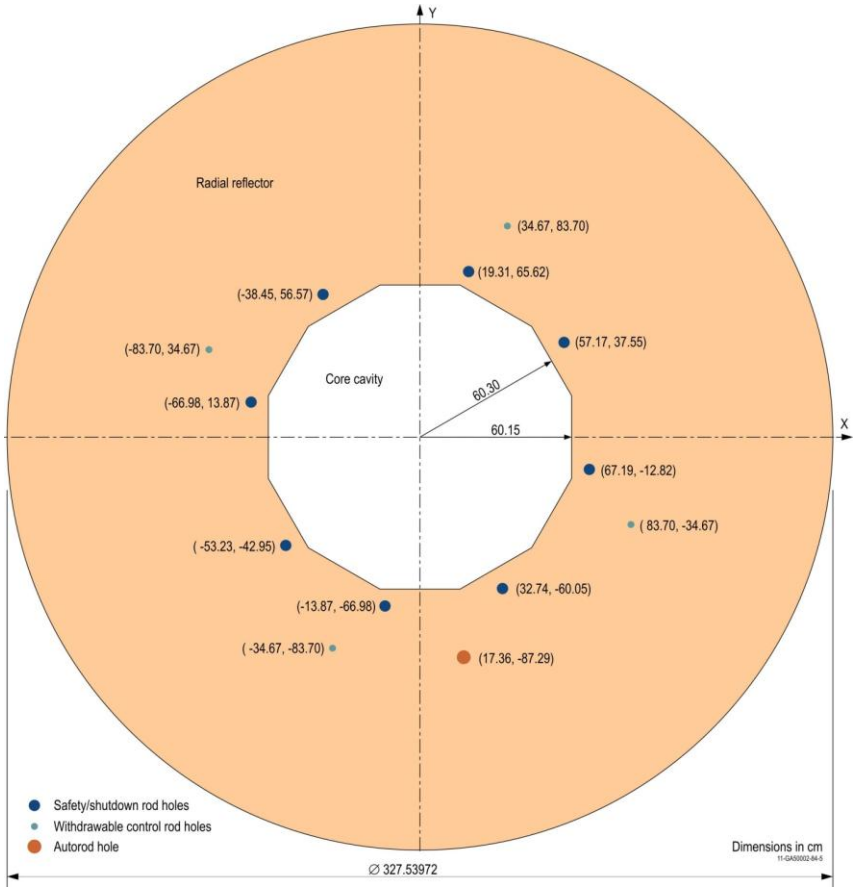




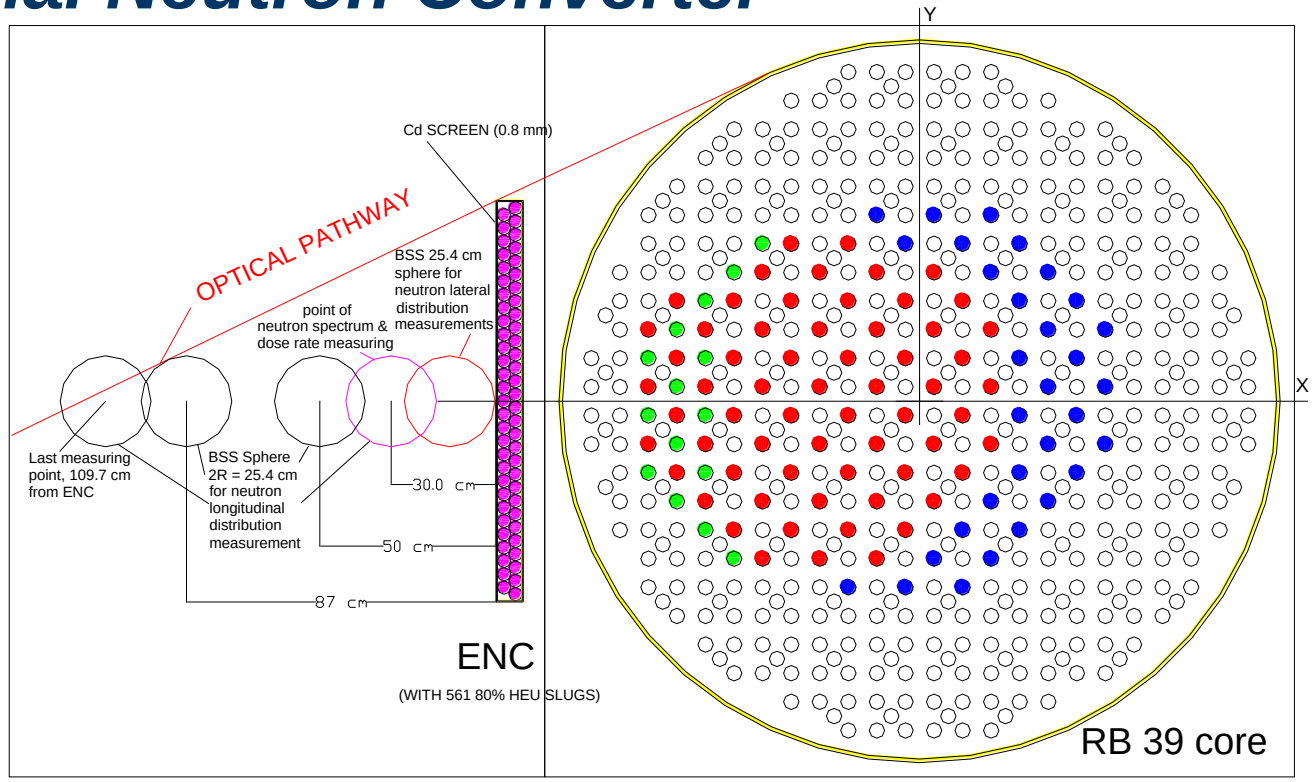
Currently k_{eff}; to evaluate reaction-rate and power distributions

