DOE/NBM--4014796

DE84 014796

THE LARGE CORE CODE EVALUATION WORKING GROUP
BENCHMARK PROBLEM FOUR:
NEUTRONICS AND BURNUP BENCHMARK ANALYSES
OF A LARGE HETEROGENEOUS FAST REACTOR

Part II: Individual Contributions

By
C. L. Cowan
R. Protsik
J. W. Lewellen

General Electric Company
Schenectady, New York
and
U. S. Department of Energy
Washington, D. C.

Technical Information Center
Office of Scientific and Technical Information
United States Department of Energy

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

THE LARGE CORE CODE EVALUATION WORKING GROUP
BENCHMARK PROBLEM FOUR:
NEUTRONICS AND BURNUP BENCHMARK ANALYSES
OF A LARGE HETEROGENEOUS FAST REACTOR

PART II: INDIVIDUAL CONTRIBUTIONS

EDITORS:

C. L. Cowan and R. Protsik
Advanced Reactor Systems Department
Energy Systems and Technology Division
General Electric Company

J. W. Lewellen
Reactor Physics Branch
Division of Reactor Research and Technology
U. S. Department of Energy

ANL Results for the Large Core Code Evaluation Working
Group (LCCEWG) Fourth Benchmark Problem*

by

B. J. Toppel and H. Henryson II

Applied Physics Division
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, Illinois 60439

July 7, 1982

*Work performed under the auspices of the U.S. Department of Energy

Lumped Fission Products1,2

1. Recommended - 2 Fission Product Pairs (odd, even)
2. Recommended - 1 Fission Product Pair
3. Other (describe)

Energy Deposition1

1. In-Situ fission plus capture gamma's
2. In-Situ fission only
3. Other (describe)

Treatment of Control Rods1

1. Control positioned at the recommended BOC location during the first half of the irradiation cycle, and at the recommended EOC location during the last half of the irradiation cycle
2. Positioned as recommended at the beginning-of-cycle and left unchanged during the burnup calculations
3. All control out
4. Other (describe)

Calculation of Control Rod Worth1

1. Direct 3-D calculation
2. Synthesis 3-D calculations
3. R-Z calculations
4. R-Z calculations (Modified B^{10} Density)
5. X-Y HEX
6. Other (describe)

Core Layout1

1. Recommended
2. Other (describe)

Mesh Spacings1

1. Recommended
2. Other (describe)

Flux Solutions During Irradiation Cycle1

1. Recommended
2. Other (describe)

- (N)** BATCH LOADING SEQUENCE - ALL ASSEMBLIES LABELLED "N" ARE REPLACED AT THE END OF IRRADIATION CYCLE "N".
- (C)** PRIMARY CONTROL ROD USED FOR CRITICALITY ADJUSTMENTS DURING BURNUP
- (P)** PRIMARY CONTROL ROD
- (S)** SECONDARY CONTROL ROD

FIGURE 1. SIXTY DEGREE SECTOR OF CORE LAYOUT

FIGURE 2. REACTOR DIAGRAM INDICATING AXIAL DIMENSIONS

FIGURE 3. FUEL BURNUP CHAINS FOR THE BENCHMARK ANALYSES.

FIGURE B.1 - SIXTY DEGREE SECTOR OF CORE LAYOUT FOR BENCHMARK PROBLEM FOUR SHOWING DRIVER, BLANKET AND SHIELD ASSEMBLY IDENTIFICATION.

Table 1. DESCRIPTION OF CASES EXAMINED

Case 1.	Beginning-of-irradiation cycle 1 ^a
Case 2.	End-of-irradiation cycle 1 ^b
Case 3.	Beginning-of-irradiation cycle 2 ^c
Case 4.	End-of-irradiation cycle 2 ^d

^aEach irradiation cycle was 383.5 effective full power days and used a constant power of 2740 MWth.

^bControl rod position C (see Fig. 1) at 172.72 cm above the lower surface of the lower axial shield at BOC1 and moved to 193.04 cm at the MOC1.

^cControl rod position C moved to 182.88 cm and refueling accomplished as indicated in Fig. 1

^dControl rod position C moved from 182.88 cm to 198.12 cm at the MOC2.

Table 2. AXIAL DEFINITION USED IN THE BENCHMARK CALCULATIONS

Axial Range (cm)	Number of Axial Regions	Number of Mesh Intervals
0 - 60.96	1	2
60.96 - 96.52	2	6
96.52 - 218.44	8	24
218.44 - 254.0	2	6
254.0 - 388.62	1	4

RESULTS FOR CASE 1

A. General

1. k_{eff}	1.00377
5. Peak Power (kw/cm ³)-Position	
Driver Fuel	5.28E-01, D-III-2-6, 149.86 cm
Inner Blankets	8.05E-02, IB-II-1-3, 149.86 cm
Radial Blankets	6.27E-02, RB-6-6, 154.94 cm
6. Driver Fuel Peak-Average Power	1.61E+00
7. Driver Fuel Axial Peak-To-Average Power (at position of peak power)	1.35E+00

RESULTS FOR CASE 1

B. Power

Zone	<u>Power Fraction</u>			Peak Power Density (kw/cm ³)
	Fission	Capture	Total	
D-I	0.1174	0.0037	0.1211	4.576E-01
D-II	0.2330	0.0072	0.2402	5.172E-01
D-III	0.5313	0.0159	0.5472	5.280E-01
IB-I	0.0038	0.0016	0.0054	6.458E-02
IB-II	0.0104	0.0032	0.0136	8.048E-02
IB-III	0.0227	0.0086	0.0314	7.720E-02
RB	0.0172	0.0071	0.0243	6.272E-02
AB	0.0080	0.0036	0.0116	2.584E-02
S	0.0000	0.0017	0.0017	1.831E-03
C	0.0000	0.0034	<u>0.0034</u>	1.578E-01
			1.0000	

RESULTS FOR CASE 1
D. Fuel Inventories

	Inventory (kg)			
	Driver Fuel	Inner Blankets	Radial Blanket	Axial Blanket Extensions
U-234				
U-235	5.687E+01	6.297E+01	7.181E+01	4.838E+01
U-236				
U-237				
U-238	2.612E+04	2.891E+04	3.297E+04	2.222E+04
U-239				
Np-237				
Np-238				
Np-239				
Pu-238				
Pu-239	4.101E+03			
Pu-240	1.236E+03			
Pu-241	6.206E+02			
Pu-242	1.481E+02			
Pu-243				
Pu-244				
Am-241				
Am-242m				
Am-242				
Am-243				
Am-244				
Cm-242				
Cm-243				
Cm-244				

RESULTS FOR CASE 1
E. Neutron Balance for Reactor

<u>Source</u>		
Fission	1.00000	
n,2n	0.00254	
Total Source		1.00254

<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00246	0.00748
U-236	0.00000	0.00000
U-238	0.48336	0.05952
Pu-238	0.00000	0.00000
Pu-239	0.05638	0.21647
Pu-240	0.01848	0.01532
Pu-241	0.00791	0.04394
Pu-242	0.00179	0.00132
Other Actinides	0.00000	0.00000
Fission Products	0.00000	0.00000
Structure*	0.06010	0.00000
Coolant	0.00254	0.00000
Control	0.02030	0.00000
Total	0.65332	0.34405
Total Absorptions		0.99737

<u>Leakage</u>		
Axial	0.00039	
Radial	0.00476	
Total Leakage		0.00515
Total Losses		1.00252

*Includes O^{16}

RESULTS FOR CASE 2

A. General

1. k_{eff}	1.00153
2. Control Rod Worth (Δk) ^a	0.00540
4. Kg Gain of Fissile Plutonium ^b	484.4
5. Peak Power (kw/cm ³) - Position	
Driver Fuel	5.36E-01, D-II-1-3, 154.99
Inner Blankets	2.23E-01, IB-II-1-4, 154.99
Radial Blankets	7.29E-02, RB-6-6, 154.99
6. Driver Fuel Peak-To-Average Power	1.80E+00
7. Driver Fuel Axial Peak-To-Average Power (at position of peak power)	1.31E+00

^aAt middle of cycle 1.^bCase 1 to Case 2.

RESULTS FOR CASE 2

B. Power

Zone	<u>Power Fraction</u>			Peak Power Density (kw/cm ³)
	Fission	Capture	Total	
D-I	0.1321	0.0049	0.1370	5.017E-01
D-II	0.2540	0.0094	0.2634	5.360E-01
D-III	0.4113	0.0145	0.4258	4.316E-01
IB-I	0.0119	0.0021	0.0140	1.466E-01
IB-II	0.0328	0.0041	0.0369	2.230E-01
IB-III	0.0610	0.0093	0.0703	1.606E-01
RB	0.0251	0.0058	0.0309	7.290E-02
AB	0.0135	0.0036	0.0171	4.375E-02
S	0.0000	0.0016	0.0016	1.463E-03
C	0.0000	0.0028	<u>0.0028</u>	1.379E-01
			1.0000	

RESULTS FOR CASE 2

C. Burnup

Zone	Average Burnup (MWD/MT)	Peak Burnup ^a (MWD/MT)
D-I	3.154E+04	4.272E+04
D-II	3.063E+04	4.610E+04
D-III	2.554E+04	4.308E+04
IB-I	1.822E+03	5.894E+03
IB-II	4.033E+03	9.512E+03
IB-III	2.417E+03	7.008E+03
RB	6.996E+02	3.701E+03
AB	5.185E+02	2.143E+03

^aAverage burnup times the EOC peak-to-average power.

RESULTS FOR CASE 2

D. Fuel Inventories

	Inventory (kg)			
	Driver Fuel	Inner Blankets	Radial Blanket	Axial Blanket Extensions
U-234				
U-235	4.602E+01	5.413E+01	6.704E+01	4.570E+01
U-236	2.378E+00	2.183E+00	1.265E+00	7.183E-01
U-237				
U-238	2.537E+04	2.838E+04	3.274E+04	2.209E+04
U-239				
Np-237				
Np-238				
Np-239				
Pu-238				
Pu-239	3.920E+03	4.491E+02	2.115E+02	1.182E+02
Pu-240	1.299E+03	1.244E+01	3.102E+00	1.349E+00
Pu-241	5.075E+02	2.536E-01	3.297E-02	1.148E-02
Pu-242	1.602E+02	3.498E-03	1.915E-04	5.373E-05
Pu-243				
Pu-244				
Am-241				
Am-242m				
Am-242				
Am-243				
Am-244				
Cm-242				
Cm-243				
Cm-244				

RESULTS FOR CASE 2
E. Neutron Balance for Reactor

<u>Source</u>		
Fission	1.00000	
n,2n	0.00256	
Total Source		1.00256

<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>	
U-235	0.00197	0.00604	
U-236	0.00009	0.00000	
U-238	0.46740	0.05886	
Pu-238	0.00000	0.00000	
Pu-239	0.06334	0.22722	
Pu-240	0.01947	0.01545	
Pu-241	0.00627	0.03462	
Pu-242	0.00192	0.00135	
Other Actinides	0.00000	0.00000	
Fission Products	0.01608	0.00000	
Structure ^a	0.05860	0.00000	
Coolant	0.00253	0.00000	
Control	0.01628	0.00000	
Total	0.65395	0.34354	
Total Absorptions			0.99749

<u>Leakage</u>		
Axial	0.00047	
Radial	0.00458	
Total Leakage		0.00506
Total Losses		1.00255

^aIncludes O^{16}

RESULTS FOR CASE 2

F. Reactivity Effects

Global reactivity loss per cycle ^a $(k_{\text{eff}}(2) - k_{\text{eff}}(1))/k_{\text{eff}}(1)$	-0.00720
Reactivity gain due to Pu build-up in the blankets ^a $(k_{\text{eff}}(3) - k_{\text{eff}}(1))/k_{\text{eff}}(1)$	0.04063
Reactivity loss due to fission product build-up ^a $(k_{\text{eff}}(4) - k_{\text{eff}}(1))/k_{\text{eff}}(1)$	-0.01270
Reactivity loss due to burnup of Pu and U Isotopes ^a $(k_{\text{eff}}(5) - k_{\text{eff}}(1))/k_{\text{eff}}(1)$	-0.03618
Reactivity change due to build-up of heavy actinides ^a $(k_{\text{eff}}(6) - k_{\text{eff}}(1))/k_{\text{eff}}(1)$	---

^a $k_{\text{eff}}(1) = k_{\text{eff}}$ corresponding to the beginning-of-cycle-composition.

$k_{\text{eff}}(2) = k_{\text{eff}}$ corresponding to the end-of-cycle composition with the beginning-of-cycle control.

$k_{\text{eff}}(3) = k_{\text{eff}}$ corresponding to the beginning-of-cycle compositions for the driver zones and the end-of-cycle compositions for the blankets.

$k_{\text{eff}}(4) = k_{\text{eff}}$ corresponding to the beginning-of-cycle compositions but including the end-of-cycle fission product densities.

$k_{\text{eff}}(5) = k_{\text{eff}}$ corresponding to the end-of-cycle plutonium and uranium densities for the driver fuel and the beginning-of-cycle compositions for all other zones.

$k_{\text{eff}}(6) = k_{\text{eff}}$ corresponding to the beginning-of-cycle compositions but including the end-of-cycle actinide densities for other than plutonium and uranium isotopes.

RESULTS FOR CASE 3

A. General

1. k_{eff}	1.00439
5. Peak Power (kw/cm ³)-Position	
Driver Fuel	5.23E-01, D-II-3-4, 149.86 cm
Inner Blankets	1.86E-01, IB-II-2-5, 154.99 cm
Radial Blankets	7.62E-01, RB-1-6, 154.99 cm
6. Driver Fuel Peak-Average Power	1.68E+00
7. Driver Fuel Axial Peak-To-Average Power (at position of peak power)	1.35E+00

RESULTS FOR CASE 3

B. Power

Zone	<u>Power Fraction</u>			Peak Power Density (kw/cm ³)
	Fission	Capture	Total	
D-I	0.1291	0.0043	0.1334	5.087E-01
D-II	0.2387	0.0082	0.2469	5.231E-01
D-III	0.4691	0.0152	0.4843	4.830E-01
IB-I	0.0087	0.0019	0.0106	1.400E-01
IB-II	0.0203	0.0036	0.0239	1.865E-01
IB-III	0.0424	0.0089	0.0513	1.500E-01
RB	0.0244	0.0065	0.0309	7.621E-02
AB	0.0104	0.0036	0.0140	3.992E-02
S	0.0000	0.0017	0.0017	1.645E-03
C	0.0000	0.0031	<u>0.0031</u>	1.470E-01
			1.0000	

RESULTS FOR CASE 3
D. Fuel Inventories

	Inventory (kg)			
	Driver Fuel	Inner Blankets	Radial Blanket	Axial Blanket Extensions
U-234				
U-235	5.180E+01	5.822E+01	6.838E+01	4.713E+01
U-236	1.110E+00	1.177E+00	9.147E-01	3.353E-01
U-238	2.577E+04	2.862E+04	3.280E+04	2.216E+04
U-239				
Np-237				
Np-238				
Np-239				
Pu-238				
Pu-239	4.016E+03	2.412E+02	1.515E+02	5.519E+01
Pu-240	1.265E+03	6.597E+00	2.180E+00	6.304E-01
Pu-241	5.678E+02	1.324E-01	2.270E-02	5.382E-03
Pu-242	1.537E+02	1.789E-03	1.279E-04	2.534E-05
Pu-243				
Pu-244				
Am-241				
Am-242m				
Am-242				
Am-243				
Am-244				
Cm-242				
Cm-243				
Cm-244				

RESULTS FOR CASE 3
E. Neutron Balance for Reactor

<u>Source</u>		
Fission	1.00000	
n,2n	0.00255	
Total Source		1.00255

<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>	
U-235	0.00220	0.00674	
U-236	0.00005	0.00000	
U-238	0.47471	0.05927	
Pu-238	0.00000	0.00000	
Pu-239	0.06038	0.22239	
Pu-240	0.01888	0.01530	
Pu-241	0.00711	0.03940	
Pu-242	0.00184	0.00133	
Other Actinides	0.00000	0.00000	
Fission Products	0.00760	0.00000	
Structure*	0.05945	0.00000	
Coolant	0.00253	0.00000	
Control	0.01798	0.00000	
Total	0.65273	0.34443	
Total Absorptions			0.99716

<u>Leakage</u>		
Axial	0.00043	
Radial	0.00496	
Total Leakage		0.00539
Total Losses		1.00255

*Includes 0^{16}

RESULTS FOR CASE 4

A. General

1. k_{eff}	1.00320
2. Control Rod Worth (Δk) ^a	0.00332
4. Kg Gain of Fissile Plutonium ^b	447.0
5. Peak Power (kw/cm ³) - Position	
Driver Fuel	5.10E-01, D-II-3-5, 154.99
Inner Blankets	2.93E-01, IB-II-2-5, 154.99
Radial Blankets	8.06E-02, RB-1-6, 154.99
6. Driver Fuel Peak-To-Average Power	1.79E+00
7. Driver Fuel Axial Peak-To-Average Power (at position of peak power)	1.29E+00

^aAt middle of cycle 2.^bCase 3 to Case 4.

RESULTS FOR CASE 4

B. Power

Zone	<u>Power Fraction</u>			Peak Power Density (kw/cc)
	Fission	Capture	Total	
D-I	0.1328	0.0053	0.1381	5.091E-01
D-II	0.2437	0.0098	0.2535	5.100E-01
D-III	0.3831	0.0143	0.3974	4.023E-01
IB-I	0.0181	0.0023	0.0204	2.197E-01
IB-II	0.0411	0.0042	0.0453	2.930E-01
IB-III	0.0766	0.0095	0.0861	2.020E-01
RB	0.0296	0.0056	0.0353	8.062E-02
AB	0.0157	0.0037	0.0194	5.782E-02
S	0.0000	0.0016	0.0016	1.392E-03
C	0.0000	0.0026	<u>0.0026</u>	1.232E-01
			1.0000	

RESULTS FOR CASE 4

C. Burnup

Zone	Average Burnup (MWD/MT)	Peak Burnup ^a (MWD/MT)
D-I	6.476E+04	8.827E+04
D-II	6.128E+04	9.121E+04
D-III	4.904E+04	8.264E+04
IB-I	4.945E+03	1.649E+04
IB-II	9.809E+03	2.476E+04
IB-III	5.837E+03	1.737E+04
RB	1.579E+03	8.086E+03
AB	1.149E+03	5.527E+03

^a Average burnup times the EOC peak-to-average power.

RESULTS FOR CASE 4
D. Fuel Inventories

	Inventory (kg)			
	Driver Fuel	Inner Blankets	Radial Blanket	Axial Blanket Extensions
U-234				
U-235	4.216E+01	5.014E+01	6.426E+01	4.457E+01
U-236	3.162E+00	3.093E+00	1.979E+00	1.014E+00
U-237				
U-238	2.505E+04	2.808E+04	3.259E+04	2.203E+04
U-239				
Np-237				
Np-238				
Np-239				
Pu-238				
Pu-239	3.849E+03	6.519E+02	3.364E+02	1.692E+02
Pu-240	1.322E+03	2.926E+01	8.273E+00	3.077E+00
Pu-241	4.716E+00	9.828E-01	1.489E-01	4.454E-02
Pu-242	1.635E+02	2.510E-02	1.567E-03	3.930E-04
Pu-243				
Pu-244				
Am-241				
Am-242m				
Am-242				
Am-243				
Am-244				
Cm-242				
Cm-243				
Cm-244				

RESULTS FOR CASE 4
E. Neutron Balance for Reactor

<u>Source</u>		
Fission	1.00000	
n,2n	0.00257	
Total Source		1.00257

<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00178	0.00548
U-236	0.00012	0.00000
U-238	0.45839	0.05852
Pu-238	0.00000	0.00000
Pu-239	0.06572	0.23181
Pu-240	0.01991	0.01551
Pu-241	0.00572	0.03152
Pu-242	0.00193	0.00134
Other Actinides	0.00000	0.00000
Fission Products	0.02348	0.00000
Structure*	0.05830	0.00000
Coolant	0.00252	0.00000
Control	0.01520	0.00000
Total	0.65307	0.34418
Total Absorptions		0.99725

<u>Leakage</u>		
Axial	0.00051	
Radial	0.00480	
Total Leakage		0.00531
Total Losses		1.00256

*Includes 0^{16}

RESULTS FOR CASE 1 WITH TWO LUMPED FISSION PRODUCTS

A. General

1. k_{eff}	1.00377
5. Peak Power (kw/cm ³)-Position	
Driver Fuel	5.28E-01, D-III-2-6, 149.86 cm
Inner Blankets	8.05E-02, IB-II-1-3, 149.86 cm
Radial Blankets	6.27E-02, RB-6-6, 154.94 cm
6. Driver Fuel Peak-Average Power	1.61E+00
7. Driver Fuel Axial Peak-To-Average Power (at position of peak power)	1.35E+00

RESULTS FOR CASE 1 WITH TWO LUMPED FISSION PRODUCTS

B. Power

Zone	<u>Power Fraction</u>			Peak Power Density (kw/cm ³)
	Fission	Capture	Total	
D-I	0.1174	0.0037	0.1211	4.576E-01
D-II	0.2330	0.0072	0.2402	5.172E-01
D-III	0.5313	0.0159	0.5472	5.280E-01
IB-I	0.0038	0.0016	0.0054	6.458E-02
IB-II	0.0104	0.0032	0.0136	8.048E-02
IB-III	0.0227	0.0086	0.0314	7.720E-02
RB	0.0172	0.0071	0.0243	6.272E-02
AB	0.0080	0.0036	0.0116	2.584E-02
S	0.0000	0.0017	0.0017	1.831E-03
C	0.0000	0.0034	<u>0.0034</u>	1.578E-01
			1.0000	

RESULTS FOR CASE 1 WITH TWO LUMPED FISSION PRODUCTS

D. Fuel Inventories

	Inventory (kg)			
	Driver Fuel	Inner Blankets	Radial Blanket	Axial Blanket Extensions
U-234				
U-235	5.687E+01	6.297E+01	7.181E+01	4.838E+01
U-236				
U-237				
U-238	2.612E+04	2.891E+04	3.297E+04	2.222E+04
U-239				
Np-237				
Np-238				
Np-239				
Pu-238				
Pu-239	4.101E+03			
Pu-240	1.236E+03			
Pu-241	6.206E+02			
Pu-242	1.481E+02			
Pu-243				
Pu-244				
Am-241				
Am-242m				
Am-242				
Am-243				
Am-244				
Cm-242				
Cm-243				
Cm-244				

RESULTS FOR CASE 1 WITH TWO LUMPED FISSION PRODUCTS

E. Neutron Balance for Reactor

<u>Source</u>		
Fission	1.00000	
n,2n	0.00254	
Total Source		1.00254
<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00246	0.00748
U-236	0.00000	0.00000
U-238	0.48336	0.05952
Pu-238	0.00000	0.00000
Pu-239	0.05638	0.21647
Pu-240	0.01848	0.01532
Pu-241	0.00791	0.04394
Pu-242	0.00179	0.00132
Other Actinides	0.00000	0.00000
Fission Products	0.00000	0.00000
Structure*	0.06010	0.00000
Coolant	0.00254	0.00000
Control	0.02030	0.00000
Total	0.65332	0.34405
Total Absorptions		0.99737
<u>Leakage</u>		
Axial	0.00039	
Radial	0.00476	
Total Leakage		0.00515
Total Losses		1.00252

*Includes O^{16}

RESULTS FOR CASE 2 WITH TWO LUMPED FISSION PRODUCTS

A. General

1. k_{eff}	1.00141
2. Control Rod Worth (Δk) ^a	0.00540
4. Kg Gain of Fissile Plutonium ^b	484.8
5. Peak Power (kw/cm ³) - Position	
Driver Fuel	5.36E-01, D-II-1-3, 154.99
Inner Blankets	2.23E-01, IB-II-1-4, 154.99
Radial Blankets	7.30E-02, RB-6-6, 154.99
6. Driver Fuel Peak-To-Average Power	1.80E+00
7. Driver Fuel Axial Peak-To-Average Power (at position of peak power)	1.30E+00

^aAt middle of cycle 1.^bCase 1 to Case 2.

RESULTS FOR CASE 2 WITH TWO LUMPED FISSION PRODUCTS

B. Power

Zone	<u>Power Fraction</u>			Peak Power Density (kw/cm ³)
	Fission	Capture	Total	
D-I	0.1324	0.0046	0.1370	5.014E-01
D-II	0.2546	0.0088	0.2634	5.358E-01
D-III	0.4119	0.0138	0.4257	4.314E-01
IB-I	0.0119	0.0021	0.0140	1.469E-01
IB-II	0.0329	0.0040	0.0369	2.231E-01
IB-III	0.0611	0.0092	0.0703	1.606E-01
RB	0.0252	0.0058	0.0310	7.296E-02
AB	0.0135	0.0036	0.0172	4.381E-02
S	0.0000	0.0016	0.0016	1.465E-03
C	0.0000	0.0028	<u>0.0028</u>	1.381E-01
			1.0000	

RESULTS FOR CASE 2 WITH TWO LUMPED FISSION PRODUCTS

C. Burnup

Zone	Average Burnup (MWD/MT)	Peak Burnup ^a (MWD/MT)
D-I	3.158E+04	4.275E+04
D-II	3.066E+04	4.614E+04
D-III	2.556E+04	4.312E+04
IB-I	1.825E+03	5.905E+03
IB-II	4.039E+03	9.524E+03
IB-III	2.420E+03	7.017E+03
RB	7.002E+02	3.705E+03
AB	5.190E+02	2.146E+03

^aAverage burnup times the EOC peak-to-average power.

RESULTS FOR CASE 2 WITH TWO LUMPED FISSION PRODUCTS

D. Fuel Inventories

	Inventory (kg)			
	Driver Fuel	Inner Blankets	Radial Blanket	Axial Blanket Extensions
U-234				
U-235	4.601E+01	5.413E+01	6.704E+01	4.570E+01
U-236	2.381E+00	2.185E+00	1.266E+00	7.189E-01
U-237				
U-238	2.537E+04	2.838E+04	3.274E+04	2.209E+04
U-239				
Np-237				
Np-238				
Np-239				
Pu-238				
Pu-239	3.920E+03	4.495E+02	2.116E+02	1.183E+02
Pu-240	1.299E+03	1.247E+01	3.106E+00	1.351E+00
Pu-241	5.075E+02	2.545E-01	3.304E-02	1.151E-02
Pu-242	1.602E+02	3.514E-03	1.920E-04	5.393E-05
Pu-243				
Pu-244				
Am-241				
Am-242m				
Am-242				
Am-243				
Am-244				
Cm-242				
Cm-243				
Cm-244				

RESULTS FOR CASE 2 WITH TWO LUMPED FISSION PRODUCTS

E. Neutron Balance for Reactor

<u>Source</u>		
Fission	1.00000	
n,2n	0.00256	
Total Source		1.00256

<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00197	0.00604
U-236	0.00009	0.00000
U-238	0.46739	0.05884
Pu-238	0.00000	0.00000
Pu-239	0.06340	0.22721
Pu-240	0.01948	0.01545
Pu-241	0.00628	0.03462
Pu-242	0.00192	0.00135
Other Actinides	0.00000	0.00000
Fission Products	0.01605	0.00000
Structure ^a	0.05859	0.00000
Coolant	0.00253	0.00000
Control	0.01628	0.00000
Total	0.65398	0.34351
Total Absorptions		0.99749

<u>Leakage</u>		
Axial	0.00047	
Radial	0.00458	
Total Leakage		0.00506
Total Losses		1.00255

^aIncludes O¹⁶

RESULTS FOR CASE 3 WITH TWO LUMPED FISSION PRODUCTS

A. General

1. k_{eff}	1.00434
5. Peak Power (kw/cm ³)-Position	
Driver Fuel	5.24E-01, D-II-3-4, 149.86 cm
Inner Blankets	1.86E-01, IB-II-2-5, 154.99 cm
Radial Blankets	7.62E-01, RB-1-6, 154.99 cm
6. Driver Fuel Peak-Average Power	1.68E+00
7. Driver Fuel Axial Peak-To-Average Power (at position of peak power)	1.35E+00

RESULTS FOR CASE 3 WITH TWO LUMPED FISSION PRODUCTS

B: Power

Zone	<u>Power Fraction</u>			Peak Power Density (kw/cm ³)
	Fission	Capture	Total	
D-I	0.1292	0.0042	0.1334	5.092E-01
D-II	0.2390	0.0079	0.2469	5.236E-01
D-III	0.4694	0.0148	0.4842	4.833E-01
IB-I	0.0087	0.0019	0.0106	1.400E-01
IB-II	0.0203	0.0036	0.0239	1.864E-01
IB-III	0.0424	0.0089	0.0513	1.500E-01
RB	0.0244	0.0065	0.0309	7.623E-02
AB	0.0104	0.0036	0.0140	3.994E-02
S	0.0000	0.0017	0.0017	1.646E-03
C	0.0000	0.0031	<u>0.0031</u>	1.471E-01
			1.0000	

RESULTS FOR CASE 3 WITH TWO LUMPED FISSION PRODUCTS

D. Fuel Inventories

	Inventory (kg)			
	Driver Fuel	Inner Blankets	Radial Blanket	Axial Blanket Extensions
U-234				
U-235	5.180E+01	5.822E+01	6.838E+01	4.713E+01
U-236	1.111E+00	1.178E+00	9.153E-01	3.355E-01
U-238	2.577E+04	2.862E+04	3.280E+04	2.216E+04
U-239				
Np-237				
Np-238				
Np-239				
Pu-238				
Pu-239	4.016E+03	2.414E+02	1.516E+02	5.524E+01
Pu-240	1.266E+03	6.611E+00	2.184E+00	6.315E-01
Pu-241	5.677E+02	1.329E-01	2.275E-02	5.397E-03
Pu-242	1.538E+02	1.797E-03	1.283E-04	2.544E-05
Pu-243				
Pu-244				
Am-241				
Am-242m				
Am-242				
Am-243				
Am-244				
Cm-242				
Cm-243				
Cm-244				

RESULTS FOR CASE 3 WITH TWO LUMPED FISSION PRODUCTS

E. Neutron Balance for Reactor

<u>Source</u>		
Fission	1.00000	
n,2n	0.00255	
Total Source		1.00255

<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>	
U-235	0.00220	0.00673	
U-236	0.00005	0.00000	
U-238	0.47470	0.05926	
Pu-238	0.00000	0.00000	
Pu-239	0.06040	0.22238	
Pu-240	0.01889	0.01530	
Pu-241	0.00712	0.03940	
Pu-242	0.00184	0.00132	
Other Actinides	0.00000	0.00000	
Fission Products	0.00759	0.00000	
Structure*	0.05945	0.00000	
Coolant	0.00253	0.00000	
Control	0.01797	0.00000	
Total	0.65274	0.34439	
Total Absorptions			0.99713

<u>Leakage</u>		
Axial	0.00043	
Radial	0.00496	
Total Leakage		0.00539
Total Losses		1.00252

*Includes O^{16}

RESULTS FOR CASE 4 WITH TWO LUMPED FISSION PRODUCTS

A. General

1. k_{eff}	1.00316
2. Control Rod Worth (Δk) ^a	0.00332
4. Kg Gain of Fissile Plutonium ^b	447.7
5. Peak Power (kw/cm ³) - Position	
Driver Fuel	5.10E-01, D-II-3-5, 154.99
Inner Blankets	2.93E-01, IB-II-2-5, 154.99
Radial Blankets	8.07E-02, RB-1-6, 154.99
6. Driver Fuel Peak-To-Average Power	1.80E+00
7. Driver Fuel Axial Peak-To-Average Power (at position of peak power)	1.29E+00

^aAt middle of cycle 2.^bCase 3 to Case 4.

RESULTS FOR CASE 4 WITH TWO LUMPED FISSION PRODUCTS

B. Power

Zone	<u>Power Fraction</u>			Peak Power Density (kw/cc)
	Fission	Capture	Total	
D-I	0.1334	0.0048	0.1382	5.096E-01
D-II	0.2444	0.0090	0.2534	5.104E-01
D-III	0.3839	0.0133	0.3972	4.024E-01
IB-I	0.0181	0.0023	0.0204	2.202E-01
IB-II	0.0413	0.0041	0.0454	2.932E-01
IB-III	0.0769	0.0093	0.0862	2.022E-01
RB	0.0298	0.0056	0.0354	8.069E-02
AB	0.0158	0.0037	0.0195	5.796E-02
S	0.0000	0.0016	0.0016	1.394E-03
C	0.0000	0.0026	<u>0.0026</u>	1.235E-01
			1.0000	

RESULTS FOR CASE 4 WITH TWO LUMPED FISSION PRODUCTS

C. Burnup

Zone	Average Burnup (MWD/MT)	Peak Burnup ^a (MWD/MT)
D-I	6.488E+04	8.848E+04
D-II	6.138E+04	9.146E+04
D-III	4.909E+04	8.279E+04
IB-I	4.958E+03	1.653E+04
IB-II	9.833E+03	2.480E+04
IB-III	5.848E+03	1.740E+04
RB	1.581E+03	8.097E+03
AB	1.151E+03	5.540E+03

^aAverage burnup times the EOC peak-to-average power.

