October 21, 1993 19:51

Burnup Credit Criticality Benchmark

Phase II-A   Effect of Axial Burnup Profile
(Infinite fuel pin array in water)

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OCTOBER 1993

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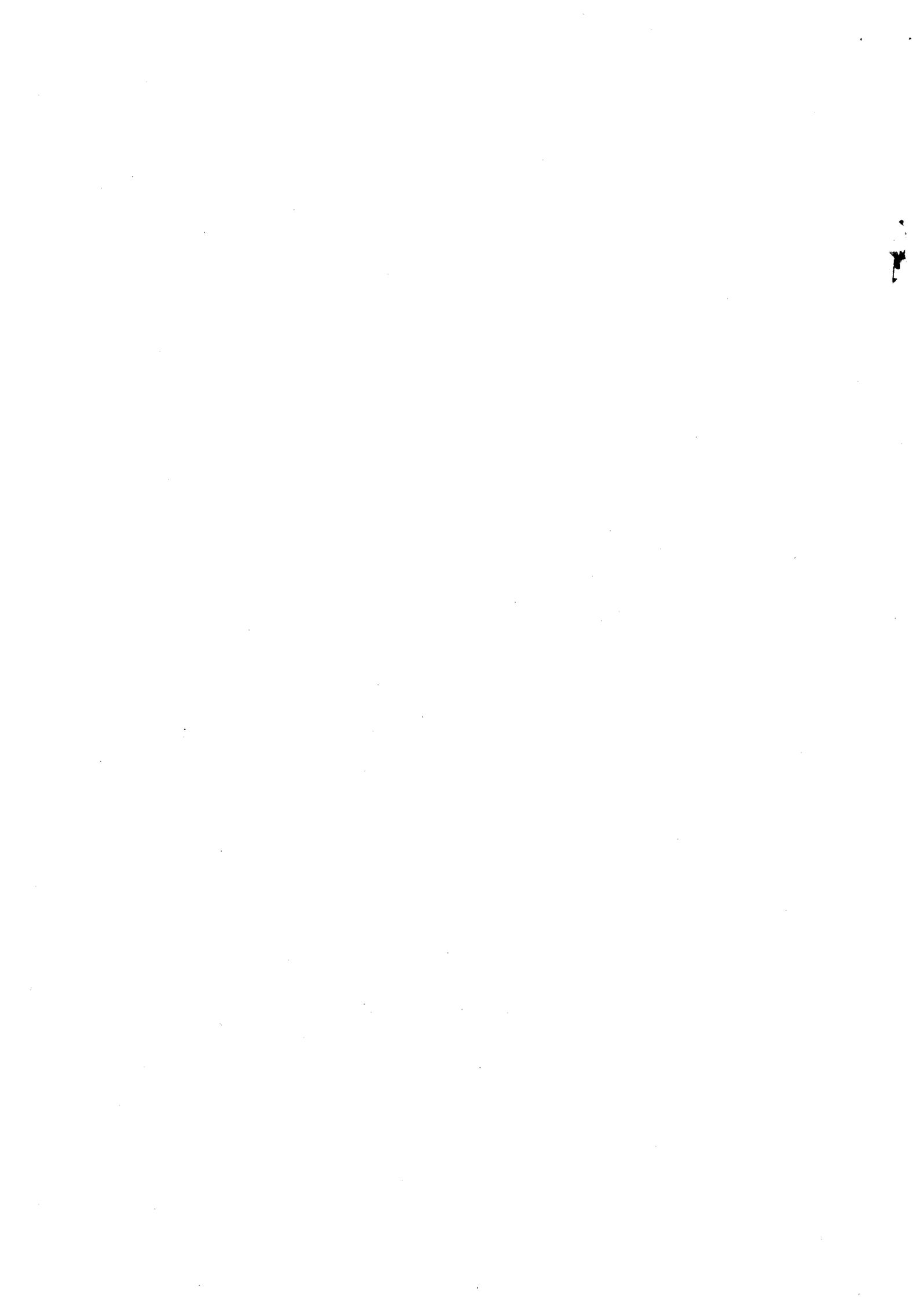
1. Introduction

For the criticality calculation of a spent fuel system, burnup profile of the spent fuel needs to be considered. The effect of the axial burnup profile on criticality will be studied in Phase II of the Burnup Credit Criticality Benchmark. The Phase II will be divided by two programs, namely, Phase II-A and Phase II-B. In Phase II-A, the criticality calculation of an infinite array of PWR spent fuel rods is performed to grasp the effect of axial burnup profile (end effect) on criticality. In Phase II-B, the criticality of a spent fuel cask will be evaluated.

It is considered that the end effect is a function of the initial fuel enrichment, the burnup and the cooling time. The selection of these parameter values were discussed at meetings in Paris and at ORNL. The selected parameters are 10, 30 GWd/t burnups for 3.6 w/o initial fuel enrichment, 30, 50 GWd/t burnups for 4.5 w/o initial fuel enrichment, 1 and 5 years of cooling times. Further, the the effect of fission products on the end effect is also investigated. The multiplication factors of spent fuel systems with these combinations of parameters will be obtained by all participants using their code and data. Here, the end effect is measured by the difference of multiplication factors between the cases with and without burnup distribution.

It is expected that the results will be helpful to know the degree of importance of the end effect in the burnup credit. The results can be utilized, for example, to obtain a unique Dk value of the end effect, by which the criticality of the spent fuel system can be evaluated by disregarding the burnup profile but employing the average burnup over the rod then simply adding the Dk value.

The burnup profiles of spent fuels at 10, 30, 40 and 50 GWd/t have been measured and supplied for the benchmark by Dr. A. Santamarina and Dr. P. Albarede. The profiles are digitized to obtain region-wise burnup values for the benchmark problem. In total, 60 sets of atomic number densities have been prepared by Dr. M. Brady (see Appendix A).

2. Geometry Data

The geometry of the fuel pin cell is defined by the following data. The cell is used to obtain the multiplication factor of the infinite fuel pin array.

A. Radial dimensions (see Fig. 1)

Fuel Cell Pitch	1.33 cm
Fuel Radius	0.412 cm
Cladding Inner Radius	0.412 cm
Outer Radius	0.475 cm
Radial Boundary Condition	Reflective

B. Axial dimensions (see Fig. 2)

Fuel length	365.7 cm
End plug(Each side)	1.75 cm
Water thickness(Each side)	30.0 cm
Axial Boundary Condition	Vacuum

C. Axial Fuel Modeling

There are 9 regions from top to bottom of the fuel.

Region 1	(Fuel top) 5 cm
Region 2	5 cm
Region 3	10 cm
Region 4	20 cm
Region 5 (Central region)	285.7 cm
Region 6	20 cm
Region 7	10 cm
Region 8	5 cm
Region 9	(Fuel bottom) 5 cm

3. Material Data (at 300 K)

A. Fuel

Fresh Fuel (3.6 w/o)	Number density (atoms/barn*cm)	
(for Case 1 in Table 1)	U-234	7.5174E-06
	U-235	8.4209E-04
	U-236	3.7268E-06
	U-238	2.2254E-02
	O	4.6215E-02
Fresh Fuel (4.5 w/o)	Number density (atoms/barn*cm)	
(for Case 2 in Table 1)	U-234	8.4100E-06
	U-235	1.0526E-03
	U-236	6.4752E-06
	U-238	2.2042E-02
	O	4.6219E-02

The number densities of spent fuels are given in Appendix A.

B. Cladding and End plug

Zircalloy-4	Number density (atoms/barn*cm)	
	Cr	7.5891E-05
	Fe	1.4838E-04
	Zr	4.2982E-02

C Moderator

Water	Number density (atoms/barn*cm)	
	H	6.6621E-02
	O	3.3310E-02

4. Parameters and Case Numbers

In total 26 cases of multiplication factors are requested to be evaluated. Parameters and case numbers for reference are tabulated in Table 1. For the cases of No FP, the following fission products should be omitted from the nuclides listed in Appendix A.