HTR-PROTEUS Cores 5-8 Rod Worth Measurements



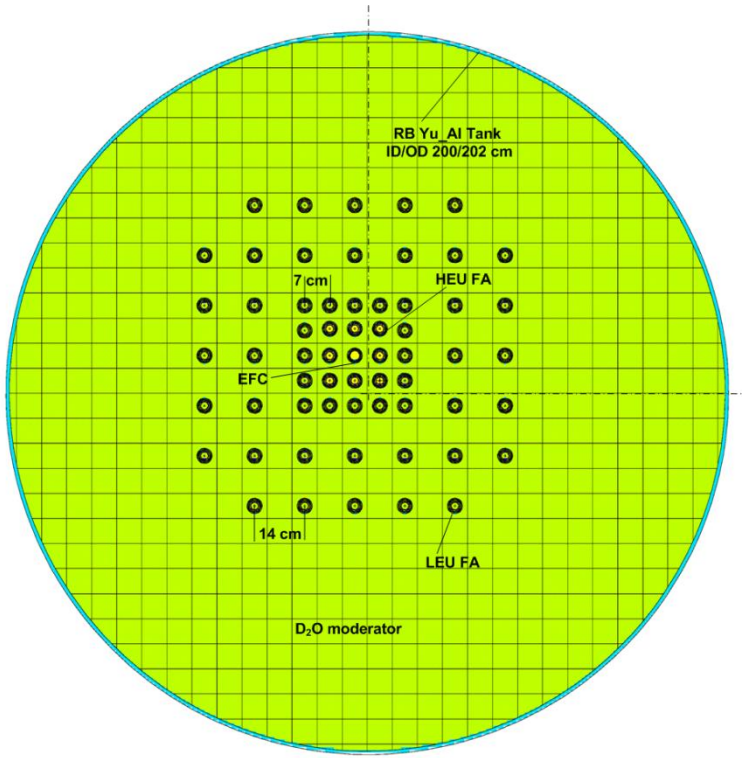


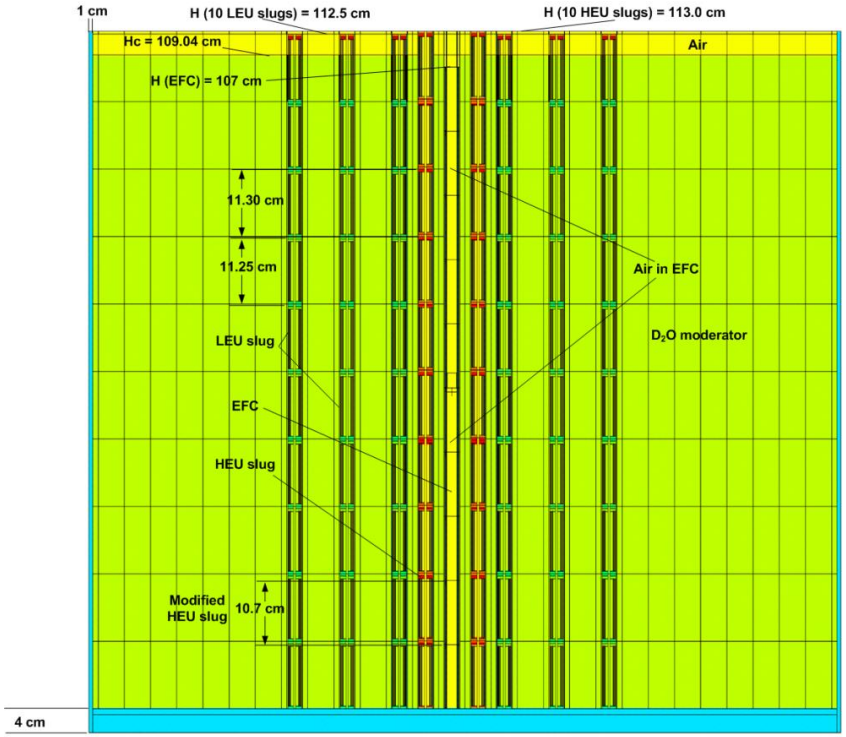
RB Reactor RB39/1978 – External Neutron Converter



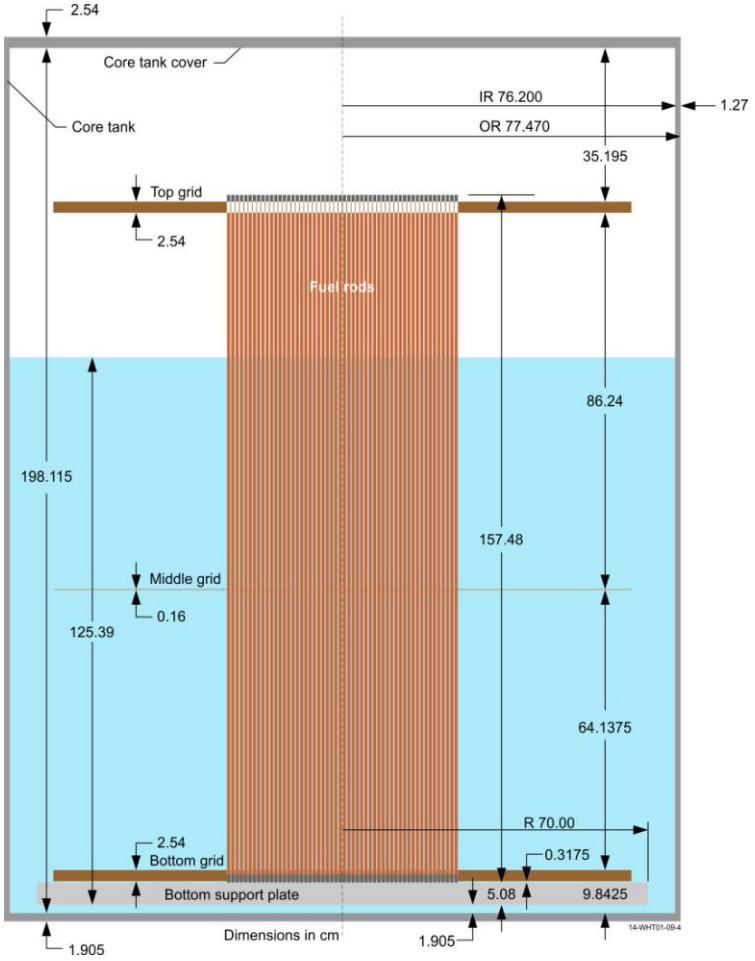
- 2% ENRICHED U METAL FA, LATTICE PITCH 11.31 cm
- 2% ENRICHED U METAL FA, LATTICE PITCH 8.0 cm
- NATURAL U METAL RODS, LATTICE PITCH 11.31 cm
- EMPTY POSITION IN LATTICE
- 80% ENRICHED URANIUM DIOXIDE SLUGS IN ENC