RESULTS FOR CASE 4 WITH TWO LUMPED FISSION PRODUCTS

D. Fuel Inventories

	Inventory (kg)			
	Driver Fuel	Inner Blankets	Radial Blanket	Axial Blanket Extensions
U-234				
U-235	4.214E+01	5.012E+01	6.425E+01	4.456E+01
U-236	3.168E+00	3.097E+00	1.981E+00	1.015E+00
U-237				
U-238	2.505E+04	2.808E+04	3.259E+04	2.203E+04
U-239				
Np-237				
Np-238				
Np-239				
Pu-238				
Pu-239	3.849E+03	6.527E+02	3.367E+02	1.694E+02
Pu-240	1.323E+03	2.936E+01	8.290E+00	3.085E+00
Pu-241	4.715E+00	9.880E-01	1.494E-01	4.472E-02
Pu-242	1.636E+02	2.528E-02	1.574E-03	3.953E-04
Pu-243				
Pu-244				
Am-241				
Am-242m				
Am-242				
Am-243				
Am-244				
Cm-242				
Cm-243				
Cm-244				

RESULTS FOR CASE 4 WITH TWO LUMPED FISSION PRODUCTS

E. Neutron Balance for ReactorSource

Fission	1.00000	
n,2n	0.00257	
Total Source		1.00257

AbsorptionsCapturesFissions

U-235	0.00178	0.00547
U-236	0.00012	0.00000
U-238	0.45843	0.05849
Pu-238	0.00000	0.00000
Pu-239	0.06584	0.23184
Pu-240	0.01995	0.01550
Pu-241	0.00572	0.03153
Pu-242	0.00193	0.00134
Other Actinides	0.00000	0.00000
Fission Products	0.02330	0.00000
Structure*	0.05830	0.00000
Coolant	0.00252	0.00000
Control	0.01519	0.00000
Total	0.65308	0.34417
Total Absorptions		0.99725

Leakage

Axial	0.00051	
Radial	0.00480	
Total Leakage		0.00531
Total Losses		1.00256

*Includes O^{16}

C-E RESULTS FOR THE
LARGE CORE CODE EVALUATION WORKING GROUP
BENCHMARK PROBLEM IV

by

J.J Prabulos
Advanced Development Department
Combustion Engineering Inc.
1000 Prospect Hill Road
Windsor, CT 06095

May 18-19, 1982

Work Performed Under Auspices of Combustion Engineering, Inc.

GENERAL COMMENTS

A. Codes Used

DIFPB, a C-E developed diffusion theory code, based on 2DB, but containing the DIF3D solution algorithm.

B. Convergence Criteria

Keff - 1.0 E-6

Pointwise Fission Source - 1.0 E-5

C. Method of Burnup Calculations (continue on following pages)

Burnup was evaluated using the 2DB burnup model incorporated in DIFPB for 14 lumped burnup regions

D. Analysis Procedures

Geometry

3

1. HEX-Z Direct
2. HEX-Z Synthesis
3. HEX X-Y
4. R-Z
5. Linked R-Z and HEX X-Y
6. Other (describe)

Cross Sections

1

1. GE-8 Group
2. Other (describe)

Data supplied in ISOTXS SI format were converted to DIFPB input format using LCC. No (n,2n) corrections are present in microscopic absorption cross-sections output by LCC. No microscopic cross-section substitutions were employed in X-Y analysis.

Fuel Management Plan

1

1. Recommended two cycle reload plan
2. Other (describe)

Fuel Burnup Chain

1

1. Abbreviated burnup chain with uranium and plutonium isotopes only (including Pu-241 decay)
2. Extended burnup chain
3. Other (describe)

Lumped Fission Products2

1. Recommended - 2 Fission Product Pairs (odd, even)
2. Recommended - 1 Fission Product Pair
3. Other (describe)

Energy Deposition1

1. In-Situ fission plus capture gamma's
2. In-Situ fission only
3. Other (describe)

Capture reaction rates from complementary RZ analysis performed first were used to obtain the following effective energy release values in Mev per stainless steel capture for use with microscopic stainless steel cross-sections formulated with the FSIG code: (1) driver - 8.5170; (2) internal blanket - 8.4277; (3) radial blanket - 8.4003; (4) radial shield - 8.2344; (5) control channel - 8.4627; and (6) inserted control - 8.5131.

Treatment of Control Rods1

1. Control positioned at the recommended BOC location during the first half of the irradiation cycle, and at the recommended EOC location during the last half of the irradiation cycle
2. Positioned as recommended at the beginning-of-cycle and left unchanged during the burnup calculations
3. All control out
4. Other (describe)

Atom densities in the primary control rod region used for criticality adjustments during burnup were obtained by flux-volume weighting the values from the preceding RZ analysis. Inserted control assembly and withdrawn sodium channel atom density fractions obtained via the flux-volume weighting are given below.

<u>Atom Density Fraction</u>	<u>BOC1</u>	<u>MOC1-EOC1</u>	<u>BOC2</u>	<u>MOC2-EOC2</u>
Sodium Channel	.79507	.91022	.85769	.93180
Inserted Portion	.20493	.08978	.14231	.06820

Calculation of Control Rod WorthNot Performed

Core Layout1

1. Recommended
2. Other (describe) .

The calculational model used is depicted in Figure 1. Six mesh-points were used to define each hexagonal subassembly. The 17 zones indicated on the figure are as follows:

<u>Zone</u>	<u>Description</u>
1	IB-I assemblies managed at EOC1
2	Remaining IB-I assemblies
3	D-I assemblies managed at EOC1
4	Remaining D-I assemblies
5	Control rod channels
6	IB-II assemblies managed at EOC1
7	Remaining IB-II assemblies
8	D-II assemblies managed at EOC1
9	Remaining D-II assemblies
10	IB-III assemblies managed at EOC1
11	Remaining IB-III assemblies
12	Adjustable control rod assembly
13	D-III assemblies managed at EOC1
14	Remaining D-III assemblies
15	RB assemblies managed at EOC1
16	Remaining RB assemblies
17	Radial Shield

Mesh Spacings1

1. Recommended
2. Other (describe)

Flux Solutions During Irradiation Cycle1

1. Recommended
2. Other (describe)

FIGURE 1 - SIXTY DEGREE SECTOR OF CORE LAYOUT FOR BENCHMARK PROBLEM FOUR (ASSEMBLIES GIVEN FOR FULL CORE LAYOUT)

GENERAL COMMENTS (CONTINUED)

ADDITIONAL DESCRIPTION OF BENCHMARK SPECIFICATIONS

A radial 1D analog of the RZ model was first prepared and used for transverse buckling searches on the RZ eigenvalues at six time points. The hex x-y analysis was then carried out with these group-and-region independent transverse buckling values. Input power normalization values were corrected at each time point by subtracting RZ estimated contributions from regions not adjacent to the seed. These and other RZ model links for the xy calculation are summarized below.

<u>Time</u>	<u>B²</u>	<u>MWt/cm</u>	<u>Zone 12 Inserted Atom Density Fraction</u>
BOC1	0.000415125	3.6719	0.20493
MOC1	0.000420521	3.6570	0.089784
EOC1	0.00043168	3.6416	0.089784
BOC2	0.000420025	3.6577	0.14231
MOC2	0.000431728	3.6424	0.06820
EOC2	0.000438214	3.6270	0.06820

CASE 1

BEGINNING-OF-IRRADIATION CYCLE 1

RESULTS FOR CASE 1A. General

1. k_{eff}	1.00165	
2. Control Rod Worth (Δk) ^a		
3. Sodium Void Worth (Δk) ^a		
4. Breeding Gain (kg of fissile plutonium) ^b		
5. Peak Power (kw/cm ³)-Position		
Driver Fuel	3.96 E-1	- Position D-III-4-6
Inner Blankets	5.91 E-2	- Position IB-III-3-3
Radial Blankets	4.96 E-2	- Position RB-6-6
6. Driver Fuel Peak-to-Average Power	1.21 E+0	
7. Driver Fuel Axial Peak-to-Average Power
(at position of peak power)		

a. Optional calculations

b. Required for Cases 2 and 4 only

RESULTS FOR CASE 1B. Power

<u>ZONE^a</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY (KW/CM³)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	0.1159	0.0036	0.1195	3.338 E-1
D-II	0.2223	0.0068	0.2291	3.536 E-1
D-III	0.5607	0.0166	0.5773	3.965 E-1
IB-I	0.0035	0.0014	0.0049	4.749 E-2
IB-II	0.0096	0.0028	0.0124	5.710 E-2
IB-III	0.0216	0.0076	0.0292	5.912 E-2
RB	0.0172	0.0067	0.0239	4.956 E-2
AB	-	-	-	-
S	-	0.0010	0.0010	1.432 E-3
C	-	0.0027	0.0027	4.050 E-2
	0.9508	0.0492	1.0	

- a) A partial description of the zone designators is given for Figure B.1.
Other terms are:

AB - Axial blanket extensions to the driver fuel
S - All axial and radial shields
C - All control channels

RESULTS FOR CASE 1D. Fuel Inventories

	<u>Inventory (kg)</u>			
	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blankets</u>	<u>Axial Blanket Extension</u>
U-234				
U-235	5.687 E+1	3.977 E+1	4.535 E+1	-
U-236				
U-237				
U-238	2.612 E+4	1.826 E+4	2.082 E+4	-
U-239				
N _p -237				
N _p -238				
N _p -239				
P _u -238				
P _u -239	4.101 E+3			
P _u -240	1.236 E+3			
P _u -241	6.205 E+2			
P _u -242	1.481 E+2			
P _u -243				
P _u -244				
Am-241				
Am-242m				
Am-242				
Am-243				
Am-244				
Cm-242				
Cm-243				
Cm-244				

RESULTS FOR CASE 1E. Neutron Balance for ReactorSource

Fission

1.00000 n/sec

n,2n

0.00246

total source

1.00246

AbsorptionsCapturesFissions

U-235

0.00204

0.00640

U-236

U-238

0.41792

0.05754

Pu-238

Pu-239

0.05569

0.21796

Pu-240

0.01834

0.01562

Pu-241

0.00786

0.04404

Pu-242

0.00178

0.00134

Fission Products

* Other Captures

0.01857

Structure

0.04630

Coolant

0.00216

Total

0.57066

0.34290

Total Absorptions

0.91356

Leakage

Axial

0.08476

Radial

0.00414

Total

0.08890

Total Losses

1.00246

All values are normalized to the unit fission source

*016, B10, B11, C

CASE 2

END-OF-IRRADIATION CYCLE 1

RESULTS FOR CASE 2A. General

1. k_{eff} .99429
2. Control Rod Worth (Δk)^a
3. Sodium Void Worth (Δk)^a
4. Breeding Gain (kg of fissile plutonium)^b
5. Peak Power (kw/cm³)-Position

Driver Fuel	4.05 E-1	- Position D-II-1-3
Inner Blankets	1.44 E-1	- Position IB-II-1-2
Radial Blankets	5.48 E-2	- Position RB-6-6
6. Driver Fuel Peak-to-Average Power 1.35 E+0
7. Driver Fuel Axial Peak-to-Average Power
(at position of peak power)

a. Optional calculations

b. Required for Cases 2 and 4 only

RESULTS FOR CASE 2B. Power

<u>ZONE^a</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY (KW/CM³)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	0.1383	0.0047	0.1430	3.932 E-1
D-II	0.2567	0.0087	0.2654	4.046 E-1
D-III	0.4330	0.0143	0.4473	3.214 E-1
IB-I	0.0111	0.0019	0.0130	1.002 E-1
IB-II	0.0302	0.0036	0.0338	1.443 E-1
IB-III	0.0558	0.0081	0.0639	9.461 E-2
RB	0.0254	0.0054	0.0308	5.478 E-2
AB	-	-	-	-
S	-	0.0009	0.0009	1.143 E-3
C	-	0.0019	0.0019	2.785 E-2
	0.9505	0.0495	1.0	

- a) A partial description of the zone designators is given for Figure B.1.
Other terms are:

AB - Axial blanket extensions to the driver fuel
S - All axial and radial shields
C - All control channels

RESULTS FOR CASE 2C. Burnup

<u>ZONE^b</u>	<u>AVERAGE BURNUP (MWD/MT)</u>	<u>PEAK BURNUP (MWD/MT)^c</u>
D-I	3.127 E+4	3.271 E+4
D-II	2.946 E+4	3.418 E+4
D-III	2.715 E+4	3.340 E+4
IB-I	3.182 E+3	4.948 E+3
IB-II	6.505 E+3	7.050 E+3
IB-III	4.049 E+3	4.934 E+3
RB	1.346 E+3	3.482 E+3
AB		

a) Required for Cases 2 and 4 only

b) A partial description of the zone designations is given for Figure B.1.
Other terms are:

AB-Axial blanket extensions to the driver fuel

c) Optional calculation-if this calculation is performed please describe procedure.

Average burnup times the EOC peak-to-average power.

RESULTS FOR CASE 2D. Fuel Inventories

	<u>Inventory (kg)</u>			
	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blankets</u>	<u>Axial Blanket Extension</u>
U-234				
U-235	4.596 E+1	3.230 E+1	4.081 E+1	
U-236	2.381 E+0	1.834 E+0	1.196 E+0	
U-237				
U-238	2.537 E+4	1.781 E+4	2.060 E+4	
U-239				
N _p -237				
N _p -238				
N _p -239				
P _u -238				
P _u -239	3.915 E+3	3.808 E+2	2.025 E+2	
P _u -240	1.297 E+3	1.045 E+1	3.358 E+0	
P _u -241	5.063 E+2	1.908 E-1	3.660 E-2	
P _u -242	1.600 E+2	2.200 E-3	2.066 E-4	
P _u -243				
P _u -244				
Am-241				
Am-242m				
Am-242				
Am-243				
Am-244				
Cm-242				
Cm-243				
Cm-244				

RESULTS FOR CASE 2E. Neutron Balance for Reactor

<u>Source</u>		
Fission	1.00000 n/sec	
n,2n	.00250	
total source		1.00250
<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00162	0.00515
U-236	0.00008	0.00001
U-238	0.40411	0.05683
Pu-238		
Pu-239	0.06129	0.22622
Pu-240	0.01928	0.01578
Pu-241	0.00634	0.03528
Pu-242	0.00191	0.00138
Fission Products	0.01472	
* Other Captures	0.01323	
Structure	0.04437	
Coolant	0.00215	
Total	0.56910	0.34065
Total Absorptions	0.90975	
<u>Leakage</u>		
Axial	0.08880	
Radial	0.00395	
Total		
Total Losses		0.09275
		1.00250

All values are normalized to the unit fission source

*016, B10, B11, C

CASE 3

BEGINNING-OF-IRRADIATION CYCLE 2

RESULTS FOR CASE 3A. General

1. k_{eff}	.99998	
2. Control Rod Worth (Δk) ^a		
3. Sodium Void Worth (Δk) ^a		
4. Breeding Gain (kg of fissile plutonium) ^b		
5. Peak Power (kw/cm ³)-Position		
Driver Fuel	3.80 E-1	- Position D-I-3-6
Inner Blankets	1.18 E-1	- Position IB-II-2-5
Radial Blankets	5.61 E-2	- Position RB-1-6
6. Driver Fuel Peak-to-Average Power	1.22 E+0	
7. Driver Fuel Axial Peak-to-Average Power
(at position of peak power)		

a. Optional calculations

b. Required for Cases 2 and 4 only

RESULTS FOR CASE 3B. Power

<u>ZONE^a</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY (KW/CM³)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	0.1306	0.0399	0.1705	3.803 E-1
D-II	0.2343	0.0076	0.2419	3.736 E-1
D-III	0.4952	0.0154	0.5106	3.627 E-1
IB-I	0.0078	0.0017	0.0095	9.141 E-2
IB-II	0.0184	0.0032	0.0216	1.181 E-1
IB-III	0.0396	0.0078	0.0474	1.008 E-1
RB	0.0249	0.0062	0.0311	5.610 E-2
AB				
S		0.0010	0.0010	1.290 E-3
C		0.0037	0.0023	3.434 E-2

- a) A partial description of the zone designators is given for Figure B.1.
Other terms are:

AB - Axial blanket extensions to the driver fuel
S - All axial and radial shields
C - All control channels

RESULTS FOR CASE 3C. Burnup

<u>ZONE^b</u>	<u>AVERAGE BURNUP (MWD/MT)</u>	<u>PEAK BURNUP (MWD/MT)^c</u>
D-I	1.060 E+4	3.269 E+4
D-II	1.509 E+4	3.415 E+4
D-III	1.301 E+4	3.332 E+4
IB-I	1.977 E+3	4.945 E+3
IB-II	3.086 E+3	6.431 E+3
IB-III	2.170 E+3	4.941 E+3
RB	9.408 E+2	3.127 E+3
AB		

a) Required for Cases 2 and 4 only

b) A partial description of the zone designations is given for Figure B.1.
Other terms are:

AB-Axial blanket extensions to the driver fuel

c) Optional calculation-if this calculation is performed please describe procedure.

EOC1 average burnup times the EOC1 peak-to-average power for fuel regions in reactor at BOC2.

RESULTS FOR CASE 3D. Fuel Inventories

	<u>Inventory (kg)</u>			
	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blankets</u>	<u>Axial Blanket Extension</u>
U-234				
U-235	5.177 E+1	3.572 E+1	4.208 E+1	
U-236	1.113 E+0	9.987 E-1	8.653 E-1	
U-237				
U-238	2.577 E+4	1.802 E+4	2.066 E+4	
U-239				
N _p -237				
N _p -238				
N _p -239				
P _u -238				
P _u -239	4.014 E+3	2.061 E+2	1.451 E+2	
P _u -240	1.264 E+3	5.675 E+0	2.365 E+0	
P _u -241	5.671 E+2	1.035 E-1	2.527 E-2	
P _u -242	1.537 E+2	1.186 E-3	1.386 E-4	
P _u -243				
P _u -244				
Am-241				
Am-242m				
Am-242				
Am-243				
Am-244				
Cm-242				
Cm-243				
Cm-244				

RESULTS FOR CASE 3E. Neutron Balance for Reactor

<u>Source</u>		
Fission	1.00000 n/sec	
n,2n	.00249	
total source		1.00249
<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00182	0.00574
U-236	0.00004	0.00001
U-238	0.41052	0.05726
Pu-238		
Pu-239	0.05905	0.22275
Pu-240	0.01872	0.01562
Pu-241	0.00712	0.03975
Pu-242	0.00183	0.00136
Fission Products	0.00699	
*Other Captures	0.01593	
Structure	0.04548	
Coolant	0.00215	
Total	0.56965	0.34249
Total Absorptions	0.91214	
<u>Leakage</u>		
Axial	0.08603	
Radial	0.00432	
Total		0.09035
Total Losses		1.00249

All values are normalized to the unit fission source

*O16, B10, B11, C

CASE 4

BEGINNING OF IRRADIATION CYCLE 4

RESULTS FOR CASE 4A. General

1. k_{eff}	.99448	
2. Control Rod Worth (Δk) ^a		
3. Sodium Void Worth (Δk) ^a		
4. Breeding Gain (kg of fissile plutonium) ^b		
5. Peak Power (kw/cm ³)-Position		
Driver Fuel	4.03 E-1	- Position D-I-3-6-
Inner Blankets	1.93 E-1	- Position IB-II-2-1
Radial Blankets	5.81 E-2	- Position RB-1-6
6. Driver Fuel Peak-to-Average Power	1.40 E+0	
7. Driver Fuel Axial Peak-to-Average Power
(at position of peak power)		

-
- a. Optional calculations
- b. Required for Cases 2 and 4 only

RESULTS FOR CASE 4B. Power

<u>ZONE^a</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY (KW/CM³)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	0.1402	0.0050	0.1452	4.027 E-1
D-II	0.2501	0.0089	0.2590	3.934 E-1
D-III	0.4039	0.0138	0.4177	3.053 E-1
IB-I	0.0166	0.0021	0.0187	1.455 E-1
IB-II	0.0385	0.0037	0.0422	1.933 E-1
IB-III	0.0710	0.0083	0.0793	1.270 E-1
RB	0.0302	0.0053	0.0355	5.814 E-2
AB				
S		0.0009	0.0009	1.085 E-3
C		0.0016	0.0016	2.298 E-2

- a) A partial description of the zone designators is given for Figure B.1.
Other terms are:

AB - Axial blanket extensions to the driver fuel

S - All axial and radial shields

C - All control channels

RESULTS FOR CASE 4C. Burnup

<u>ZONE^b</u>	<u>AVERAGE BURNUP (MWD/MT)</u>	<u>PEAK BURNUP (MWD/MT)^c</u>
D-I	3.323 E+4	3.521 E+4
D-II	2.972 E+4	3.449 E+4
D-III	2.450 E+4	3.078 E+4
IB-I	5.007 E+3	7.842 E+3
IB-II	8.965 E+3	1.046 E+4
IB-III	5.481 E+3	7.271 E+3
RB	1.629 E+3	3.905 E+3
AB		

a) Required for Cases 2 and 4 only

b) A partial description of the zone designations is given for Figure B.1.
Other terms are:

AB-Axial blanket extensions to the driver fuel

c) Optional calculation-if this calculation is performed please describe procedure.

$$\text{Peak} = (\text{AVG BU}) (\text{PAP (EOC2)})$$

RESULTS FOR CASE 4D. Fuel Inventories

	<u>Inventory (kg)</u>			
	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blankets</u>	<u>Axial Blanket Extension</u>
U-234				
U-235	4.199 E+1	2.887 E+1	3.826 E+1	
U-236	3.189 E+0	2.608 E+0	1.840 E+0	
U-237				
U-238	2.504 E+4	1.755 E+4	2.045 E+4	
U-239				
N _p -237				
N _p -238				
N _p -239				
P _u -238				
P _u -239	3.842 E+3	5.561 E+2	3.182 E+2	
P _u -240	1.319 E+3	2.540 E+1	8.819 E+0	
P _u -241	4.692 E+2	7.903 E-1	1.625 E-1	
P _u -242	1.635 E+2	1.734 E-2	1.657 E-3	
P _u -243				
P _u -244				
Am-241				
Am-242m				
Am-242				
Am-243				
Am-244				
Cm-242				
Cm-243				
Cm-244				

RESULTS FOR CASE 4E. Neutron Balance for Reactor

<u>Source</u>		
Fission	1.00000 n/sec	
n,2n	.00251	
total source		1.00251
<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00145	0.00463
U-236	0.00011	0.00002
U-238	0.39626	0.05647
Pu-238		
Pu-239	0.06338	0.23020
Pu-240	0.01971	0.01585
Pu-241	0.00580	0.03222
Pu-242	0.00193	0.00138
Fission Products	0.02165	
* Other Captures	0.01137	
Structure	0.04389	
Coolant	0.00214	
Total	0.56769	0.34077
Total Absorptions	0.90846	
<u>Leakage</u>		
Axial	0.08992	
Radial	0.00413	
Total		0.09405
Total Losses		1.00251

All values are normalized to the unit fission source

*016, B10, B11, C

Hex XY - RZ Parameter Comparison

LCCEWG Benchmark 4
Hex XY and RZ Parameter Comparison

A. Keffective

	BOC1	MOC1	EOC1	BOC2	MOC2	EOC2
RZ	1.00376	1.00226	.99801	1.00371	1.00290	.99972
Hex XY	1.00165	.99932	.99429	.99998	.99781	.99447

B. $\Delta k/kk'$

	Cycle 1	Cycle 2
RZ	-.00573	-.00397
Hex XY	-.00739	-.00554

C. Breeding Gain (kg U235 + Pu239 + Pu241)

A. RZ	MOC1-BOC1	EOC1-MOC1	CYCLE 1	MOC2-BOC2	EOC2-MOC2	CYCLE 2
Driver	-164.1	-145.0	-309.1	-146.6	-130.2	-276.8
IB	191.8	188.2	380.0	181.7	169.3	351.0
RB	109.4	85.9	195.2	87.5	74.7	162.1
IBAB	23.5	25.0	48.5	24.7	25.5	50.2
RBAB	13.2	11.2	24.4	11.6	10.6	22.2
DAB	53.8	52.7	106.4	52.7	51.8	104.4
Total	227.4	218.1	445.5	211.7	201.6	413.3

B. Hex XY						
Driver	-164.8	-146.7	-311.5	-147.9	-132.2	-280.1
IB	190.4	183.1	373.5	177.8	166.0	343.8
RB	109.2	88.8	198.0	91.7	77.7	169.4
IBAB	23.5	25.0	48.5	24.7	25.5	50.2
(from RZ)						
RBAB	13.2	11.2	24.4	11.6	10.6	22.2
(from RZ)						
DAB	53.8	52.7	106.4	52.7	51.8	104.4
(from RZ)						
Total	225.2	214.2	439.4	210.6	199.5	410.0

C. Hex/RZ

	Cycle 1	Cycle 2
Driver	1.0077	1.0119
IB	.9828	.9794
RB	1.0143	1.0450
Total	.9863	.9920

GE-ARSD RESULTS FOR LARGE CORE CODE EVALUATION
WORKING GROUP (LCCEWG) BENCHMARK PROBLEM 4*

by

R. PROTSIK AND C.L. COWAN

ADVANCED REACTOR SYSTEMS DEPARTMENT
GENERAL ELECTRIC COMPANY
310 DEGUIGNE DRIVE
P.O. BOX 508
SUNNYVALE, CALIFORNIA 94086

AUGUST 25, 1982

* Work performed under U.S. Department of Energy Contract
DE-AT03-76SF71031

TABLE OF CONTENTS

	<u>Page</u>
Introduction	1
Analysis	1
Results	3
References	5

LIST OF FIGURES

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1	LCCEWG Benchmark 4 RZ Model	6
2	LCCEWG Benchmark 4 Sixty Degree Sector Layout and Refueling Scheme	8

LIST OF TABLES

<u>TABLE</u>	<u>TITLE</u>	<u>PAGE</u>
1	LCCEWG Benchmark 4 Region Nomenclature	7
2	LCCEWG Benchmark 4 RZ Model General Comments	9-11
3	LCCEWG Benchmark 4 RZ Model Procedure	12-13
4	LCCEWG Benchmark 4 RZ/XY Model General Comments	14-16
5	LCCEWG Benchmark 4 XY Model Procedure	17-18
6	LCCEWG Benchmark 4 RZ Model (GE Approach)	19-21
	General Comments	
7	LCCEWG Benchmark 4 RZ Model Procedure (GE Approach)	22-23
8	LCCEWG Benchmark 4 RZ 20 Group Model General Comments	24-26
9	LCCEWG Benchmark 4 RZ 20 Group Model Procedure	27-28
10	LCCEWG Benchmark 4 RZ Model Results	29-35
11	LCCEWG Benchmark 4 RZ/XY Model Results	36-41
12	LCCEWG Benchmark 4 RZ Model Results (GE Approach)	42-48
13	LCCEWG Benchmark 4 RZ 20 Group Results	49-55

Introduction

The Large Core Code Evaluation Working Group (LCCEWG) Benchmark 4 has been specified⁽¹⁾ to provide a stringent test of the current methods used in the nuclear design and analysis process. The primary emphasis of benchmark is on detailed burnup calculations over the first two irradiation cycles for a three-dimensional model of the LMFBR design analyzed in LCCEWG Benchmark 3. Two-dimensional approximate models in RZ and XY geometries are also specified. Evaluation of approximate methods used by each of the LCCEWG participants will be made relative to three-dimensional analyses performed at Argonne (ANL), Oak Ridge (ORNL), and Hanford (HEDL) national laboratories.

Analysis

Analysis of LCCEWG Benchmark 4 has been completed by GE-ARSD for the specified RZ and RZ/XY approximations to the three-dimensional configuration. The RZ model is shown in Figure 1; a key to the region nomenclature used in Figure 1 is provided in Table 1. Note that the model is split axially into 8 core zones and 2 lower and upper axial blanket zones; each of these zones are specified to be burned separately. A 60 degree sector of the XY model is shown in Figure 2. A detailed refueling scheme is shown for the XY model; however, for the reference calculation of the benchmark problem, burnup is to be computed in each plane only by region, with the refueling fractions determined from the detailed refueling scheme.

Except for the 6 primary control rods used for criticality adjustments during irradiation (C in the XY model and CI3 in the RZ model), all control rods are positioned at the core/upper axial blanket interface. The positions of the criticality adjustment control rods are provided in the benchmark specifications at the beginning and end of irradiation cycles 1 and 2. In the RZ model, all control positions are represented by annuli. In the XY model, the criticality adjustment control rods were approximated at GE-ARSD by flux and volume weighting the control-in and control-out densities, using the fluxes in zones CI3 and C03 from the RZ analysis. Control-out

densities were used in the XY model for all other control rods, but the axial bucklings in the control rods, obtained from the RZ analysis for all regions including control regions, reflect the presence of the control rods in the upper axial blanket.

In the reference calculations, burnup is to be carried out for the first half of the irradiation cycle based upon the flux solution at the beginning-of-cycle (BOC) with the control inserted to the specified BOC position. Burnup calculations for the last half of the irradiation cycle are to be carried out based upon the flux solution at the middle-of-cycle (MOC) utilizing the isotopic compositions from the first burn step, but with the control inserted to the specified end-of-cycle (EOC) position. The procedure is to be used for both irradiation cycles.

In addition to the reference calculations, an alternative burnup procedure normally used at GE-ARSD was evaluated. In the GE approach, burnup is carried out over the entire irradiation cycle based upon flux solutions at BOC and EOC (with control inserted to the specified BOC and EOC positions), with linear interpolation of the fluxes used for several burnup steps over the cycle. Since the EOC densities are not initially known, this procedure is iterative. However, for the LCCEWG Benchmark 4 analysis, using the reference approach EOC results to initiate the iteration, nearly negligible differences were detected between the results of the first and second iterations.

In addition to the reference calculations, GE-ARSD was assigned the task of evaluating the effect of using more (20) energy groups. The RZ model was used in this analysis.

In summary, all calculations were made as specified except for the treatment of the control rods in the XY model (where no recommended procedure was given). In addition, the RZ model was computed using the GE alternative to the specified burnup procedure. The RZ model was also computed using 20 energy groups with the specified burnup procedure.

The computer codes DIF3D⁽²⁾, FUMBLE⁽³⁾ and LASIP⁽⁴⁾ were used in the analyses. Data was transferred between codes using the Committee on Computer Code Coordination (CCCC) standard interface files⁽⁵⁾. DIF3D performs the flux solution, FUMBLE does the burnup calculations, and LASIP is used to modify the standard interface files. Tables 2-9 summarize the assumptions and steps taken to compute the RZ, XY, the GE alternative RZ, and the 20 group RZ models.

Results

The results obtained for the RZ, RZ/XY, the GE alternative RZ, and the RZ 20 group models are given, respectively, in Tables 10, 11, 12 and 13. The format of these tables is approximately as specified, except that the results for BOC1 through EOC2 are grouped together to facilitate comparison of the changes with burnup.

To obtain the RZ/XY results, data from the XY calculations have been combined with data from the above core and below core regions of the RZ calculations. The major differences between the RZ and RZ/XY results all relate to the difference in the radial peaking factors produced by the RZ and XY calculations, with the XY radial peaking factors being larger. This is due to the smoothing effect produced by replacing the actual heterogeneous arrangement of driver, inner and radial blanket, and control regions by annuli.

There is a substantial shift in the power (and flux) distribution from the outer core regions towards the inner core regions over the irradiation period. This shift is more pronounced in the first irradiation cycle and in the RZ/XY model. This shift is produced by the Pu breeding in the inner blankets.

In the specified burnup procedure, the flux used for the burn remains constant at the BOC condition until the middle-of-cycle is reached; then again, the flux remains constant at the MOC condition (but with the EOC control position) for the second burn step. Therefore, the effect of the radial shift in the flux (and power) is delayed for one-half cycle using the specified procedure.

In the GE alternative, the flux during the burn calculation is obtained by interpolation between the end points; therefore, the effect of the radial shift in the flux is accounted for immediately.

The effect of these two approaches are best seen at EOC1. Using the GE alternative procedure, the radial power shift is greater, additional Pu breeding and burnup is seen in the central regions, and the final k_{eff} is greater (i.e., the burnup reactivity is smaller).

Except for k_{eff} and the burnup reactivity, there is little significant difference between the reference RZ and the 20 group RZ calculations. In the latter calculations, k_{eff} is lower by 0.00154 at BOC1 to 0.00113 at EOC2; the burnup reactivity is reduced from 0.00146 to 0.00131 in cycle 1 and from 0.00064 to 0.00036 in cycle 2. These trends are consistent with the results obtained for LCCEWG Benchmark 3.

References

1. C.L. Cowan and R. Protsik, "Specifications for the Large Core Code Evaluation Working Group Benchmark Problem Four", Letter to LCCEWG, September 29, 1981.
2. D.R. Ferguson and K.L. Derstine, "Optimized Iteration Strategies and Data Management Considerations for Fast Reactor Finite Difference Diffusion Theory Codes", Nucl. Sci. Eng. 64, 593 (1977).
3. C.L. Cowan and C.S. Russell, "FUMBLE-II: A Fast Reactor Fuel Management and Burnup code with an Influence Function Option for Predicting the Three-Dimensional Effects of Control Rod Movements", GEAP-1438, November 1976.
4. G.E. Bosler, R.D. O'Dell and W.M. Resnick, "LASIP-III, A Generalized Processor for Standard Interface Files", LA6280-MS, April 1976.
5. R.D. O'Dell, "Standard Interface Files and Procedures for Reactor Physics codes, version III, LA-6241-MS, September 1977.