Mo-95, Tc-99, Ru-101, Rh-103, Ag-109, Cs-133, Sm-147,Sm149, Sm-150, Sm-151, Sm-152, Nd-143, Nd-145, Eu-153, Gd-155

For Cases 2, 6 and 19, the fission densities of Region 1 to 5 are also requested. The fission density is defined as;

Fission Density $= \int \Sigma_f \, \phi \, dE$ (per unit fuel volume),

and the sum of fission densities of 5 regions should be nomalized to unity, i.e.,

$$\sum_{i=1 \sim 5}^{Region} \text{Fission Density of Region } i = 1.0 \, .$$

5. Requested Information and Results

Please forward the results by <u>an electronic mail</u> to Dr. Takano at JAERI. The e-mail is the most convenient way for us to receive your data. Please avoid sending the results by a diskette. In Phase-IA, we had many problems in handling diskettes recorded by various PCs since we have no full IBM PC compatible in our laboratory. However, the results recorded as a <u>text file</u> on a <u>3.5 inch</u> HD diskette of Macintosh or MSDOS may be also accepted.

Line No.	Contents
1	Date
2	Institute
3	Contact Person
4	E-mail address or Telefax Number of the contact person
5	Computer Code
6 to 31	Multiplication Factors of Cases 1 to 26
32 to 36	Fission densities from Region 1 to 5 of Case 2
37 to 41	Fission densities from Region 1 to 5 of Case 6
42 to 46	Fission densities from Region 1 to 5 of Case 19
47~	Please describe your analysis environment here. It will be included in Phase IIA report The description should include;

        Institute and Country,
        Participants,
        Neutron data library,
        Neutron data processing code or method,

Neutron energy groups,
Description of your code system,
Geometry modeling (3-D , 2-D etc.),
Omitted nuclides if any.
Employed convergence limit or statistical errors for
eigenvalues
Other related information.

6. Schedule

Mid October	Distribution of the specification
Mid January	Results should be sent to JAERI
Mid March	Distribution of draft report Phase-IIA
End March	Comments to draft report Phase IIA
End April	Final draft of Phase IIA for NSC

Fig. 1 Radial Dimensions

(Vacuum Boundary Condition)

Water	30 cm
End Plug	1.75 cm
Fuel Region-1	5 cm
Fuel Region-2	5 cm
Fuel Region-3	10 cm
Fuel Region-4	20 cm
Fuel Region-5	285.7 cm
Fuel Region-6	20 cm
Fuel Region-7	10 cm
Fuel Region-8	5 cm
Fuel Region-9	5 cm
End Plug	1.75 cm
Water	30 cm

WATER

FUEL

(Vacuum Boundary Condition)
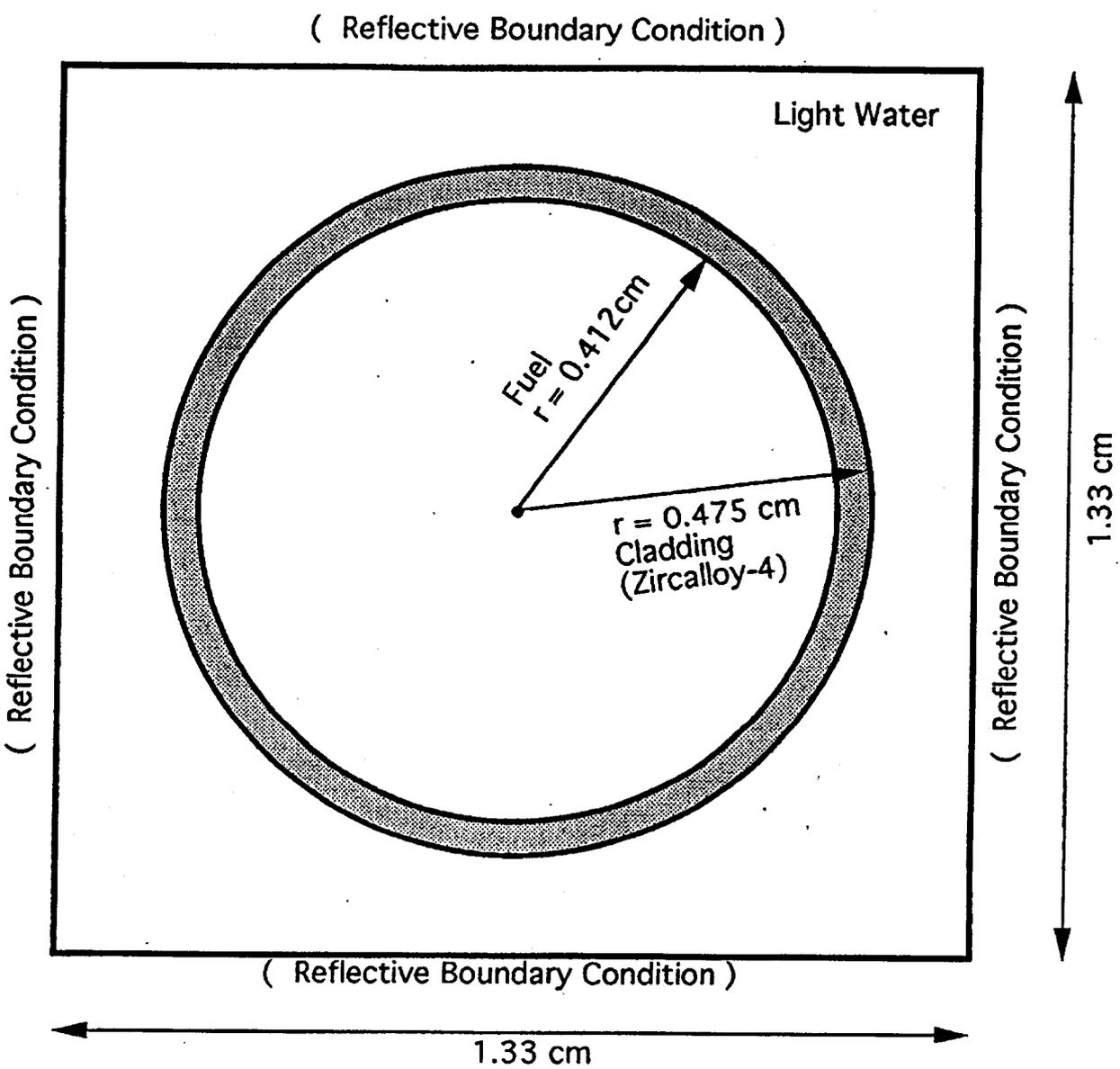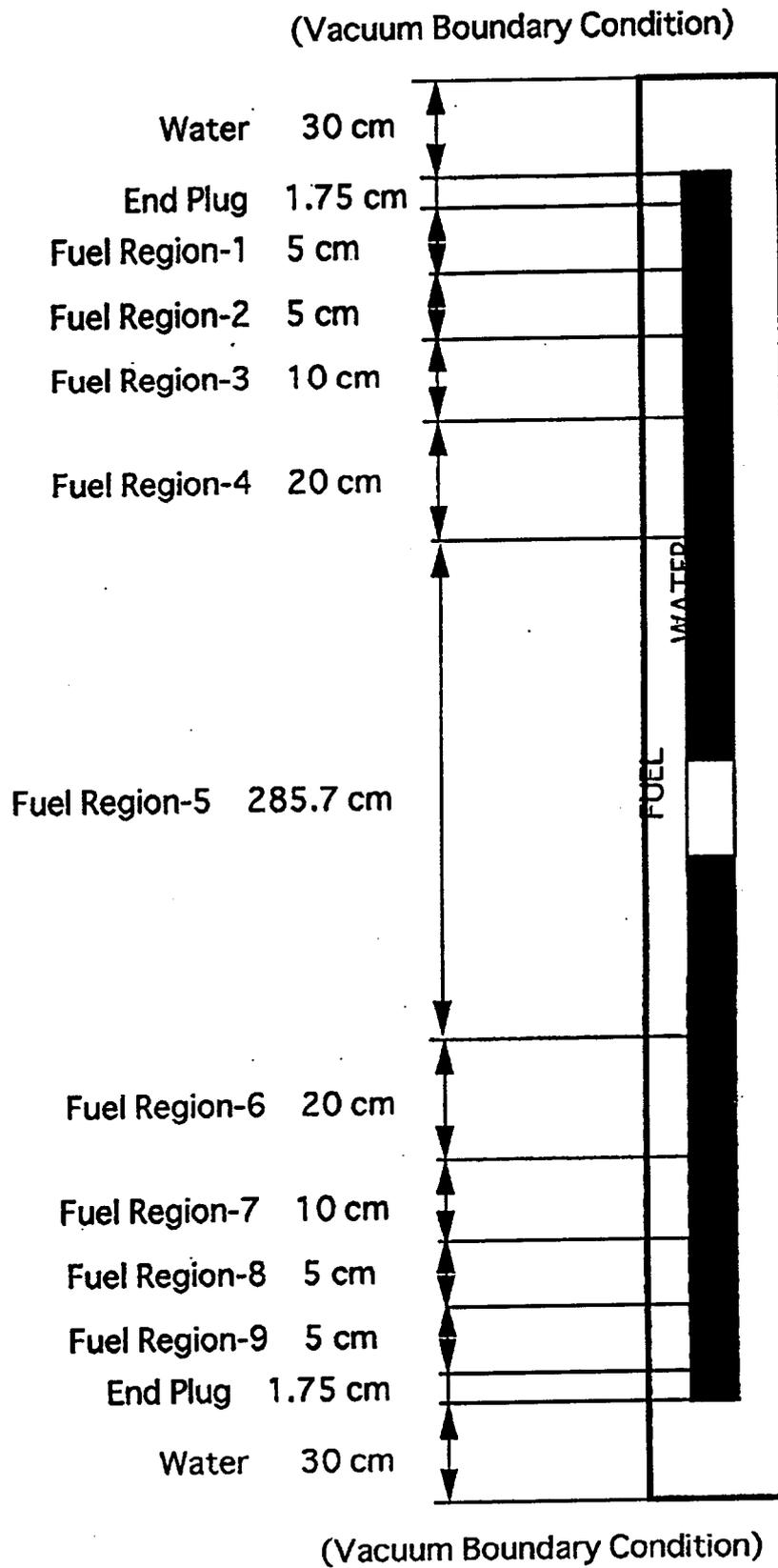
Fig. 2 Axial Dimensions