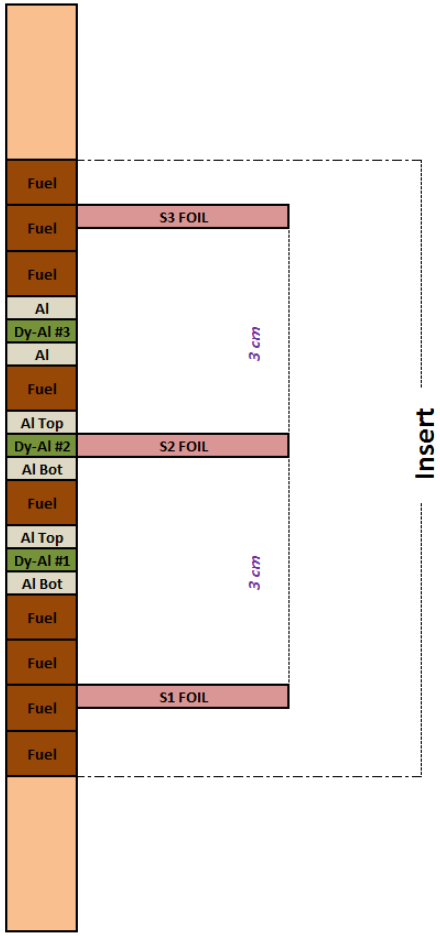
RB Reactor RB58/1982 – VINET: Experimental Fuel Channel





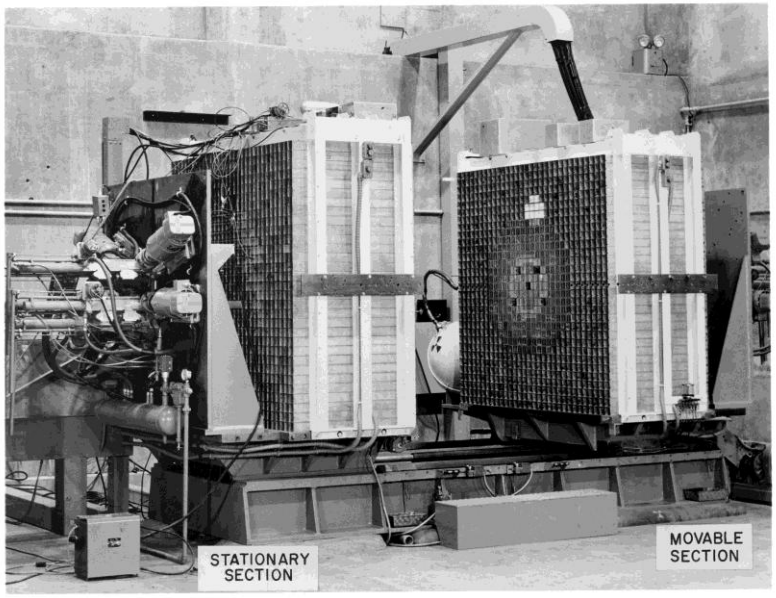
SSCR Spectral Measurements for Uranium-Thorium Rods in Heavy-Light Water Mixture