FIGURE 1. LCCEWG Benchmark 4 RZ Model

TABLE 1
LCCEWG Benchmark 4
Region Nomenclature

IB	Inner Blanket (I, II and III)
DR	Driver (I, II and III)
RB	Radial Blanket
AB	Axial Blanket (above Driver zones only)
CI	Control In
CO	Control Out
RS	Radial Shield
FGP	Fission Gas Plenum
LAS	Lower Axial Shield

FIGURE 2 LCCWG BENCHMARK 4
SIXTY DEGREE SECTOR CORE LAYOUT
AND REFUELING SCHEME

TABLE 2
LCCEWG Benchmark 4
RZ Model
General Comments

- A. Codes Used DIF3D, FUMBLE, LASIP
- B. Convergence Criteria Eigenvalue: 10^{-6}
Pointwise & average fission source: 10^{-5}
- C. Method of Burnup Calculations As specified, except fluxes are renormalized such that average power over burnup step equals input fission power.
- D. Analysis Procedures

Geometry

4

1. HEX-Z Direct
2. HEX-Z Synthesis
3. HEX X-Y
4. R-Z
5. Linked R-Z and HEX X-Y
6. Other (describe)

Cross Sections

1

1. GE-8 Group
2. Other (describe)

Fuel Management Plan

1

1. Recommended two cycle reload plan
2. Other (describe)

Fuel Burnup Chain

1

1. Abbreviated burnup chain with uranium and plutonium isotopes only (including Pu-241 decay)
2. Extended burnup chain
3. Other (describe)

TABLE 2 (CONTINUED)Lumped Fission Products2

1. Recommended - 2 Fission Product Pairs (odd, even)
2. Recommended - 1 Fission Product Pair
3. Other (describe)

Energy Deposition1

1. In-Situ fission plus capture gamma's
2. In-Situ fission only
3. Other (describe)

Treatment of Control Rods1

1. Control positioned at the recommended BOC location during the first half of the irradiation cycle, and at the recommended EOC location during the last half of the irradiation cycle
2. Positioned as recommended at the beginning-of-cycle and left unchanged during the burnup calculations
3. All control out
4. Other (describe)

Calculation of Control Rod WorthNone

1. Direct 3-D calculation
2. Synthesis 3-D calculations
3. R-Z calculations
4. R-Z calculations (Modified B_{10} Density)
5. X-Y HEX
6. Other (describe)

TABLE 2 (CONTINUED)Core Layout1

1. Recommended
2. Other (describe)

Mesh Spacings1

1. Recommended
2. Other (describe)

Flux Solutions During Irradiation Cycle1

1. Recommended
2. Other (describe)

TABLE 3
LCCEWG Benchmark 4
RZ Model Procedure

<u>Step</u>	<u>Code</u>	<u>Input</u>	<u>Output</u>	<u>Comments</u>
1	DIF3D	ISOTXS	LABELS GEODST/BOC1 NDXSRF ZNATDN/BOC1 RTFLUX/BOC1 RZFLUX/BOC1	k = 1.002493 Fission Power = 2583.9 Mw
2	FUMBLE	ISOTXS NDXSRF ZNATDN/BOC1 RZFLUX/BOC1	ZNATDN/MOC1	Fluxes renormalized such that average power over burnup step equals input fission power.
3	LASIP	GEODST/BOC1	GEODST/EOC1	New control position
4	DIF3D	LABELS GEODST/EOC1 ISOTXS NDXSRF ZNATDN/MOC1	RTFLUX/MOC1 RZFLUX/MOC1	k = 1.003342 Fission Power = 2582.3 Mw
5	FUMBLE	ISOTXS NDXSRF ZNATDN/MOC1 RZFLUX/MOC1	ZNATDN/EOC1 ZNATDN/BOC2	Fluxes renormalized such that average power over burnup step equals input fission power.
6	DIF3D	LABELS GEODST/EOC1 ISOTXS NDXSRF ZNATDN/EOC1	RTFLUX/EOC1 RZFLUX/EOC1	k = 1.001029 Fission Power = 2578.5 Mw
7	LASIP	GEODST/BOC1	GEODST/BOC2	New control position
8	DIF3D	LABELS GEODST/BOC2 ISOTXS NDXSRF ZNATDN/BOC2	RTFLUX/BOC2 RZFLUX/BOC2	k = 1.004744 Fission Power = 2582.1 Mw
9	FUMBLE	ISOTXS NDXSRF ZNATDN/BOC2 RZFLUX/BOC2	ZNATDN/MOC2	Fluxes renormalized such that average power over burnup step equals input fission power.

TABLE 3 (CONTINUED)LCCEWG Benchmark 4RZ Model Procedures

<u>Step</u>	<u>Code</u>	<u>Input</u>	<u>Output</u>	<u>Comments</u>
10	LASIP	GEODST/BOC1	GEODST/EOC2	New control position
11	DIF3D	LABELS GEODST/EOC2 ISOTXS NDXSRF ZNATDN/MOC2	RTFLUX/MOC2 RZFLUX/MOC2	k = 1.005971 Fission Power = 2580.2 Mw
12	FUMBLE	ISOTXS NDXSRF ZNATDN/MOC2 RZFLUX/MOC2	ZNATDN/EOC2	Fluxes renormalized such that average power over burnup step equals input fission power.
13	DIF3D	LABELS GEODST/EOC2 ISOTXS NDXSRF ZNATDN/EOC2	RTFLUX/EOC2 RZFLUX/EOC2	k = 1.004106 Fission Power = 2576.6 Mw

TABLE 4
 LCCEWG Benchmark 4
 RZ/XY Model
 General Comments

- A. Codes Used DIF3D, FUMBLE, LASIP
- B. Convergence Criteria Eigenvalue: 10^{-6}
 Pointwise & average fission source: 10^{-5}
- C. Method of Burnup Calculations As specified, except fluxes are renormalized such that average power over burnup step equals input fission power.
- D. Analysis Procedures

Geometry

5

1. HEX-Z Direct
2. HEX-Z Synthesis
3. HEX X-Y
4. R-Z
5. Linked R-Z and HEX X-Y
6. Other (describe)

Cross Sections

1

1. GE-8 Group
2. Other (describe)

Fuel Management Plan

1

1. Recommended two cycle reload plan
2. Other (describe)

Fuel Burnup Chain

1

1. Abbreviated burnup chain with uranium and plutonium isotopes only (including Pu-241 decay)
2. Extended burnup chain
3. Other (describe)

TABLE 4 (CONTINUED)Lumped Fission Products2

1. Recommended - 2 Fission Product Pairs (odd, even)
2. Recommended - 1 Fission Product Pair
3. Other (describe)

Energy Deposition1

1. In-Situ fission plus capture gamma's
2. In-Situ fission only
3. Other (describe)

Treatment of Control Rods4

1. Control positioned at the recommended BOC location during the first half of the irradiation cycle, and at the recommended EOC location during the last half of the irradiation cycle
2. Positioned as recommended at the beginning-of-cycle and left unchanged during the burnup calculations
3. All control out
4. Other Control in & out densities in XY are RZ flux and volume weighted.

Calculation of Control Rod WorthNone

1. Direct 3-D calculation
2. Synthesis 3-D calculations
3. R-Z calculations
4. R-Z calculations (Modified B_{10} Density)
5. X-Y HEX
6. Other (describe)

TABLE 4 (CONTINUED)Core Layout1

1. Recommended
2. Other (describe)

Mesh Spacings1

1. Recommended
2. Other (describe)

Flux Solutions During Irradiation Cycle1

1. Recommended
2. Other (describe)

TABLE 5
LCCEWG Benchmark 4
XY Model Procedures

<u>Step</u>	<u>Code</u>	<u>Input</u>	<u>Output</u>	<u>Comments</u>
1	DIF3D	ISOTXS	LABELS GEODST/BOC1 NDXSRF ZNATDN/BOC1 RTFLUX/BOC1 RZFLUX/BOC1	K = 1.000359 Power = 447.64 Mw Fission Power = 425.48 Mw Axial B ² from RZ/BOC1 Control in/out densities are flux-weighted from RZ/BOC1
2	FUMBLE	ISOTXS NDXSRF ZNATDN/BOC1 RZFLUX/BOC1	ZNATDN/MOC1	Fluxes renormalized such that average power over burnup step equals input fission power.
3	LASIP	ZNATDN/MOC1	ZNATDN/MOC1	New control densities and axial B ² from RZ/MOC1
4	DIF3D	LABELS GEODST/MOC1 ISOTXS NDXSRF ZNATDN/MOC1	RTFLUX/MOC1	K = 1.000209 Power = 445.84 Mw Fission Power = 432.46 Mw
5	FUMBLE	ISOTXS NDXSRF ZNATDN/MOC1 RZFLUX/MOC1	ZNATDN/EOC1 ZNATDN/BOC2	Fluxes renormalized such that average power over burnup step equals input fission power.
6	LASIP	GEODST/BOC1	GEODST/EOC1	New axial B ² from RZ/EOC1
7	DIF3D	LABELS GEODST/EOC1 ISOTXS NDXSRF ZNATDN/EOC1	RTFLUX/EOC1 RZFLUX/EOC1	k = 0.997863 Power = 443.99 Mw
8	LASIP	ZNATDN/BOC2 GEODST/BOC1	ZNATDN/BOC2 GEODST/BOC2	New control densities and axial B ² from RZ/BOC2
9	DIF3D	LABELS GEODST/BOC2 ISOTXS ZNATDN/BOC2 RZFLUX/BOC2	RTFLUX/BOC2 RZFLUX/BOC2	k = 1.001667 Power = 445.94 Mw Fission Power = 423.52 Mw

LCCEWG Benchmark 4XY Model Procedures

<u>Step</u>	<u>Code</u>	<u>Input</u>	<u>Output</u>	<u>Comments</u>
10	FUMBLE	ISOTXS NDXSRF ZNATDN/BOC2 RZFLUX/BOC2	ZNATDN/MOC2	Fluxes renormalized such that average power over burnup step equals input fission power.
11	LASIP	ZNATDN/MOC2	ZNATDN/MOC2	New control densities and axial B^2 from RZ/MOC2
12	DIF3D	LABELS GEODST/MOC2 ISOTXS NDXSRF ZNATDN/MOC2	RTFLUX/MOC2 RZFLUX/MOC2	$k = 1.002614$ Power = 444.11 Mw Fission Power = 421.48 Mw
13	FUMBLE	ISOTXS	ZNATDN/EOC2	Fluxes renormalized such that average power over burnup step equals input fission power.
14	LASIP	GEODST/BOC1	GEODST/EOC2	New axial B^2 from RZ/EOC2
15	DIF3D	LABELS GEOSDST/EOC2 ISOTXS NDXSRF ZNATDN/EOC2	RTFLUX/EOC2 RZFLUX/EOC2	$K = 1.001026$ Power = 442.27 Mw

TABLE 6

LCCEWG Benchmark 4
RZ Model (GE Approach)
General Comments

- A. Codes Used DIF3D, FUMBLE, LASIP
- B. Convergence Criteria Eigenvalue: 10^{-6}
 Pointwise & average fission source: 10^{-5}
- C. Method of Burnup Calculations Fluxes were interpolated between BOC & EOC and renormalized such that the average power over each burnup step equals the input fission power. Two iterations used to obtain the EOC condition.
- D. Analysis Procedures

Geometry

4

1. HEX-Z Direct
2. HEX-Z Synthesis
3. HEX X-Y
4. R-Z
5. Linked R-Z and HEX X-Y
6. Other (describe)

Cross Sections

1

1. GE-8 Group
2. Other (describe)

Fuel Management Plan

1

1. Recommended two cycle reload plan
2. Other (describe)

Fuel Burnup Chain

1

1. Abbreviated burnup chain with uranium and plutonium isotopes only (including Pu-241 decay)
2. Extended burnup chain
3. Other (describe)

TABLE 6 (CONTINUED)Lumped Fission Products2

1. Recommended - 2 Fission Product Pairs (odd, even)
2. Recommended - 1 Fission Product Pair
3. Other (describe)

Energy Deposition1

1. In-Situ fission plus capture gamma's
2. In-Situ fission only
3. Other (describe)

Treatment of Control Rods1

1. Control positioned at the recommended BOC location during the first half of the irradiation cycle, and at the recommended EOC location during the last half of the irradiation cycle
2. Positioned as recommended at the beginning-of-cycle and left unchanged during the burnup calculations
3. All control out
4. Other (describe)

Calculation of Control Rod WorthNone

1. Direct 3-D calculation
2. Synthesis 3-D calculations
3. R-Z calculations
4. R-Z calculations (Modified B_{10} Density)
5. X-Y HEX
6. Other (describe)

TABLE 6 (CONTINUED)Core Layout1

1. Recommended
2. Other (describe)

Mesh Spacings1

1. Recommended
2. Other (describe)

Flux Solutions During Irradiation Cycle2

1. Recommended
2. Other; Only BOC & EOC fluxes were computed

TABLE 7
LCCEWG Benchmark 4
RZ Model Procedure (GE Approach)

<u>Step</u>	<u>Code</u>	<u>Input</u>	<u>Output</u>	<u>Comments</u>
1*	DIF3D	ISOTXS	LABELS GEODST/BOC1 NDXSRF ZNATDN/BOC1 RTFLUX/BOC1 RZFLUX/BOC1	k = 1.002493 Fission Power = 2583.9 Mw
2	FUMBLE	ISOTXS NDXSRF ZNATDN/BOC1 RZFLUX/BOC1 ZNATDN/EOC1 RZFLUX/EOC1	ZNATDN/EOC1 ZNATDN/BOC2	Fluxes renormalized such that average power over burnup steps equals input fission power.
3*	LASIP	GEODST/BOC1	GEODST/EOC1	New control position
4	DIF3D	LABELS GEODST/EOC1 ISOTXS NDXSRF ZNATDN/EOC1	RTFLUX/EOC1 RZFLUX/EOC2	k = 1.001907 Fission Power = 2578.5 Mw
5	-	-	-	Repeat steps 2 and 4 to convergence.
6*	LASIP	GEODST/BOC1	GEODST/BOC2	New control position
7	DIF3D	LABELS GEODST/BOC2 ISOTXS NDXSRF ZNATDN/BOC2	RTFLUX/BOC2 RZFLUX/BOC2	k = 1.005228 Fission Power = 2582.1 Mw

TABLE 7 (CONTINUED)LCCEWG Benchmark 4RZ Model Procedure (GE Approach)

<u>Step</u>	<u>Code</u>	<u>Input</u>	<u>Output</u>	<u>Comments</u>
8	FUMBLE	ISOTXS NDXSRF ZNATDN/BOC2 RZFLUX/BOC2 ZNATDN/EOC2 RZFLUX/EOC2	ZNATDN/EOC2	Fluxes renormalized such that average power over burnup steps equal input fission power.
9*	LASIP	GEODST/BOC1	GEODST/EOC2	New control position
10	DIF3D	LABELS GEODST/EOC2 ISOTXS NDXSRF ZNATDN/EOC2	RTFLUX/EOC2 RZFLUX/EOC2	k = 1.004081 Fission Power = 2576.6 Mw
11	-	-	-	Repeat steps 8 and 10 to convergence

* This step is identical to an equivalent step of the reference RZ model, and therefore, was not repeated.

TABLE 8LCCEWG Benchmark 4RZ 20 Group ModelGeneral Comments

- A. Codes Used DIF3D, FUMBLE, LASIP
- B. Convergence Criteria Eigenvalue: 10^{-6}
Pointwise & average fission source: 10^{-5}
- C. Method of Burnup Calculations As specified, except fluxes are renormalized such that average power over burnup step equals input fission power.
- D. Analysis Procedures

Geometry4

1. HEX-Z Direct
2. HEX-Z Synthesis
3. HEX X-Y
4. R-Z
5. Linked R-Z and HEX X-Y
6. Other (describe)

Cross Sections2

1. GE-8 Group
2. GE-20 Group

Fuel Management Plan1

1. Recommended two cycle reload plan
2. Other (describe)

Fuel Burnup Chain1

1. Abbreviated burnup chain with uranium and plutonium isotopes only (including Pu-241 decay)
2. Extended burnup chain
3. Other (describe)

TABLE 8 (CONTINUED)Lumped Fission Products2

1. Recommended - 2 Fission Product Pairs (odd, even)
2. Recommended - 1 Fission Product Pair
3. Other (describe)

Energy Deposition1

1. In-Situ fission plus capture gamma's
2. In-Situ fission only
3. Other (describe)

Treatment of Control Rods1

1. Control positioned at the recommended BOC location during the first half of the irradiation cycle, and at the recommended EOC location during the last half of the irradiation cycle
2. Positioned as recommended at the beginning-of-cycle and left unchanged during the burnup calculations
3. All control out
4. Other (describe)

Calculation of Control Rod WorthNone

1. Direct 3-D calculation
2. Synthesis 3-D calculations
3. R-Z calculations
4. R-Z calculations (Modified B_{10} Density)
5. X-Y HEX
6. Other (describe)

TABLE-8 (CONTINUED)Core Layout1

1. Recommended
2. Other (describe)

Mesh Spacings1

1. Recommended
2. Other (describe)

Flux Solutions During Irradiation Cycle1

1. Recommended
2. Other (describe)

TABLE 9

LCCEWG Benchmark 4

RZ 20 Group Model Procedure

<u>Step</u>	<u>Code</u>	<u>Input</u>	<u>Output</u>	<u>Comments</u>
1	DIF3D	ISOTXS	LABELS GEODST/BOC1 NDXSRF ZNATDN/BOC1 RTFLUX/BOC1 RZFLUX/BOC1	k = 1.000953 Fission Power = 2583.6 Mw
2	FUMBLE	ISOTXS NDXSRF ZNATDN/BOC1 RZFLUX/BOC1	ZNATDN/MOC1	Fluxes renormalized such that average power over burnup step equals input fission power.
3	LASIP	GEODST/BOC1	GEODST/EOC1	New control position
4	DIF3D	LABELS GEODST/EOC1 ISOTXS NDXSRF ZNATDN/MOC1	RTFLUX/MOC1 RZFLUX/MOC1	k = 1.001863 Fission Power = 2581.9 Mw
5	FUMBLE	ISOTXS NDXSRF ZNATDN/MOC1 RZFLUX/MOC1	ZNATDN/EOC1 ZNATDN/BOC2	Fluxes renormalized such that average power over burnup step equals input fission power.
6	DIF3D	LABELS GEODST/EOC1 ISOTXS NDXSRF ZNATDN/EOC1	RTFLUX/EOC1 RZFLUX/EOC1	k = 0.999643 Fission Power = 2578.2 Mw
7	LASIP	GEODST/BOC1	GEODST/BOC2	New control position
8	DIF3D	LABELS GEODST/BOC2 ISOTXS NDXSRF ZNATDN/BOC2	RTFLUX/BOC2 RZFLUX/BOC2	k = 1.003343 Fission Power = 2581.8 Mw
9	FUMBLE	ISOTXS NDXSRF ZNATDN/BOC2 RZFLUX/BOC2	ZNATDN/MOC2	Fluxes renormalized such that average power over burnup step equals input fission power.

TABLE 9 (CONTINUED)LCCEWG Benchmark 4RZ Model Procedures

<u>Step</u>	<u>Code</u>	<u>Input</u>	<u>Output</u>	<u>Comments</u>
10	LASIP	GEODST/BOC1	GEODST/EOC2	New control position
11	DIF3D	LABELS GEODST/EOC2 ISOTXS NDXSRF ZNATDN/MOC2	RTFLUX/MOC2 RZFLUX/MOC2	k = 1.004585 Fission Power = 2579.9 Mw
12	FUMBLE	ISOTXS NDXSRF ZNATDN/MOC2 RZFLUX/MOC2	ZNATDN/EOC2	Fluxes renormalized such that average power over burnup step equals input fission power.
13	DIF3D	LABELS GEODST/EOC2 ISOTXS NDXSRF ZNATDN/EOC2	RTFLUX/EOC2 RZFLUX/EOC2	k = 1.002980 Fission Power = 2576.4 Mw

TABLE 10
LCCEWG Benchmark 4
RZ Model Results

<u>A. General</u>	<u>BOC1</u>	<u>EOC1</u>	<u>BOC2</u>	<u>EOC2</u>
1. K_{eff}	1.00249	1.00103	1.00474	1.00411
4. Breeding Gain (kg fissile Pu)	-	462.5	-	422.1
5. Peak Power (w/cm ³)				
Driver - Peak	509.6	513.7	507.8	502.5
- Position	(45,20)	(24,20)	(11,20)	(12,20)
Inner Blanket - Peak	70.2	214.2	140.6	265.9
- Position	(19,19)	(19,20)	(19,19)	(19,20)
Radial Blanket- Peak	47.3	53.4	55.3	59.1
- Position	(52,20)	(52,20)	(52,20)	(52,20)
6. Driver Peak/Average Power	1.556	1.722	1.630	1.765
7. Driver Axial Peak/Average Power	1.348	1.312	1.335	1.299

B.1 Power - BOC1

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	<u>(w/cc)</u>
D-I	0.1119	0.0035	0.1154	431.0
D-II	0.2252	0.0068	0.2320	462.8
D-III	0.5451	0.0162	0.5614	509.6
IB-I	0.0035	0.0015	0.0050	51.7
IB-II	0.0100	0.0031	0.0131	70.2
IB-III	0.0225	0.0084	0.0309	65.0
RB	0.0169	0.0072	0.0241	47.3
AB	0.0078	0.0033	0.0112	23.4
S	-	0.0016	0.0016	1.26
C	-	<u>0.0052</u>	<u>0.0052</u>	207.0
	0.9430	0.0570	1.0000	

LCCEWG Benchmark 4RZ Model ResultsB.2 Power - EOC1

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	<u>(w/cc)</u>
D-I	0.1333	0.0050	0.1383	504.1
D-II	0.2605	0.0095	0.2700	513.7
D-III	0.4049	0.0144	0.4192	409.7
IB-I	0.0114	0.0021	0.0134	128.7
IB-II	0.0333	0.0042	0.0374	214.2
IB-III	0.0608	0.0091	0.0699	145.9
RB	0.0241	0.0056	0.0297	53.4
AB	0.0128	0.0034	0.0162	42.5
S	-	0.0015	0.0015	1.00
C	-	<u>0.0042</u>	<u>0.0042</u>	179.1
	0.9411	0.0589	1.0000	

B.3 Power - BOC2

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	<u>(w/cc)</u>
D-I	0.1327	0.0044	0.1370	507.8
D-II	0.2482	0.0083	0.2564	501.6
D-III	0.4559	0.0148	0.4707	417.5
IB-I	0.0084	0.0019	0.0103	102.0
IB-II	0.0214	0.0038	0.0251	140.6
IB-III	0.0420	0.0087	0.0507	102.1
RB	0.0238	0.0063	0.0301	55.3
AB	0.0100	0.0033	0.0134	32.8
S	-	0.0016	0.0016	1.11
C	-	<u>0.0047</u>	<u>0.0047</u>	197.8
	0.9424	0.0576	1.0000	

TABLE 10 (CONTINUED)

LCCEWG Benchmark 4RZ Model ResultsB.4 Power - EOC2

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	<u>(w/cc)</u>
D-I	0.1344	0.0053	0.1397	502.5
D-II	0.2512	0.0100	0.2612	488.3
D-III	0.3749	0.0140	0.3890	397.7
IB-I	0.0174	0.0023	0.0197	180.6
IB-II	0.0428	0.0044	0.0471	265.9
IB-III	0.0762	0.0093	0.0856	176.6
RB	0.0285	0.0054	0.0339	59.1
AB	0.0149	0.0035	0.0183	50.7
S	-	0.0015	0.0015	0.97
C	-	0.0039	0.0039	160.9
	0.9404	0.0596	1.0000	

C. Burnup (MWd/MT)

<u>ZONE</u>	<u>EOC1</u>		<u>EOC2</u>	
	<u>AVG. BURNUP</u>	<u>PEAK BURNUP*</u>	<u>AVG. BURNUP</u>	<u>PEAK BURNUP*</u>
D-I	2.910+4	3.974+4	6.126+4	8.319+4
D-II	2.927+4	4.219+4	5.962+4	8.514+4
D-III	2.634+4	3.905+4	4.923+4	7.271+4
IB-I	1.521+3	4.753+3	4.315+3	1.306+4
IB-II	3.675+3	8.068+3	9.418+3	2.071+4
IB-III	2.288+3	6.081+3	5.561+3	1.455+4
RB	6.968+2	2.978+3	1.556+3	6.472+3
AB	4.773+2	1.822+3	1.055+3	4.263+3

*Average Burnup x $\frac{(\text{BOC} + \text{EOC})}{2}$ Region Peak/Average Power)

TABLE 10 (CONTINUED)LCCEWG Benchmark 4RZ Model ResultsD.1 Fuel Inventory (kg) - BOC1

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	5.684+1	6.294+1	7.176+1	4.835+1
U-236	-	-	-	-
U-238	2.610+4	2.890+4	3.295+4	2.220+4
Pu-239	4.099+3	-	-	-
Pu-240	1.235+3	-	-	-
Pu-241	6.201+2	-	-	-
Pu-242	1.480+2	-	-	-
<u>FP</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>-</u>
Total	3.226+4	2.896+4	3.302+4	2.225+4

D.2 Fuel Inventory (kg) - EOC1

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	4.601+1	5.442+1	6.683+1	4.590+1
U-236	2.361+0	2.113+0	1.313+0	6.538-1
U-238	2.536+4	2.839+4	3.271+4	2.208+4
Pu-239	3.914+3	4.320+2	2.177+2	1.097+2
Pu-240	1.296+3	1.223+1	3.433+0	1.183+0
Pu-241	5.074+2	2.559-1	3.924-2	1.000-2
Pu-242	1.599+2	3.593-3	2.431-4	4.691-5
<u>FP</u>	<u>9.773+2</u>	<u>7.592+1</u>	<u>2.472+1</u>	<u>1.143+1</u>
Total	3.226+4	2.897+4	3.302+4	2.225+4

TABLE 10 (CONTINUED)

LCCEWG Benchmark 4RZ Model ResultsD.3 Fuel Inventory (kg) - BOC2

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	5.186+1	5.832+1	6.811+1	4.720+1
U-236	1.098+0	1.143+0	9.701-1	3.035-1
U-238	2.576+4	2.862+4	3.277+4	2.215+4
Pu-239	4.013+3	2.335+2	1.609+2	5.094+1
Pu-240	1.263+3	6.556+0	2.537+0	5.490-1
Pu-241	5.677+2	1.361-1	2.901-2	4.609-3
Pu-242	1.536+2	1.890-3	1.705-4	1.881-5
<u>FP</u>	<u>4.552+2</u>	<u>4.070+1</u>	<u>1.827+1</u>	<u>5.315+0</u>
Total	3.226+4	2.897+4	3.302+4	2.225+4

D.4 Fuel Inventory (kg) - EOC2

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	4.222+1	5.042+1	6.410+1	4.485+1
U-236	3.142+0	3.015+0	2.005+0	9.222-1
U-238	2.504+4	2.809+4	3.256+4	2.203+4
Pu-239	3.843+3	6.339+2	3.406+2	1.569+2
Pu-240	1.319+3	2.967+1	8.966+0	2.725+0
Pu-241	4.717+2	1.048+0	1.739-1	3.953-2
Pu-242	1.632+2	2.822-2	1.963-3	3.517-4
<u>FP</u>	<u>1.367+3</u>	<u>1.551+2</u>	<u>4.871+1</u>	<u>1.913+1</u>
Total	3.225+4	2.896+4	3.302+4	2.225+4

TABLE 10 (CONTINUED)LCCEWG Benchmark 4RZ Model ResultsE.1 Neutron Balance for Reactor - Cycle 1

<u>Source (n/sec)</u>	<u>BOC1</u>		<u>EOC1</u>	
Fission	1.00000		1.00000	
n,2n	<u>0.00254</u>		<u>0.00257</u>	
<u>Total Source</u>	1.00254		1.00257	

	<u>BOC1</u>		<u>EOC1</u>	
<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00241	0.00735	0.00193	0.00594
U-236	-	-	0.00009	0.00001
U-238	0.47547	0.05958	0.46115	0.05883
Pu-239	0.05546	0.21610	0.06273	0.22704
Pu-240	0.01824	0.01545	0.01931	0.01555
Pu-241	0.00782	0.04371	0.00624	0.03460
Pu-242	0.00177	0.00133	0.00193	0.00133
FP	-	-	0.01644	-
Structure	0.09070	-	0.08254	-
Coolant	<u>0.00245</u>	-	<u>0.00245</u>	-
Total	0.65432	0.34352	0.65479	0.34333

<u>Leakage</u>	<u>BOC1</u>		<u>EOC1</u>	
Axial	0.00036		0.00042	
Radial	<u>0.00435</u>		<u>0.00403</u>	
Total	0.00471		0.00445	

<u>Total Losses</u>	1.00254		1.00257	
---------------------	---------	--	---------	--

TABLE 10 (CONTINUED)

LCCEWG Benchmark 4RZ Model ResultsE.2 Neutron Balance for Reactor - Cycle 2

<u>Source (n/sec)</u>	<u>BOC2</u>		<u>EOC2</u>	
Fission	1.00000		1.00000	
n,2n	<u>0.00255</u>		<u>0.00257</u>	
Total Source	1.00255		1.00257	
	<u>BOC2</u>		<u>EOC2</u>	
<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00214	0.00660	0.00173	0.00537
U-236	0.00004	0.00001	0.00012	0.00002
U-238	0.46711	0.05927	0.45208	0.05845
Pu-239	0.05987	0.22255	0.06533	0.23211
Pu-240	0.01871	0.01540	0.01981	0.01562
Pu-241	0.00706	0.03930	0.00570	0.03154
Pu-242	0.00182	0.00134	0.00192	0.00135
FP	0.00777	-	0.02395	-
Structure	0.08640	-	0.08040	-
Coolant	<u>0.00245</u>	-	<u>0.00243</u>	-
Total	0.65337	0.34447	0.65349	0.34445
	<u>BOC2</u>		<u>EOC2</u>	
<u>Leakage</u>				
Axial	0.00039		0.00046	
Radial	<u>0.00432</u>		<u>0.00418</u>	
Total	0.00471		0.00464	
<u>Total Losses</u>	1.00255		1.00257	

TABLE 11
LCCEWG Benchmark 4
RZ/XY Model Results

<u>A. General</u>	<u>BOC1</u>	<u>EOC1</u>	<u>BOC2</u>	<u>EOC2</u>
1. k_{eff} - RZ	1.00249	1.00103	1.00474	1.00411
- XY	1.00036	0.99786	1.00167	1.00103
Δk_{cycle} - RZ	-	0.00146	-	0.00064
- XY	-	0.00250	-	0.00064
4. Breeding Gain (kg fissile Pu)	-	396.4	-	359.6
5. Peak Power (w/cm ³)				
Driver - Peak	525.8	546.0	534.3	523.1
- Position	D-III-4-6	D-II-1-3	D-II-1-3	D-II-1-3
Inner Blanket - Peak	81.3	214.9	144.7	269.1
- Position	IB-III-3-3	IB-II-1-4	IB-II-1-4	IB-II-1-4
Radial Blanket - Peak	64.8	73.5	75.8	79.7
- Position	RB-6-6	RB-6-6	RB-6-6	RB-6-6
6. Driver Peak/Average Power	1.607	1.822	1.713	1.827
7. Driver Axial Peak/Average Power	1.348	1.312	1.335	1.299

TABLE 11 (CONTINUED)

LCCEWG Benchmark 4
RZ/XY Model Results

B.1 Power - BOC1

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u> <u>(w/cc)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	0.1152	0.0036	0.1188	451.0
D-II	0.2214	0.0067	0.2281	496.2
D-III	0.5446	0.0162	0.5608	525.8
IB-I	0.0037	0.0016	0.0053	63.7
IB-II	0.0101	0.0031	0.0132	77.4
IB-III	0.0226	0.0084	0.0310	81.3
RB	0.0175	0.0075	0.0250	64.8
AB	0.0079	0.0033	0.0112	23.4
S	-	0.0017	0.0017	1.26
C	-	<u>0.0051</u>	<u>0.0051</u>	207.0
	0.9430	0.0570	1.0000	

B.2 Power - EOC1

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u> <u>(w/cc)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	0.1358	0.0051	0.1409	519.6
D-II	0.2530	0.0092	0.2622	546.0
D-III	0.4134	0.0147	0.4281	416.0
IB-I	0.0115	0.0021	0.0136	148.3
IB-II	0.0317	0.0040	0.0357	214.9
IB-III	0.0577	0.0086	0.0663	143.5
RB	0.0252	0.0059	0.0311	73.5
AB	0.0128	0.0034	0.0162	42.5
S	-	0.0015	0.0015	1.00
C	-	<u>0.0044</u>	<u>0.0044</u>	179.1
	0.9411	0.0589	1.0000	