Table 1　Parameters and Case Numbers

Cooling Time	F.P.s	Burnup Profile	Initial Fuel Enrichment						
			3.6 w/o				4.5 w/o		
			Fresh	Burnup			Fresh	Burnup	
				10 GWd/t	30 GWd/t	40 GWd/t		30 GWd/t	50 GWd/t
			CASE NUMBERS						
1 year	Yes	Yes	1	2	6	N/A	14	15	19
		No		3	7	N/A		16	20
	No	Yes		4	8	N/A		17	21
		No		5	9	N/A		18	22
5 years	Yes	Yes		N/A	10	N/A		N/A	23
		No		N/A	11	N/A		N/A	24
	No	Yes		N/A	12	N/A		N/A	25
		No		N/A	13	N/A		N/A	26

The multiplication factors of 26 cases and related information should be sent to JAERI by 15 January 1994.

Fission Densities of Regions 1 to 5 for Cases 2, 6 and 19 are also requested.

Table 2 Parameters and Data Set Numbers of Appendix A for Analysis

Cooling Time	F.P.s	Burnup Profile	Initial Fuel Enrichment						
			3.6 w/o				4.5 w/o		
			Fresh	Burnup			Fresh	Burnup	
				10 GWd/t	30 GWd/t	40 GWd/t		30 GWd/t	50 GWd/t
			Data Set Numbers for Atomic Number Densities						
1 year	Yes	Yes	See Chap.3	11,13,15,17,19	21,23,25,27,29	N/A	See Chap.3	41,43,45,47,49	51,53,55,57,59
		No		1	3	N/A		7	9
	No	Yes		11,13,15,17,19	21,23,25,27,29	N/A		41,43,45,47,49	51,53,55,57,59
		No		1	3	N/A		7	9
5 years	Yes	Yes		N/A	22,24,26,28,30	N/A		N/A	52,54,56,58,60
		No		N/A	4	N/A		N/A	10
	No	Yes		N/A	22,24,26,28,30	N/A		N/A	52,54,56,58,60
		No		N/A	4	N/A		N/A	10

Please DO NOT MIXUP Case Numbers and Data Set Numbers.
(Case Numbers are NOT equal to Data Set Numbers.)

For cases of No F.P.s, omit F.P. nuclides as described in Chap.4.

Appendix A

Atomic Number Densities
of Spent Fuels

Prepared by Dr. M. Brady

INFORMATION REGARDING THE CALCULATION
OF ORIGEN-S/SAS2H ISOTOPICS TO GENERATE
THE SPENT FUEL ATOMIC NUMBER DENSITIES FOR PHASE II A
PWR assembly design description for tabulated cases

Parameter	Data
Assembly general data	
Designer	Westinghouse
Lattice	17 x 17
Water temperature,	570 K
Water density, av, g-cm-3	0.7295
Soluble boron cycle av, ppm (wt)	550
Number of fuel rods	264
Number of guide tubes	24
Number of instrument tubes	1
Fuel rod data	
Type fuel pellet UO2	
Fellet stack density, % TD	94.5
Rod pitch, cm	1.25984
Rod OD, cm	0.94966
Rod ID, cm	0.83566
Pellet diameter, cm	0.81915
Active fuel length, cm	365.8
Effective fuel temperature, K	811
Clad temperature, K	620
Clad material	Zircalloy
Guide tube data	
Inner radius, cm	0.5715
Outer radius, cm	0.61214
Tube material	Zircalloy

Operating History Data and Fuel Isotopic Content of PWR Cases

Specific Power: 40 kW/kgU

Case Descriptions:

Case 1 -   4 cycle depletion of 3.6 wt% U-235 fuel assembly to 14 GWd/MTU

	Cycle 1	Cycle 2	Cycle 3	Cycle 4
Burnup (GWd/MTU)	3	3	4	4
Uptime (Days)	75	75	100	100
Downtime (Days)	0	0	0	62.5

Case 2 -   5 cycle depletion of 3.6 wt% U-235 fuel assembly to 50 GWd/MTU
Uniform cycles with the following cycle data:

Burnup (GWd/MTU)	10
Uptime (Days)	250
Downtime (Days)	62.5

Case 3 -   6 cycle depletion of 4.5 wt% U-235 fuel assembly to 60 GWd/MTU
Uniform cycles with the following cycle data:

Burnup (GWd/MTU)	10
Uptime (Days)	250
Downtime (Days)	62.5

Uranium Content (wt%)

3.6 wt% U-235		4.5 wt% U-235	
U-234	0.032	U-234	0.0358
U-235	3.600	U-235	4.5000
U-236	0.016	U-236	0.0278
U-238	96.352	U-238	95.4364

Notes on how the nuclide concentrations were obtained:

The nuclide concentrations for the 3.6 wt% 10 GWd/MTU assembly were obtained from Case 1. The concentrations for the 3.6 wt% 30 and 40 GWd/MTU assemblies were obtained from Case 2. The concentrations for the 4.5 wt% 30 and 50 GWd/MTU assemblies were obtained from Case 3. The SAS2 multi-cycle depletions saved nuclide concentrations at the end of each cycle prior to downtime in a single dataset (e.g., the 4.5 wt% depletion saved concentrations at 10, 20, 30, 40, 50 and 60 GWd/MTU). A utility program then interpolated on the values saved at these burnups to obtain the nuclide concentrations at the specified burnups for each axial region and for the assembly average burnup. (Since the assembly average burnups are consistent with the burnups where concentrations were saved, these interpolations are trivial but convenient.) The interpolated concentrations were then input to ORIGEN-S, where they were decayed for 1 year and 5 year cooling times. The concentrations for each axial region of a fuel assembly are taken from a single SAS2 multi-cycle depletion by interpolating between different cycles in the depletion. The result of this method is that the nuclide concentrations for the lower burnup regions at the end of the assemblies are generated at the same specific power as the higher burnup region in the center of the assembly. In our judgment, the effects of this approximation on k-eff are minor. The assembly average nuclide concentrations are based on the assembly average burnup, not on a volume-weighted average of the axial region concentrations. The assembly average burnup is already volume-weighted, and this method is consistent with the way that concentrations would be generated for an axially uniform assembly average analysis.