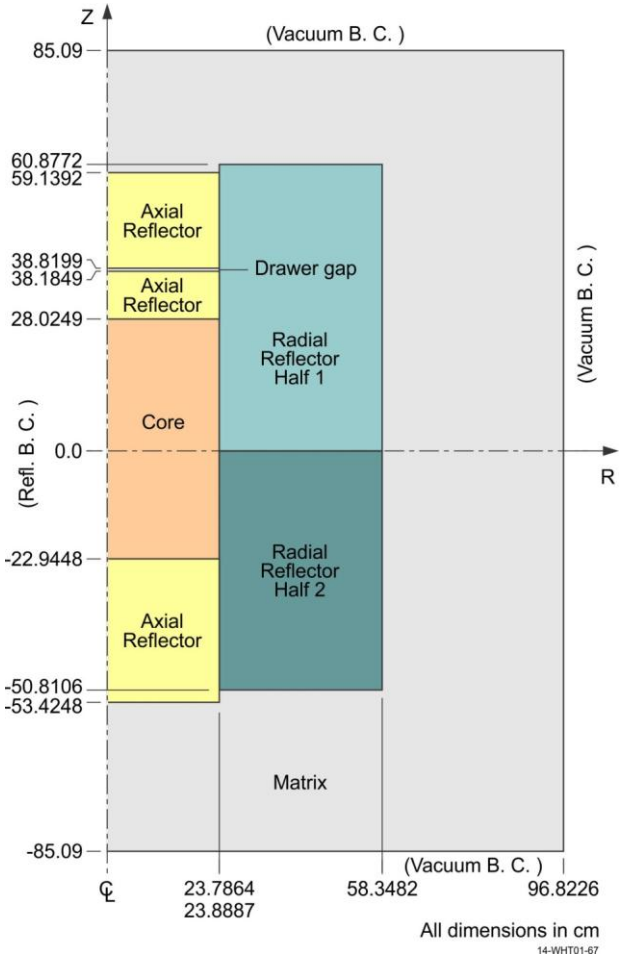




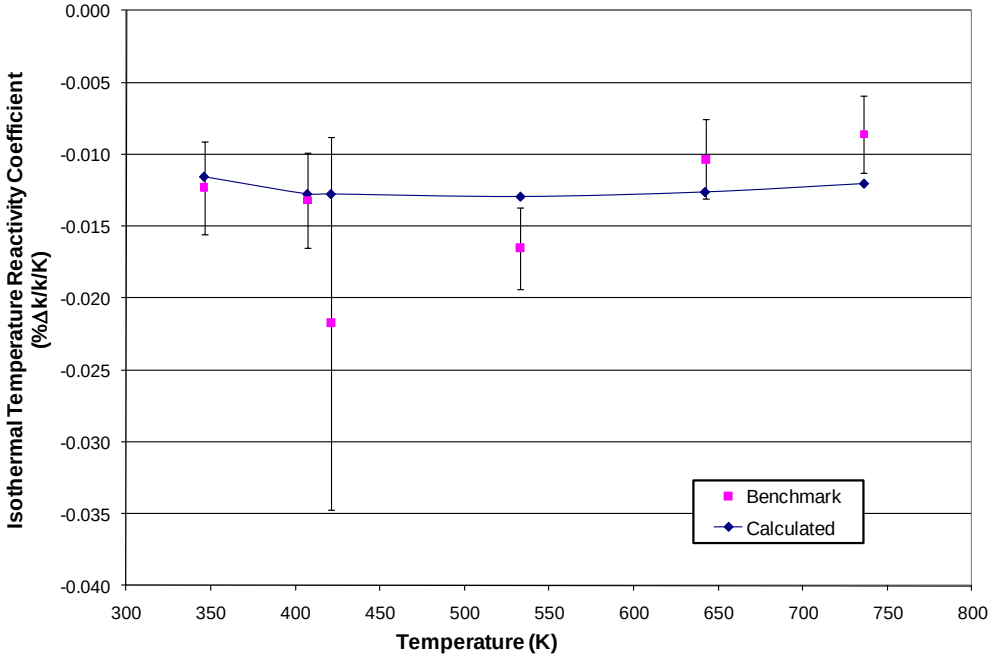
Thermal Disadvantage Factor: C/E-1 ~ 4%

