LA-UR-03-7941

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Title: ENDF/B-V and ENDF/B-VI Calculations for the LWBR SB Core Benchmarks with MCNP5

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Submitted to: Annual Meeting of the Cross Section Evaluation Working Group
Brookhaven National Laboratory, Upton, NY
November 4 - 6, 2003

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ENDF/B-V and ENDF/B-VI Calculations for the LWBR SB Core Benchmarks with MCNP5™

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To Be Presented at the Annual Meeting of the Cross Section Evaluation Working Group
Brookhaven National Laboratory, Upton, NY November 4 - 6, 2003

ABSTRACT

The Light Water Breeder Reactor (LWBR) Seed and Blanket (SB) critical experiments were conducted by Bettis Atomic Power Laboratory in the 1960s. Recently, detailed benchmark specifications have been issued for them. The benchmarks are of particular interest because they include critical configurations of ^{233}U and highly enriched uranium (HEU) fuel pins completely immersed in water. Consequently, all of the benchmarks have thermal spectra.

Calculations were performed for each benchmark with the MCNP5 Monte Carlo code and nuclear data libraries derived from ENDF/B-V and ENDF/B-VI. The calculated results tend to be lower than the benchmark values, sometimes substantially so. The ENDF/B-V results are superior to the ENDF/B-VI results for five of the eight cases, and they are statistically indistinguishable for the other three. More specifically, four of the ENDF/B-V results differ from the benchmark value by less than one standard deviation, and none of them differs by more than two standard deviations. In contrast, only two of the ENDF/B-VI results differ by less than one standard deviation, and three of them differ by more than two standard deviations.

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ENDF/B-V AND ENDF/B-VI CALCULATIONS FOR THE LWBR SB CORE BENCHMARKS WITH MCNP5™

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Presented at
2003 Annual Meeting of the Cross Section Evaluation Working Group
Brookhaven National Laboratory November 4 - 7, 2003

SB CORE EXPERIMENTS

SB Core experiments were conducted at the High Temperature Test Facility at Bettis Atomic Power Laboratory in the 1960s, in support of the Light Water Breeder Reactor Program

Benchmark experiments were conducted at room temperature and pressure

Cores were completely immersed in unborated water

Criticality was achieved by inserting a bank of 4 control blades into the seed region of the core (precise insertion is known only for core SB-2½; insertion for others was “about an inch”)

“All cores were approximately clean critical, with an excess reactivity of only a few tenths of one percent” (WAPD-TM-614, p. 5)

Except for core SB-2½, experimental k_{eff} was taken to be 1.0015 ± 0.0009 (corresponds to a flat probability distribution between 1.0000 and 1.0030)

SIGNIFICANCE OF SB CORE BENCHMARKS

Critical thermal lattices of ^{233}U or HEU fuel pins in water (only such benchmarks in ICSBEP Handbook)