TABLE 11 (CONTINUED)

LCCEWG Benchmark 4
RZ/XY Model Results

B.3 Power - BOC2

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u> <u>(w/cc)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	0.1347	0.0045	0.1392	520.9
D-II	0.2406	0.0080	0.2486	534.3
D-III	0.4626	0.0150	0.4776	453.8
IB-I	0.0086	0.0019	0.0105	119.0
IB-II	0.0207	0.0036	0.0243	144.7
IB-III	0.0405	0.0084	0.0489	116.1
RB	0.0247	0.0066	0.0313	75.8
AB	0.0100	0.0033	0.0134	32.8
S	-	0.0016	0.0016	1.11
C	-	<u>0.0047</u>	<u>0.0047</u>	197.8
	0.9424	0.0576	1.0000	

B.4 Power - EOC2

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u> <u>(w/cc)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	0.1382	0.0055	0.1437	521.8
D-II	0.2474	0.0098	0.2572	523.1
D-III	0.3791	0.0142	0.3934	384.9
IB-I	0.0178	0.0023	0.0201	204.9
IB-II	0.0413	0.0043	0.0456	269.1
IB-III	0.0722	0.0088	0.0810	172.3
RB	0.0295	0.0056	0.0351	79.7
AB	0.0149	0.0035	0.0183	50.7
S	-	0.0015	0.0015	0.97
C	-	<u>0.0041</u>	<u>0.0041</u>	160.9
	0.9404	0.0596	1.0000	

TABLE 11 (CONTINUED)

LCCEWG Benchmark 4RZ/XY Model ResultsC. Burnup (MWd/MT)

<u>Zone</u>	<u>EOC1</u>		<u>EOC2</u>	
	<u>Avg. Burnup</u>	<u>Peak Burnup*</u>	<u>Avg. Burnup</u>	<u>Peak Burnup*</u>
D-I	2.958+4	4.094+4	6.233+4	8.561+4
D-II	2.836+4	4.467+4	5.789+4	9.038+4
D-III	2.679+4	4.258+4	5.020+4	8.015+4
IB-I	1.552+3	5.599+3	4.376+3	1.510+4
IB-II	3.518+3	8.265+3	9.001+3	2.100+4
IB-III	2.199+3	7.836+3	5.305+5	1.684+4
RB	7.298+2	4.116+3	1.627+3	8.901+3
AB	4.773+2	1.822+3	1.055+3	4.263+3

*Average Burnup $\times \left(\frac{\text{BOC} + \text{EOC}}{2} \right)$ Region Peak/Average Power)

TABLE 11 (CONTINUED)

LCCEWG Benchmark 4
RZ/XY Model Results

D.1 Fuel Inventory (kg) - BOC1

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	5.684+1	6.294+1	7.176+1	4.835+1
U-236	-	-	-	-
U-238	2.610+4	2.890+4	3.295+4	2.220+4
Pu-239	4.099+3	-	-	-
Pu-240	1.235+3	-	-	-
Pu-241	6.201+2	-	-	-
Pu-242	1.480+2	-	-	-
FP	-	-	-	-
TOTAL	3.226+4	2.896+4	3.302+4	2.225+4

D.2 Fuel Inventory (kg) - EOC1

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	4.589+1	5.441+1	6.670+1	4.590+1
U-236	2.395+0	2.115+0	1.342+0	6.538-1
U-238	2.535+4	2.839+4	3.271+4	2.208+4
Pu-239	3.914+3	4.331+2	2.237+2	1.097+2
Pu-240	1.297+3	1.121+1	3.402+0	1.183+0
Pu-241	5.064+2	2.031-1	3.587-2	1.000-2
Pu-242	1.601+2	2.354-3	1.981-4	4.691-5
FP	<u>9.471+2</u>	<u>7.327+1</u>	<u>2.588+1</u>	<u>1.143+1</u>
TOTAL	3.224+4	2.896+4	3.303+4	2.225+4

TABLE 11 (CONTINUED)LCCEWG Benchmark 4RZ/XY Model ResultsD.3 Fuel Inventory (kg) - BOC2

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	5.179+1	5.831+1	6.802+1	4.720+1
U-236	1.114+0	1.145+0	9.921-1	3.035-1
U-238	2.575+4	2.862+4	3.277+4	2.215+4
Pu-239	4.011+3	2.344+2	1.654+2	5.094+1
Pu-240	1.264+3	6.016+0	2.515+0	5.490-1
Pu-241	5.670+2	1.083-1	2.652-2	4.609-3
Pu-242	1.536+2	1.245-3	1.463-4	1.881-5
FP	<u>4.408+2</u>	<u>3.933+1</u>	<u>1.913+1</u>	<u>5.315+0</u>
TOTAL	3.224+4	2.896+4	3.303+4	2.225+4

D.4 Fuel Inventory (kg) - EOC2

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	4.199+1	5.036+1	6.387+1	4.485+1
U-236	3.202+0	3.036+0	2.061+0	9.222-1
U-238	2.502+4	2.810+4	3.255+4	2.203+4
Pu-239	3.841+3	6.387+2	3.517+2	1.569+2
Pu-240	1.320+3	2.760+1	9.015+0	2.725+0
Pu-241	4.698+2	8.615-1	1.632-1	3.953-2
Pu-242	1.635+2	1.934-2	1.662-3	3.517-4
FP	<u>1.343+3</u>	<u>1.488+2</u>	<u>5.090+1</u>	<u>1.913+1</u>
TOTAL	3.222+4	2.897+4	3.303+4	2.225+4

TABLE 12
LCCEWG Benchmark 4
RZ Model Results (GE Approach)

A. <u>General</u>	<u>BOC1</u>	<u>EOC1</u>	<u>BOC2</u>	<u>EOC2</u>
1. K_{eff}	1.00249	1.00191	1.00523	1.00408
ΔK_{cycle}	-	0.00058	-	0.00115
4. Breeding Gain (kg fissile Pu)	-	468.80	-	417.10
5. Peak Power (w/cm ³)				
Driver - Peak	509.6	510.6	507.3	509.2
- Position	(45,20)	(24,20)	(11,20)	(12,20)
Inner Blanket - Peak	70.2	214.2	140.6	265.9
- Position	(19,19)	(19,20)	(19,19)	(19,20)
Radial Blanket - Peak	47.3	53.4	55.3	59.1
- Position	(52,20)	(52,20)	(52,20)	(52,20)
6. Driver Peak/Average Power	1.556	1.714	1.630	1.788
7. Driver Axial Peak/Average Power	1.348	1.313	1.335	1.299

B.1 Power - BOC1

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	<u>(w/cc)</u>
D-I	0.1119	0.0035	0.1154	431.0
D-II	0.2252	0.0068	0.2320	462.8
D-III	0.5451	0.0162	0.5614	509.6
IB-I	0.0035	0.0015	0.0050	51.7
IB-II	0.0100	0.0031	0.0131	70.2
IB-III	0.0225	0.0084	0.0309	65.0
RB	0.0169	0.0072	0.0241	47.3
AB	0.0078	0.0033	0.0112	23.4
S	-	0.0016	0.0016	1.26
C	-	0.0052	0.0052	207.0
	0.9430	0.0570	1.0000	

TABLE 12 (CONTINUED)

LCCEWG Benchmark 4RZ Model Results (GE Approach)

B.2 Power - EOC1

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	<u>(w/cc)</u>
D-I	0.1325	0.0049	0.1374	500.5
D-II	0.2590	0.0094	0.2685	510.6
D-III	0.4065	0.0146	0.4208	408.6
IB-I	0.0117	0.0021	0.0138	131.7
IB-II	0.0336	0.0041	0.0378	215.8
IB-III	0.0610	0.0091	0.0702	146.0
RB	0.0239	0.0057	0.0296	53.1
AB	0.0129	0.0034	0.0163	42.9
S	-	0.0015	0.0015	1.00
C	-	0.0041	0.0041	178.5
	0.9412	0.0588	1.0000	

B.3 Power - BOC2

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	<u>(w/cc)</u>
D-I	0.1326	0.0044	0.1369	507.3
D-II	0.2476	0.0082	0.2559	499.4
D-III	0.4562	0.0147	0.4709	417.9
IB-I	0.0087	0.0019	0.0106	104.2
IB-II	0.0216	0.0038	0.0253	141.6
IB-III	0.0421	0.0087	0.0508	101.7
RB	0.0236	0.0063	0.0299	55.0
AB	0.0101	0.0033	0.0134	33.1
S	-	0.0016	0.0016	1.11
C	-	0.0047	0.0047	197.5
	0.9424	0.0576	1.0000	

TABLE 12 (CONTINUED)

LCCEWG Benchmark 4RZ Model Results (GE Approach)B.4 Power - EOC2

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	<u>(w/cc)</u>
D-I	0.1362	0.0054	0.1416	509.2
D-II	0.2539	0.0100	0.2640	493.8
D-III	0.3708	0.0139	0.3847	399.2
IB-I	0.0175	0.0023	0.0198	181.9
IB-II	0.0428	0.0044	0.0472	266.7
IB-III	0.0758	0.0093	0.0851	177.5
RB	0.0285	0.0054	0.0339	59.0
AB	0.0149	0.0035	0.0184	51.0
S	-	0.0015	0.0015	0.96
C	-	0.0040	0.0040	161.5
	0.9404	0.0576	1.0000	

C. Burnup (MWd/MT)

<u>ZONE</u>	<u>EOC1</u>		<u>EOC2</u>	
	<u>AVG. BURNUP</u>	<u>PEAK BURNUP*</u>	<u>AVG. BURNUP</u>	<u>PEAK BURNUP*</u>
D-I	3.011+4	4.110+4	6.117+4	8.306+4
D-II	2.982+4	4.299+4	5.890+4	8.415+4
D-III	2.588+4	3.837+4	4.981+4	7.345+4
IB-I	1.700+3	5.299+3	4.342+3	1.312+4
IB-II	3.911+3	8.573+3	9.640+3	2.060+4
IB-III	2.383+3	6.420+3	5.718+3	1.472+4
RB	6.853+2	2.932+3	1.637+3	6.603+3
AB	4.928+2	1.885+3	1.062+3	4.305+3

*Average Burnup x $\frac{(\text{BOC} + \text{EOC})}{2}$ Region Peak/Average Power)

TABLE 12 (CONTINUED)
LCCEWG Benchmark 4
RZ Model Results (GE Approach)

D.1 Fuel Inventory (kg) - BOC1

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	5.684+1	6.294+1	7.176+1	4.835+1
U-236	-	-	-	-
U-238	2.610+4	2.890+4	3.295+4	2.220+4
Pu-239	4.099+3	-	-	-
Pu-240	1.235+3	-	-	-
Pu-241	6.201+2	-	-	-
Pu-242	1.480+2	-	-	-
FP	-	-	-	-
Total	3.226+4	2.896+4	3.302+4	2.225+4

D.2 Fuel Inventory (kg) - EOC1

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	4.599+1	5.428+1	6.696+1	4.587+1
U-236	2.368+0	2.136+0	1.275+0	6.592-1
U-238	2.536+4	2.838+4	3.271+4	2.208+4
Pu-239	3.915+3	4.402+2	2.132+2	1.113+2
Pu-240	1.297+3	1.246+1	3.235+0	1.217+0
Pu-241	5.073+2	2.611-1	3.558-2	1.042-2
Pu-242	1.599+2	3.698-3	2.125-4	5.021-5
FP	9.444+2	8.010+1	2.433+1	1.180+1
Total	3.223+4	2.897+4	3.302+4	2.225+4

TABLE 12 (CONTINUED)

LCCEWG Benchmark 4RZ Model Results (GE Approach)D.3 Fuel Inventory (kg) - BOC2

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	5.185+1	5.824+1	6.820+1	4.719+1
U-236	1.100+0	1.156+0	9.424-1	3.056-1
U-238	2.576+4	2.862+4	3.278+4	2.215+4
Pu-239	4.013+3	2.382+2	1.576+2	5.165+1
Pu-240	1.276+3	6.686+0	2.391+0	5.611-1
Pu-241	5.677+2	1.858-1	2.630-2	4.779-3
Pu-242	1.536+2	1.952-3	1.571-4	2.296-5
<u>FP</u>	<u>4.393+2</u>	<u>4.298+1</u>	<u>1.798+1</u>	<u>5.473+0</u>
Total	3.226+4	2.897+4	3.302+4	2.225+4

D.4 Fuel Inventory (kg) - EOC2

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	4.220+1	5.054+1	6.396+1	4.484+1
U-236	3.144+0	2.991+0	2.042+0	9.250-1
U-238	2.503+4	2.810+4	3.255+4	2.203+4
Pu-239	3.842+3	6.274+2	3.467+2	1.569+2
Pu-240	1.318+3	2.961+1	9.357+0	2.772+0
Pu-241	4.714+2	1.048+0	1.844-1	4.069-2
Pu-242	1.632+2	2.800-2	2.095-3	3.646-4
<u>FP</u>	<u>1.341+3</u>	<u>1.522+2</u>	<u>4.991+1</u>	<u>1.909+1</u>
Total	3.221+4	2.896+4	3.302+4	2.225+4

TABLE 12 (CONTINUED)

LCCEWG Benchmark 4RZ Model Results (GE Approach)E.1 Neutron Balance for Reactor - Cycle 1

<u>Source (n/sec)</u>	<u>BOC1</u>		<u>EOC1</u>	
Fission	1.00000		1.00000	
n,2n	<u>0.00254</u>		<u>0.00256</u>	
<u>Total Source</u>	1.00254		1.00256	

	<u>BOC1</u>		<u>EOC1</u>	
<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00241	0.00735	0.00192	0.00594
U-236	-	-	0.00009	0.00001
U-238	0.47547	0.05958	0.46105	0.05885
Pu-239	0.05546	0.21610	0.06286	0.22735
Pu-240	0.01824	0.01545	0.01933	0.01555
Pu-241	0.00782	0.04371	0.00624	0.03457
Pu-242	0.00177	0.00133	0.00190	0.00136
FP	-	-	0.01611	-
Structure	0.09070	-	0.08253	-
Coolant	<u>0.00245</u>	-	<u>0.00245</u>	-
Total	0.65432	0.34352	0.65448	0.34363

<u>Leakage</u>	<u>BOC1</u>		<u>EOC1</u>	
Axial	0.00036		0.00043	
Radial	<u>0.00435</u>		<u>0.00403</u>	
Total	0.00471		0.00445	

<u>Total Losses</u>	1.00254		1.00256	
---------------------	---------	--	---------	--

TABLE 12 (CONTINUED)

LCCEWG Benchmark 4RZ Model Results (GE Approach)E.2 Neutron Balance for Reactor - Cycle 2

<u>Source (n/sec)</u>	<u>BOC2</u>	<u>EOC2</u>
Fission	1.00000	1.00000
n,2n	<u>0.00255</u>	<u>0.00257</u>
<u>Total Source</u>	1.00255	1.00257

	<u>BOC2</u>		<u>EOC2</u>	
<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00214	0.00660	0.00173	0.00537
U-236	0.00005	0.00001	0.00012	0.00002
U-238	0.46708	0.05928	0.45246	0.05847
Pu-239	0.05993	0.22272	0.06536	0.23205
Pu-240	0.01871	0.01541	0.01984	0.01561
Pu-241	0.00706	0.03929	0.00571	0.03157
Pu-242	0.00183	0.00134	0.00192	0.00135
FP	0.00760	-	0.02351	-
Structure	0.08638	-	0.08043	-
Coolant	<u>0.00245</u>	-	<u>0.00244</u>	-
Total	0.65322	0.34464	0.65352	0.34444

<u>Leakage</u>	<u>BOC2</u>	<u>EOC2</u>
Axial	0.00039	0.00046
Radial	<u>0.00430</u>	<u>0.00416</u>
Total	0.00469	0.00461
<u>Total Losses</u>	1.00255	1.00258

TABLE 13
LCCEWG Benchmark 4
RZ 20 Group Results

<u>A. General</u>	<u>BOC1</u>	<u>EOC1</u>	<u>BOC2</u>	<u>EOC2</u>
1. K_{eff}	1.00095	0.99964	1.00334	1.00298
4. Breeding Gain (kg fissile Pu)	-	465.5	-	424.8
5. Peak Power (w/cm ³)				
Driver - Peak	510.3	514.5	507.6	503.5
- Position	(45,20)	(24,20)	(11,20)	(12,20)
Inner Blanket - Peak	70.3	214.4	140.9	266.1
- Position	(19,19)	(19,20)	(19,19)	(19,20)
Radial Blanket- Peak	47.7	53.0	55.1	58.5
- Position	(52,20)	(52,20)	(52,20)	(52,20)
6. Driver Peak/Average Power	1.558	1.726	1.630	1.769
7. Driver Axial Peak/Average Power	1.348	1.313	1.336	1.300

B.1 Power - BOC1

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	<u>(w/cc)</u>
D-I	0.1114	0.0035	0.1149	429.1
D-II	0.2242	0.0068	0.2310	460.6
D-III	0.5465	0.0162	0.5627	510.3
IB-I	0.0035	0.0015	0.0050	51.5
IB-II	0.0100	0.0031	0.0131	70.3
IB-III	0.0225	0.0085	0.0310	65.4
RB	0.0170	0.0073	0.0243	47.7
AB	0.0078	0.0033	0.0111	23.2
S	-	0.0016	0.0016	1.27
C	-	<u>0.0052</u>	<u>0.0052</u>	206.6
	0.9429	0.0571	1.0000	

TABLE 13 (CONTINUED)

LLCEWG Benchmark 4RZ 20 Group ResultsB.2 Power - EOC1

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	<u>(w/cc)</u>
D-I	0.1335	0.0050	0.1384	504.8
D-II	0.2608	0.0095	0.2703	514.5
D-III	0.4042	0.0144	0.4185	411.2
IB-I	0.0115	0.0021	0.0135	128.9
IB-II	0.0334	0.0042	0.0375	214.4
IB-III	0.0612	0.0092	0.0704	146.7
RB	0.0241	0.0056	0.0297	53.0
AB	0.0125	0.0034	0.0159	41.7
S	-	0.0015	0.0015	1.00
C	-	0.0042	0.0042	179.0
	0.9401	0.0599	1.0000	

B.3 Power - BOC2

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	<u>(w/cc)</u>
D-I	0.1327	0.0044	0.1371	507.6
D-II	0.2481	0.0083	0.2564	501.6
D-III	0.4556	0.0148	0.4703	417.1
IB-I	0.0085	0.0019	0.0104	102.2
IB-II	0.0214	0.0038	0.0252	140.9
IB-III	0.0423	0.0087	0.0510	102.8
RB	0.0239	0.0063	0.0302	55.1
AB	0.0098	0.0033	0.0132	32.4
S	-	0.0016	0.0016	1.11
C	-	0.0047	0.0047	197.6
	0.9423	0.0577	1.0000	

TABLE 13 (CONTINUED)
LCCEWG Benchmark 4
RZ 20 Group Results

B.4 Power - EOC2

<u>ZONE</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	<u>(w/cc)</u>
D-I	0.1346	0.0053	0.1399	503.5
D-II	0.2515	0.0100	0.2616	489.6
D-III	0.3743	0.0140	0.3883	399.1
IB-I	0.0175	0.0023	0.0199	181.1
IB-II	0.0428	0.0043	0.0472	266.1
IB-III	0.0767	0.0094	0.0861	177.3
RB	0.0283	0.0054	0.0337	58.5
AB	0.0145	0.0034	0.0179	49.6
S	-	0.0015	0.0015	0.96
C	-	<u>0.0039</u>	<u>0.0039</u>	160.7
	0.9403	0.0597	1.0000	

C. Burnup (MWd/MT)

<u>ZONE</u>	<u>EOC1</u>			
	<u>AVG. BURNUP</u>	<u>PEAK BURNUP*</u>	<u>AVG. BURNUP</u>	<u>PEAK BURNUP*</u>
D-I	2.904+4	3.965+4	6.122+4	8.312+4
D-II	2.921+4	4.211+4	5.957+4	8.509+4
D-III	2.635+4	3.905+4	4.922+4	7.268+4
IB-I	1.527+3	4.677+3	4.340+3	1.291+4
IB-II	3.679+3	7.970+3	9.435+3	2.060+4
IB-III	2.305+3	6.136+3	5.600+3	1.466+4
RB	6.994+2	2.939+3	1.557+3	6.367+3
AB	4.687+2	1.791+3	1.033+3	4.179+3

* Average Burnup x $\frac{(\text{BOC} + \text{EOC Region Peak/Average Power})}{2}$

TABLE 13 (CONTINUED)
LCCEWG Benchmark 4
RZ 20 Group Results

D.1 Fuel Inventory (kg) - BOC1

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	5.684+1	6.294+1	7.176+1	4.835+1
U-236	-	-	-	-
U-238	2.610+4	2.890+4	3.295+4	2.220+4
Pu-239	4.099+3	-	-	-
Pu-240	1.235+3	-	-	-
Pu-241	6.201+2	-	-	-
Pu-242	1.480+2	-	-	-
FP	-	-	-	-
Total	3.226+4	2.896+4	3.302+4	2.225+4

D.2 Fuel Inventory (kg) - EOC1

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	4.601+1	5.432+1	6.680+1	4.597+1
U-236	2.363+0	2.146+0	1.321+0	6.298-1
U-238	2.536+4	2.839+4	3.271+4	2.208+4
Pu-239	3.913+3	4.346+2	2.191+2	1.094+2
Pu-240	1.297+3	1.248+1	3.435+0	1.098+0
Pu-241	5.075+2	2.628-1	3.898-2	8.551-3
Pu-242	1.599+2	3.715-3	2.434-4	3.893-5
FP	9.768+2	7.631+1	2.485+1	9.561+0
Total	3.226+4	2.897+4	3.302+4	2.225+4

TABLE 13 (CONTINUED)

LCCEWG Benchmark 4RZ 20 Group ResultsD.3 Fuel Inventory (kg) - BOC2

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	5.186+1	5.827+1	6.808+1	4.723+1
U-236	1.099+0	1.162+0	9.761-1	2.923-1
U-238	2.576+4	2.862+4	3.277+4	2.215+4
Pu-239	4.012+3	2.350+2	1.619+2	5.084+1
Pu-240	1.264+3	6.696+0	2.539+0	5.076-1
Pu-241	5.677+2	1.400-1	2.881-2	3.939-3
Pu-242	1.536+2	1.964-3	1.799-4	1.790-5
<u>FP</u>	<u>4.551+2</u>	<u>4.091+1</u>	<u>1.836+1</u>	<u>5.221+0</u>
Total	3.226+4	2.896+4	3.302+4	2.225+4

D.4 Fuel Inventory (kg) - EOC2

<u>Isotope</u>	<u>Driver</u>	<u>IB</u>	<u>RB</u>	<u>AB</u>
U-235	4.221+1	5.032+1	6.410+1	4.495+1
U-236	3.146+0	3.049+0	2.004+0	8.875-1
U-238	2.504+4	2.809+4	3.256+4	2.203+4
Pu-239	3.843+3	6.377+2	3.425+2	1.568+2
Pu-240	1.319+3	3.001+1	8.845+0	2.515+0
Pu-241	4.718+2	1.059+0	1.679-1	3.361-2
Pu-242	1.633+2	2.860-2	1.913-3	2.926-4
<u>FP</u>	<u>1.352+3</u>	<u>1.558+2</u>	<u>4.873+1</u>	<u>1.872+1</u>
Total	3.223+4	2.897+4	3.302+4	2.225+4

TABLE 13 (CONTINUED)

LCCEWG Benchmark 4RZ 20 Group ResultsE.1 Neutron Balance for Reactor - Cycle 1

Source (n/sec)	<u>BOC1</u>		<u>EOC1</u>	
Fission	1.00000		1.00000	
n,2n	<u>0.00254</u>		<u>0.00258</u>	
<u>Total Source</u>	1.00254		1.00258	

	<u>BOC1</u>		<u>EOC1</u>	
<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00241	0.00737	0.00192	0.00593
U-236	-	-	0.00009	0.00001
U-238	0.47609	0.05949	0.46156	0.05882
Pu-239	0.05544	0.21572	0.06283	0.22665
Pu-240	0.01823	0.01544	0.01935	0.01551
Pu-241	0.00781	0.04363	0.00625	0.03458
Pu-242	0.00177	0.00133	0.00190	0.00136
FP	-	-	0.01645	-
Structure	0.09069	-	0.08250	-
Coolant	<u>0.00247</u>	<u>-</u>	<u>0.00247</u>	<u>-</u>
Total	0.65497	0.34298	0.65531	0.34285

<u>Leakage</u>	<u>BOC1</u>		<u>EOC1</u>	
Axial	0.00033		0.00041	
Radial	<u>0.00426</u>		<u>0.00401</u>	
Total	0.00459		0.00442	

<u>Total Losses</u>	1.00254		1.00258	
---------------------	---------	--	---------	--

TABLE 13 (CONTINUED)
LCCEWG Benchmark 4
RZ 20 Group Results

E.2 Neutron Balance for Reactor - Cycle 2

<u>Source (n/sec)</u>	<u>BOC2</u>		<u>EOC2</u>	
Fission	1.00000		1.00000	
n,2n	<u>0.00256</u>		<u>0.00259</u>	
<u>Total Source</u>	1.00256		1.00259	

	<u>BOC2</u>		<u>EOC2</u>	
<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00214	0.00659	0.00172	0.00535
U-236	0.00005	0.00001	0.00012	0.00002
U-238	0.46755	0.05923	0.45263	0.05847
Pu-239	0.05998	0.22220	0.06536	0.23174
Pu-240	0.01871	0.01538	0.01987	0.01558
Pu-241	0.00706	0.03925	0.00572	0.03155
Pu-242	0.00183	0.00133	0.00192	0.00135
FP	0.00777	-	0.02377	-
Structure	0.08637	-	0.08036	-
Coolant	<u>0.00246</u>	-	<u>0.00245</u>	-
Total	0.65392	0.34399	0.65391	0.34405

<u>Leakage</u>	<u>BOC2</u>		<u>EOC2</u>	
Axial	0.00037		0.00044	
Radial	<u>0.00429</u>		<u>0.00419</u>	
Total	0.00466		0.00463	
<u>Total Losses</u>	1.00256		1.00259	

HEDL'S FINAL RESULTS FOR LARGE CORE CODE EVALUATION WORKING
GROUP (LCCEWG) BENCHMARK PROBLEM 4*

by

R. M. Wu and J. S. Lan

Hanford Engineering Development Laboratory
P. O. Box 1970
Richland, Washington 99352

March 7, 1983

*Work performed under U. S. Department of Energy Contract DE-AC06-76FF02170

Analysis of the LCCEWG Benchmark problem 4 has been completed by HEDL for the specified configurations using a modified version of 3DB¹ (3DB-R2²). The results of these analyses are presented in the attached tables in the formats as specified. Also presented are results for odd even pairs of fission products included in the tables labeled cases 2', 3', and 4', which represent the cases of EOC1, BOC2, EOC2, respectively.

The model used is a 60 degree sector of the core. Two flux calculations for each burn cycle with the control rod at their respective BOC and EOC positions are carried out for the burns. Since fresh subassemblies are loaded at the beginning of cycle 2, the burnup data of cycle 2 are not cumulative from that of cycle 1.

Comparison of results from both one pair and two pairs of fission products shows very good agreement. The differences in k_{eff} , power distribution, material inventory, and reactor neutron balance are too small to make any further investigation or analysis. However, from the supplied $n,2n$ cross sections, it appears the $n,2n$ threshold was not considered for the fission products in preparing the cross sections.

¹RW Hardie, WW Little, Jr., "3DB, A Three-Dimensional Diffusion Theory Burnup Code," BNWL-1264, March 1970.

²To be published.

GENERAL COMMENTS

- A. Codes Used: 3DB-R2 (a modified version of 3DB)
- B. Convergence Criteria: 1.0×10^{-6}
- C. Method of Burnup Calculations (continue on following pages)
- D. Analysis Procedures

Geometry

1

1. HEX-Z Direct
2. HEX-Z Synthesis
3. HEX X-Y
4. R-Z
5. Linked R-Z and HEX X-Y
6. Other (describe)

Cross Sections

1

1. GE-8 Group
2. Other (describe)

Fuel Management Plan

1

1. Recommended two cycle reload plan
2. Other (describe)

Fuel Burnup Chain

1

1. Abbreviated burnup chain with uranium and plutonium isotopes only (including Pu-241 decay)
2. Extended burnup chain
3. Other (describe)

Lumped Fission Products1 and 2

1. Recommended - 2 Fission Product Pairs (odd, even)
2. Recommended - 1 Fission Product Pair
3. Other (describe)

Energy Deposition1

1. In-Situ fission plus capture gamma's
2. In-Situ fission only
3. Other (describe)

Treatment of Control Rods1

1. Control positioned at the recommended BOC location during the first half of the irradiation cycle, and at the recommended EOC location during the last half of the irradiation cycle
2. Positioned as recommended at the beginning-of-cycle and left unchanged during the burnup calculations
3. All control out
4. Other (describe)

Calculation of Control Rod WorthNone

1. Direct 3-D calculation
2. Synthesis 3-D calculations
3. R-Z calculations
4. R-Z calculations (Modified B_{10} Density)
5. X-Y HEX
6. Other (describe)

Core Layout1

1. Recommended
2. Other (describe)

Mesh Spacings1

1. Recommended
2. Other (describe)

Flux Solutions During Irradiation Cycle1

1. Recommended
2. Other (describe)

Refueling Scheme for Benchmark Problem 4.

RESULTS FOR CASE 1

A. General

k_{eff} 1.00377

Peak Power of Driver Fuel

5.2551-01 KW/CM-3 At 2-6 in Zone D-3
z = 149.86 CM

Driver Fuel Peak-to-Average Power: 1.6047 + 00

Driver Fuel Axial Peak-to-Average: 1.3484 + 00

Peak Power of Inner Blankets

8.1359-02 KW/CM-3 At 1-3 in Zone IB-2
z = 149.86 CM

Peak Power of Radial Blankets

6.2104-02 KW/CM-3 At 6-6
z = 154.94 CM

RESULTS FOR CASE 1

B. Power

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (KW/CM-3)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-1	.1193	.0037	.1230	4.644 - 01
D-2	.2351	.0073	.2424	5.220 - 01
D-3	.5274	.0158	.5432	5.255 - 01
IB-1	.0039	.0016	.0055	6.557 - 02
IB-2	.0105	.0033	.0138	8.136 - 02
IB-3	.0227	.0087	.0314	7.665 - 02
RB	.0170	.0070	.0241	6.210 - 02
AB	.0080	.0035	.0116	2.604 - 02
S	.0000	.0017	.0017	1.804 - 03
C	<u>.0000</u>	<u>.0034</u>	<u>.0034</u>	1.586 - 01
Total	.9440	.0560	1.0000	

RESULTS FOR CASE 1

D. Fuel Inventories

	<u>Inventory (kg)</u>			
	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blanket</u>	<u>Axial Blanket Extensions</u>
U-235	9.477 + 00	1.049 + 01	1.197 + 01	8.062 + 00
U-236	0.0	0.0	0.0	0.0
U-238	4.352 + 03	4.818 + 03	5.494 + 03	3.702 + 03
Pu-239	6.835 + 02	0.0	0.0	0.0
Pu-240	2.060 + 02	0.0	0.0	0.0
Pu-241	1.034 + 02	0.0	0.0	0.0
Pu-242	2.469 + 01	0.0	0.0	0.0

RESULTS FOR CASE 1

E. Neutron Balance for ReactorSource

Fission	1.00000 N/Sec	
N,2N	.00254	
Total Source		1.00254

AbsorptionsCapturesFissions

U-235	.00246	.00748	
U-236	.00000	.00000	
U-238	.48340	.05952	
Pu-239	.05639	.21647	
Pu-240	.01848	.01532	
Pu-241	.00791	.04395	
Pu-242	.00179	.00132	
Fission Products	.00000	.00000	
Structure	.05711	.00000	
Coolant	.00254	.00000	
O-16	.00294	.00000	
Boron and Carbon	<u>.02035</u>	<u>.00000</u>	
Total	.65338	.34404	
Total Absorptions			.99742

Leakage

Axial Leakage	.00039	
Radial Leakage	.00473	
Total Leakage		.00512
Total Losses		1.00254

RESULTS FOR CASE 2

A. General

k_{eff}	.99014
Peak Power of Driver Fuel	
5.4570-01 KW/CM-3	At 2-6 in Zone D-2 z = 154.94 CM
Driver Fuel Peak-to-Average Power:	1.7933 + 00
Driver Fuel Axial Peak-to-Average:	1.3393 + 00
Peak Power of Inner Blankets	
1.6363-01 KW/CM-3	At 1-3 in Zone IB-2 z = 154.94 CM
Peak Power of Radial Blankets	
6.6570-02 KW/CM-3	At 6-6 z = 154.94 CM

RESULTS FOR CASE 2

B. Power

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (KW/CM-3)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-1	.1291	.0045	.1336	4.986 - 01
D-2	.2526	.0087	.2613	5.457 - 01
D-3	.4349	.0145	.4494	4.574 - 01
IB-1	.0095	.0020	.0114	1.120 - 01
IB-2	.0270	.0039	.0309	1.636 - 01
IB-3	.0524	.0092	.0616	1.241 - 01
RB	.0242	.0062	.0304	6.657 - 02
AB	.0131	.0037	.0168	3.910 - 02
S	.0000	.0017	.0017	1.549 - 03
C	<u>.0000</u>	<u>.0028</u>	<u>.0028</u>	1.383 - 01
Total	.9427	.0573	1.0000	

RESULTS FOR CASE 2

C. Burnup

<u>Zone</u>	<u>Average Burnup (MWD/MT)</u>	<u>Peak Burnup* (MWD/MT)</u>
D-1	3.092 + 4	4.311 + 4
D-2	3.082 + 4	4.869 + 4
D-3	2.826 + 4	4.640 + 4
IB-1	1.569 + 3	5.439 + 3
IB-2	3.275 + 3	7.274 + 3
IB-3	2.207 + 3	6.347 + 3
RB	8.222 + 2	4.522 + 3
AB	6.060 + 2	2.221 + 3

*Average of peak burnup at BOC and MOC.