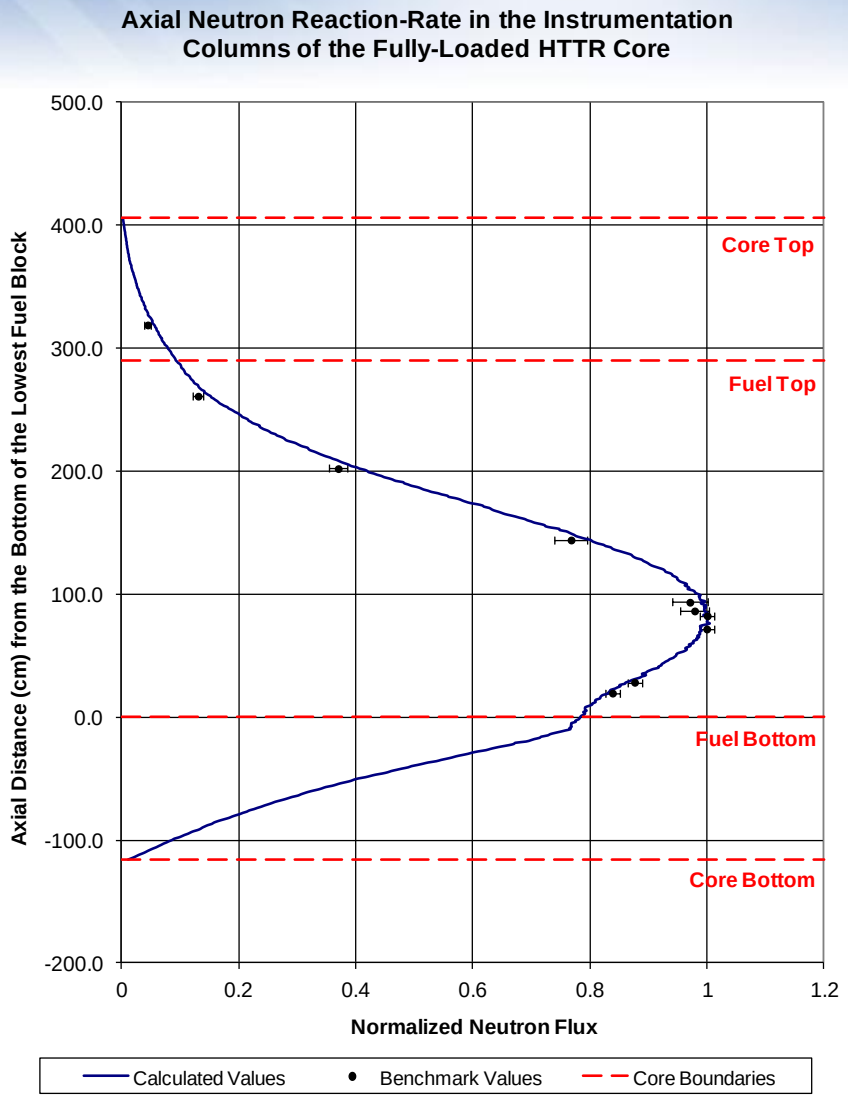
ZPR-3/58: Pu-C Reflected by DU
ZPR-3/59: Pu-C Reflected by Pb