Seed / blanket design, with Th in blanket pins

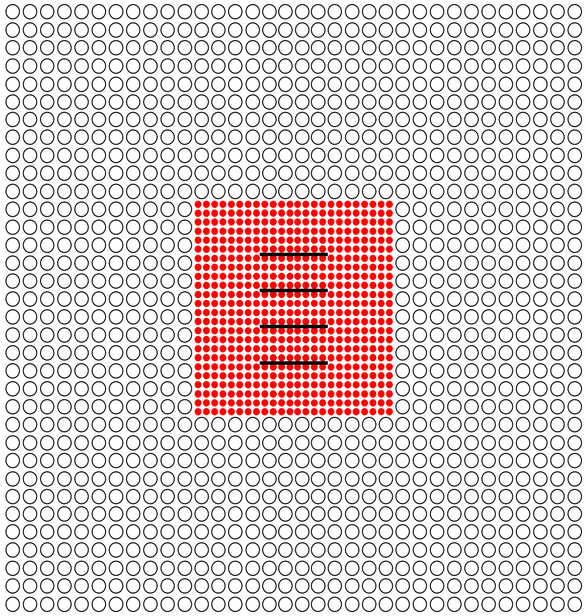
Rectangular or hexagonal pitch

SUMMARY OF CORE CONFIGURATIONS

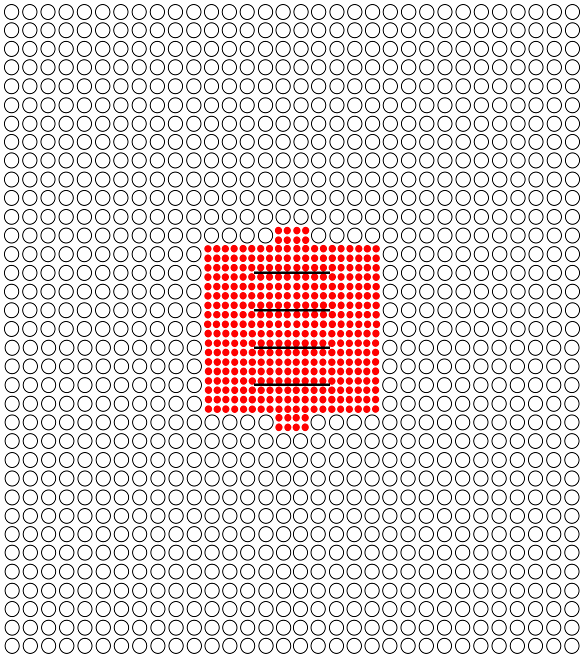
Core	SB-1	SB-2	SB-2½	SB-3	SB-4	SB-5	SB-6	SB-7
Geometry	Rect	Rect	Rect	Rect	Rect.	Hex	Hex	Hex
Seed Rods	576	340	288	224	376	217	148	115
Blanket Rods	1012	1140	—	1064	1026	1044	1113	1146
Fissile Material	^{235}U	^{233}U	^{233}U	^{233}U	^{235}U	^{235}U	^{233}U	^{233}U
Blanket Material	ThO_2	ThO_2	—	UO_2-ThO_2	UO_2-ThO_2	ThO_2	ThO_2	UO_2-ThO_2

Th in blankets contains small amount of Gd (2.9 ppm in ThO_2, 5 ppm in UO_2-ThO_2)