Isotopics for Phase IIA

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ISOTOPICS FOR AVERAGE
BURNUP CASES
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	Data set No. 1 3.6wt%u235, 10gwd/mtu cooling time (yr)=1.0	Data set No. 2 3.6wt%u235, 10gwd/mtu cooling time (yr)=5.0	Data set No. 3 3.6wt%u235, 30gwd/mtu cooling time (yr)=1.0
u-234	6.5794E-06	6.5852E-06	4.8804E-06
u-235	5.9967E-04	5.9968E-04	2.8377E-04
u-236	4.7807E-05	4.7812E-05	9.9398E-05
u-238	2.2103E-02	2.2103E-02	2.1759E-02
pu-238	1.8519E-07	1.8036E-07	2.8704E-06
pu-239	8.4685E-05	8.4675E-05	1.3551E-04
pu-240	1.1749E-05	1.1744E-05	4.2931E-05
pu-241	4.7672E-06	3.9295E-06	2.8085E-05
pu-242	3.3278E-07	3.3278E-07	7.4143E-06
am-241	2.7770E-07	1.1109E-06	2.1081E-06
am-243	1.7490E-08	1.7484E-08	1.3695E-06
np-237	2.2679E-06	2.2724E-06	1.0284E-05
mo-95	1.4902E-05	1.5117E-05	4.1124E-05
tc-99	1.4751E-05	1.4751E-05	4.0326E-05
ru-101	1.2768E-05	1.2768E-05	3.8144E-05
rh-103	8.4763E-06	8.4798E-06	2.3427E-05
ag-109	6.7934E-07	6.7934E-07	3.6406E-06
cs-133	1.6145E-05	1.6145E-05	4.3935E-05
sm-147	1.3283E-06	3.4563E-06	3.9475E-06
sm-149	1.4063E-07	1.4063E-07	1.7755E-07
sm-150	3.0773E-06	3.0773E-06	1.0241E-05
sm-151	3.8042E-07	3.6888E-07	5.9020E-07
sm-152	1.4113E-06	1.4113E-06	4.2236E-06
nd-143	1.3086E-05	1.3086E-05	3.0965E-05
nd-145	9.0337E-06	9.0337E-06	2.4165E-05
eu-153	7.1408E-07	7.1408E-07	3.3822E-06
gd-155	1.1869E-08	4.3474E-08	6.3853E-08
o	4.6215E-02	4.6215E-02	4.6215E-02

Nuclide	Data set No. 4 3.6wt%u235, 30gwd/mtu cooling time (yr)=5.0	Data set No. 5 3.6wt%u235, 40gwd/mtu cooling time (yr)=1.0	Data set No. 6 3.6wt%u235, 40gwd/mtu cooling time (yr)=5.0	Data set No. 7 4.5wt%u235, 30gwd/mtu cooling time (yr)=1.0
u-234	4.9710E-06	4.1448E-06	4.3224E-06	5.7455E-06
u-235	2.8379E-04	1.8507E-04	1.8509E-04	4.3273E-04
u-236	9.9416E-05	1.1190E-04	1.1192E-04	1.1635E-04
u-238	2.1759E-02	2.1565E-02	2.1565E-02	2.1595E-02
pu-238	2.8294E-06	5.6243E-06	5.5437E-06	2.6453E-06
pu-239	1.3550E-04	1.4152E-04	1.4151E-04	1.4176E-04
pu-240	4.2953E-05	5.5277E-05	5.5398E-05	3.8360E-05
pu-241	2.3150E-05	3.6150E-05	2.9797E-05	2.5933E-05
pu-242	7.4143E-06	1.3914E-05	1.3914E-05	5.3890E-06
am-241	7.0135E-06	2.8937E-06	9.2066E-06	1.9697E-06
am-243	1.3690E-06	3.4343E-06	3.4330E-06	9.1029E-07
np-237	1.0314E-05	1.4570E-05	1.4610E-05	1.0650E-05
mo-95	4.1322E-05	5.2430E-05	5.2617E-05	4.2217E-05
tc-99	4.0326E-05	5.1400E-05	5.1399E-05	4.0848E-05
ru-101	3.8144E-05	5.0489E-05	5.0489E-05	3.8040E-05
rh-103	2.3431E-05	2.9115E-05	2.9120E-05	2.3005E-05
ag-109	3.6406E-06	5.3636E-06	5.3636E-06	3.0914E-06
cs-133	4.3935E-05	5.5752E-05	5.5752E-05	4.4521E-05
sm-147	7.4917E-06	4.8850E-06	8.5053E-06	4.1903E-06
sm-149	1.7755E-07	1.7826E-07	1.7826E-07	1.9919E-07
sm-150	1.0241E-05	1.3787E-05	1.3787E-05	1.0286E-05
sm-151	5.7230E-07	6.6650E-07	6.4628E-07	6.7718E-07
sm-152	4.2238E-06	5.3740E-06	5.3742E-06	4.1136E-06
nd-143	3.0965E-05	3.6479E-05	3.6479E-05	3.3064E-05
nd-145	2.4165E-05	3.0439E-05	3.0439E-05	2.4862E-05
eu-153	3.3822E-06	4.8428E-06	4.8429E-06	3.1728E-06
gd-155	2.3399E-07	1.0618E-07	3.8944E-07	5.8933E-08
o	4.6215E-02	4.6215E-02	4.6215E-02	4.6219E-02

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Data set No. 8
4.5wt%u235, 30gwd/mtu
cooling time (yr)=5.0

u-234	5.8288E-06
u-235	4.3275E-04
u-236	1.1637E-04
u-238	2.1595E-02
pu-238	2.6014E-06
pu-239	1.4175E-04
pu-240	3.8367E-05
pu-241	2.1376E-05
pu-242	5.3890E-06
am-241	6.4992E-06
am-243	9.0995E-07
np-237	1.0678E-05
mo-95	4.2421E-05
tc-99	4.0847E-05
ru-101	3.8040E-05
rh-103	2.3009E-05
ag-109	3.0914E-06
cs-133	4.4521E-05
sm-147	7.9467E-06
sm-149	1.9919E-07
sm-150	1.0286E-05
sm-151	6.5663E-07
sm-152	4.1139E-06
nd-143	3.3064E-05
nd-145	2.4862E-05
eu-153	3.1728E-06
gd-155	2.1404E-07
o	4.6219E-02

Data set No. 9
4.5wt%u235, 50gwd/mtu
cooling time (yr)=1.0

u-234	4.2810E-06
u-235	2.0683E-04
u-236	1.4592E-04
u-238	2.1232E-02
pu-238	8.8422E-06
pu-239	1.5300E-04
pu-240	6.1274E-05
pu-241	4.1552E-05
pu-242	1.7100E-05
am-241	3.5503E-06
am-243	4.8107E-06
np-237	1.9862E-05
mo-95	6.5040E-05
tc-99	6.2619E-05
ru-101	6.2443E-05
rh-103	3.3579E-05
ag-109	6.2520E-06
cs-133	6.7704E-05
sm-147	6.0644E-06
sm-149	1.9567E-07
sm-150	1.7185E-05
sm-151	8.1981E-07
sm-152	6.3275E-06
nd-143	4.4452E-05
nd-145	3.7428E-05
eu-153	5.9933E-06
gd-155	1.4556E-07
o	4.6219E-02