RESULTS FOR CASE 2

D. Fuel Inventories

	<u>Inventory (kg)</u>			
	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blanket</u>	<u>Axial Blanket Extensions</u>
U-235	7.633 + 0	9.004 + 0	1.110 + 1	7.611 + 0
U-236	4.041 - 1	3.731 - 1	2.305 - 1	1.213 - 1
U-238	4.225 + 3	4.730 + 3	5.453 + 3	3.680 + 3
Pu-239	6.524 + 2	7.551 + 1	3.804 + 1	1.982 + 1
Pu-240	2.167 + 2	1.576 + 0	4.596 - 1	1.986 - 1
Pu-241	8.250 + 1	2.184 - 2	3.626 - 3	1.389 - 3
Pu-242	2.669 + 1	1.873 - 4	1.452 - 5	4.997 - 6
FP Total	1.586 + 2	1.128 + 1	4.037 + 0	1.932 + 0

RESULTS FOR CASE 2

E. Neutron Balance for ReactorSource

Fission	1.00000 N/Sec	
N,2N	.00256	
Total Source		1.00256

AbsorptionsCapturesFissions

U-235	.00205	.00628
U-236	.00008	.00001
U-238	.47270	.05890
Pu-239	.06187	.22308
Pu-240	.01947	.01554
Pu-241	.00625	.03450
Pu-242	.00193	.00136
Fission Products	.01467	.00000
Structure	.05677	.00000
Coolant	.00256	.00000
O-16	.00295	.00000
Boron and Carbon	<u>.01634</u>	<u>.00000</u>
Total	.65764	.33968
Total Absorptions		.99732

Leakage

Axial Leakage	.00054	
Radial Leakage	.00470	
Total Leakage		.00524
Total Losses		1.00256

RESULTS FOR CASE 3

A. General k_{eff}

.99737

Peak Power of Driver Fuel

5.2169-01 KW/CM-3

At 2-6 in Zone D-2

z = 149.86 CM

Driver Fuel Peak-to-Average Power:

1.6570 + 00

Driver Fuel Axial Peak-to-Average:

1.3584 + 00

Peak Power of Inner Blankets

1.1569-01 KW/CM-3

At 1-3 in Zone IB-2

z = 154.94 CM

Peak Power of Radial Blankets

7.1249-02 KW/CM-3

At 6-6

z = 154.94 CM

RESULTS FOR CASE 3

B. Power

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (KW/CM-3)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-1	.1145	.0038	.1183	4.464 - 01
D-2	.2378	.0078	.2456	5.217 - 01
D-3	.4941	.0156	.5096	5.024 - 01
IB-1	.0065	.0017	.0082	8.521 - 02
IB-2	.0173	.0034	.0207	1.157 - 01
IB-3	.0385	.0090	.0475	1.013 - 01
RB	.0245	.0069	.0314	7.125 - 02
AB	.0103	.0036	.0139	3.146 - 02
S	.0000	.0018	.0018	1.747 - 03
C	<u>.0000</u>	<u>.0031</u>	<u>.0031</u>	1.496 - 01
Total	.9434	.0566	1.0000	

RESULTS FOR CASE 3

D. Fuel Inventories

	<u>Inventory (kg)</u>			
	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blanket</u>	<u>Axial Blanket Extensions</u>
U-235	8.531 + 0	9.688 + 0	1.133 + 1	7.853 + 0
U-236	2.074 - 1	2.019 - 1	1.704 - 1	5.644 - 2
U-238	4.287 + 3	4.770 + 3	5.464 + 3	3.692 + 3
Pu-239	6.675 + 2	4.082 + 1	2.812 + 1	9.220 + 0
Pu-240	2.115 + 2	8.458 - 1	3.397 - 1	9.212 - 2
Pu-241	9.270 + 1	1.164 - 2	2.680 - 3	6.432 - 4
Pu-242	2.571 + 1	9.905 - 5	1.073 - 5	2.311 - 6
FP Total	8.130 + 1	6.052 + 0	2.984 + 0	8.992 - 1

RESULTS FOR CASE 3

E. Neutron Balance for ReactorSource

Fission	1.00000 N/Sec	
N,2N	.00255	
Total Source		1.00255

AbsorptionsCapturesFissions

U-235	.00223	.00682
U-236	.00004	.00001
U-238	.47689	.05920
Pu-239	.05955	.22023
Pu-240	.01894	.01542
Pu-241	.00704	.03899
Pu-242	.00186	.00134
Fission Products	.00757	.00000
Structure	.05732	.00000
Coolant	.00254	.00000
O-16	.00294	.00000
Boron and Carbon	<u>.01802</u>	<u>.00000</u>
Total	.65496	.34201
Total Absorptions		.99698

Leakage

Axial Leakage	.00046	
Radial Leakage	.00511	
Total Leakage		.00557
Total Losses		1.00255

RESULTS FOR CASE 4

A. General

K_{eff} .98565

Peak Power of Driver Fuel

5.2212-01 KW/CM-3

At 2-6 in Zone D-2

$z = 154.94 \text{ CM}$

Driver Fuel Peak-to-Average Power:

1.7846 + 00

Driver Fuel Axial Peak-to-Average:

1.3282 + 00

Peak Power of Inner Blankets

1.9144-01 KW/CM-3

At 1-3 in Zone 1B-2

$z = 154.94 \text{ CM}$

Peak Power of Radial Blankets

7.3902-02 KW/CM-3

At 6-6

$z = 154.94 \text{ CM}$

RESULTS FOR CASE 4

B. Power

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (KW/CM-3)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-1	.1217	.0045	.1262	4.688 - 01
D-2	.2457	.0089	.2546	5.221 - 01
D-3	.4165	.0145	.4310	4.380 - 01
IB-1	.0124	.0020	.0144	1.302 - 01
IB-2	.0331	.0039	.0370	1.914 - 01
IB-3	.0674	.0095	.0769	1.482 - 01
RB	.0300	.0062	.0362	7.390 - 02
AB	.0155	.0038	.0193	4.432 - 02
S	.0000	.0018	.0018	1.534 - 03
C	<u>.0000</u>	<u>.0027</u>	<u>.0027</u>	1.267 - 01
Total	.9422	.0578	1.0000	

RESULTS FOR CASE 4

C. Burnup*

<u>Zone</u>	<u>Average Burnup (MWD/MT)</u>	<u>Peak Burnup (MWD/MT)</u>
D-1	3.056 + 4	4.249 + 4
D-2	3.144 + 4	4.890 + 4
D-3	2.693 + 4	4.474 + 4
IB-1	2.239 + 3	6.915 + 3
IB-2	4.564 + 3	9.720 + 3
IB-3	3.106 + 3	8.137 + 3
RB	1.033 + 3	5.110 + 3
AB	7.192 + 2	2.648 + 3

*Since fresh subassemblies were loaded at the beginning of Cycle 2, the burnup data are not cumulative from Cycle 1.

RESULTS FOR CASE 4

D. Fuel Inventories

	<u>Inventory (kg)</u>			
	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blanket</u>	<u>Axial Blanket Extensions</u>
U-235	6.883 + 0	8.299 + 0	1.055 + 1	7.413 + 0
U-236	5.574 - 1	5.385 - 1	3.738 - 1	1.732 - 1
U-238	4.163 + 3	4.682 + 3	5.423 + 3	3.670 + 3
Pu-239	6.386 + 2	1.114 + 2	6.297 + 1	2.877 + 1
Pu-240	2.212 + 2	3.878 + 0	1.348 + 0	4.636 - 1
Pu-241	7.513 + 1	9.229 - 2	1.908 - 2	5.548 - 3
Pu-242	2.730 + 1	1.505 - 3	1.469 - 4	3.760 - 5
FP Total	2.336 + 2	2.192 + 1	8.235 + 0	3.259 + 0

RESULTS FOR CASE 4

E. Neutron Balance for ReactorSource

Fission	1.00000 N/Sec	
N ₂ N	.00257	
Total Source		1.00257

AbsorptionsCapturesFissions

U-235	.00187	.00574
U-236	.00011	.00002
U-238	.46533	.05856
Pu-239	.06396	.22599
Pu-240	.01988	.01561
Pu-241	.00562	.03095
Pu-242	.00195	.00136
Fission Products	.02196	.00000
Structure	.05710	.00000
Coolant	.00255	.00000
O-16	.00295	.00000
Boron and Carbon	<u>.01539</u>	<u>.00000</u>
Total	.65866	.33823
Total Absorptions		.99689

Leakage

Axial Leakage	.00061	
Radial Leakage	.00507	
Total Leakage		.00567
Total Losses		1.00257

RESULTS FOR CASE 2'

A. General

k_{eff} .99006

Peak Power of Driver Fuel

5.4545-01 KW/CM-3 At 2-6 in Zone D-2
z = 154.94 CM

Driver Fuel Peak-to-Average Power: 1.7926 + 00

Driver Fuel Axial Peak-to-Average: 1.3393 + 00

Peak Power of Inner Blankets

1.6403-01 KW/CM-3 At 1-3 in Zone IB-2
z = 154.94 CM

Peak Power of Radial Blankets

6.6488-02 KW/CM-3 At 6-6
z = 154.94 CM

RESULTS FOR CASE 2'

B. Power

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (KW/CM-3)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-1	.1290	.0045	.1335	4.984 - 01
D-2	.2525	.0087	.2612	5.454 - 01
D-3	.4350	.0145	.4495	4.576 - 01
IB-1	.0095	.0020	.0115	1.123 - 01
IB-2	.0271	.0039	.0310	1.640 - 01
IB-3	.0524	.0092	.0616	1.240 - 01
RB	.0241	.0062	.0303	6.649 - 02
AB	.0131	.0037	.0168	3.914 - 02
S	.0000	.0017	.0017	1.548 - 03
C	<u>.0000</u>	<u>.0028</u>	<u>.0028</u>	1.383 - 01
Total	.9427	.0573	1.0000	

RESULTS FOR CASE 2'

C. Burnup

<u>Zone</u>	<u>Average Burnup (MWD/MT)</u>	<u>Peak Burnup* (MWD/MT)</u>
D-1	3.118 + 4	4.346 + 4
D-2	3.096 + 4	4.892 + 4
D-3	2.813 + 4	4.626 + 4
IB-1	1.586 + 3	5.493 + 3
IB-2	3.301 + 3	7.324 + 3
IB-3	2.205 + 3	6.342 + 3
RB	8.174 + 2	4.498 + 3
AB	6.061 + 2	2.233 + 3

*Average of peak burnup at BOC and MOC.

RESULTS FOR CASE 2'

D. Fuel Inventories

	<u>Inventory (kg)</u>			
	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blanket</u>	<u>Axial Blanket Extensions</u>
U-235	7.633 + 0	9.001 + 0	1.111 + 1	7.611 + 0
U-236	4.042 - 1	3.739 - 1	2.294 - 1	1.213 - 1
U-238	4.225 + 3	4.730 + 3	5.453 + 3	3.681 + 3
Pu-239	6.524 + 2	7.567 + 1	3.785 + 1	1.991 + 1
Pu-240	2.167 + 2	1.586 + 0	4.551 - 1	1.988 - 1
Pu-241	8.250 + 1	2.201 - 2	3.573 - 3	1.395 - 3
Pu-242	2.669 + 1	1.893 - 4	1.423 - 5	5.034 - 6
FP-Odd	7.807 + 1	5.590 + 0	1.991 + 0	9.604 - 1
FP-Even	8.050 + 1	5.726 + 0	2.020 + 0	9.722 - 1

RESULTS FOR CASE 2'

E. Neutron Balance for ReactorSource

Fission	1.00000 N/Sec	
N ₂ N	.00256	
Total Source		1.00256

AbsorptionsCapturesFissions

U-235	.00205	.00628	
U-236	.00008	.00001	
U-238	.47265	.05888	
Pu-239	.06193	.22306	
Pu-240	.01948	.01553	
Pu-241	.00625	.03451	
Pu-242	.00193	.00136	
Fission Products	.01466	.00000	
Structure	.05677	.00000	
Coolant	.00256	.00000	
O-16	.00294	.00000	
Boron and Carbon	<u>.01633</u>	<u>.00000</u>	
Total	.65767	.33965	
Total Absorptions			.99732

Leakage

Axial Leakage	.00054	
Radial Leakage	.00470	
Total Leakage		.00523
Total Losses		1.00256

RESULTS FOR CASE 3'

A. General k_{eff}

.99732

Peak Power of Driver Fuel

5.2393-01 KW/CM-3

At 2-6 in Zone D-2

z = 149.86 CM

Driver Fuel Peak-to-Average Power:

1.6642 + 00

Driver Fuel Axial Peak-to-Average:

1.3582 + 00

Peak Power of Inner Blankets

1.1652-01 KW/CM-3

At 1-3 in Zone IB-2

z = 154.94 CM

Peak Power of Radial Blankets

7.0858-02 KW/CM-3

At 6-6

z = 154.94 CM

RESULTS FOR CASE 3'

B. Power

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (KW/CM-3)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-1	.1153	.0039	.1192	4.495 - 01
D-2	.2388	.0078	.2466	5.239 - 01
D-3	.4922	.0155	.5077	5.012 - 01
IB-1	.0066	.0017	.0083	8.608 - 02
IB-2	.0174	.0034	.0208	1.165 - 01
IB-3	.0385	.0090	.0475	1.012 - 01
RB	.0243	.0069	.0312	7.086 - 02
AB	.0103	.0036	.0139	3.161 - 02
S	.0000	.0017	.0017	1.738 - 03
C	<u>.0000</u>	<u>.0031</u>	<u>.0031</u>	1.499 - 01
Total	.9434	.0566	1.0000	

RESULTS FOR CASE 3'

D. Fuel Inventories

	<u>Inventory (kg)</u>			
	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blanket</u>	<u>Axial Blanket Extensions</u>
U-235	8.531 + 0	9.686 + 0	1.133 + 1	7.853 + 0
U-236	2.075 - 1	2.023 - 1	1.696 - 1	5.643 - 2
U-238	4.287 + 3	4.770 + 3	5.464 + 3	3.692 + 3
Pu-239	6.675 + 2	4.091 + 1	2.798 + 1	9.218 + 0
Pu-240	2.115 + 2	8.498 - 1	3.364 - 1	9.218 - 2
Pu-241	9.270 + 1	1.172 - 2	2.641 - 3	6.450 - 4
Pu-242	2.571 + 1	1.001 - 4	1.052 - 5	2.325 - 6
FP-Odd	4.004 + 1	3.000 + 0	1.472 + 0	4.468 - 1
FP-Even	4.129 + 1	3.072 + 0	1.493 + 0	4.522 - 1

RESULTS FOR CASE 3'

E. Neutron Balance for ReactorSource

Fission	1.00000 N/Sec	
N ₂ N	.00255	
Total Source		1.00255

AbsorptionsCapturesFissions

U-235	.00223	.00682
U-236	.00004	.00001
U-238	.47690	.05919
Pu-239	.05959	.22023
Pu-240	.01895	.01541
Pu-241	.00704	.03899
Pu-242	.00186	.00134
Fission Products	.00757	.00000
Structure	.05728	.00000
Coolant	.00254	.00000
O-16	.00294	.00000
Boron and Carbon	<u>.01805</u>	<u>.00000</u>
Total	.65500	.34200

Total Absorptions		.99701
-------------------	--	--------

Leakage

Axial Leakage	.00046	
Radial Leakage	.00508	
Total Leakage		.00554
Total Losses		1.00255

RESULTS FOR CASE 4

A. General

K_{eff} .98558

Peak Power of Driver Fuel

5.2170-01 KW/CM-3

At 2-6 in Zone D-2

z = 154.94 CM

Driver Fuel Peak-to-Average Power:

1.7831 + 00

Driver Fuel Axial Peak-to-Average:

1.3282 + 00

Peak Power of Inner Blankets

1.9161-01 KW/CM-3

At 1-3 in Zone IB-2

z = 154.94 CM

Peak Power of Radial Blankets

7.3867-02 KW/CM-3

At 6-6

z = 154.94 CM

RESULTS FOR CASE 4'

B. Power

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (KW/CM-3)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-1	.1215	.0045	.1260	4.681 - 01
D-2	.2455	.0089	.2544	5.217 - 01
D-3	.4169	.0145	.4314	4.383 - 01
IB-1	.0124	.0020	.0144	1.304 - 01
IB-2	.0331	.0039	.0370	1.916 - 01
IB-3	.0674	.0095	.0769	1.482 - 01
RB	.0300	.0062	.0361	7.387 - 02
AB	.0155	.0038	.0193	4.433 - 02
S	.0000	.0018	.0018	1.534 - 03
C	<u>.0000</u>	<u>.0027</u>	<u>.0027</u>	1.267 - 01
Total	.9422	.0578	1.0000	

RESULTS FOR CASE 4'

C. Burnup*

<u>Zone</u>	<u>Average Burnup (MWD/MT)</u>	<u>Peak Burnup (MWD/MT)</u>
D-1	3.056 + 4	4.249 + 4
D-2	3.144 + 4	4.889 + 4
D-3	2.693 + 4	4.475 + 4
IB-1	2.244 + 3	6.925 + 3
IB-2	4.571 + 3	9.733 + 3
IB-3	3.105 + 3	8.135 + 3
RB	1.032 + 3	5.107 + 3
AB	7.192 + 2	2.649 + 3

*Since fresh subassemblies were loaded at the beginning of Cycle 2, the burnup data are not cumulative from Cycle 1.

RESULTS FOR CASE 4'

D. Fuel Inventories

	<u>Inventory (kg)</u>			
	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blanket</u>	<u>Axial Blanket Extensions</u>
U-235	6.882 + 0	8.296 + 0	1.055 + 1	7.413 + 0
U-236	5.576 - 1	5.392 - 1	3.726 - 1	1.732 - 1
U-238	4.163 + 3	4.682 + 3	5.423 + 3	3.670 + 3
Pu-239	6.386 + 2	1.116 + 2	6.275 + 1	2.876 + 1
Pu-240	2.212 + 2	3.890 + 0	1.339 + 0	4.638 - 1
Pu-241	7.513 + 1	9.276 - 2	1.888 - 2	5.560 - 3
Pu-242	2.730 + 1	1.516 - 3	1.449 - 4	3.779 - 5
FP-Odd	1.138 + 2	1.077 + 1	4.046 + 0	1.614 + 0
FP-Even	1.198 + 2	1.120 + 1	4.147 + 0	1.645 + 0

RESULTS FOR CASE 4'

E. Neutron Balance for ReactorSource

Fission	1.00000 N/Sec	
N ₂ N	.00257	
Total Source		1.00257

AbsorptionsCapturesFissions

U-235	.00187	.00574	
U-236	.00011	.00002	
U-238	.46538	.05853	
U-239	.06406	.01560	
Pu-240	.01991	.01560	
Pu-241	.00562	.03097	
Pu-242	.00195	.00136	
Fission Products	.02180	.00000	
Structure	.05711	.00000	
Coolant	.00255	.00000	
O-16	.00294	.00000	
Boron and Carbon	<u>.01538</u>	<u>.00000</u>	
Total	.65868	.33821	
Total Absorptions			.99690

Leakage

Axial Leakage	.00061	
Radial Leakage	.00506	
Total Leakage		.00567
Total Losses		1.00257

MIT RESULTS FOR THE LARGE CORE
CODE EVALUATION WORKING GROUP (LCCEWG)
FOURTH BENCHMARK PROBLEM*

by

A. J. WOLFORD

M. J. DRISCOLL

NUCLEAR ENGINEERING DEPARTMENT
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS 02139

January 17, 1983

*Work performed under the auspices of the U. S. Department of Energy

GENERAL COMMENTS

- A. Codes Used NEW2DB (R. Wu, Hanford)
- B. Convergence Criteria Eigenvalue: 10^{-6}
- C. Method of Burnup Calculations Normal 2DB zonewise burnup model, 10 time intervals.

D. Analysis ProceduresGeometry4

1. HEX-Z Direct
2. HEX-Z Synthesis
3. HEX X-Y
4. R-Z
5. Linked R-Z and HEX X-Y
6. Other (describe)

Cross Sections1

1. GE-8 Group
2. Other (describe)

Fuel Management Plan1

1. Recommended two cycle reload plan
2. Other (describe)

Fuel Burnup Chain1

1. Abbreviated burnup chain with uranium and plutonium isotopes only (including Pu-241 decay)
2. Extended burnup chain
3. Other (describe)

Lumped Fission Products2

1. Recommended - 2 Fission Product Pairs (odd, even)
2. Recommended - 1 Fission Product Pair
3. Other (describe)

Energy Deposition1

1. In-Situ fission plus capture gamma's
2. In-Situ fission only
3. Other (describe)

Treatment of Control Rods1

1. Control positioned at the recommended BOC location during the first half of the irradiation cycle, and at the recommended EOC location during the last half of the irradiation cycle
2. Positioned as recommended at the beginning-of-cycle and left unchanged during the burnup calculations
3. All control out
4. Other (describe)

Calculation of Control Rod WorthNot performed

1. Direct 3-D calculation
2. Synthesis 3-D calculations
3. R-Z calculations
4. R-Z calculations (Modified B_{10} Density)
5. X-Y HEX
6. Other (describe)

Core Layout1

1. Recommended
2. Other (describe)

Mesh Spacings1

1. Recommended
2. Other (describe)

Flux Solutions During Irradiation Cycle1

1. Recommended
2. Other (describe)

RESULTS FOR CASE 1A. General

1. k_{eff}	1.00239	
2. Control Rod Worth (Δk) ^a	-	
3. Sodium Void Worth (Δk) ^a	-	
4. Breeding Gain (kg of fissile plutonium) ^b	-	
5. Peak Power (kw/cm ³)-Position	-	
Driver Fuel	5.25 E-1	Position 45020
Inner Blankets	5.90 E-2	19019
Radial Blankets	4.03 E-2	52020
6. <u>Driver Fuel Peak-to-Average Power</u>	(1.60)	
7. <u>Driver Fuel Axial Peak-to-Average Power</u> (at position of peak power)	1.34	

a. Optional calculations

b. Required for Cases 2 and 4 only

RESULTS FOR CASE 1B. Power

<u>ZONE^a</u>	<u>POWER FRACTION</u>			<u>PEAK POWER DENSITY (KW/CM³)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	0.1117	0.0035	0.1152	0.452
D-II	0.2257	0.0069	0.2326	0.482
D-III	0.5424	0.0162	0.5586	0.520
IB-I	0.0027	0.0013	0.0040	0.044
IB-II	0.0104	0.0033	0.0137	0.060
IB-III	0.0230	0.0087	0.0317	0.054
RB	0.0181	0.0075	0.0256	0.040
AB	0.0074	0.0033	0.0107	0.020
S	0.0	0.0025	0.0025	0.0
C	0.0	0.0054	<u>0.0054</u>	0.0
			1.0000	

- a) A partial description of the zone designators is given for Figure B.1.
Other terms are:

AB - Axial blanket extensions to the driver fuel
 S - All axial and radial shields
 C - All control channels

RESULTS FOR CASE 1D. Fuel Inventories

	<u>Inventory (kg)</u>			
	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blankets</u>	<u>Axial Blanket Extension</u>
U-234				
U-235	5.685+1	6.296+1	7.178+1	4.837+1
U-236				
U-237				
U-238	2.611+4	2.891+4	3.296+4	2.221+4
U-239				
N _p -237				
N _p -238				
N _p -239				
P _u -238				
P _u -239	4.100+3			
P _u -240	1.236+3			
P _u -241	6.203+2			
P _u -242	1.481+2			
P _u -243				
P _u -244				
Am-241				
Am-242m				
Am-242				
Am-243				
Am-244				
Cm-242				
Cm-243				
Cm-244				

RESULTS FOR CASE 1E. Neutron Balance for ReactorSource

Fission 1.00000 n/sec

n,2n

total source

<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00217	0.00735
U-236		
U-238	0.47304	0.05958
Pu-238		
Pu-239	0.05535	0.21611
Pu-240	0.01824	0.01545
Pu-241	0.00778	0.04370
Pu-242	0.00177	0.00133
Fission Products		
Other Captures*	0.03486	
Structure	0.05598	
Coolant	0.00245	
Total	0.65164	0.34352
Total Absorptions		0.99516
<u>Leakage</u>		
Axial	0.00036	
Radial	0.00435	
Total	0.00471	0.00471
Total Losses		0.99987

All values are normalized to the unit fission source

* 016, B10, B11, C

CORE DIAGRAM IN R-Z GEOMETRY FOR BENCHMARK
PROBLEM FOUR (NOT TO SCALE)

ORNL Results for the Large Core Code
Evaluation Working Group (LCCEWG)
Benchmark Problem IV*

J.R. White
Mechanical and Energy Engineering Dept.
University of Lowell
Lowell, Massachusetts 01854

and

J.H. Marable
Engineering Physics Division
Oak Ridge National Laboratory
Post Office Box X
Oak Ridge, Tennessee 37830

December 15, 1982

*Work performed under the auspices of the U.S. Department of Energy,
Division of Reactor Research and Technology.

ORNL Results for LCCEWG Benchmark Problem IV

J. R. White and J. H. Marable

ORNL's final results for the LCCEWG Benchmark Problem IV (BM4) are presented in the following tables and figures. ORNL's contribution to this benchmark effort consists of the following cases.

1. Reference Hex-Z VENTURE solution (VENTURE #1 - Tables 1-11, 34)
2. Reference RZ VENTURE solution (VENTURE #2 - Tables 12-22)
3. Reference Hex-Z VALE solution (VALE #1 - Tables 23-34)
4. Fine-mesh Hex-Z VALE solution for cycle 1 (VALE #2 - Tables 35-40)
5. Extrapolated Hex-Z VALE solution for cycle 1 (VALE #2E - Tables 41-46)
6. Extended burnup chain solution using the reference Hex-Z VALE fluxes (VALE #3 - Tables 47-53)

In addition, a set of time-dependent sensitivity calculations were made for several nuclide inventory responses in the middle driver region of the RZ BM4 model. This sensitivity data was generated in an attempt to answer some questions relative to the proposed Benchmark Problem V analysis of FFTF burnup data. The preliminary sensitivity information given in Figures 1-6 is primarily for the benefit of the LCCEWG participants in drafting the specifications for the next benchmark.

We qualify our Benchmark IV results with the following general comments:

1. The codes used in this analysis include:

VENTURE - mesh-centered finite difference formulation

VALE - mesh-edge in the plane and mesh-centered along axial
direction

BURNER - performs depletion calculation

FUELMANG - performs fuel management and control positioning

DEPTH-CHARGE - static/time-dependent generalized perturbation
theory capability

2. The convergence criteria used for all BM4 solutions were:

$$K_{\text{eff}} - 10^{-6}$$

$$\text{Pointwise flux} - 10^{-5}$$

3. The burnup calculations used the matrix exponential solution technique. An abbreviated burnup chain (including, n, γ reactions up the chain and $n, 2n$ reactions down the chain) was used for all but the extended burnup case - VALE #3. This latter case used the extended fuel chain as specified in the "Specifications for the Large Core Code Evaluation Working Group Benchmark Four" dated September 1981, and the nuclides for which data was not given in the "LCCEWG Benchmark IV Actinide Library" dated September 1982, were not treated. Decay constants were those given in the BM4 specifications.
4. A single fission product pair was utilized in all calculations.
5. Fuel depletion was performed using zone-averaged fluxes. The zone definitions were as specified except for the 3-D cases where each fuel batch was treated as a separate zone. The depletion calculations had two 191.75-day burnup intervals per cycle with six power normalizations per interval. Fission and capture energy deposition was treated, and the recommended control rod treatment (positioning at BOC1, MOC1, BOC2 and MOC2) and fuel management specifications were utilized.

6. All calculations utilized the 8-group ISOTXS cross sections provided by GE-ARSD and the specified reference mesh spacings were used as follows:
 - VENTURE #1 - 6 points/hex and 42 points axially
 - VENTURE #2 - 61 radial and 42 axial mesh points
 - VALE #1 - 3 points/hex and 42 points axially
 - VALE #2 - 12 points/hex and 84 points axially
 - VALE #3 - same as VALE #1
7. The extra regions at the outer boundaries of the 3-D models utilized a black absorber zone (non-return boundary condition) instead of the recommended low density filler material, since the latter specification resulted in slow pointwise convergence in the outer regions of the model.
8. The extrapolated VALE #2E results were obtained from the reference and fine-mesh VALE solutions using the following extrapolation formula.

$$X_{\infty} = (4X_2 - X_1)/3$$
 where X_{∞} - extrapolated result for infinite number of mesh points
 X_2 - fine-mesh result
 X_1 - reference result
9. Extended chain nuclide inventories (VALE #3) were obtained by depleting with the reference VALE #1 fluxes. The EOC1 and EOC2 reactivities were then calculated using the full complement of higher actinides.
10. Tabulated results for each case include a summary table followed by detailed neutron balance data, power distribution results and

nuclide inventory data. It should be noted that the neutron balance data needs to be multiplied by K_{eff} for it to be consistent with the data reported by some of the other LCCEWG participants.

11. Auxiliary sensitivity calculations were performed with the BM4 RZ model in an attempt to answer some questions relative to the proposed FFTF Benchmark Problem Five. Basically, the burnup part of this new benchmark proposes to compare calculated EOC1 nuclide densities with those measured in FFTF after approximately 100 full power days of irradiation. Thus, our brief pre-analysis has focused on calculating the important sensitivities versus exposure for several nuclide inventory responses. Figures 1-6 describe the sensitivity of the Pu239 and Pu240 concentrations and Pu240/Pu239 ratio responses to some important cross sections and initial nuclide concentrations in the second driver zone of the BM4 RZ model. From this data and the expected full power exposure at the EOC1 in FFTF, we can crudely estimate the important sensitivities in the system. This type of analysis indicates nuclear data sensitivities on the order of 0.1 (or less) and initial concentration sensitivities of approximately 0.8 - 1.0 for 100 full power days of exposure. This distribution of sensitivities indicates that the EOC1 responses are very sensitive to the initial nuclide concentrations and depend relatively little on the depletion of the initial state. This present analysis indicates that there may be potential problems in the interpretation of low-burnup FFTF data due mainly to the inherent

uncertainties in the BOC state and in the EOC1 measured concentrations. It appears that calculations should certainly compare well within the given uncertainties and therefore may provide only limited information as to the accuracy of the methods and data utilized. As seen in the figures, however, the overall situation improves considerably with increased burnup. These pre-analysis results indicate that further study (specific to FFTF) may be required if one is to achieve maximum benefit from FFTF experimental analyses.

12. Lastly, it should be noted that ORNL's results for the axial leakage component are consistently lower than other reported solutions by approximately a factor of three. This difference, which is observed in both the Hex-Z and RZ models, is not yet understood. The dimensions and extrapolated vacuum boundary conditions were utilized as given in the LCCEWG Benchmark IV specifications.