LAYOUT OF ^{235}U RECTANGULAR CORES

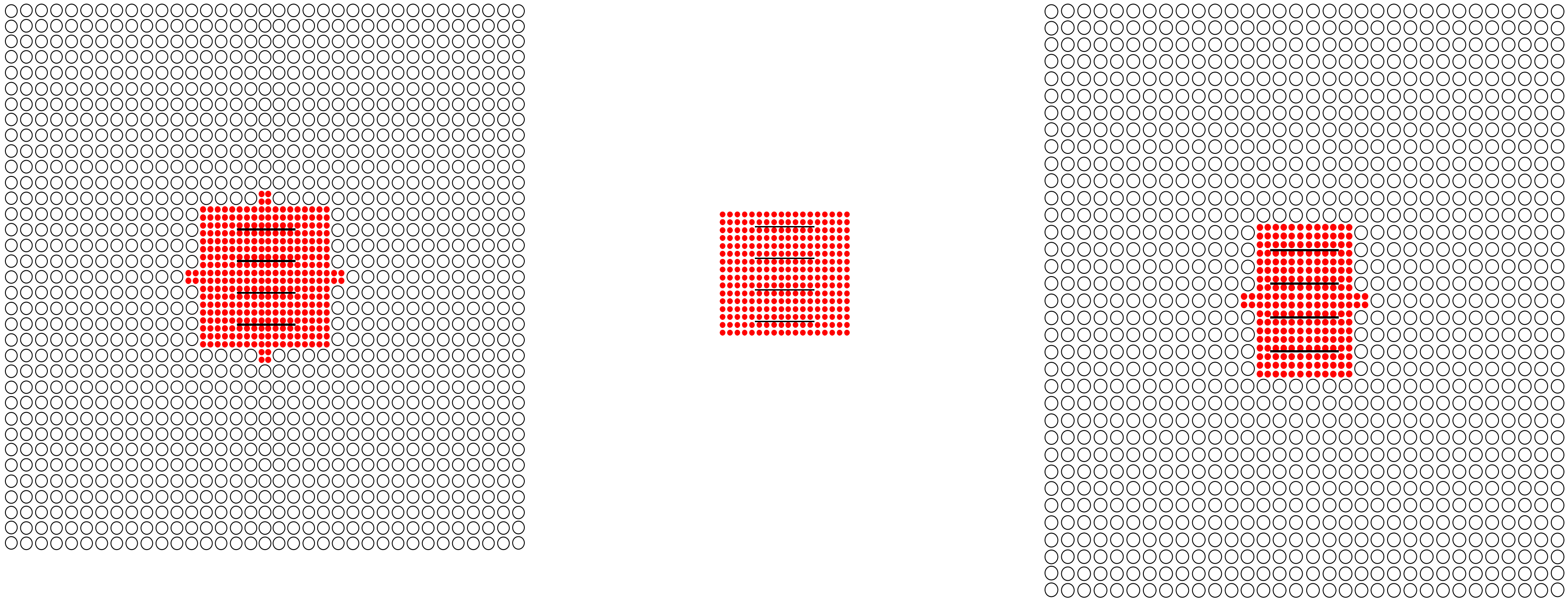


SB-1



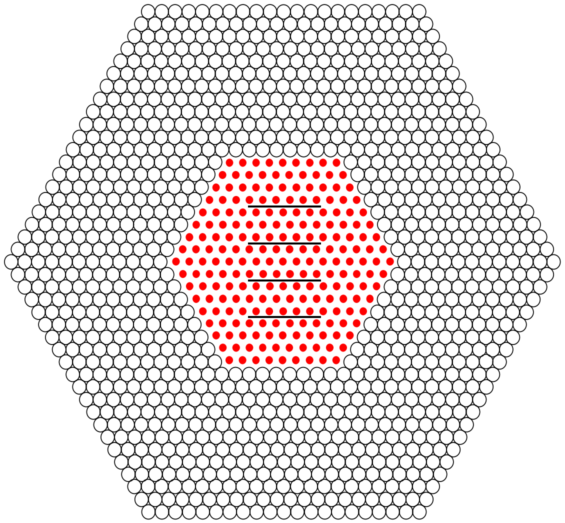
SB-4

LAYOUT OF ^{233}U RECTANGULAR CORES

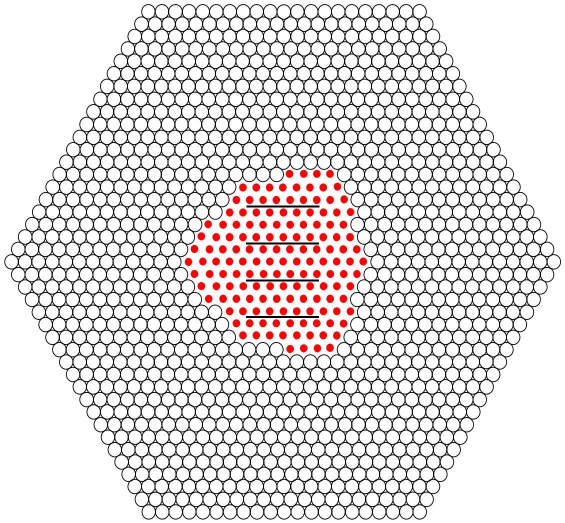


SB-2 SB-2½ SB-3

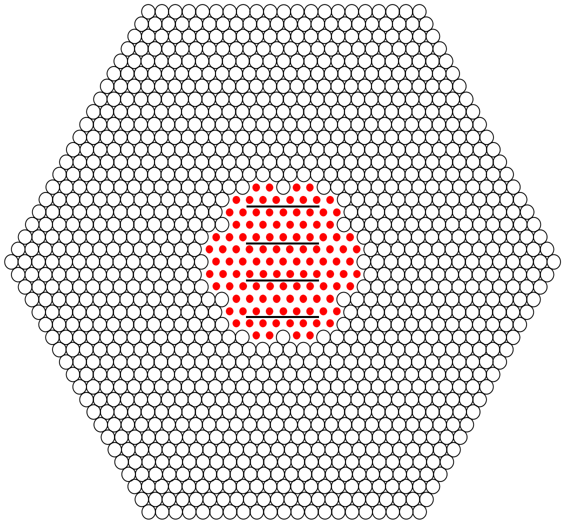
LAYOUT OF HEXAGONAL CORES



SB-5



SB-6



SB-7

DESCRIPTION OF SEED REGION

UO_2-ZrO_2 pins (26 wt.% UO_2) clad in Zircaloy-2

Uranium is highly enriched in ^{233}U (97.29 wt.%) or ^{235}U (92.73 wt.%)