Data set No. 10
4.5wt%u235, 50gwd/mtu
cooling time (yr)=5.0

u-234	4.5595E-06
u-235	2.0685E-04
u-236	1.4594E-04
u-238	2.1232E-02
pu-238	8.6947E-06
pu-239	1.5299E-04
pu-240	6.1487E-05
pu-241	3.4251E-05
pu-242	1.7100E-05
am-241	1.0805E-05
am-243	4.8089E-06
np-237	1.9909E-05
mo-95	6.5226E-05
tc-99	6.2619E-05
ru-101	6.2443E-05
rh-103	3.3584E-05
ag-109	6.2520E-06
cs-133	6.7704E-05
sm-147	9.9022E-06
sm-149	1.9567E-07
sm-150	1.7185E-05
sm-151	7.9494E-07
sm-152	6.3277E-06
nd-143	4.4452E-05
nd-145	3.7428E-05
eu-153	5.9934E-06
gd-155	5.3051E-07
o	4.6219E-02

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Axially Dependent Isotopics
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The axial regions are of the following widths:

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1 & 9  -   5 cm
2 & 8  -   5 cm
3 & 7  -  10 cm
4 & 6  -  20 cm
5      -285.7 cm
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The shapes of the burnup profiles were taken from data provided by A. Santamarina and P. Albarede of C.E.N. - Cadarache. The case of an average burnup of 10 GWd/MTU used the French EOC1 profile, the cases of 30 and 40 GWd/MTU used the EOC3 profile and the 50 GWd/MTU case used the EOC4 profile.

	Data set No. 11 3.6wt%u235, 10gwd/mtu cooling time (yr)=1.0 axial locations 1 & 9 (3.618 GWd/MTU)	Data set No. 12 3.6wt%u235, 10gwd/mtu cooling time (yr)=5.0 axial locations 1 & 9 (3.618 GWd/MTU)	Data set No. 13 3.6wt%u235, 10gwd/mtu cooling time (yr)=1.0 axial locations 2 & 8 (4.311 GWd/MTU)
u-234	7.1727E-06	7.1731E-06	7.1073E-06
u-235	7.4542E-04	7.4543E-04	7.2820E-04
u-236	2.1526E-05	2.1527E-05	2.4671E-05
u-238	2.2201E-02	2.2201E-02	2.2191E-02
pu-238	1.4782E-08	1.4322E-08	2.2662E-08
pu-239	3.9529E-05	3.9524E-05	4.5703E-05
pu-240	2.3787E-06	2.3777E-06	3.2047E-06
pu-241	4.2604E-07	3.5118E-07	6.7465E-07
pu-242	5.5378E-09	5.5377E-09	1.2935E-08
am-241	2.1921E-08	9.6399E-08	3.5244E-08
am-243	1.2915E-12	1.2910E-12	3.2474E-12
np-237	5.7921E-07	5.7959E-07	7.2613E-07
mo-95	5.4768E-06	5.6240E-06	6.5196E-06
tc-99	5.4625E-06	5.4624E-06	6.4947E-06
ru-101	4.5948E-06	4.5948E-06	5.4795E-06
rh-103	2.9969E-06	2.9994E-06	3.5905E-06
ag-109	1.3026E-07	1.3026E-07	1.7303E-07
cs-133	5.9784E-06	5.9784E-06	7.1063E-06
sm-147	4.7018E-07	1.3987E-06	5.6264E-07
sm-149	1.2328E-07	1.2328E-07	1.2673E-07
sm-150	8.8301E-07	8.8301E-07	1.0822E-06
sm-151	2.3324E-07	2.2616E-07	2.5674E-07
sm-152	4.2030E-07	4.2031E-07	5.2286E-07
nd-143	5.0905E-06	5.0905E-06	6.0185E-06
nd-145	3.3973E-06	3.3973E-06	4.0303E-06
eu-153	1.8745E-07	1.8745E-07	2.3222E-07
gd-155	4.2592E-09	1.5670E-08	5.0199E-09
o	4.6215E-02	4.6215E-02	4.6215E-02

	Data set No. 14	Data set No. 15	Data set No. 16	Data set No. 17
	3.6wt%u235, 10gwd/mtu	3.6wt%u235, 10gwd/mtu	3.6wt%u235, 10gwd/mtu	3.6wt%u235, 10gwd/mtu
	cooling time (yr)=5.0	cooling time (yr)=1.0	cooling time (yr)=5.0	cooling time (yr)=1.0
	axial locations 2 & 8	axial locations 3 & 7	axial locations 3 & 7	axial locations 4 & 6
	(4.311 GWd/MTU)	(5.647 GWd/MTU)	(5.647 GWd/MTU)	(7.558 GWd/MTU)
u-234	7.1079E-06	6.9819E-06	6.9833E-06	6.8042E-06
u-235	7.2821E-04	6.9597E-04	6.9598E-04	6.5206E-04
u-236	2.4673E-05	3.05535E-05	3.0537E-05	3.8459E-05
u-238	2.2191E-02	2.2170E-02	2.2170E-02	2.2141E-02
pu-238	2.1957E-08	4.5152E-08	4.3819E-08	9.4031E-08
pu-239	4.5698E-05	5.6731E-05	5.6724E-05	7.0502E-05
pu-240	3.2034E-06	4.9284E-06	4.9264E-06	7.6945E-06
pu-241	5.5609E-07	1.3069E-06	1.0773E-06	2.5613E-06
pu-242	1.2935E-08	4.6519E-08	4.6519E-08	1.3880E-07
am-241	1.5318E-07	7.0854E-08	2.9930E-07	1.4450E-07
am-243	3.2462E-12	1.1026E-09	1.1022E-09	6.0436E-09
np-237	7.2675E-07	1.0344E-06	1.0356E-06	1.5325E-06
mo-95	6.6812E-06	8.5164E-06	8.7008E-06	1.1341E-05
tc-99	6.4946E-06	8.4682E-06	8.4681E-06	1.1253E-05
ru-101	5.4795E-06	7.1866E-06	7.1866E-06	9.6322E-06
rh-103	3.5931E-06	4.7355E-06	4.7385E-06	6.3753E-06
ag-109	1.7303E-07	2.6703E-07	2.6703E-07	4.2798E-07
cs-133	7.1063E-06	9.2639E-06	9.2639E-06	1.2312E-05
sm-147	1.6463E-06	7.4136E-07	2.1071E-06	9.9805E-07
sm-149	1.2673E-07	1.3232E-07	1.3232E-07	1.3783E-07
sm-150	1.0822E-06	1.4931E-06	1.4931E-06	2.1420E-06
sm-151	2.4895E-07	2.9689E-07	2.8788E-07	3.4245E-07
sm-152	5.2287E-07	7.2402E-07	7.2403E-07	1.0196E-06
nd-143	6.0185E-06	7.7663E-06	7.7663E-06	1.0171E-05
nd-145	4.0303E-06	5.2361E-06	5.2361E-06	6.9273E-06
eu-153	2.3222E-07	3.2705E-07	3.2705E-07	4.8217E-07
gd-155	1.8445E-08	6.5311E-09	2.3961E-08	8.7956E-09
o	4.6215E-02	4.6215E-02	4.6215E-02	4.6215E-02

Data set No. 18
3.6wt%u235, 10gwd/mtu
cooling time (yr)=5.0
axial locations 4 & 6
(7.558 GWd/MTU)

u-234	6.8071E-06
u-235	6.5207E-04
u-236	3.8462E-05
u-238	2.2141E-02
pu-238	9.1440E-08
pu-239	7.0494E-05
pu-240	7.6913E-06
pu-241	2.1112E-06
pu-242	1.3880E-07
am-241	5.9217E-07
am-243	6.0413E-09
np-237	1.5349E-06
mo-95	1.1547E-05
tc-99	1.1253E-05
ru-101	9.6322E-06
rh-103	6.3786E-06
ag-109	4.2798E-07
cs-133	1.2312E-05
sm-147	2.7278E-06
sm-149	1.3783E-07
sm-150	2.1420E-06
sm-151	3.3206E-07
sm-152	1.0196E-06
nd-143	1.0171E-05
nd-145	6.9273E-06
eu-153	4.8218E-07
gd-155	3.2233E-08
o	4.6215E-02