Table 1. Summary Results for VENTURE #1
(Reference Hex-Z Case)

Parameter	BOC1	MOC1	EOC1	BOC2	MOC2	EOC2
K_{eff}	1.003772	1.003669	1.001252	1.004090	1.004227	1.002762
Fissile Pu (Kg)	4.7216+3	4.9685+3	5.2003+3	5.0303+3	5.2589+3	5.4730+3
Breeding Gain (Kg)	-	-	4.787 +2	-	-	4.427 +2
Peak Power (Kw/cm ³)						
Driver Fuel	5.280 -1	5.537 -1	5.400 -1	5.250 -1	5.292 -1	5.135 -1
Inner Blkt	8.051 -2	1.542 -1	2.215 -1	1.829 -1	2.410 -1	2.903 -1
Radial Blkt	6.271 -2	6.818 -2	7.307 -2	8.099 -2	8.417 -2	8.668 -2
Control Rod	1.578 -1	1.372 -1	1.384 -1	1.474 -1	1.235 -1	1.238 -1
Driver Fuel Ave. Power Density (Kw/cm ³)	3.275 -1	3.124 -1	2.980 -1	3.117 -1	2.977 -1	2.846 -1
Driver Fuel Peak/Ave. Power Density	1.612	1.772	1.812	1.684	1.778	1.804

Table 2. Neutron Balance Results for VENTURE #1 BOC1

<u>Source</u>		
fission	1.00000	
n,2n	0.00253	
TOTAL		1.00253
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00244	0.00744
U236	0.0	0.0
U238	0.48136	0.05930
Pu239	0.05617	0.21566
Pu240	0.01841	0.01526
Pu241	0.00788	0.04378
Pu242	0.00179	0.00131
FPT	0.0	0.0
Structure	0.05753	0.0
Coolant	0.00248	0.0
Other	0.02312	0.0
TOTAL	0.65118	0.34275
TOTAL Absorption		0.99393
<u>Leakage</u>		
Axial	0.00013	
Radial	0.00471	
TOTAL		0.00484
TOTAL Losses		0.99877

Table 3. Neutron Balance Results for VENTURE #1 EOC1

<u>Source</u>		
fission	1.00000	
n,2n	0.00256	
TOTAL		1.00256
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00196	0.00603
U236	0.00009	0.00001
U238	0.46682	0.05880
Pu239	0.06322	0.22681
Pu240	0.01944	0.01543
Pu241	0.00627	0.03461
Pu242	0.00191	0.00135
FPT	0.01596	0.0
Structure	0.05621	0.0
Coolant	0.00248	0.0
Other	0.01920	0.0
TOTAL	0.65356	0.34304
TOTAL Absorption		0.99660
<u>Leakage</u>		
Axial	0.00016	
Radial	0.00453	
TOTAL		0.00469
TOTAL Losses		1.00129

Table 4. Neutron Balance Results for VENTURE #1 BOC2

<u>Source</u>		
fission	1.00000	
n,2n	0.00254	
TOTAL		1.00254
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00218	0.00670
U236	0.00005	0.00001
U238	0.47267	0.05903
Pu239	0.06011	0.22139
Pu240	0.01881	0.01524
Pu241	0.00709	0.03924
Pu242	0.00184	0.00132
FPT	0.00755	0.0
Structure	0.05690	0.0
Coolant	0.00247	0.0
Other	0.02082	0.0
TOTAL	0.65049	0.34293
TOTAL Absorption		0.99342
<u>Leakage</u>		
Axial	0.00014	
Radial	0.00492	
TOTAL		0.00506
TOTAL Losses		0.99848

Table 5. Neutron Balance Results for VENTURE #1 EOC2

<u>Source</u>		
fission	1.00000	
n,2n	0.00257	
TOTAL		1.00257
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00177	0.00546
U236	0.00012	0.00002
U238	0.45717	0.05836
Pu239	0.06550	0.23100
Pu240	0.01986	0.01546
Pu241	0.00571	0.03145
Pu242	0.00193	0.00134
FPT	0.02329	0.0
Structure	0.05588	0.0
Coolant	0.00245	0.0
Other	0.01809	0.0
TOTAL	0.65177	0.34309
TOTAL Absorption		0.99486
<u>Leakage</u>		
Axial	0.00017	
Radial	0.00476	
TOTAL		0.00493
TOTAL Losses		0.99979

Table 6. Power Density Results for VENTURE #1 BOC1

Region	Power Fraction			Peak Power Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1175	0.0037	0.1212	4.578 - 1
D-II	0.2331	0.0072	0.2403	5.174 - 1
D-III	0.5312	0.0159	0.5471	5.280 - 1
IB-I	0.0038	0.0016	0.0054	6.460 - 2
IB-II	0.0104	0.0032	0.0136	8.051 - 2
IB-III	0.0228	0.0086	0.0314	7.719 - 2
RB	0.0172	0.0071	0.0243	6.271 - 2
AB	0.0080	0.0035	0.0115	2.586 - 2
S	0.0000	0.0018	0.0018	1.831 - 3
C	<u>0.0000</u>	<u>0.0034</u>	<u>0.0034</u>	1.578 - 1
TOTALS	0.9440	0.0560	1.0000	

Table 7. Power Density Results for VENTURE #1 EOC1

Region	Power Fraction			Peak Power Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1332	0.0049	0.1381	5.060 - 1
D-II	0.2557	0.0095	0.2652	5.400 - 1
D-III	0.4091	0.0145	0.4236	4.299 - 1
IB-I	0.0117	0.0021	0.0138	1.449 - 1
IB-II	0.0325	0.0041	0.0366	2.215 - 1
IB-III	0.0608	0.0093	0.0701	1.605 - 1
RB	0.0253	0.0058	0.0311	7.307 - 2
AB	0.0134	0.0036	0.0170	4.356 - 2
S	0.0	0.0017	0.0017	1.458 - 3
C	<u>0.0</u>	<u>0.0028</u>	<u>0.0028</u>	1.384 - 1
TOTALS	0.9417	0.0583	1.0000	

Table 8. Power Density Results for VENTURE #1 BOC2

Region	Power Fraction			Peak Power Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1293	0.0042	0.1335	5.090 - 1
D-II	0.2397	0.0081	0.2478	5.250 - 1
D-III	0.4682	0.0152	0.4834	4.825 - 1
IB-I	0.0084	0.0019	0.0103	1.360 - 1
IB-II	0.0200	0.0036	0.0236	1.829 - 1
IB-III	0.0423	0.0089	0.0512	1.496 - 1
RB	0.0248	0.0066	0.0314	8.099 - 2
AB	0.0104	0.0036	0.0140	3.949 - 2
S	0.0	0.0017	0.0017	1.645 - 3
C	<u>0.0</u>	<u>0.0031</u>	<u>0.0031</u>	1.474 - 1
TOTALS	0.9431	0.0569	1.0000	

Table 9. Power Density Results for VENTURE #1 EOC2

Region	Power Fraction			Peak Power ₃ Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1337	0.0052	0.1389	5.121 - 1
D-II	0.2454	0.0098	0.2552	5.135 - 1
D-III	0.3812	0.0144	0.3956	4.011 - 1
IB-I	0.0175	0.0023	0.0198	2.148 - 1
IB-II	0.0407	0.0043	0.0450	2.903 - 1
IB-III	0.0765	0.0095	0.0860	2.025 - 1
RB	0.0302	0.0056	0.0358	8.668 - 2
AB	0.0156	0.0037	0.0193	5.709 - 2
S	0.0	0.0017	0.0017	1.392 - 3
C	<u>0.0</u>	<u>0.0027</u>	<u>0.0027</u>	1.238 - 1
TOTALS	0.9408	0.0592	1.0000	

Table 10. Inventory Results for VENTURE #1 - Cycle 1

<u>BOC1 Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	5.687 + 1	6.296 + 1	7.181 + 1	4.838 + 1
U236	0.0	0.0	0.0	0.0
U238	2.612 + 4	2.891 + 4	3.297 + 4	2.221 + 4
Pu239	4.101 + 3	0.0	0.0	0.0
Pu240	1.236 + 3	0.0	0.0	0.0
Pu241	6.205 + 2	0.0	0.0	0.0
Pu242	1.481 + 2	0.0	0.0	0.0
FPT	0.0	0.0	0.0	0.0
<u>EOC1 Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	4.598 + 1	5.429 + 1	6.683 + 1	4.574 + 1
U236	2.382 + 0	2.154 + 0	1.322 + 0	7.082 - 1
U238	2.536 + 4	2.839 + 4	3.272 + 4	2.209 + 4
Pu239	3.917 + 3	4.394 + 2	2.194 + 2	1.167 + 2
Pu240	1.299 + 3	1.217 + 1	3.435 + 0	1.320 + 0
Pu241	5.071 + 2	2.471 - 1	3.912 - 2	1.112 - 2
Pu242	1.601 + 2	3.363 - 3	2.441 - 4	5.087 - 5
FPT	9.411 + 2	7.613 + 1	2.539 + 1	1.183 + 1

Table 11. Inventory Results for VENTURE #1 - Cycle 2

<u>BOC2 Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	5.178 + 1	5.831 + 1	6.822 + 1	4.714 + 1
U236	1.112 + 0	1.161 + 0	9.558 - 1	3.308 - 1
U238	2.576 + 4	2.863 + 4	3.279 + 4	2.215 + 4
Pu239	4.015 + 3	2.359 + 2	1.571 + 2	5.455 + 1
Pu240	1.265 + 3	6.451 + 0	2.419 + 0	6.177 - 1
Pu241	5.675 + 2	1.292 - 1	2.709 - 2	5.218 - 3
Pu242	1.537 + 2	1.724 - 3	1.654 - 4	2.399 - 5
FPT	4.402 + 2	3.952 + 1	1.762 + 1	5.528 + 0

<u>EOC 2 Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	4.210 + 1	5.033 + 1	6.399 + 1	4.461 + 1
U236	3.170 + 0	3.063 + 0	2.052 + 0	1.000 + 0
U238	2.504 + 4	2.810 + 4	3.257 + 4	2.203 + 4
Pu239	3.846 + 3	6.407 + 2	3.469 + 2	1.673 + 2
Pu240	1.322 + 3	2.875 + 1	9.037 + 0	3.016 + 0
Pu241	4.710 + 2	9.631 - 1	1.732 - 1	4.326 - 2
Pu242	1.635 + 2	2.433 - 2	1.959 - 3	3.736 - 4
FPT	1.335 + 3	1.515 + 2	4.972 + 1	1.994 + 1

Table 12. Summary Results for VENTURE #2
(Reference RZ Model)

Parameter	BOC1	MOC1	EOC1	BOC2	MOC2	EOC2
K_{eff}	1.002507	1.003487	1.001332	1.004853	1.006050	1.004349
Fissile Pu (Kg)	4.7218+3	4.9593+3	5.1830+3	5.0282+3	5.2454+3	5.4492+3
Breeding Gain (Kg)	-	-	4.612 +2	-	-	4.210 +2
Peak Power (Kw/cm ³)						
Driver Fuel	5.092 -1	5.249 -1	5.132 -1	5.061 -1	5.144 -1	5.021 -1
Inner Blkt	7.039 -2	1.462 -1	2.141 -1	1.406 -1	2.106 -1	2.657 -1
Radial Blkt	4.668 -2	4.901 -2	5.283 -2	5.475 -2	5.583 -2	5.860 -2
Control Rod	2.065 -1	1.764 -1	1.789 -1	1.974 -1	1.601 -1	1.607 -1
Driver Fuel Ave. Power Density (Kw/cm ³)	3.275 -1	3.127 -1	2.983 -1	3.115 -1	2.976 -1	2.847 -1
Driver Fuel Peak/Ave. Power Density	1.555	1.679	1.720	1.625	1.728	1.764

Table 13. Neutron Balance Results for VENTURE #2 BOC1

<u>Source</u>		
fission	1.00000	
n,2n	0.00254	
TOTAL		1.00254
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00239	0.00733
U236	0.0	0.0
U238	0.47421	0.05943
Pu239	0.05532	0.21556
Pu240	0.01820	0.01541
Pu241	0.00780	0.04360
Pu242	0.00177	0.00133
FPT	0.0	0.0
Structure	0.05634	0.0
Coolant	0.00241	0.0
Other	0.03449	0.0
TOTAL	0.65293	0.34266
TOTAL Absorption		0.99559
<u>Leakage</u>		
Axial	0.00012	
Radial	0.00433	
TOTAL		0.00445
TOTAL Losses		1.00004

Table 14. Neutron Balance Results for VENTURE #2 EOC1

<u>Source</u>		
fission	1.00000	
n,2n	0.00256	
TOTAL		1.00256
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00192	0.00593
U236	0.00009	0.00001
U238	0.46067	0.05878
Pu239	0.06271	0.22683
Pu240	0.01930	0.01553
Pu241	0.00623	0.03454
Pu242	0.00190	0.00136
FPT	0.01595	0.0
Structure	0.05474	0.0
Coolant	0.00241	0.0
Other	0.02816	0.0
TOTAL	0.65408	0.34298
TOTAL Absorption		0.99706
<u>Leakage</u>		
Axial	0.00015	
Radial	0.00401	
TOTAL		0.00416
TOTAL Losses		1.00122

Table 15. Neutron Balance Results for VENTURE #2 BOC2

<u>Source</u>		
fission	1.00000	
n,2n	0.00254	
TOTAL		1.00254
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00213	0.00656
U236	0.00005	0.00001
U238	0.46489	0.05900
Pu239	0.05960	0.22152
Pu240	0.01862	0.01533
Pu241	0.00703	0.03910
Pu242	0.00182	0.00133
FPT	0.00751	0.0
Structure	0.05518	0.0
Coolant	0.00240	0.0
Other	0.03122	0.0
TOTAL	0.65045	0.34285
TOTAL Absorption		0.99330
<u>Leakage</u>		
Axial	0.00013	
Radial	0.00429	
TOTAL		0.00442
TOTAL Losses		0.99772

Table 16. Neutron Balance Results for VENTURE #2 EOC2

<u>Source</u>		
fission	1.00000	
n,2n	0.00256	
TOTAL		1.00256
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00172	0.00534
U236	0.00012	0.00002
U238	0.45025	0.05821
Pu239	0.06510	0.23119
Pu240	0.01975	0.01555
Pu241	0.00567	0.03138
Pu242	0.00191	0.00135
FPT	0.02342	0.0
Structure	0.05429	0.0
Coolant	0.00239	0.0
Other	0.02626	0.0
TOTAL	0.65088	0.34304
TOTAL Absorption		0.99392
<u>Leakage</u>		
Axial	0.00016	
Radial	0.00415	
TOTAL		0.00431
TOTAL Losses		0.99823

Table 17. Power Distribution Results for VENTURE #2 BOC1

Region	Power Fraction			Peak Power ₃ Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1114	0.0035	0.1149	4.293 - 1
D-II	0.2246	0.0068	0.2314	4.623 - 1
D-III	0.5462	0.0163	0.5625	5.092 - 1
IB-I	0.0036	0.0015	0.0051	5.877 - 2
IB-II	0.0099	0.0031	0.0130	7.039 - 2
IB-III	0.0225	0.0084	0.0309	6.581 - 2
RB	0.0169	0.0073	0.0242	4.668 - 2
AB	0.0078	0.0033	0.0111	2.328 - 2
S	0.0	0.0017	0.0017	1.248 - 3
C	<u>0.0</u>	<u>0.0052</u>	<u>0.0052</u>	2.065 - 1
TOTALS	0.9429	0.0571	1.0000	

Table 18. Power Distribution Results for VENTURE #2 EOC1

Region	Power Fraction			Peak Power ₃ Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1332	0.0049	0.1381	5.030 - 1
D-II	0.2604	0.0095	0.2699	5.132 - 1
D-III	0.4052	0.0144	0.4196	4.095 - 1
IB-I	0.0114	0.0021	0.0135	1.382 - 1
IB-II	0.0332	0.0041	0.0373	2.141 - 1
IB-III	0.0608	0.0091	0.0699	1.449 - 1
RB	0.0241	0.0057	0.0298	5.283 - 2
AB	0.0128	0.0034	0.0162	4.251 - 2
S	0.0	0.0015	0.0015	9.916 - 4
C	<u>0.0</u>	<u>0.0042</u>	<u>0.0042</u>	1.789 - 1
TOTALS	0.9411	0.0589	1.0000	

Table 19. Power Distribution Results for VENTURE #2 BOC2

Region	Power Fraction			Peak Power Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1322	0.0044	0.1366	5.061 - 1
D-II	0.2478	0.0083	0.2561	5.010 - 1
D-III	0.4567	0.0148	0.4715	4.195 - 1
IB-I	0.0085	0.0019	0.0104	1.110 - 1
IB-II	0.0213	0.0037	0.0250	1.406 - 1
IB-III	0.0420	0.0087	0.0507	1.012 - 1
RB	0.0239	0.0062	0.0301	5.475 - 2
AB	0.0100	0.0033	0.0133	3.278 - 2
S	0.0	0.0016	0.0016	1.104 - 3
C	<u>0.0</u>	<u>0.0047</u>	<u>0.0047</u>	1.974 - 1
TOTALS	0.9424	0.0576	1.0000	

Table 20. Power Distribution Results for VENTURE #2 EOC2

Region	Power Fraction			Peak Power Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1343	0.0053	0.1396	5.021 - 1
D-II	0.2512	0.0099	0.2611	4.886 - 1
D-III	0.3752	0.0140	0.3892	3.976 - 1
IB-I	0.0175	0.0023	0.0198	1.904 - 1
IB-II	0.0427	0.0043	0.0470	2.657 - 1
IB-III	0.0762	0.0094	0.0856	1.756 - 1
RB	0.0285	0.0054	0.0339	5.860 - 2
AB	0.0149	0.0034	0.0183	5.067 - 2
S	0.0	0.0016	0.0016	9.605 - 4
C	<u>0.0</u>	<u>0.0039</u>	<u>0.0039</u>	1.607 - 1
TOTALS	0.9405	0.0595	1.0000	

Table 21. Inventory Results for VENTURE #2 - Cycle 1

<u>BOC1 Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	5.687 + 1	6.298 + 1	7.180 + 1	4.838 + 1
U236	0.0	0.0	0.0	0.0
U238	2.612 + 4	2.892 + 4	3.297 + 4	2.221 + 4
Pu239	4.101 + 3	0.0	0.0	0.0
Pu240	1.236 + 3	0.0	0.0	0.0
Pu241	6.205 + 2	0.0	0.0	0.0
Pu242	1.481 + 2	0.0	0.0	0.0
FPT	0.0	0.0	0.0	0.0
<u>EOC1 Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	4.604 + 1	5.446 + 1	6.687 + 1	4.594 + 1
U236	2.361 + 0	2.110 + 0	1.311 + 0	6.479 - 1
U238	2.537 + 4	2.840 + 4	3.272 + 4	2.209 + 4
Pu239	3.917 + 3	4.317 + 2	2.178 + 2	1.095 + 2
Pu240	1.297 + 3	1.222 + 1	3.434 + 0	1.179 + 0
Pu241	5.072 + 2	2.552 - 1	3.924 - 2	9.922 - 3
Pu242	1.599 + 2	3.578 - 3	2.431 - 4	4.656 - 5
FPT	9.419 + 2	7.563 + 1	2.466 + 1	1.138 + 1

Table 22. Inventory Results for VENTURE #2 - Cycle 2

<u>BOC2 Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	5.183 + 1	5.837 + 1	6.816 + 1	4.725 + 1
U236	1.099 + 0	1.142 + 0	9.691 - 1	3.008 - 1
U238	2.577 + 4	2.864 + 4	3.279 + 4	2.216 + 4
Pu239	4.015 + 3	2.334 + 2	1.610 + 2	5.089 + 1
Pu240	1.264 + 3	6.548 + 0	2.538 + 0	5.454 - 1
Pu241	5.677 + 2	1.357 - 1	2.901 - 2	4.574 - 3
Pu242	1.536 + 2	1.888 - 3	1.797 - 4	2.142 - 5
FPT	4.388 + 2	4.056 + 1	1.823 + 1	5.293 + 0
<u>EOC2 Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	4.219 + 1	5.048 + 1	6.416 + 1	4.491 + 1
U236	3.141 + 0	3.013 + 0	2.003 + 0	9.139 - 1
U238	2.504 + 4	2.811 + 4	3.257 + 4	2.204 + 4
Pu239	3.846 + 3	6.337 + 2	3.408 + 2	1.568 + 2
Pu240	1.320 + 3	2.964 + 1	8.969 + 0	2.707 + 0
Pu241	4.712 + 2	1.046 + 0	1.738 - 1	3.922 - 2
Pu242	1.633 + 2	2.812 - 2	1.972 - 3	3.518 - 4
FPT	1.334 + 3	1.545 + 2	4.860 + 1	1.904 + 1

Table 23. Summary Results for VALE #1
(Reference Hex-Z Case)

Parameter	BOC1	MOC1	EOC1	BOC2	MOC2	EOC2
K_{eff}	0.996033	0.998190	0.996742	0.998225	0.999957	0.999273
Fissile Pu (Kg)	4.7217+3	4.9692+3	5.2005+3	5.0310+3	5.2591+3	5.4719+3
Breeding Gain (Kg)	-	-	4.788 +2	-	-	4.409 +2
Peak Power (Kw/cm ³)						
Driver Fuel	5.308 -1	5.632 -1	5.469 -1	5.420 -1	5.423 -1	5.222 -1
Inner Blkt	1.058 -1	1.807 -1	2.447 -1	2.117 -1	2.674 -1	3.143 -1
Radial Blkt	8.345 -2	8.608 -2	8.974 -2	9.581 -2	9.773 -2	9.940 -2
Control Rod	2.107 -1	1.804 -1	1.816 -1	1.953 -1	1.617 -1	1.617 -1
Driver Fuel Ave. Power Density (Kw/cm ³)	3.249 -1	3.100 -1	2.958 -1	3.091 -1	2.955 -1	2.826 -1
Driver Fuel Peak/Ave. Power Density	1.634	1.817	1.849	1.753	1.835	1.848

Table 24. Neutron Balance Results for VALE #1 BOC1

<u>Source</u>		
fission	1.00000	
n,2n	0.00256	
TOTAL		1.00256
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00243	0.00744
U236	0.0	0.0
U238	0.48272	0.06033
Pu239	0.05724	0.21515
Pu240	0.01868	0.01487
Pu241	0.00798	0.04394
Pu242	0.00181	0.00127
FPT	0.0	0.0
Structure	0.05699	0.0
Coolant	0.00247	0.0
Other	0.02769	0.0
TOTAL	0.65801	0.34300
TOTAL Absorption		1.00101
<u>Leakage</u>		
Axial	0.00013	
Radial	0.00541	
TOTAL		0.00554
TOTAL Losses		1.00655

Table 25. Neutron Balance Results for VALE #1 EOC1

<u>Source</u>		
fission	1.00000	
n,2n	0.00258	
TOTAL		1.00258
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00195	0.00601
U236	0.00009	0.00001
U238	0.46666	0.05945
Pu239	0.06384	0.22662
Pu240	0.01971	0.01512
Pu241	0.00633	0.03466
Pu242	0.00194	0.00131
FPT	0.01622	0.0
Structure	0.05547	0.0
Coolant	0.00246	0.0
Other	0.02270	0.0
TOTAL	0.65737	0.34318
TOTAL Absorption		1.00055
<u>Leakage</u>		
Axial	0.00016	
Radial	0.00515	
TOTAL		0.00531
TOTAL Losses		1.00586

Table 26. Neutron Balance Results for VALE #1 BOC2

<u>Source</u>		
fission	1.00000	
n,2n	0.00257	
TOTAL		1.00257
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00217	0.00668
U236	0.00005	0.00001
U238	0.47311	0.05985
Pu239	0.06098	0.22109
Pu240	0.01907	0.01488
Pu241	0.00716	0.03933
Pu242	0.00186	0.00128
FPT	0.00769	0.0
Structure	0.05618	0.0
Coolant	0.00245	0.0
Other	0.02478	0.0
TOTAL	0.65550	0.34312
TOTAL Absorption		0.99861
<u>Leakage</u>		
Axial	0.00014	
Radial	0.00559	
TOTAL		0.00573
TOTAL Losses		1.00434

Table 27. Neutron Balance Results for VALE #1 EOC2

<u>Source</u>		
fission	1.00000	
n,2n	0.00258	
TOTAL		1.00258
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00175	0.00543
U236	0.00012	0.00002
U238	0.45648	0.05888
Pu239	0.06597	0.23090
Pu240	0.02011	0.01520
Pu241	0.00575	0.03149
Pu242	0.00195	0.00131
FPT	0.02364	0.0
Structure	0.05503	0.0
Coolant	0.00243	0.0
Other	0.02132	0.0
TOTAL	0.65455	0.34323
TOTAL Absorption		0.99778
<u>Leakage</u>		
Axial	0.00017	
Radial	0.00537	
TOTAL		0.00554
TOTAL Losses		1.00332

Table 28. Power Distribution Results for VALE #1 BOC1

Region	Power Fraction			Peak Power Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1215	0.0039	0.1254	4.748 - 1
D-II	0.2347	0.0075	0.2422	5.308 - 1
D-III	0.5180	0.0157	0.5337	5.198 - 1
IB-I	0.0045	0.0016	0.0061	8.690 - 2
IB-II	0.0122	0.0033	0.0155	1.058 - 1
IB-III	0.0256	0.0086	0.0342	9.945 - 2
RB	0.0188	0.0070	0.0258	8.345 - 2
AB	0.0079	0.0034	0.0113	2.674 - 2
S	0.0	0.0017	0.0017	1.907 - 3
C	<u>0.0</u>	<u>0.0041</u>	<u>0.0041</u>	2.107 - 1
TOTALS	0.9432	0.0568	1.0000	

Table 29. Power Distribution Results for VALE #1 EOC1

Region	Power Fraction			Peak Power ₃ Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1341	0.0051	0.1392	5.128 - 1
D-II	0.2549	0.0096	0.2645	5.469 - 1
D-III	0.4026	0.0144	0.4170	4.301 - 1
IB-I	0.0127	0.0022	0.0149	1.716 - 1
IB-II	0.0343	0.0040	0.0383	2.447 - 1
IB-III	0.0633	0.0093	0.0726	1.757 - 1
RB	0.0263	0.0058	0.0321	8.974 - 2
AB	0.0130	0.0035	0.0165	4.479 - 2
S	0.0	0.0016	0.0016	1.480 - 3
C	<u>0.0</u>	<u>0.0033</u>	<u>0.0033</u>	1.816 - 1
TOTALS	0.9412	0.0588	1.0000	

Table 30. Power Distribution Results for VALE #1 BOC2

Region	Power Fraction			Peak Power ₃ Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1319	0.0045	0.1364	5.269 - 1
D-II	0.2404	0.0083	0.2487	5.420 - 1
D-III	0.4575	0.0151	0.4726	4.799 - 1
IB-I	0.0094	0.0019	0.0113	1.645 - 1
IB-II	0.0220	0.0036	0.0256	2.117 - 1
IB-III	0.0451	0.0088	0.0539	1.703 - 1
RB	0.0260	0.0065	0.0325	9.581 - 2
AB	0.0102	0.0034	0.0136	4.078 - 2
S	0.0	0.0017	0.0017	1.667 - 3
C	<u>0.0</u>	<u>0.0037</u>	<u>0.0037</u>	1.953 - 1
TOTALS	0.9425	0.0575	1.0000	

Table 31. Power Distribution Results for VALE #1 EOC2

Region	Power Fraction			Peak Power ₃ Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1343	0.0054	0.1397	5.206 - 1
D-II	0.2445	0.0100	0.2545	5.222 - 1
D-III	0.3756	0.0143	0.3899	4.069 - 1
IB-I	0.0188	0.0024	0.0212	2.437 - 1
IB-II	0.0422	0.0043	0.0465	3.143 - 1
IB-III	0.0788	0.0094	0.0882	2.298 - 1
RB	0.0310	0.0056	0.0366	9.940 - 2
AB	0.0152	0.0035	0.0187	5.893 - 2
S	0.0	0.0016	0.0016	1.383 - 3
C	<u>0.0</u>	<u>0.0031</u>	<u>0.0031</u>	1.617 - 1
TOTALS	0.9404	0.0596	1.0000	

Table 32. Inventory Results for VALE #1 - Cycle 1

<u>BOC1 Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	5.687 + 1	6.296 + 1	7.181 + 1	4.838 + 1
U236	0.0	0.0	0.0	0.0
U238	2.612 + 4	2.891 + 4	3.297 + 4	2.221 + 4
Pu239	4.101 + 3	0.0	0.0	0.0
Pu240	1.236 + 3	0.0	0.0	0.0
Pu241	6.205 + 2	0.0	0.0	0.0
Pu242	1.481 + 2	0.0	0.0	0.0
FPT	0.0	0.0	0.0	0.0
<u>EOC1 Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	4.595 + 1	5.431 + 1	6.688 + 1	4.583 + 1
U236	2.404 + 0	2.126 + 0	1.302 + 0	6.812 - 1
U238	2.536 + 4	2.838 + 4	3.273 + 4	2.209 + 4
Pu239	3.921 + 3	4.401 + 2	2.175 + 2	1.136 + 2
Pu240	1.302 + 3	1.190 + 1	3.326 + 0	1.267 + 0
Pu241	5.075 + 2	2.372 - 1	3.701 - 2	1.084 - 2
Pu242	1.604 + 2	3.195 - 3	2.264 - 4	5.133 - 5
FPT	9.328 + 2	8.245 + 1	2.686 + 1	1.157 + 1

Table 33. Inventory Results for VALE #1 - Cycle 2

<u>BOC Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	5.177 + 1	5.830 + 1	6.825 + 1	4.719 + 1
U236	1.123 + 0	1.150 + 0	9.432 - 1	3.185 - 1
U238	2.576 + 4	2.863 + 4	3.280 + 4	2.216 + 4
Pu239	4.017 + 3	2.370 + 2	1.560 + 2	5.311 + 1
Pu240	1.267 + 3	6.357 + 0	2.353 + 0	5.936 - 1
Pu241	5.677 + 2	1.253 - 1	2.582 - 2	5.091 - 3
Pu242	1.539 + 2	1.660 - 3	1.548 - 4	2.425 - 5
FPT	4.363 + 2	4.297 + 1	1.864 + 1	5.401 + 0
<u>EOC Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	4.208 + 1	5.034 + 1	6.405 + 1	4.475 + 1
U236	3.194 + 0	3.025 + 0	2.025 + 0	9.604 - 1
U238	2.504 + 4	2.809 + 4	3.257 + 4	2.203 + 4
Pu239	3.851 + 3	6.411 + 2	3.441 + 2	1.626 + 2
Pu240	1.327 + 3	2.837 + 1	8.828 + 0	2.892 + 0
Pu241	4.717 + 2	9.429 - 1	1.668 - 1	4.216 - 2
Pu242	1.639 + 2	2.380 - 2	1.861 - 3	3.776 - 4
FPT	1.324 + 3	1.613 + 2	5.187 + 1	1.943 + 1

Table 34. Comparison of VENTURE #1 and VALE #1
3-D Solutions for LCCEWG BM #4

Time	K_{eff}			Driver Peak Power Density (Kw/cm^3)		
	VENTURE	VALE	% Diff.*	VENTURE	VALE	% Diff.*
BOC1	1.003772	0.996033	-0.77	0.5280	0.5308	0.53
MOC1	1.003669	0.998190	-0.55	0.5537	0.5632	1.72
EOC1	1.001252	0.996742	-0.45	0.5400	0.5469	1.28
BOC2	1.004090	0.998225	-0.58	0.5250	0.5420	3.24
MOC2	1.004227	0.999957	-0.43	0.5292	0.5423	2.48
EOC2	1.002762	0.999273	-0.35	0.5135	0.5222	1.69

*% Diff. is relative to the VENTURE solution

Table 35. Summary Results for VALE #2
(Fine mesh results for 1st cycle)

Parameter	BOC1	MOC1	EOC1
K_{eff}	0.997883	0.999299	0.997614
Fissile Pu (Kg)	4.7217 + 3	4.9693 + 3	5.2010 + 3
Breeding Gain (Kg)	-	-	4.793 + 2
Peak Power (Kw/cm ³)			
Driver Fuel	5.270 - 1	5.599 - 1	5.445 - 1
Inner Blkt	1.041 - 1	1.789 - 1	2.432 - 1
Radial Blkt	8.514 - 2	8.766 - 2	9.116 - 2
Control Rod	2.571 - 1	2.210 - 1	2.229 - 1
Driver Fuel Ave. Power Density (Kw/cm ³)	3.258 - 1	3.108 - 1	2.965 - 1
Driver Fuel Peak/Ave. Power Density	1.618	1.802	1.836

Table 36. Neutron Balance Results for VALE #2 BOC1

<u>Source</u>		
fission	1.00000	
n,2n	0.00255	
TOTAL		1.00255
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00243	0.00744
U236	0.0	0.0
U238	0.48239	0.05999
Pu239	0.05674	0.21529
Pu240	0.01855	0.01504
Pu241	0.00793	0.04385
Pu242	0.00180	0.00129
FPT	0.0	0.0
Structure	0.05802	0.0
Coolant	0.00248	0.0
Other	0.02632	0.0
TOTAL	0.65666	0.34290
TOTAL Absorption		0.99956
<u>Leakage</u>		
Axial	0.00009	
Radial	0.00503	
TOTAL		0.00512
TOTAL Losses		1.00468

Table 37. Neutron Balance Results for VALE #2 EOC1

<u>Source</u>		
fission	1.00000	
n,2n	0.00257	
TOTAL		1.00257
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00195	0.00602
U236	0.00009	0.00001
U238	0.46660	0.05924
Pu239	0.06356	0.22667
Pu240	0.01958	0.01525
Pu241	0.00630	0.03462
Pu242	0.00193	0.00133
FPT	0.01610	0.0
Structure	0.05656	0.0
Coolant	0.00247	0.0
Other	0.02175	0.0
TOTAL	0.65689	0.34314
TOTAL Absorption		1.00003
<u>Leakage</u>		
Axial	0.00011	
Radial	0.00483	
TOTAL		0.00494
TOTAL Losses		1.00497