Outer diameter of fuel rods is 0.211 inch

Inner and outer diameters of cladding are 0.220 inch and 0.255 inch, respectively

Pitch is 0.362 inch for rectangular cores, 0.571 inch for hexagonal cores

DESCRIPTION OF BLANKET REGION

ThO_2 or UO_2-ThO_2 pins (1 wt.% UO_2) clad in Zircaloy-2

U, if present, was enriched to 97.19 wt.% in ^{233}U

Outer diameters of ThO_2 and UO_2-ThO_2 rods are 0.490 inch and 0.489 inch, respectively

Outer diameters of cladding for ThO_2 and UO_2-ThO_2 pins are 0.569 inch and 0.570 inch, respectively

Cladding thickness for both types of rods is 0.071 inch

Pitch is 0.724 inch for rectangular cores, 0.571 inch for hexagonal cores (twice the seed pitch for rectangular cores, same as seed pitch for hexagonal cores)

MCNP5 CALCULATIONS FOR SB CORE BENCHMARKS

All calculations were run with 350 generations of 10,000 neutron histories per generation

Results from the first 50 generations were excluded from the statistics

Final results therefore are based on 3,000,000 active histories for each case

MCNP5 RESULTS FOR SB CORE BENCHMARKS

Core	Benchmark k_{eff}	Calculated k_{eff}		
		ENDF/B-VI.8	ENDF/B-VI.6	ENDFB-V
SB-1	1.0006 ± 0.0027	0.9963 ± 0.0005	0.9978 ± 0.0006	0.9988 ± 0.0005
SB-2	1.0015 ± 0.0025	0.9993 ± 0.0006	1.0002 ± 0.0006	1.0013 ± 0.0006
SB-2½	1.0000 ± 0.0024	0.9961 ± 0.0006	0.9980 ± 0.0005	1.0010 ± 0.0006
SB-3	1.0007 ± 0.0025	0.9933 ± 0.0005	0.9947 ± 0.0005	0.9976 ± 0.0005
SB-4	1.0015 ± 0.0026	0.9945 ± 0.0004	0.9951 ± 0.0005	0.9966 ± 0.0005
SB-5	1.0015 ± 0.0028	0.9963 ± 0.0005	0.9976 ± 0.0005	0.9966 ± 0.0005
SB-6	0.9995 ± 0.0027	0.9983 ± 0.0006	0.9986 ± 0.0006	0.9977 ± 0.0006
SB-7	1.0004 ± 0.0028	0.9931 ± 0.0005	0.9944 ± 0.0005	0.9947 ± 0.0005

blue: $1\sigma < |\Delta k| \leq 2\sigma$

red: $|\Delta k| > 2\sigma$

OBSERVATIONS AND CONCLUSIONS

Calculated values for k_{eff} tend to be lower than the corresponding benchmark values, sometimes substantially so

Consistently low results for SB-3, SB-4, and SB-7 may be due to overestimate of Gd content in thorium (Gd worth is approximately -0.004 Δk for SB-3 and SB-4 and approximately -0.002 Δk for SB-7)

ENDF/B-V produces better agreement with benchmark values than ENDF/B-VI does: all of the ENDF/B-V results are within 2 standard deviations of the corresponding benchmark value, but only 5 of the 8 ENDF/B-VI results are

Overall, ENDF/B-VI.6 produces better agreement with benchmark values than ENDF/B-VI.8 does

Differences between ENDF/B-VI.6 and ENDF/B-VI.8 results are due to changes to ^{16}O; sensitivity studies confirmed the decrease in reactivity not only for the SB cores but also for water-reflected uranium and plutonium spheres