HTTR – Additional Benchmark Calculations





HTR-PROTEUS Calculations

Idaho National Laboratory

Calculations of HTR-PROTEUS Rod Worth Measurements with MCNP5 and ENDF/B-VII.0

Core Number	Measured Parameter	Method	Benchmark Worth $\rho_B \pm 1\sigma$	Calculated Worth $\rho_C \pm 1\sigma$	$\frac{\rho_C - \rho_B}{\rho_B}$ (%)
4	Control rod 1	SP	−0.40 ± 0.04	−0.35 ± 0.02	−13
	Control rod 2	SP	−0.38 ± 0.03	−0.34 ± 0.02	−11
	Control rod 3	SP	−0.37 ± 0.03	−0.35 ± 0.02	−5
	Control rod 4	SP	−0.39 ± 0.04	−0.37 ± 0.02	−5
	Control rod bank	SP	−1.54 ± 0.09	−1.44 ± 0.07	−6
9	Control rod 1	IK	−0.41 ± 0.02	−0.38 ± 0.02	−7
	Control rod 2	IK	−0.41 ± 0.02	−0.37 ± 0.02	−10
	Control rod 3	IK	−0.41 ± 0.02	−0.38 ± 0.02	−7
	Control rod 4	IK	−0.41 ± 0.02	−0.38 ± 0.02	−7
	Control rod bank	SP	−1.58 ± 0.09	−1.55 ± 0.08	−2
	Partial bank insertion	SP	−0.73 ± 0.04	−0.70 ± 0.04	−4
	Autorod	IK	−0.10 ± 0.01	−0.12 ± 0.02	20
	Safety/shutdown rod 5	IK	−3.74 ± 0.17	−3.78 ± 0.19	1
	Safety/shutdown rod 6	IK and PNS	−3.82 ± 0.10	−3.82 ± 0.19	<1
	Safety/shutdown rod 7	IK	−3.70 ± 0.30	−3.82 ± 0.19	3
	Safety/shutdown rod 8	IK	−3.60 ± 0.29	−3.70 ± 0.19	3
	Safety/shutdown rods 5+6	IK and PNS	−8.02 ± 0.20	−8.03 ± 0.40	<1
	Safety/shutdown rods 5+7	IK	−7.44 ± 0.60	−7.76 ± 0.39	4
	Safety/shutdown rods 5+8	IK	−7.40 ± 0.59	−7.69 ± 0.38	4
	Safety/shutdown rods 5+6+7	IK and PNS	−12.11 ± 0.28	−12.30 ± 0.61	2
	Safety/shutdown rods 5+6+7+8	IK and PNS	−16.52 ± 0.42	−16.98 ± 0.85	3
10	Control rod 1	IK	−0.30 ± 0.02	−0.29 ± 0.02	−3
	Control rod 2	IK	−0.29 ± 0.02	−0.28 ± 0.02	−3
	Control rod 3	IK	−0.29 ± 0.02	−0.25 ± 0.02	−14
	Control rod 4	IK	−0.30 ± 0.02	−0.28 ± 0.02	−7
	Control rod bank	SP	−1.15 ± 0.07	−1.11 ± 0.06	−3
	Partial bank insertion	SP	−0.39 ± 0.02	−0.37 ± 0.02	−5
	Autorod	IK	−0.073 ± 0.004	−0.08 ± 0.01	10
	Safety/shutdown rod 5	IK	−2.82 ± 0.11	−2.73 ± 0.14	−3
	Safety/shutdown rod 6	IK and PNS	−2.82 ± 0.09	−2.75 ± 0.14	−2
	Safety/shutdown rod 7	IK	−2.80 ± 0.16	−2.73 ± 0.14	−2
	Safety/shutdown rod 8	IK	−2.72 ± 0.15	−2.66 ± 0.13	−2
	Safety/shutdown rods 5+6	IK and PNS	−5.95 ± 0.17	−5.70 ± 0.29	−4
	Safety/shutdown rods 5+7	IK	−5.73 ± 0.32	−5.54 ± 0.28	−3
	Safety/shutdown rods 5+8	IK	−5.75 ± 0.33	−5.49 ± 0.27	−5
	Safety/shutdown rods 5+6+7	IK and PNS	−9.29 ± 0.21	−8.65 ± 0.43	−7
	Safety/shutdown rods 5+6+7+8	IK and PNS	−12.67 ± 0.31	−11.81 ± 0.59	−7

*For cores 4, 9, and 10, the calculated β_{eff} values are 694, 693, and 685 pcm, respectively.