Table 38. Power Distribution Results for VALE #2 BOC1

Region	Power Fraction			Peak Power ₃ Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1193	0.0037	0.1230	4.683 - 1
D-II	0.2328	0.0073	0.2401	5.233 - 1
D-III	0.5250	0.0159	0.5409	5.270 - 1
IB-I	0.0042	0.0016	0.0058	8.578 - 2
IB-II	0.0114	0.0032	0.0146	1.041 - 1
IB-III	0.0244	0.0087	0.0331	1.006 - 1
RB	0.0182	0.0071	0.0253	8.514 - 2
AB	0.0081	0.0034	0.0115	3.107 - 2
S	0.00	0.0018	0.0018	1.941 - 3
C	<u>0.00</u>	<u>0.0039</u>	<u>0.0039</u>	2.571 - 1
TOTALS	0.9434	0.0566	1.0000	

Table 39. Power Distribution Results for VALE #2 EOC1

Region	Power Fraction			Peak Power Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1336	0.0050	0.1386	5.133 - 1
D-II	0.2549	0.0095	0.2644	5.445 - 1
D-III	0.4053	0.0144	0.4197	4.356 - 1
IB-I	0.0123	0.0021	0.0144	1.701 - 1
IB-II	0.0336	0.0040	0.0376	2.432 - 1
IB-III	0.0625	0.0092	0.0717	1.765 - 1
RB	0.0260	0.0059	0.0319	9.116 - 2
AB	0.0132	0.0035	0.0167	4.982 - 2
S	0.00	0.0018	0.0018	1.500 - 3
C	<u>0.00</u>	<u>0.0032</u>	<u>0.0032</u>	2.229 - 1
TOTALS	0.9414	0.0586	1.0000	

Table 40. Inventory Results for VALE #2

<u>BOC 1 Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	5.687 + 1	6.296 + 1	7.181 + 1	4.838 + 1
U236	0.0	0.0	0.0	0.0
U238	2.612 + 4	2.891 + 4	3.297 + 4	2.221 + 4
Pu239	4.101 + 3	0.0	0.0	0.0
Pu240	1.236 + 3	0.0	0.0	0.0
Pu241	6.205 + 2	0.0	0.0	0.0
Pu242	1.481 + 2	0.0	0.0	0.0
FPT	0.0	0.0	0.0	0.0
<u>EOC 1 Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	4.597 + 1	5.430 + 1	6.683 + 1	4.583 + 1
U236	2.393 + 0	2.137 + 0	1.318 + 0	6.800 - 1
U238	2.536 + 4	2.838 + 4	3.272 + 4	2.209 + 4
Pu239	3.920 + 3	4.400 + 2	2.197 + 2	1.138 + 2
Pu240	1.301 + 3	1.205 + 1	3.420 + 0	1.253 + 0
Pu241	5.074 + 2	2.427 - 1	3.875 - 2	1.050 - 2
Pu242	1.603 + 2	3.291 - 3	2.411 - 4	4.862 - 5
FPT	9.358 + 2	7.982 + 1	2.643 + 1	1.179 + 1

Table 41. Summary Results for VALE #2E
(Fine mesh extrapolated results for 1st cycle)

Parameter	BOC1	MOC1	EOC1
K_{eff}	0.998500	0.999669	0.997905
Fissile Pu (Kg)	4.7217 + 3	4.9693 + 3	5.2012 + 3
Breeding Gain (Kg)	-	-	4.795 + 2
Peak Power (Kw/cm ³)			
Driver Fuel	5.294 - 1	5.588 - 1	5.437 - 1
Inner Blkt	1.035 - 1	1.783 - 1	2.427 - 1
Radial Blkt	8.570 - 2	8.819 - 2	9.163 - 2
Control Rod	2.726 - 1	2.345 - 1	2.367 - 1
Driver Fuel Ave. Power Density (Kw/cm ³)	3.261 - 1	3.111 - 1	2.967 - 1
Driver Fuel Peak/Ave. Power Density	1.623	1.797	1.832

Table 42. Neutron Balance Results for VALE #2E BOC1

<u>Source</u>		
fission	1.00000	
n,2n	0.00256	
TOTAL		1.00256
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00243	0.00744
U236	0.0	0.0
U238	0.48228	0.05988
Pu239	0.05657	0.21534
Pu240	0.01851	0.01510
Pu241	0.00791	0.04382
Pu242	0.00180	0.00130
FPT	0.0	0.0
Structure	0.05836	0.0
Coolant	0.00248	0.0
Other	0.02586	0.0
TOTAL	0.65621	0.34287
TOTAL Absorption		0.99908
<u>Leakage</u>		
Axial	0.00008	
Radial	0.00490	
TOTAL		0.00498
TOTAL Losses		1.00406

Table 43. Neutron Balance Results for VALE #2E EOC1

Source

fission	1.00000
n,2n	0.00257

TOTAL		1.00257
-------	--	---------

AbsorptionsCaptureFission

U235	0.00195	0.00602
U236	0.00009	0.00001
U238	0.46658	0.05917
Pu239	0.06347	0.22669
Pu240	0.01954	0.01529
Pu241	0.00629	0.03461
Pu242	0.00193	0.00134
FPT	0.01606	0.0
Structure	0.05692	0.0
Coolant	0.00247	0.0
Other	0.02143	0.0

TOTAL	0.65673	0.34313
-------	---------	---------

TOTAL Absorption		0.99986
------------------	--	---------

Leakage

Axial	0.00009
Radial	0.00472

TOTAL		0.00482
-------	--	---------

TOTAL Losses		1.00467
--------------	--	---------

Table 44. Power Distribution Results for VALE #2E B0C1

Region	Power Fraction			Peak Power ₃ Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1186	0.0036	0.1222	4.661 - 1
D-II	0.2322	0.0072	0.2394	5.208 - 1
D-III	0.5273	0.0160	0.5433	5.294 - 1
IB-I	0.0041	0.0016	0.0057	8.541 - 2
IB-II	0.0111	0.0032	0.0143	1.035 - 1
IB-III	0.0240	0.0087	0.0327	1.010 - 1
RB	0.0180	0.0071	0.0251	8.570 - 2
AB	0.0082	0.0034	0.0116	3.251 - 2
S	0.00	0.0018	0.0018	1.952 - 3
C	<u>0.00</u>	<u>0.0038</u>	<u>0.0038</u>	2.726 - 1
TOTALS	0.9435	0.0565	1.0000	

Table 45. Power Distribution Results for VALE #2E EOC1

Region	Power Fraction			Peak Power Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1334	0.0050	0.1384	5.135 - 1
D-II	0.2549	0.0095	0.2644	5.437 - 1
D-III	0.4062	0.0144	0.4206	4.374 - 1
IB-I	0.0122	0.0021	0.0142	1.696 - 1
IB-II	0.0334	0.0040	0.0374	2.427 - 1
IB-III	0.0622	0.0092	0.0714	1.768 - 1
RB	0.0259	0.0059	0.0318	9.163 - 2
AB	0.0133	0.0035	0.0168	5.150 - 2
S	0.00	0.0019	0.0019	1.507 - 3
C	<u>0.00</u>	<u>0.0032</u>	<u>0.0032</u>	2.367 - 1
TOTALS	0.9415	0.0585	1.0000	

Table 46. Inventory Results for VALE #2E

<u>BOCI Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	5.687 + 1	6.296 + 1	7.181 + 1	4.838 + 1
U236	0.0	0.0	0.0	0.0
U238	2.612 + 4	2.891 + 4	3.297 + 4	2.221 + 4
Pu239	4.101 + 3	0.0	0.0	0.0
Pu240	1.236 + 3	0.0	0.0	0.0
Pu241	6.205 + 2	0.0	0.0	0.0
Pu242	1.481 + 2	0.0	0.0	0.0
FPT	0.0	0.0	0.0	0.0

<u>EOCI Inventory (Kg)</u>				
	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U235	4.598 + 1	5.430 + 1	6.681 + 1	4.583 + 1
U236	2.389 + 0	2.141 + 0	1.323 + 0	6.796 - 1
U238	2.536 + 4	2.838 + 4	3.272 + 4	2.209 + 4
Pu239	3.920 + 3	4.400 + 2	2.204 + 2	1.139 + 2
Pu240	1.301 + 3	1.210 + 1	3.451 + 0	1.248 + 0
Pu241	5.074 + 2	2.445 - 1	3.933 - 2	1.039 - 2
Pu242	1.603 + 2	3.323 - 3	2.460 - 4	4.772 - 5
FPT	9.368 + 2	7.894 + 1	2.629 + 1	1.186 + 1

Table 47. Summary Results for VALE #3
(Extended Burnup Chains)

Parameter	BOC1	EOC1	EOC2
K_{eff}	0.996033	0.996421	0.998985
Fissile Pu (Kg)	4.7217 + 3	5.2003 + 3	5.4718 + 3
Breeding Gain (Kg)	-	4.786 + 2	4.409 + 2
Peak Power (Kw/cm ³)			
Driver Fuel	5.308 - 1	5.472 - 1	5.223 - 1
Inner Blkt	1.058 - 1	2.446 - 1	3.142 - 1
Radial Blkt	8.345 - 2	8.970 - 2	9.925 - 2
Control Rod	2.107 - 1	1.813 - 1	1.613 - 1
Driver Fuel Ave. Power Density (Kw/cm ³)	3.249 - 1	2.958 - 1	2.827 - 1
Driver Fuel Peak/Ave. Power Density	1.634	1.850	1.848

Table 48. Neutron Balance Results for VALE #3 EOC1

Source

fission	1.00000	
n,2n	0.00258	
TOTAL		1.00258

AbsorptionsCaptureFission

U235	0.00194	0.00600
U236	0.00009	0.00001
U238	0.46576	0.05944
Pu239	0.06362	0.22624
Pu240	0.01965	0.01512
Pu241	0.00631	0.03459
Pu242	0.00194	0.00132
Other Actinides	0.00176	0.00042
FPT	0.01617	0.0
Structure	0.05537	0.0
Coolant	0.00245	0.0
Other	0.02268	0.0
TOTAL	0.65774	0.34314

TOTAL Absorption		1.00088
------------------	--	---------

Leakage

Axial	0.00016	
Radial	0.00515	
TOTAL		0.00531
TOTAL Losses		1.00619

Table 49. Neutron Balance Results for VALE #3 EOC2

<u>Source</u>		
fission	1.00000	
n,2n	0.00258	
TOTAL		1.00258
<u>Absorptions</u>	<u>Capture</u>	<u>Fission</u>
U235	0.00175	0.00542
U236	0.00012	0.00002
U238	0.45520	0.05884
Pu239	0.06567	0.23035
Pu240	0.02002	0.01519
Pu241	0.00573	0.03140
Pu242	0.00195	0.00131
Other Actinides	0.00236	0.00062
FPT	0.02355	0.0
Structure	0.05488	0.0
Coolant	0.00242	0.0
Other	0.02129	0.0
TOTAL	0.65494	0.34315
TOTAL Absorption		0.99809
<u>Leakage</u>		
Axial	0.00017	
Radial	0.00536	
TOTAL		0.00553
TOTAL Losses		1.00362

Table 50. Power Distribution Results for VALE #3 EOC1

Region	Power Fraction			Peak Power ₃ Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1341	0.0051	0.1392	5.128 - 1
D-II	0.2549	0.0096	0.2645	5.472 - 1
D-III	0.4027	0.0144	0.4171	4.302 - 1
IB-I	0.0127	0.0022	0.0149	1.714 - 1
IB-II	0.0342	0.0041	0.0383	2.446 - 1
IB-III	0.0633	0.0092	0.0725	1.755 - 1
RB	0.0263	0.0058	0.0321	8.970 - 2
AB	0.0130	0.0035	0.0165	4.474 - 2
S	0.00	0.0016	0.0016	1.478 - 3
C	<u>0.00</u>	<u>0.0033</u>	<u>0.0033</u>	1.813 - 1
TOTALS	0.9412	0.0588	1.0000	

Table 51. Power Distribution Results for VALE #3 EOC2

Region	Power Fraction			Peak Power ₃ Density (Kw/cm ³)
	Fission	Capture	Total	
D-I	0.1344	0.0054	0.1398	5.207 - 1
D-II	0.2446	0.0100	0.2546	5.223 - 1
D-III	0.3756	0.0143	0.3899	4.068 - 1
IB-I	0.0188	0.0024	0.0212	2.435 - 1
IB-II	0.0422	0.0042	0.0464	3.142 - 1
IB-III	0.0787	0.0095	0.0882	2.296 - 1
RB	0.0309	0.0056	0.0365	9.925 - 2
AB	0.0151	0.0036	0.0187	5.883 - 2
S	0.00	0.0016	0.0016	1.380 - 3
C	<u>0.00</u>	<u>0.0031</u>	<u>0.0031</u>	1.613 - 1
TOTALS	0.9403	0.0597	1.0000	

Table 52. Inventory Results for VALE #3

EOCT Inventory (Kg)

	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U234	4.436 - 3	1.515 - 3	6.005 - 4	2.576 - 4
U235	4.596 + 1	5.431 + 1	6.688 + 1	4.583 + 1
U236	2.403 + 0	2.126 + 0	1.302 + 0	6.810 - 1
U237	1.199 - 1	4.597 - 2	1.491 - 2	6.762 - 3
U238	2.536 + 4	2.838 + 4	3.273 + 4	2.209 + 4
Np237	4.373 + 0	1.539 + 0	5.858 - 1	2.487 - 1
Pu238	1.003 + 0	1.262 - 1	2.374 - 2	7.312 - 3
Pu239	3.922 + 3	4.400 + 2	2.175 + 2	1.136 + 2
Pu240	1.302 + 3	1.189 + 1	3.324 + 0	1.267 + 0
Pu241	5.076 + 2	2.370 - 1	3.697 - 2	1.083 - 2
Pu242	1.607 + 2	3.209 - 3	2.274 - 4	5.155 - 5
Am241	2.588 + 1	2.934 - 3	5.069 - 4	1.392 - 4
Am242	8.426 - 3	1.287 - 6	9.233 - 8	2.140 - 8
Am242m	2.149 - 1	1.327 - 5	1.063 - 6	2.320 - 7
Am243	5.583 + 0	3.520 - 5	1.327 - 3	2.521 - 7
Cm242	9.037 - 1	6.706 - 5	5.083 - 6	1.117 - 6
Cm243	9.741 - 3	5.141 - 7	2.230 - 8	4.221 - 9
Cm244	2.654 - 1	8.338 - 7	1.542 - 8	2.461 - 9
FPT	9.331 + 2	8.244 + 1	2.686 + 1	1.156 + 1

Table 53. Inventory Results for VALE #3

EOC2 Inventory (Kg)

	<u>Driver</u>	<u>Inner Blkt</u>	<u>Radial Blkt</u>	<u>Axial Blkt</u>
U234	5.774 - 3	2.232 - 3	9.534 - 4	3.766 - 4
U235	4.208 + 1	5.034 + 1	6.405 + 1	4.475 + 1
U236	3.193 + 0	3.024 + 0	2.025 + 0	9.601 - 1
U237	1.152 - 1	5.063 - 2	1.513 - 2	7.150 - 3
U238	2.504 + 4	2.809 + 4	3.257 + 4	2.203 + 4
Np237	5.992 + 0	2.452 + 0	9.883 - 1	3.800 - 1
Pu238	2.437 + 0	3.207 - 1	6.625 - 2	1.794 - 2
Pu239	3.851 + 3	6.409 + 2	3.440 + 2	1.625 + 2
Pu240	1.327 + 3	2.835 + 1	8.822 + 0	2.890 + 0
Pu241	4.718 + 2	9.421 - 1	1.667 - 1	4.212 - 2
Pu242	1.645 + 2	2.403 - 2	1.881 - 3	3.813 - 4
Am241	3.409 + 1	2.206 - 2	4.476 - 3	1.067 - 3
Am242	1.078 - 2	9.378 - 6	7.329 - 7	1.562 - 7
Am242m	4.178 - 1	1.797 - 4	1.663 - 5	3.205 - 6
Am243	7.984 + 0	4.989 - 4	1.996 - 5	3.611 - 6
Cm242	1.445 + 0	7.919 - 4	6.545 - 5	1.300 - 5
Cm243	2.659 - 2	1.128 - 5	5.344 - 7	9.641 - 8
Cm244	5.962 - 1	2.250 - 5	4.242 - 7	6.996 - 8
FPT	1.325 + 3	1.613 + 2	5.185 + 1	1.942 + 1

Figure 1. Sensitivity of Nuclide Responses in Subzone 26
of BM4 RZ Model to U238 Capture Cross Section

Figure 2 Sensitivity of Nuclide Responses in Subzone 26
of BM4 RZ Model to Pu 239 Capture Cross Section

Figure 3 Sensitivity of Nuclide Responses in Subzone 26
of BM4 RZ Model to Pu 239 Fission Cross Section

Figure 4 Sensitivity of Pu 239 Inventory Response in Subzone 26
of BM4 R2 Model to Initial Nuclide Concentrations in
Subzone 26

Figure 5 Sensitivity of Pu 240 Inventory Response in Subzone 26 of BM4 R2 Model to Initial Nuclide Concentrations in Subzone 26

Figure 6 Sensitivity of Pu 240/Pu 239 Ratio Response in Subzone 26 of BM4 RZ Model to Initial Nuclide Concentrations in Subzone 26

May 28, 1983

To: LCCEWG Distribution

From: J. R. White JRW

Subject: Power Distribution Data for LCCEWG Benchmark Four

As an action item from the Large Core Code Evaluation Working Group (LCCEWG) meeting at ANL on March 22-23, 1983, ORNL was to supply the working group with comprehensive 3-D power distribution data for the beginning-of-life (BOL) Case 1 Benchmark Four (BM4) configuration. This data is included as Tables 1-4 in this letter and this compilation of axial power profiles for several driver assemblies should allow a more-detailed comparison with the linked RZ-XY calculations.

Tables 1-3 contain VENTURE-calculated axial power densities by triangle for assemblies D-I-1, D-II-2, and D-III-2, respectively (assembly D-III-2 contains the core peak power density of 528.0 watts/cc). The assembly notation is that given in Figure 1. The axial mesh is from the top to the bottom of the reactor, with the mesh spacing as specified for the BM4 reference configuration. Because of symmetry, the axial power distribution for triangle 4 is the same as that for triangle 2 and similarly for triangles 5 and 1.

The 'Total' columns in Tables 1-3 contain the sum of the power densities in the six triangles comprising the assembly of interest. This entry gives a measure of the assembly-averaged axial power distribution. Also tabulated in the last column of Tables 1-3 is an axial 'zone-averaged' distribution. These various degrees of detail should allow a comprehensive comparison with the linked RZ-XY axial (and radial) power distributions.

Table 4 contains a brief comparison of the ORNL VENTURE 3-D and RZ region-averaged axial power profiles for the three driver regions. Qualitatively, there is generally fairly good agreement between the HEX-Z and RZ computations. However, closer analysis shows that the RZ model gives a slight radial power shift to the outer regions of the core and an axial power bias toward the lower half of the reactor. Also as seen for the second driver region, there are absolute differences of up to 10-15% for the first few axial driver zones. These types of differences can be substantial in certain applications. Thus, these results indicate that careful attention is generally required in the quantitative interpretation and application of RZ power distributions.

Table 1. Axial Power Density for BM4 Case 1
in Driver Assembly D-I-1

		Power Density (Watts/cc)						
Triangle #	Zone	Mesh#	1	2	3	6	Total	Zone Ave.
Top Refl	1	1	3.563-3	3.556-3	3.553-3	3.565-3	2.135-2	2.575-1
		2	1.307-2	1.305-2	1.304-2	1.308-2	7.833-2	
		3	3.762-2	3.740-2	3.723-2	3.767-2	2.246-1	
		4	1.172-1	1.270-1	1.082-1	1.181-1	7.057-1	
Ax1 Blkt	1	5	1.062	9.918-1	8.700-1	1.058	5.844	1.090+1
		6	1.779	1.676	1.483	1.761	9.858	
		7	3.016	2.896	2.612	2.959	1.699+1	
	2	8	5.192	5.096	4.702	5.027	2.982+1	6.043+1
		9	9.115	9.157	8.650	8.677	5.341+1	
		10	1.645+1	1.687+1	1.628+1	1.533+1	9.808+1	
Driver	1	11	1.455+2	1.499+2	1.505+2	1.393+2	8.856+2	1.123+3
		12	1.835+2	1.906+2	1.926+2	1.749+2	1.125+3	
		13	2.210+2	2.301+2	2.325+2	2.103+2	1.357+3	
	2	14	2.569+2	2.676+2	2.703+2	2.444+2	1.577+3	1.778+3
		15	2.905+2	3.028+2	3.058+2	2.763+2	1.784+3	
		16	3.215+2	3.351+2	3.384+2	3.057+2	1.974+3	
	3	17	3.492+2	3.642+2	3.679+2	3.320+2	2.145+3	2.287+3
		18	3.735+2	3.897+2	3.937+2	3.550+2	2.295+3	
		19	3.940+2	4.112+2	4.156+2	3.744+2	2.422+3	
	4	20	4.103+2	4.284+2	4.332+2	3.899+2	2.523+3	2.589+3
		21	4.223+2	4.411+2	4.463+2	4.012+2	2.598+3	
		22	4.297+2	4.491+2	4.545+2	4.081+2	2.645+3	
	5	23	4.324+2	4.521+2	4.578+2	4.106+2	2.663+3	2.641+3
		24	4.303+2	4.501+2	4.560+2	4.086+2	2.651+3	
		25	4.233+2	4.431+2	4.490+2	4.019+2	2.609+3	
	6	26	4.115+2	4.310+2	4.369+2	3.907+2	2.538+3	2.429+3
		27	3.951+2	4.139+2	4.199+2	3.749+2	2.438+3	
		28	3.741+2	3.922+2	3.981+2	3.549+2	2.310+3	
	7	29	3.487+2	3.660+2	3.719+2	3.308+2	2.155+3	1.970+3
		30	3.194+2	3.357+2	3.416+2	3.029+2	1.977+3	
		31	2.866+2	3.018+2	3.079+2	2.716+2	1.778+3	
	8	32	2.508+2	2.649+2	2.714+2	2.375+2	1.561+3	1.332+3
		33	2.129+2	2.260+2	2.332+2	2.015+2	1.333+3	
		34	1.744+2	1.868+2	1.950+2	1.649+2	1.103+3	
Ax1 Blkt	1	35	2.011+1	2.170+1	2.253+1	1.848+1	1.271+2	8.530+1
		36	1.191+1	1.321+1	1.446+1	1.102+1	7.827+1	
		37	7.431	8.483	9.637	6.882	5.055+1	
	2	38	4.838	5.671	6.622	4.462	3.389+1	2.501+1
		39	3.286	3.951	4.730	3.012	2.366+1	
		40	2.363	2.903	3.576	2.152	1.747+1	
Bot Refl	1	41	2.775-1	3.153-1	3.420-1	2.600-1	1.852	1.022
		42	2.960-2	3.246-2	3.401-2	2.814-2	1.907-1	

Table 2. Axial Power Density for BM4 Case 1
in Driver Assembly D-II-2

			Power Density (Watts/cc)					
Triangle # Zone		Mesh#	1	2	3	6	Total	Zone Ave.
Top Refl	1	1	3.408-3	3.373-3	3.354-3	3.425-3	2.029-2	2.415-1
		2	1.265-2	1.255-2	1.250-2	1.269-2	7.544-2	
		3	3.663-2	3.639-2	3.620-2	3.672-2	2.185-1	
		4	1.125-1	1.085-1	1.044-1	1.134-1	6.517-1	
Ax1 Blkt	1	5	1.030	9.113-1	7.775-1	1.061	5.469	1.004+1
		6	1.725	1.515	1.292	1.783	9.122	
		7	2.930	2.569	2.208	3.035	1.552+1	
	2	8	5.053	4.424	3.828	5.243	2.680+1	5.293+1
		9	8.895	7.760	6.727	9.247	4.712+1	
		10	1.612+1	1.398+1	1.202+1	1.679+1	8.491+1	
Driver	1	11	1.362+2	1.157+2	9.496+1	1.429+2	7.004+2	8.883+2
		12	1.722+2	1.465+2	1.205+2	1.807+2	8.869+2	
		13	2.089+2	1.780+2	1.467+2	2.192+2	1.078+3	
	2	14	2.453+2	2.094+2	1.730+2	2.572+2	1.267+3	1.455+3
		15	2.811+2	2.406+2	1.992+2	2.944+2	1.455+3	
		16	3.161+2	2.719+2	2.258+2	3.305+2	1.642+3	
	3	17	3.504+2	3.038+2	2.539+2	3.654+2	1.831+3	2.037+3
		18	3.843+2	3.375+2	2.860+2	3.991+2	2.030+3	
		19	4.174+2	3.742+2	3.271+2	4.311+2	2.251+3	
	4	20	4.485+2	4.128+2	3.814+2	4.602+2	2.497+3	2.671+3
		21	4.745+2	4.445+2	4.203+2	4.843+2	2.688+3	
		22	4.938+2	4.677+2	4.478+2	5.023+2	2.827+3	
	5	23	5.059+2	4.826+2	4.654+2	5.134+2	2.915+3	2.939+3
		24	5.106+2	4.893+2	4.740+2	5.174+2	2.955+3	
		25	5.081+2	4.883+2	4.744+2	5.142+2	2.948+3	
	6	26	4.983+2	4.800+2	4.673+2	5.040+2	2.897+3	2.791+3
		27	4.818+2	4.647+2	4.530+2	4.869+2	2.804+3	
		28	4.587+2	4.430+2	4.324+2	4.634+2	2.673+3	
	7	29	4.296+2	4.153+2	4.059+2	4.338+2	2.506+3	2.297+3
		30	3.949+2	3.823+2	3.742+2	3.897+2	2.307+3	
		31	3.552+2	3.445+2	3.380+2	3.585+2	2.079+3	
	8	32	3.113+2	3.028+2	2.983+2	3.141+2	1.828+3	1.559+3
		33	2.644+2	2.583+2	2.563+2	2.665+2	1.560+3	
		34	2.164+2	2.131+2	2.138+2	2.178+2	1.288+3	
Ax1 Blkt	1	35	2.570+1	2.515+1	2.501+1	2.586+1	1.519+2	1.009+2
		36	1.503+1	1.516+1	1.589+1	1.504+1	9.217+1	
		37	9.261	9.624	1.048+1	9.223	5.869+1	
	2	38	5.974	6.371	7.139	5.922	3.892+1	2.855+1
		39	4.034	4.404	5.061	3.982	2.695+1	
		40	2.891	3.218	3.805	2.843	1.978+1	
Bot Refl	1	41	3.396-1	3.524-1	3.704-1	3.393-1	2.125	1.172
		42	3.604-2	3.635-2	3.698-2	3.622-2	2.190-1	

Table 3. Axial Power Density for BM4 Case 1
in Driver Assembly D-III-2

		Power Density (Watts/cc)						
Triangle # Zone	Mesh#	1	2	3	6	Total	Zone Ave.	
Top Refl	1	1	2.822-3	2.709-3	2.650-3	2.875-3	1.642-2	2.307-1
		2	1.087-2	1.046-2	1.024-2	1.105-2	6.332-2	
		3	3.363-2	3.240-2	3.162-2	3.408-2	1.958-1	
		4	1.140-1	1.077-1	1.014-1	1.151-1	6.473-1	
Axl Blkt	1	5	1.152	1.067	9.301-1	1.155	6.301	1.203+1
		6	1.967	1.839	1.618	1.963	1.084+1	
		7	3.387	3.220	2.887	3.363	1.896+1	
	2	8	5.915	5.724	5.244	5.840	3.369+1	6.907+1
		9	1.053+1	1.035+1	9.686	1.034+1	6.094+1	
		10	1.921+1	1.910+1	1.818+1	1.881+1	1.126+2	
Driver	1	11	1.634+2	1.631+2	1.580+2	1.599+2	9.655+2	1.225+3
		12	2.067+2	2.074+2	2.016+2	2.020+2	1.227+3	
		13	2.500+2	2.508+2	2.435+2	2.443+2	1.483+3	
	2	14	2.919+2	2.925+2	2.837+2	2.856+2	1.730+3	1.959+3
		15	3.320+2	3.320+2	3.216+2	3.251+2	1.964+3	
		16	3.697+2	3.689+2	3.569+2	3.626+2	2.184+3	
	3	17	4.047+2	4.028+2	3.891+2	3.979+2	2.386+3	2.561+3
		18	4.367+2	4.332+2	4.178+2	4.304+2	2.569+3	
		19	4.650+2	4.596+2	4.426+2	4.597+2	2.729+3	
	4	20	4.889+2	4.815+2	4.630+2	4.850+2	2.863+3	2.955+3
		21	5.077+2	4.983+2	4.784+2	5.051+2	2.966+3	
		22	5.207+2	5.096+2	4.886+2	5.193+2	3.036+3	
	5	23	5.274+2	5.149+2	4.933+2	5.270+2	3.071+3	3.056+3
		24	5.276+2	5.142+2	4.922+2	5.280+2	3.068+3	
		25	5.212+2	5.073+2	4.852+2	5.222+2	3.028+3	
	6	26	5.083+2	4.942+2	4.725+2	5.097+2	2.951+3	2.827+3
		27	4.891+2	4.751+2	4.542+2	4.907+2	2.838+3	
		28	4.637+2	4.503+2	4.305+2	4.655+2	2.691+3	
	7	29	4.327+2	4.200+2	4.018+2	4.345+2	2.511+3	2.293+3
		30	3.964+2	3.849+2	3.685+2	3.981+2	2.301+3	
		31	3.554+2	3.453+2	3.313+2	3.570+2	2.066+3	
	8	32	3.105+2	3.022+2	2.909+2	3.119+2	1.809+3	1.536+3
		33	2.627+2	2.566+2	2.485+2	2.639+2	1.537+3	
		34	2.141+2	2.103+2	2.059+2	2.150+2	1.262+3	
Axl Blkt	1	35	2.552+1	2.523+1	2.487+1	2.555+1	1.513+2	9.977+1
		36	1.483+1	1.505+1	1.558+1	1.480+1	9.089+1	
		37	9.061	9.409	1.010+1	9.013	5.709+1	
	2	38	5.780	6.124	6.750	5.738	3.727+1	2.704+1
		39	3.857	4.163	4.704	3.823	2.541+1	
		40	2.738	3.004	3.491	2.708	1.844+1	
Bot Refl	1	41	3.110-1	3.169-1	3.284-1	3.135-1	1.915	1.054
		42	3.226-2	3.195-2	3.210-2	3.273-2	1.913-1	

Table 4. Comparison of BM4 BOL HEX-Z and RZ Zonewise Axial Power Distributions

		Power by Axial Zone* (MWth)					
Zone		D-I		D-II		D-III	
		HEX-Z	RZ	HEX-Z	RZ	HEX-Z	RZ
Top Axl Blkt	1	0.05	0.04	0.09	0.06	0.22	0.20
	2	0.25	0.21	0.44	0.36	1.15	1.13
Driver	1	3.86	3.51	6.85	5.77	17.33	17.58
	2	6.10	5.64	11.02	9.62	27.41	28.11
	3	7.85	7.34	14.70	13.41	35.41	36.43
	4	8.88	8.40	17.55	16.95	40.32	41.65
	5	9.06	8.65	18.53	18.41	41.20	42.54
	6	8.33	8.00	17.34	17.46	37.77	38.93
	7	6.74	6.52	14.18	14.36	30.36	31.19
	8	4.52	4.40	9.58	9.71	20.03	20.45
Bot Axl Blkt	1	0.32	0.32	0.70	0.71	1.42	1.44
	2	0.09	0.09	0.19	0.19	0.35	0.34

*Power tabulated is for 1/6 of total reactor.

Figure 1. Notation Used to Designate Assembly Location

WARD RESULTS FOR THE
LARGE CORE CODE EVALUATION WORKING GROUP
BENCHMARK PROBLEM IV

S. K. Varner
Westinghouse Advanced Reactors Division
P.O. Box 158
Madison, Pennsylvania 15663

October 29, 1982

Work Performed Under Auspices of the U.S. Department of Energy, Division of
Reactor Research and Technology.

Contract: DE-AM02-76CH94000

Task: DE-AT02-80CH94050

WARD analysis of LCCEWG Benchmark 4 has been completed for the specified configuration using the RZ-hex synthesis method to simulate three-dimensions. Results are presented here for two cases - the base case utilized the specified hexagonal model with two burnup zones per ring, (one zone for each refuel batch), while the second case used a hexagonal model with burnup by individual assembly. The same RZ model was linked with each of the hex models to produce the two sets of results given in this report. The cross section set used was an eight neutron energy group library supplied by GE-ARSD.²

Figure 1 shows the hexagonal layout specified for this 2740 Mwt reactor. A scatter refueling scheme (shown in Figure 1) is employed after a cycle length of 383.5 full power days. The refueling interval for fuel and inner blanket assemblies is two cycles and for the radial blankets is four cycles.

The RZ model used is shown in Figure 2, and is the same as that specified.¹ Region and energy group dependent axial bucklings were calculated in the RZ model at beginning and end of each cycle to be applied to the hexagonal model. Both the hex and RZ burnup calculations using 2DB³ were done in two steps for each of the two cycles. The first half of each cycle was burned with the operating control rods at the appropriate depth for the beginning of that cycle and the second half of each cycle was burned with the rods at the end of cycle configuration. Refueling was performed as specified at the end of cycle one in both the RZ and hex models. The partial control rod insertions were simulated in the hex model by using reduced number densities for the control rod. The fraction by which the densities are reduced in each case was determined from a curve showing the relation between rod insertion in the RZ model and the fraction to be used in the hex model. The curve was derived by making a series of RZ calculations with different rod insertions and comparing the fraction of total worth inserted with the same parameter calculated in a series of hex calculations with different fractions of control rod. This assures that the same fraction of total rod worth is inserted in both the hex and RZ model.