Data set No. 19
3.6wt%U235, 10GWD/MTU
cooling time (yr)=1.0
axial location 5
(11.069 GWD/MTU)

u-234	6.4825E-06
u-235	5.7794E-04
u-236	5.1643E-05
u-238	2.2086E-02
pu-238	2.3783E-07
pu-239	9.0069E-05
pu-240	1.3567E-05
pu-241	5.8526E-06
pu-242	4.5786E-07
am-241	3.4621E-07
am-243	2.7360E-08
np-237	2.6147E-06
mo-95	1.6430E-05
tc-99	1.6254E-05
ru-101	1.4134E-05
rh-103	9.3808E-06
ag-109	7.9998E-07
cs-133	1.7790E-05
sm-147	1.4711E-06
sm-149	1.4238E-07
sm-150	3.4955E-06
sm-151	3.9505E-07
sm-152	1.5804E-06
nd-143	1.4304E-05
nd-145	9.9329E-06
eu-153	8.2472E-07
gd-155	1.3371E-08
o	4.6215E-02

Data set No. 20
3.6wt%U235, 10GWD/MTU
cooling time (yr)=5.0
axial location 5
(11.069 GWD/MTU)

u-234	6.4898E-06
u-235	5.7795E-04
u-236	5.1649E-05
u-238	2.2086E-02
pu-238	2.3183E-07
pu-239	9.0059E-05
pu-240	1.3561E-05
pu-241	4.8242E-06
pu-242	4.5786E-07
am-241	1.3690E-06
am-243	2.7350E-08
np-237	2.6203E-06
mo-95	1.6647E-05
tc-99	1.6254E-05
ru-101	1.4134E-05
rh-103	9.3844E-06
ag-109	7.9998E-07
cs-133	1.7790E-05
sm-147	3.7534E-06
sm-149	1.4238E-07
sm-150	3.4955E-06
sm-151	3.8307E-07
sm-152	1.5804E-06
nd-143	1.4304E-05
nd-145	9.9329E-06
eu-153	8.2472E-07
gd-155	4.8970E-08
o	4.6215E-02

Data set No. 21
3.6wt%U235, 30GWD/MTU
cooling time (yr)=1.0
axial location 1 & 9
(12.330GWD/MTU)

u-234	6.3705E-06
u-235	5.5336E-04
u-236	5.5957E-05
u-238	2.2066E-02
pu-238	3.1141E-07
pu-239	9.4448E-05
pu-240	1.5417E-05
pu-241	7.7995E-06
pu-242	6.5918E-07
am-241	4.6500E-07
am-243	4.5209E-08
np-237	3.0436E-06
mo-95	1.8236E-05
tc-99	1.7833E-05
ru-101	1.5775E-05
rh-103	1.0455E-05
ag-109	9.6301E-07
cs-133	1.9552E-05
sm-147	1.6643E-06
sm-149	1.5514E-07
sm-150	3.8040E-06
sm-151	4.1111E-07
sm-152	1.7856E-06
nd-143	1.5611E-05
nd-145	1.0993E-05
eu-153	9.6829E-07
gd-155	1.5168E-08
o	4.6215E-02

Data set No. 22
3.6wt%U235, 30GWD/MTU
cooling time (yr)=5.0
axial location 1 & 9
(12.330GWD/MTU)

u-234	6.3802E-06
u-235	5.5337E-04
u-236	5.5963E-05
u-238	2.2066E-02
pu-238	3.0368E-07
pu-239	9.4437E-05
pu-240	1.5411E-05
pu-241	6.4290E-06
pu-242	6.5918E-07
am-241	1.8281E-06
am-243	4.5192E-08
np-237	3.0511E-06
mo-95	1.8451E-05
tc-99	1.7833E-05
ru-101	1.5775E-05
rh-103	1.0459E-05
ag-109	9.6301E-07
cs-133	1.9552E-05
sm-147	4.1077E-06
sm-149	1.5514E-07
sm-150	3.8040E-06
sm-151	3.9864E-07
sm-152	1.7857E-06
nd-143	1.5611E-05
nd-145	1.0993E-05
eu-153	9.6830E-07
gd-155	5.5547E-08
o	4.6215E-02

Data set No. 23
3.6wt%U235, 30GWD/MTU
cooling time (yr)=1.0
axial location 2 & 8
(14.041GWD/MTU)

u-234	6.2178E-06
u-235	5.2093E-04
u-236	6.1572E-05
u-238	2.2039E-02
pu-238	4.3069E-07
pu-239	1.0142E-04
pu-240	1.8235E-05
pu-241	9.8114E-06
pu-242	9.7642E-07
am-241	6.0188E-07
am-243	7.7068E-08
np-237	3.6522E-06
mo-95	2.0626E-05
tc-99	2.0170E-05
ru-101	1.7961E-05
rh-103	1.1854E-05
ag-109	1.1788E-06
cs-133	2.2103E-05
sm-147	1.9070E-06
sm-149	1.5939E-07
sm-150	4.4133E-06
sm-151	4.3200E-07
sm-152	2.0469E-06
nd-143	1.7437E-05
nd-145	1.2392E-05
eu-153	1.1667E-06
gd-155	1.8028E-08
o	4.6215E-02

Data set No. 24
3.6wt%U235, 30GWD/MTU
cooling time (yr)=5.0
axial location 2 & 8
(14.041GWD/MTU)

u-234	6.2312E-06
u-235	5.2094E-04
u-236	6.1580E-05
u-238	2.2039E-02
pu-238	4.2082E-07
pu-239	1.0141E-04
pu-240	1.8228E-05
pu-241	8.0873E-06
pu-242	9.7642E-07
am-241	2.3164E-06
am-243	7.7039E-08
np-237	3.6618E-06
mo-95	2.0840E-05
tc-99	2.0170E-05
ru-101	1.7961E-05
rh-103	1.1857E-05
ag-109	1.1788E-06
cs-133	2.2103E-05
sm-147	4.5466E-06
sm-149	1.5939E-07
sm-150	4.4133E-06
sm-151	4.1889E-07
sm-152	2.0470E-06
nd-143	1.7437E-05
nd-145	1.2392E-05
eu-153	1.1667E-06
gd-155	6.6016E-08
o	4.6215E-02

Data set No. 25
3.6wt%U235, 30GWD/MTU
cooling time (yr)=1.0
axial location 3 & 7
(18.006GWD/MTU)

u-234	5.8699E-06
u-235	4.5143E-04
u-236	7.3333E-05
u-238	2.1973E-02
pu-238	8.0609E-07
pu-239	1.1449E-04
pu-240	2.4724E-05
pu-241	1.4601E-05
pu-242	2.0114E-06
am-241	9.5617E-07
am-243	2.0891E-07
np-237	5.1708E-06
mo-95	2.6014E-05
tc-99	2.5457E-05
ru-101	2.3014E-05
rh-103	1.4989E-05
ag-109	1.7249E-06
cs-133	2.7859E-05
sm-147	2.4589E-06
sm-149	1.6710E-07
sm-150	5.8464E-06
sm-151	4.7695E-07
sm-152	2.6305E-06
nd-143	2.1378E-05
nd-145	1.5528E-05
eu-153	1.6674E-06
gd-155	2.6254E-08
o	4.6215E-02

Data set No. 26
3.6wt%U235, 30GWD/MTU
cooling time (yr)=5.0
axial location 3 & 7
(18.006GWD/MTU)

u-234	5.8952E-06
u-235	4.5145E-04
u-236	7.3343E-05
u-238	2.1973E-02
pu-238	7.9081E-07
pu-239	1.1447E-04
pu-240	2.4717E-05
pu-241	1.2035E-05
pu-242	2.0114E-06
am-241	3.5074E-06
am-243	2.0884E-07
np-237	5.1854E-06
mo-95	2.6225E-05
tc-99	2.5457E-05
ru-101	2.3014E-05
rh-103	1.4993E-05
ag-109	1.7249E-06
cs-133	2.7859E-05
sm-147	5.4627E-06
sm-149	1.6710E-07
sm-150	5.8464E-06
sm-151	4.6248E-07
sm-152	2.6306E-06
nd-143	2.1378E-05
nd-145	1.5528E-05
eu-153	1.6674E-06
gd-155	9.6135E-08
o	4.6215E-02

Data set No. 27
3.6wt%U235, 30GWD/MTU
cooling time (yr)=1.0
axial location 4 & 6
(24.009GWD/MTU)

u-234	5.3620E-06
u-235	3.6010E-04
u-236	8.8047E-05
u-238	2.1869E-02
pu-238	1.6598E-06
pu-239	1.2775E-04
pu-240	3.4198E-05
pu-241	2.1718E-05
pu-242	4.3206E-06
am-241	1.5389E-06
am-243	6.2397E-07
np-237	7.6707E-06
mo-95	3.3792E-05
tc-99	3.3109E-05
ru-101	3.0617E-05
rh-103	1.9419E-05
ag-109	2.6462E-06
cs-133	3.6156E-05
sm-147	3.2457E-06
sm-149	1.7425E-07
sm-150	8.0459E-06
sm-151	5.3724E-07
sm-152	3.4583E-06
nd-143	2.6602E-05
nd-145	2.0005E-05
eu-153	2.5019E-06
gd-155	4.2823E-08
o	4.6215E-02

Data set No. 28
3.6wt%U235, 30GWD/MTU
cooling time (yr)=5.0
axial location 4 & 6
(24.009GWD/MTU)

u-234	5.4143E-06
u-235	3.6012E-04
u-236	8.8061E-05
u-238	2.1869E-02
pu-238	1.6339E-06
pu-239	1.2773E-04
pu-240	3.4197E-05
pu-241	1.7902E-05
pu-242	4.3206E-06
am-241	5.3328E-06
am-243	6.2374E-07
np-237	7.6933E-06
mo-95	3.3996E-05
tc-99	3.3108E-05
ru-101	3.0617E-05
rh-103	1.9423E-05
ag-109	2.6462E-06
cs-133	3.6156E-05
sm-147	6.6054E-06
sm-149	1.7425E-07
sm-150	8.0459E-06
sm-151	5.2094E-07
sm-152	3.4585E-06
nd-143	2.6602E-05
nd-145	2.0005E-05
eu-153	2.5020E-06
gd-155	1.5685E-07
o	4.6215E-02

Data set No. 29
3.6wt%U235, 30GWD/MTU
cooling time (yr)=1.0
axial location 5
(32.855GWD/MTU)

u-234	4.6622E-06
u-235	2.5228E-04
u-236	1.0372E-04
u-238	2.1705E-02
pu-238	3.5663E-06
pu-239	1.3790E-04
pu-240	4.6744E-05
pu-241	3.0723E-05
pu-242	9.1156E-06
am-241	2.3570E-06
am-243	1.8519E-06
np-237	1.1527E-05
mo-95	4.4455E-05
tc-99	4.3599E-05
ru-101	4.1684E-05
rh-103	2.5173E-05
ag-109	4.1267E-06
cs-133	4.7444E-05
sm-147	4.2452E-06
sm-149	1.7821E-07
sm-150	1.1269E-05
sm-151	6.1328E-07
sm-152	4.5663E-06
nd-143	3.2750E-05
nd-145	2.6033E-05
eu-153	3.8033E-06
gd-155	7.5143E-08
o	4.6215E-02

Data set No. 30
3.6wt%U235, 30GWD/MTU
cooling time (yr)=5.0
axial location 5
(32.855GWD/MTU)

u-234	4.7748E-06
u-235	2.5230E-04
u-236	1.0374E-04
u-238	2.1705E-02
pu-238	3.5160E-06
pu-239	1.3788E-04
pu-240	4.6784E-05
pu-241	2.5324E-05
pu-242	9.1156E-06
am-241	7.7230E-06
am-243	1.8512E-06
np-237	1.1560E-05
mo-95	4.4649E-05
tc-99	4.3598E-05
ru-101	4.1684E-05
rh-103	2.5178E-05
ag-109	4.1267E-06
cs-133	4.7444E-05
sm-147	7.8342E-06
sm-149	1.7821E-07
sm-150	1.1269E-05
sm-151	5.9467E-07
sm-152	4.5665E-06
nd-143	3.2750E-05
nd-145	2.6033E-05
eu-153	3.8033E-06
gd-155	2.7544E-07
o	4.6215E-02

Data set No. 31
3.6wt%U235, 40GWD/MTU
cooling time (yr)=1.0
axial location 1 & 9
(16.439GWD/MTU)

u-234	6.0062E-06
u-235	4.7798E-04
u-236	6.8888E-05
u-238	2.1999E-02
pu-238	6.4058E-07
pu-239	1.0980E-04
pu-240	2.2172E-05
pu-241	1.2698E-05
pu-242	1.5535E-06
am-241	8.1121E-07
am-243	1.4560E-07
np-237	4.5546E-06
mo-95	2.3909E-05
tc-99	2.3390E-05
ru-101	2.1020E-05
rh-103	1.3768E-05
ag-109	1.5020E-06
cs-133	2.5610E-05
sm-147	2.2431E-06
sm-149	1.6438E-07
sm-150	5.2771E-06
sm-151	4.5972E-07
sm-152	2.4035E-06
nd-143	1.9867E-05
nd-145	1.4306E-05
eu-153	1.4634E-06
gd-155	2.2737E-08
o	4.6215E-02

Data set No. 32
3.6wt%U235, 40GWD/MTU
cooling time (yr)=5.0
axial location 1 & 9
(16.439GWD/MTU)

u-234	6.0263E-06
u-235	4.7800E-04
u-236	6.8898E-05
u-238	2.1999E-02
pu-238	6.2753E-07
pu-239	1.0978E-04
pu-240	2.2165E-05
pu-241	1.0467E-05
pu-242	1.5535E-06
am-241	3.0301E-06
am-243	1.4555E-07
np-237	4.5672E-06
mo-95	2.4122E-05
tc-99	2.3389E-05
ru-101	2.1020E-05
rh-103	1.3772E-05
ag-109	1.5020E-06
cs-133	2.5610E-05
sm-147	5.1169E-06
sm-149	1.6438E-07
sm-150	5.2771E-06
sm-151	4.4577E-07
sm-152	2.4036E-06
nd-143	1.9867E-05
nd-145	1.4306E-05
eu-153	1.4634E-06
gd-155	8.3258E-08
o	4.6215E-02

Data set No. 33
3.6wt%U235, 40GWD/MTU
cooling time (yr)=1.0
axial location 2 & 8
(18.722GWD/MTU)

u-234	5.8080E-06
u-235	4.3969E-04
u-236	7.5278E-05
u-238	2.1961E-02
pu-238	8.8941E-07
pu-239	1.1644E-04
pu-240	2.5882E-05
pu-241	1.5470E-05
pu-242	2.2414E-06
am-241	1.0240E-06
am-243	2.4340E-07
np-237	5.4584E-06
mo-95	2.6965E-05
tc-99	2.6392E-05
ru-101	2.3924E-05
rh-103	1.5538E-05
ag-109	1.8295E-06
cs-133	2.8876E-05
sm-147	2.5563E-06
sm-149	1.6822E-07
sm-150	6.1075E-06
sm-151	4.8459E-07
sm-152	2.7326E-06
nd-143	2.2047E-05
nd-145	1.6079E-05
eu-153	1.7629E-06
gd-155	2.7974E-08
o	4.6215E-02

Data set No. 34
3.6wt%U235, 40GWD/MTU
cooling time (yr)=5.0
axial location 2 & 8
(18.722GWD/MTU)

nuclide	value
u-234	5.8359E-06
u-235	4.3971E-04
u-236	7.5289E-05
u-238	2.1961E-02
pu-238	8.7306E-07
pu-239	1.1643E-04
pu-240	2.5876E-05
pu-241	1.2752E-05
pu-242	2.2414E-06
am-241	3.7270E-06
am-243	2.4330E-07
np-237	5.4740E-06
mo-95	2.7176E-05
tc-99	2.6392E-05
ru-101	2.3924E-05
rh-103	1.5542E-05
ag-109	1.8295E-06
cs-133	2.8876E-05
sm-147	5.6138E-06
sm-149	1.6822E-07
sm-150	6.1075E-06
sm-151	4.6989E-07
sm-152	2.7327E-06
nd-143	2.2047E-05
nd-145	1.6079E-05
eu-153	1.7629E-06
gd-155	1.0243E-07
o	4.6215E-02