Figure 3 specifies the mesh and assembly identifications used in peak power tabulations. Following this figure are the requested results, first for the base case, then for the assembly-wise hex burnup case.

It should be noted that the burnups (average and peak) given in Section C for both cases are only for assemblies discharged at that time in life. That is, the average does not include burnup in those assemblies which will remain another cycle. The peak burnup is calculated by using the following equation:

$$\text{Peak Burnup (MWD/MT)} = \frac{2740 \text{ MW} * 383.5 \text{ Days}}{\text{HM/Assy (MT)} * \text{No. Assys} * 2} * \sum_i \text{PF}_i * F_{R_i}^N * F_{Z_i}^N$$

where the subscript i includes the start and end of consecutive cycles, i.e., BOC1 and EOC1 for assemblies discharged at EOC1, and BOC1, EOC1, BOC2, and EOC2 for assemblies discharged at EOC2,

HM/assy is the total MT of heavy metal per assembly,

PF_i is the fuel, inner blanket, radial blanket, or axial blanket power fraction at the start- or end-of-cycle,

$F_{R_i}^N$ is the radial mesh power factor for the fuel or blankets,

$F_{Z_i}^N$ is the axial peak/average power factor at the same radial mesh,

and No. Assys is the number of fuel, inner blanket, radial blanket, or axial blanket assemblies in the reactor.

The peak burnup is then determined by finding the radial mesh for which the above equation is maximized. Also, in Section E, it should be noted that the (n,2n) term is not explicitly included as a neutron source. The use of this term as a source would have necessitated major changes to the 2DB³ code.

Differences between the base case and the assembly-wise hex burn case appear to be minor. One difference which should be noted is the increase in radial blanket peak power in the assembly-wise burnup case. This is due to the better representation of the Pu buildup in the radial blankets nearest the core, resulting in higher power in these assemblies than when they were lumped with the rest of the radial blankets.

References:

1. C. L. Cowan, R. Protsik, "Specifications for the Large Core Code Evaluation Working Group Benchmark Problem Four," XL-589-10074, September 29, 1981.
2. R. Protsik, C. L. Cowan, "Group Cross Sections for LCCEWG Benchmark 4," YL-588-20031, March 8, 1982.
3. W. W. Little, Jr. and R. W. Hardie, "2DB User's Manual, Revision 1," BNWL-831-(Rev. 1), August, 1969.

FIGURE 1

REFUELING SCHEME FOR BENCHMARK PROBLEM FOUR

FIGURE 2

LCCEWG BENCHMARK 4 RZ MODEL

FIGURE 3
SIXTY DEGREE SECTOR OF CORE LAYOUT
FOR BENCHMARK PROBLEM FOUR SHOWING
DRIVER, BLANKET AND SHIELD ASSEMBLY
IDENTIFICATION

LCCEWG BENCHMARK 4
GENERAL COMMENTS

A. Codes Used 2DB

B. Convergence Criteria Eigenvalue: 10^{-6}
 Pointwise Fluxes: 10^{-5}

C. Method of Burnup Calculations The burnup calculations (both hex and RZ) were done in 2DB in the manner specified. Two different hex models were used in this analysis. The base case is a hex which has two burnup zones for each fuel or blanket ring (one zone for each refuel batch). The second hex model represents each assembly as a separate burnup zone. Region and groupwise bucklings calculated in the RZ were used in the hex models.

D. Analysis Procedures

Geometry

5

1. HEX-Z Direct
2. HEX-Z Synthesis
3. HEX X-Y
4. R-Z
5. Linked R-Z and HEX X-Y
6. Other (describe)

Cross Sections

1

1. GE-8 Group
2. Other (describe)

Fuel Management Plan

1

1. Recommended two cycle reload plan
2. Other (describe)

Fuel Burnup Chain

1

1. Abbreviated burnup chain with uranium and plutonium isotopes only (including Pu-241 decay)
2. Extended burnup chain
3. Other (describe)

Lumped Fission Products2

1. Recommended - 2 Fission Product Pairs (odd, even)
2. Recommended - 1 Fission Product Pair
3. Other (describe)

Energy Deposition1

1. In-Situ fission plus capture gamma's
2. In-Situ fission only
3. Other (describe)

Treatment of Control Rods1

1. Control positioned at the recommended BOC location during the first half of the irradiation cycle, and at the recommended EOC location during the last half of the irradiation cycle
2. Positioned as recommended at the beginning-of-cycle and left unchanged during the burnup calculations
3. All control out
4. Other (describe)

Calculation of Control Rod WorthNone

1. Direct 3-D calculation
2. Synthesis 3-D calculations
3. R-Z calculations
4. R-Z calculations (Modified B_{10} Density)
5. X-Y HEX
6. Other (describe)

Core Layout1

1. Recommended
2. Other (describe)

Mesh Spacings1

1. Recommended
2. Other (describe)

Flux Solutions During Irradiation Cycle1

1. Recommended
2. Other (describe)

LCCEWG BENCHMARK 4
Results for Base Case
 (Linked RZ and Hex)

A. General

	<u>BOC1</u>	<u>EOC1</u>	<u>BOC2</u>	<u>EOC2</u>
1. k_{eff}	1.00329	1.00038	1.00345	1.00188
4. Breeding Gain (kg Fissile Pu)	----	461.9	----	427.2
5. Peak Power (kW/cm ³)				
Driver - Peak	5.331E-1	5.446E-1	5.222E-1	5.150E-1
- Position	D-II-1-3, 149.86cm	D-II-1-3, 154.94cm	D-II-3-5, 149.86cm	D-II-3-5, 154.94cm
Inner Blanket - Peak	8.180E-2	2.154E-1	1.733E-1	2.822E-1
- Position	IB-II-1-3, 149.86cm	IB-II-1-4, 154.94cm	IB-II-2-5, 154.94cm	IB-II-2-5, 154.94cm
Radial Blanket - Peak	6.224E-2	7.333E-2	7.615E-2	8.107E-2
- Position	RB-6-6, 154.94cm	RB-6-6, 154.94cm	RB-1-6, 154.94cm	RB-1-6, 154.94cm
6. Driver Fuel Peak/ Average Power	1.629	1.816	1.671	1.796
7. Driver Fuel Axial Peak/ Average Power (at Position of Peak Power)	1.397	1.318	1.337	1.291

LCCEWG BENCHMARK 4
Results for Base Case
 (Linked RZ and Hex)

B.1 Power - BOC1

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (kW/cm³)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	.1190	.0036	.1226	4.665E-1
D-II	.2345	.0072	.2417	5.331E-1
D-III	.5284	.0154	.5438	5.232E-1
IB-I	.0039	.0015	.0054	6.561E-2
IB-II	.0106	.0031	.0137	8.180E-2
IB-III	.0230	.0082	.0312	7.708E-2
RB	.0172	.0068	.0240	6.224E-2
AB	.0078	.0033	.0111	2.557E-2
S	0.0	.0016	.0016	-----
C	0.0	.0049	.0049	-----
			1.0000	

B.2 Power - EOC1

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (kW/cm³)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	.1328	.0045	.1373	5.074E-1
D-II	.2562	.0085	.2647	5.446E-1
D-III	.4165	.0135	.4300	4.297E-1
IB-I	.0113	.0019	.0132	1.415E-1
IB-II	.0314	.0037	.0351	2.154E-1
IB-III	.0586	.0085	.0671	1.556E-1
RB	.0252	.0055	.0307	7.333E-2
AB	.0131	.0033	.0164	4.346E-2
S	0.0	.0014	.0014	-----
C	0.0	.0041	.0041	-----
			1.0000	

LCCEWG BENCHMARK 4
Results for Base Case
 (Linked RZ and Hex)

B.3 Power - BOC2

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (kW/cm³)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	.1289	.0041	.1330	5.068E-1
D-II	.2406	.0070	.2476	5.222E-1
D-III	.4720	.0145	.4865	4.793E-1
IB-I	.0083	.0018	.0101	1.308E-1
IB-II	.0197	.0034	.0231	1.733E-1
IB-III	.0414	.0083	.0497	1.458E-1
RB	.0246	.0062	.0308	7.615E-2
AB	.0098	.0035	.0133	3.135E-2
S	0.0	.0016	.0016	-----
C	0.0	.0043	.0043	-----
			1.0000	

B.4 Power - EOC2

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (kW/cm³)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	.1344	.0047	.1391	5.122E-1
D-II	.2472	.0087	.2559	5.150E-1
D-III	.3877	.0131	.4008	4.023E-1
IB-I	.0169	.0021	.0190	2.094E-1
IB-II	.0397	.0038	.0435	2.822E-1
IB-III	.0741	.0086	.0827	2.031E-1
RB	.0297	.0053	.0350	8.107E-2
AB	.0151	.0033	.0184	4.839E-2
S	0.0	.0016	.0016	-----
C	0.0	.0040	.0040	-----
			1.0000	

LCCEWG BENCHMARK 4
Results for Base Case
 (Linked RZ and Hex)

C.1 Burnup* - Assemblies Discharged at EOC1

<u>Zone</u>	<u>Average Burnup (MWD/MT)</u>	<u>Peak Burnup (MWD/MT)</u>
D-I	31463.	43796.
D-II	30295.	47710.
D-III	26511.	42339.
IB-I	2214.	6344.
IB-II	4720.	10580.
IB-III	2826.	7871.
RB	1007.	4841.
AB	646.	2625.

C.2 Burnup* - Assemblies Discharged at EOC2

<u>Zone</u>	<u>Average Burnup (MWD/MT)</u>	<u>Peak Burnup (MWD/MT)</u>
D-I	64635.	87176.
D-II	61891.	93324.
D-III	49589.	80992.
IB-I	5886.	19545.
IB-II	11458.	25668.
IB-III	7151.	19785.
RB	1905.	7831.
AB	1376.	5595.

*Burnup is Calculated From Total (Fission & Capture) Power Fraction for Each Region.

LCCEWG BENCHMARK 4
Results for Base Case
 (Linked RZ and Hex)

D.1 Fuel Inventory (Kg) - BOC1

	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blankets</u>	<u>Axial Blanket Extensions</u>
U-235	5.688E+1	6.296E+1	7.180E+1	4.837E+1
U-236	0.0	0.0	0.0	0.0
U-238	2.612E+4	2.891E+4	3.297E+4	2.221E+4
Pu-239	4.100E+3	0.0	0.0	0.0
Pu-240	1.236E+3	0.0	0.0	0.0
Pu-241	6.203E+2	0.0	0.0	0.0
Pu-242	1.481E+2	0.0	0.0	0.0
FP	0.0	0.0	0.0	0.0

D.2 Fuel Inventory (Kg) - EOC1

	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blankets</u>	<u>Axial Blanket Extensions</u>
U-235	4.594E+1	5.438E+1	6.689E+1	4.591E+1
U-236	2.387E+0	2.129E+0	1.304E+0	6.563E-1
U-238	2.537E+4	2.840E+4	3.273E+4	2.209E+4
Pu-239	3.914E+3	4.348E+2	2.166E+2	1.099E+2
Pu-240	1.298E+3	1.135E+1	3.185E+0	1.198E+0
Pu-241	5.066E+2	2.076E-1	3.255E-2	1.020E-2
Pu-242	1.601E+2	2.432E-3	1.740E-4	4.840E-5
FP	9.181E+2	7.199E+1	2.437E+1	1.134E+1

LCCEWG BENCHMARK 4
Results for Base Case
 (Linked RZ and Hex)

D.3 Fuel Inventory (Kg) - BOC2

	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blankets</u>	<u>Axial Blanket Extensions</u>
U-235	5.176E+1	5.835E+1	6.824E+1	4.723E+1
U-236	1.115E+0	1.151E+0	9.454E-1	3.046E-1
U-238	2.577E+4	2.863E+4	3.280E+4	2.216E+4
Pu-239	4.012E+3	2.339E+2	1.556E+2	5.103E+1
Pu-240	1.265E+3	6.061E+0	2.242E+0	5.539E-1
Pu-241	5.673E+2	1.099E-1	2.242E-2	4.696E-3
Pu-242	1.537E+2	1.268E-3	1.162E-4	2.224E-5
FP	4.293E+2	3.746E+1	1.695E+1	5.269E+0

D.4 Fuel Inventory (Kg) - EOC2

	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blankets</u>	<u>Axial Blanket Extensions</u>
U-235	4.195E+1	5.038E+1	6.402E+1	4.487E+1
U-236	3.205E+0	3.049E+0	2.037E+0	9.264E-1
U-238	2.504E+4	2.811E+4	3.257E+4	2.204E+4
Pu-239	3.837E+3	6.376E+2	3.446E+2	1.573E+2
Pu-240	1.322E+3	2.737E+1	8.525E+0	2.753E+0
Pu-241	4.696E+2	8.428E-1	1.483E-1	4.030E-2
Pu-242	1.635E+2	1.853E-2	1.439E-3	3.648E-4
FP	1.291E+3	1.412E+2	4.732E+1	1.888E+1

LCCEWG BENCHMARK 4
Results for Base Case
 (Linked RZ and Hex)

E.1 Neutron Balance for Reactor - BOC1

<u>Source</u>		
Fission	1.00000	
n,2n	0.00000	
Total Source		1.00000

<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>	
U-235	0.00238	0.00737	
U-236	0.00000	0.00000	
U-238	0.47545	0.05989	
Pu-239	0.05591	0.21691	
Pu-240	0.01838	0.01541	
Pu-241	0.00782	0.04394	
Pu-242	0.00176	0.00132	
Fission Products	0.00000	0.00000	
Structure*	0.05740	0.00000	
Coolant	0.00243	0.00000	
Control	0.02893	0.00000	
Total	0.65046	0.34484	
Total Absorptions			0.99530

<u>Leakage</u>		
Axial	0.00036	
Radial	0.00434	
Total Leakage		0.00470
Total Losses		1.00000

*Includes 0-16

LCCEWG BENCHMARK 4
Results for Base Case
 (Linked RZ and Hex)

E.2 Neutron Balance for Reactor - EOC1

<u>Source</u>		
Fission	1.00000	
n,2n	0.00000	
Total Source		1.00000

<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>	
U-235	0.00196	0.00606	
U-236	0.00009	0.00001	
U-238	0.46323	0.05930	
Pu-239	0.06293	0.22752	
Pu-240	0.01944	0.01554	
Pu-241	0.00634	0.03525	
Pu-242	0.00191	0.00136	
Fission Products	0.01451	0.00000	
Structure*	0.05622	0.00000	
Coolant	0.00246	0.00000	
Control	0.02141	0.00000	
Total	0.65050	0.34504	
Total Absorptions			0.99554

<u>Leakage</u>		
Axial	0.00043	
Radial	0.00403	
Total Leakage		0.00446
Total Losses		1.00000

*Includes 0-16

LCCEWG BENCHMARK 4
Results for Base Case
 (Linked RZ and Hex)

E.3 Neutron Balance for Reactor - BOC2

Source

Fission	1.00000	
n,2n	0.00000	
Total Source		1.00000

Absorptions

Captures

Fissions

U-235	0.00217	0.00669	
U-236	0.00004	0.00001	
U-238	0.46820	0.05972	
Pu-239	0.05984	0.22257	
Pu-240	0.01879	0.01540	
Pu-241	0.00709	0.03966	
Pu-242	0.00183	0.00134	
Fission Products	0.00684	0.00000	
Structure*	0.05670	0.00000	
Coolant	0.00246	0.00000	
Control	0.02596	0.00000	
Total	0.64992	0.34539	
Total Absorptions			0.99531

Leakage

Axial	0.00039	
Radial	0.00430	
Total Leakage		0.00469
Total Losses		1.00000

*Includes 0-16

LCCEWG BENCHMARK 4
Results for Base Case
 (Linked RZ and Hex)

E.4 Neutron Balance for Reactor - EOC2

<u>Source</u>		
Fission	1.00000	
n,2n	0.00000	
Total Source		1.00000
<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00177	0.00550
U-236	0.00012	0.00002
U-238	0.45462	0.05903
Pu-239	0.06561	0.23198
Pu-240	0.01986	0.01559
Pu-241	0.00578	0.03212
Pu-242	0.00193	0.00135
Fission Products	0.02106	0.00000
Structure*	0.05569	0.00000
Coolant	0.00245	0.00000
Control	0.02088	0.00000
Total	0.64977	0.34559
Total Absorptions		0.99536
<u>Leakage</u>		
Axial	0.00046	
Radial	0.00418	
Total Leakage		0.00464
Total Losses		1.00000

*Includes 0-16

LCCEWG BENCHMARK 4
Results for Base Case

F. Reactivity Effects - Cycle 1

Global Reactivity Loss Per Cycle $(k_{\text{eff}}^{(2)} - k_{\text{eff}}^{(1)})/k_{\text{eff}}^{(1)}$	-0.00832
Reactivity Gain Due to Pu Build-Up in Blankets $(k_{\text{eff}}^{(3)} - k_{\text{eff}}^{(1)})/k_{\text{eff}}^{(1)}$	+0.03977
Reactivity Loss Due to FP Build-Up $(k_{\text{eff}}^{(4)} - k_{\text{eff}}^{(1)})/k_{\text{eff}}^{(1)}$	-0.01235
Reactivity Loss Due to Burnup of Pu and U Isotopes $(k_{\text{eff}}^{(5)} - k_{\text{eff}}^{(1)})/k_{\text{eff}}^{(1)}$	-0.03731

$k_{\text{eff}}^{(1)}$ = k_{eff} Corresponding to BOC1 Composition.

$k_{\text{eff}}^{(2)}$ = k_{eff} Corresponding to EOC1 Composition With BOC1 Control Configuration.

$k_{\text{eff}}^{(3)}$ = k_{eff} Corresponding to BOC1 Compositions for Driver Zones and EOC1 Compositions for Blankets (Axial, Inner, and Radial), Including FP.

$k_{\text{eff}}^{(4)}$ = k_{eff} Corresponding to BOC1 Composition but Including EOC1 FP Densities.

$k_{\text{eff}}^{(5)}$ = k_{eff} Corresponding to EOC1 Pu and U Densities in the Driver Fuel and BOC1 Compositions for Everything Else.
 No FP Present in Driver.

LCCEWG BENCHMARK 4
Results for Assembly-Wise Hex Burn
(Linked RZ and Hex)

A. General

	BOC1	EOC1	BOC2	EOC2
1. k_{eff}	1.00329	1.00101	1.00387	1.00271
4. Breeding Gain (kg Fissile Pu)	----	461.1	----	425.7
5. Peak Power (kW/cm ³)				
Driver - Peak	5.331E-1	5.356E-1	5.183E-1	5.078E-1
- Position	D-II-1-3, 149.86cm	D-II-1-3, 154.94cm	D-II-3-5, 149.86cm	D-I-3-6, 154.94cm
Inner Blanket - Peak	8.180E-2	2.125E-1	1.722E-1	2.790E-1
- Position	IB-II-1-3, 149.86cm	IB-II-1-4, 154.94cm	IB-II-2-5, 154.94cm	IB-II-2-5, 154.94cm
Radial Blanket - Peak	6.224E-2	8.482E-2	1.011E-1	1.435E-1
- Position	RB-6-6, 154.94cm	RB-6-6, 154.94cm	RB-1-6, 154.94cm	RB-1-6, 154.94cm
6. Driver Fuel Peak/ Average Power	1.629	1.789	1.660	1.774
7. Driver Fuel Axial Peak/ Average Power (at Position of Peak Power)	1.397	1.318	1.337	1.286

LCCEWG BENCHMARK 4
Results for Assembly-Wise Hex Burn
 (Linked RZ and Hex)

B.1 Power - BOC1

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (kW/cm³)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	.1190	.0036	.1226	4.665E-1
D-II	.2345	.0072	.2417	5.331E-1
D-III	.5284	.0154	.5438	5.232E-1
IB-I	.0039	.0015	.0054	6.561E-2
IB-II	.0106	.0031	.0137	8.180E-2
IB-III	.0230	.0082	.0312	7.708E-2
RB	.0172	.0068	.0240	6.224E-2
AB	.0078	.0033	.0111	2.557E-2
S	0.0	.0016	.0016	-----
C	0.0	.0049	.0049	-----
			1.0000	

B.2 Power - EOC1

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (kW/cm³)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	.1319	.0044	.1363	5.030E-1
D-II	.2544	.0083	.2627	5.356E-1
D-III	.4182	.0133	.4315	4.246E-1
IB-I	.0114	.0019	.0133	1.513E-1
IB-II	.0311	.0037	.0348	2.125E-1
IB-III	.0585	.0084	.0669	1.599E-1
RB	.0268	.0056	.0324	8.482E-2
AB	.0131	.0033	.0164	4.346E-2
S	0.0	.0015	.0015	-----
C	0.0	.0042	.0042	-----
			1.0000	

LCCEWG BENCHMARK 4
Results for Assembly-Wise Hex Burn
 (Linked RZ and Hex)

B.3 Power - BOC2

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (kW/cm³)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	.1284	.0040	.1324	5.045E-1
D-II	.2394	.0068	.2462	5.183E-1
D-III	.4732	.0143	.4875	4.783E-1
IB-I	.0084	.0018	.0102	1.402E-1
IB-II	.0196	.0034	.0230	1.722E-1
IB-III	.0415	.0081	.0496	1.511E-1
RB	.0258	.0062	.0320	1.011E-1
AB	.0098	.0035	.0133	3.135E-2
S	0.0	.0016	.0016	-----
C	0.0	.0042	.0042	-----
			1.0000	

B.4 Power - EOC2

<u>Zone</u>	<u>Power Fraction</u>			<u>Peak Power Density (kW/cm³)</u>
	<u>Fission</u>	<u>Capture</u>	<u>Total</u>	
D-I	.1335	.0047	.1382	5.078E-1
D-II	.2453	.0086	.2539	5.052E-1
D-III	.3892	.0129	.4021	3.977E-1
IB-I	.0169	.0021	.0190	2.263E-1
IB-II	.0392	.0038	.0430	2.790E-1
IB-III	.0739	.0085	.0824	2.046E-1
RB	.0321	.0053	.0374	1.435E-1
AB	.0151	.0033	.0184	4.839E-2
S	0.0	.0016	.0016	-----
C	0.0	.0040	.0040	-----

LCCEWG BENCHMARK 4
Results for Assembly-Wise Hex Burn
 (Linked RZ and Hex)

C.1 Burnup* - Assemblies Discharged at EOC1

<u>Zone</u>	<u>Average Burnup (MWD/MT)</u>	<u>Peak Burnup (MWD/MT)</u>
D-I	31376.	43668.
D-II	30125.	47158.
D-III	26545.	42142.
IB-I	2213.	6451.
IB-II	4663.	10488.
IB-III	2805.	7892.
RB	1042.	5241.
AB	646.	2625.

C.2 Burnup* - Assemblies Discharged at EOC2

<u>Zone</u>	<u>Average Burnup (MWD/MT)</u>	<u>Peak Burnup (MWD/MT)</u>
D-I	64385.	86644.
D-II	61760.	92150.
D-III	49632.	79559.
IB-I	5930.	20839.
IB-II	11424.	25531.
IB-III	7173.	20559.
RB	1990.	8726.
AB	1376.	5595.

* Burnup is Calculated From Total (Fission & Capture)
 Power Fraction for Each Region.

LCCEWG BENCHMARK 4
Results for Assembly-Wise Hex Burn
 (Linked RZ and Hex)

D.1 Fuel Inventory (Kg) - BOC1

	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blankets</u>	<u>Axial Blanket Extensions</u>
U-235	5.688E+1	6.296E+1	7.180E+1	4.837E+1
U-236	0.0	0.0	0.0	0.0
U-238	2.612E+4	2.891E+4	3.297E+4	2.221E+4
Pu-239	4.100E+3	0.0	0.0	0.0
Pu-240	1.236E+3	0.0	0.0	0.0
Pu-241	6.203E+2	0.0	0.0	0.0
Pu-242	1.481E+2	0.0	0.0	0.0
FP	0.0	0.0	0.0	0.0

D.2 Fuel Inventory (Kg) - EOC1

	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blankets</u>	<u>Axial Blanket Extensions</u>
U-235	4.598E+1	5.439E+1	6.689E+1	4.591E+1
U-236	2.383E+0	2.126E+0	1.302E+0	6.563E-1
U-238	2.537E+4	2.840E+4	3.273E+4	2.209E+4
Pu-239	3.914E+3	4.341E+2	2.162E+2	1.099E+2
Pu-240	1.298E+3	1.135E+1	3.419E+0	1.198E+0
Pu-241	5.069E+2	2.079E-1	3.938E-2	1.020E-2
Pu-242	1.601E+2	2.442E-3	2.568E-4	4.840E-5
FP	9.172E+2	7.200E+1	2.525E+1	1.134E+1

LCCEWG BENCHMARK 4
Results for Assembly-Wise Hex Burn
 (Linked RZ and Hex)

D.3 Fuel Inventory (Kg) - BOC2

	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blankets</u>	<u>Axial Blanket Extensions</u>
U-235	5.176E+1	5.836E+1	6.824E+1	4.723E+1
U-236	1.114E+0	1.149E+0	9.447E-1	3.046E-1
U-238	2.577E+4	2.863E+4	3.280E+4	2.216E+4
Pu-239	4.012E+3	2.334E+2	1.555E+2	5.103E+1
Pu-240	1.265E+3	6.065E+0	2.389E+0	5.539E-1
Pu-241	5.673E+2	1.104E-1	2.655E-2	4.696E-3
Pu-242	1.537E+2	1.281E-3	1.641E-4	2.224E-5
FP	4.292E+2	3.750E+1	1.751E+1	5.269E+0

D.4 Fuel Inventory (Kg) - EOC2

	<u>Driver Fuel</u>	<u>Inner Blankets</u>	<u>Radial Blankets</u>	<u>Axial Blanket Extensions</u>
U-235	4.195E+1	5.042E+1	6.402E+1	4.487E+1
U-236	3.197E+0	3.040E+0	2.036E+0	9.264E-1
U-238	2.504E+4	2.811E+4	3.257E+4	2.204E+4
Pu-239	3.837E+3	6.354E+2	3.443E+2	1.573E+2
Pu-240	1.321E+3	2.727E+1	9.104E+0	2.753E+0
Pu-241	4.700E+2	8.410E-1	1.755E-1	4.030E-2
Pu-242	1.635E+2	1.856E-2	2.031E-3	3.648E-4
FP	1.289E+3	1.409E+2	4.971E+1	1.888E+1

LCCEWG BENCHMARK 4
Results for Assembly-Wise Hex Burn
 (Linked RZ and Hex)

E.1 Neutron Balance for Reactor - BOC1

<u>Source</u>		
Fission	1.00000	
n,2n	0.00000	
Total Source		1.00000
<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00238	0.00737
U-236	0.00000	0.00000
U-238	0.47545	0.05989
Pu-239	0.05591	0.21691
Pu-240	0.01838	0.01541
Pu-241	0.00782	0.04394
Pu-242	0.00176	0.00132
Fission Products	0.00000	0.00000
Structure*	0.05740	0.00000
Coolant	0.00243	0.00000
Control	0.02893	0.00000
Total	0.65046	0.34484
Total Absorptions		0.99530
<u>Leakage</u>		
Axial	0.00036	
Radial	0.00434	
Total Leakage		0.00470
Total Losses		1.00000

*Includes 0-16

LCCEWG BENCHMARK 4
Results for Assembly-Wise Hex Burn
 (Linked RZ and Hex)

E.2 Neutron Balance for Reactor - EOC1

<u>Source</u>		
Fission	1.00000	
n,2n	0.00000	
Total Source		1.00000

<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>	
U-235	0.00196	0.00606	
U-236	0.00009	0.00001	
U-238	0.46323	0.05934	
Pu-239	0.06298	0.22777	
Pu-240	0.01944	0.01554	
Pu-241	0.00632	0.03519	
Pu-242	0.00191	0.00136	
Fission Products	0.01465	0.00000	
Structure*	0.05628	0.00000	
Coolant	0.00248	0.00000	
Control	0.02093	0.00000	
Total	0.65027	0.34527	
Total Absorptions			0.99554

<u>Leakage</u>		
Axial	0.00043	
Radial	0.00403	
Total Leakage		0.00446
Total Losses		1.00000

*Includes 0-16

LCCEWG BENCHMARK 4
Results for Assembly-Wise Hex Burn
 (Linked RZ and Hex)

E.3 Neutron Balance for Reactor - BOC2

Source

Fission	1.00000	
n,2n	0.00000	
Total Source		1.00000

Absorptions

Captures

Fissions

U-235	0.00216	0.00668	
U-236	0.00005	0.00001	
U-238	0.46818	0.05974	
Pu-239	0.05983	0.22276	
Pu-240	0.01877	0.01539	
Pu-241	0.00708	0.03960	
Pu-242	0.00183	0.00133	
Fission Products	0.00690	0.00000	
Structure*	0.05660	0.00000	
Coolant	0.00244	0.00000	
Control	0.02596	0.00000	
Total	.64980	.34551	
Total Absorptions			0.99531

Leakage

Axial	0.00039	
Radial	0.00430	
Total Leakage		0.00469
Total Losses		1.00000

*Includes 0-16

LCCEWG BENCHMARK 4
Assembly-Wise Hex Burn
 (Linked RZ and Hex)

E.4 Neutron Balance for Reactor - EOC2

<u>Source</u>		
Fission	1.00000	
n,2n	0.00000	
Total Source		1.00000
<u>Absorptions</u>	<u>Captures</u>	<u>Fissions</u>
U-235	0.00177	0.00549
U-236	0.00012	0.00002
U-238	0.45483	0.05909
Pu-239	0.06562	0.23228
Pu-240	0.01986	0.01557
Pu-241	0.00577	0.03205
Pu-242	0.00193	0.00135
Fission Products	0.02120	0.00000
Structure*	0.05561	0.00000
Coolant	0.00245	0.00000
Control	0.02035	0.00000
Total	0.64951	0.34585
Total Absorptions		0.99536
<u>Leakage</u>		
Axial	0.00046	
Radial	0.00418	
Total Leakage		0.00464
Total Losses		1.00000

*Includes 0-16

SUPPLEMENT TO WAESD RESULTS FOR THE
LARGE CORE CODE EVALUATION WORKING GROUP
BENCHMARK PROBLEM IV

S. K. Varner
Westinghouse Advanced Energy Systems Division
P.O. Box 158
Madison, Pennsylvania 15663

July 12, 1983

Work Performed Under Auspices of the U.S. Department of Energy, Office
of Breeder Reactor Technology Projects.

Contract: DE-AM02-76CH94000
Task: DE-AT02-80CH94050

As requested by the Large Core Code Evaluation Working Group, WAESD has investigated the power distribution surrounding the inserted control rods in the Benchmark 4 configuration. This additional data will be used to compare the RZ-hex synthesis method (used by WAESD) with a three dimensional calculation in the region which is most difficult to represent in two dimensions.

In obtaining the results presented herein, WAESD made a slight modification to the RZ model which was specified in Reference 1 and which was used in obtaining the previously reported (Reference 2) results. Because the control rods must be represented by a thin ring in an RZ model, their worth is greatly enhanced. Therefore, to better represent the effect of the inserted control rod on the adjacent fuel and blankets, the amount of poison in the ring must be reduced. It was found that reducing the amount of poison to 66% of its original value over the entire 48 inch height of the core resulted in a worth equivalent to that calculated for the rods fully inserted in the hexagonal model. For the BOC1 configuration, the poison is inserted to the specified height but at a volume fraction of 0.66. This is the technique routinely employed by WAESD for modeling control assemblies in RZ geometry.

Using this modified RZ model and the hexagonal model used for the previous results (Reference 2), the total assembly power (in the central 48" region) and the axial peak-to-average power factors were obtained for each of the four unique assemblies surrounding the inserted control rod at beginning of Cycle 1. These results are listed in Table 1. The assemblies are designated by the system specified in Reference 1 and used in Reference 2.

TABLE 1

LCCEWG BENCHMARK 4
POWER ADJACENT TO INSERTED CONTROL ROD AT BOC1

<u>Assembly Designator</u>	<u>Total Assembly Power (Central 48" Region Only), Mw</u>	<u>Axial Peak/Average Power (Over Central 48" Region Only)</u>	
		<u>In Mesh Adjacent To Control Rod</u>	<u>In Mesh Opposite Control Rod</u>
D-II-2	9.962	1.496	1.38
D-II-4	8.717	1.496	1.38
D-III-1	9.415	1.496	1.38
IB-III-1	1.257	1.452	1.37

References

1. C. L. Cowan, R. Protsik, "Specifications for the Large Core Code Evaluation Working Group Benchmark Problem Four", XL-589-10074, September 29, 1981.
2. S. K. Varner, "W-ARD Results for LCCEWG Benchmark Problem 4", RA-82-346, November 12, 1982.