Data set No. 35
3.6wt%U235, 40GWD/MTU
cooling time (yr)=1.0
axial location 3 & 7
(24.008GWD/MTU)

nuclide	value
u-234	5.3621E-06
u-235	3.6011E-04
u-236	8.8045E-05
u-238	2.1869E-02
pu-238	1.6596E-06
pu-239	1.2775E-04
pu-240	3.4197E-05
pu-241	2.1717E-05
pu-242	4.3201E-06
am-241	1.5388E-06
am-243	6.2387E-07
np-237	7.6703E-06
mo-95	3.3791E-05
tc-99	3.3107E-05
ru-101	3.0616E-05
rh-103	1.9418E-05
ag-109	2.6460E-06
cs-133	3.6155E-05
sm-147	3.2455E-06
sm-149	1.7425E-07
sm-150	8.0456E-06
sm-151	5.3724E-07
sm-152	3.4582E-06
nd-143	2.6601E-05
nd-145	2.0004E-05
eu-153	2.5018E-06
gd-155	4.2820E-08
o	4.6215E-02

Data set No. 36
3.6wt%U235, 40GWD/MTU
cooling time (yr)=5.0
axial location 3 & 7
(24.008GWD/MTU)

nuclide	value
u-234	5.4144E-06
u-235	3.6013E-04
u-236	8.8059E-05
u-238	2.1869E-02
pu-238	1.6338E-06
pu-239	1.2773E-04
pu-240	3.4196E-05
pu-241	1.7901E-05
pu-242	4.3201E-06
am-241	5.3326E-06
am-243	6.2364E-07
np-237	7.6929E-06
mo-95	3.3995E-05
tc-99	3.3106E-05
ru-101	3.0616E-05
rh-103	1.9422E-05
ag-109	2.6460E-06
cs-133	3.6155E-05
sm-147	6.6053E-06
sm-149	1.7425E-07
sm-150	8.0456E-06
sm-151	5.2094E-07
sm-152	3.4584E-06
nd-143	2.6601E-05
nd-145	2.0004E-05
eu-153	2.5019E-06
gd-155	1.5684E-07
o	4.6215E-02

Data set No. 37
3.6wt%U235, 40GWD/MTU
cooling time (yr)=1.0
axial location 4 & 6
(32.012GWD/MTU)

nuclide	value
u-234	4.7260E-06
u-235	2.6131E-04
u-236	1.0250E-04
u-238	2.1721E-02
pu-238	3.3524E-06
pu-239	1.3726E-04
pu-240	4.5639E-05
pu-241	2.9970E-05
pu-242	8.5976E-06
am-241	2.2852E-06
am-243	1.7001E-06
np-237	1.1159E-05
mo-95	4.3479E-05
tc-99	4.2640E-05
ru-101	4.0638E-05
rh-103	2.4666E-05
ag-109	3.9821E-06
cs-133	4.6417E-05
sm-147	4.1595E-06
sm-149	1.7807E-07
sm-150	1.0966E-05
sm-151	6.0657E-07
sm-152	4.4661E-06
nd-143	3.2239E-05
nd-145	2.5486E-05
eu-153	3.6786E-06
gd-155	7.1723E-08
o	4.6215E-02

Data set No. 38
3.6wt%U235, 40GWD/MTU
cooling time (yr)=5.0
axial location 4 & 6
(32.012GWD/MTU)

u-234	4.8319E-06
u-235	2.6133E-04
u-236	1.0252E-04
u-238	2.1721E-02
pu-238	3.3050E-06
pu-239	1.3725E-04
pu-240	4.5673E-05
pu-241	2.4703E-05
pu-242	8.5976E-06
am-241	7.5195E-06
am-243	1.6995E-06
np-237	1.1191E-05
mo-95	4.3674E-05
tc-99	4.2639E-05
ru-101	4.0638E-05
rh-103	2.4671E-05
ag-109	3.9821E-06
cs-133	4.6417E-05
sm-147	7.7375E-06
sm-149	1.7807E-07
sm-150	1.0966E-05
sm-151	5.8816E-07
sm-152	4.4663E-06
nd-143	3.2239E-05
nd-145	2.5486E-05
eu-153	3.6787E-06
gd-155	2.6288E-07
o	4.6215E-02

Data set No. 39
3.6wt%U235, 40GWD/MTU
cooling time (yr)=1.0
axial location 5
(43.807GWD/MTU)

u-234	3.8901E-06
u-235	1.5577E-04
u-236	1.1482E-04
u-238	2.1488E-02
pu-238	6.8627E-06
pu-239	1.4251E-04
pu-240	5.9179E-05
pu-241	3.8375E-05
pu-242	1.6677E-05
am-241	3.1214E-06
am-243	4.4734E-06
np-237	1.6097E-05
mo-95	5.6436E-05
tc-99	5.5288E-05
ru-101	5.5095E-05
rh-103	3.0949E-05
ag-109	6.0171E-06
cs-133	5.9862E-05
sm-147	5.1613E-06
sm-149	1.7770E-07
sm-150	1.5068E-05
sm-151	6.9223E-07
sm-152	5.7726E-06
nd-143	3.8045E-05
nd-145	3.2614E-05
eu-153	5.3722E-06
gd-155	1.2348E-07
o	4.6215E-02

Data set No. 40
3.6wt%U235, 40GWD/MTU
cooling time (yr)=5.0
axial location 5
(43.807GWD/MTU)

u-234	4.1066E-06
u-235	1.5579E-04
u-236	1.1484E-04
u-238	2.1488E-02
pu-238	6.7616E-06
pu-239	1.4249E-04
pu-240	5.9366E-05
pu-241	3.1631E-05
pu-242	1.6677E-05
am-241	9.8225E-06
am-243	4.4718E-06
np-237	1.6140E-05
mo-95	5.6620E-05
tc-99	5.5287E-05
ru-101	5.5095E-05
rh-103	3.0953E-05
ag-109	6.0171E-06
cs-133	5.9862E-05
sm-147	8.7656E-06
sm-149	1.7770E-07
sm-150	1.5068E-05
sm-151	6.7123E-07
sm-152	5.7728E-06
nd-143	3.8045E-05
nd-145	3.2614E-05
eu-153	5.3723E-06
gd-155	4.5301E-07
o	4.6215E-02

Data set No. 41
4.5wt%U235, 30GWD/MTU
cooling time (yr)=1.0
axial location 1 & 9
(12.330GWD/MTU)

u-234	7.2649E-06
u-235	7.4704E-04
u-236	6.3195E-05
u-238	2.1871E-02
pu-238	2.8641E-07
pu-239	9.3233E-05
pu-240	1.2878E-05
pu-241	6.2410E-06
pu-242	4.2866E-07
am-241	3.7294E-07
am-243	2.9094E-08
np-237	3.1036E-06
mo-95	1.8489E-05
tc-99	1.7929E-05
ru-101	1.5737E-05
rh-103	1.0198E-05
ag-109	7.9138E-07
cs-133	1.9651E-05
sm-147	1.7068E-06
sm-149	1.7444E-07
sm-150	3.7319E-06
sm-151	4.7687E-07
sm-152	1.6948E-06
nd-143	1.6076E-05
nd-145	1.1161E-05
eu-153	9.0062E-07
gd-155	1.4974E-08
o	4.6219E-02

	Data set No. 42	Data set No. 43	Data set No. 44	Data set No. 45
	4.5wt%U235, 30GWD/MTU	4.5wt%U235, 30GWD/MTU	4.5wt%U235, 30GWD/MTU	4.5wt%U235, 30GWD/MTU
	cooling time (yr)=5.0	cooling time (yr)=1.0	cooling time (yr)=5.0	cooling time (yr)=1.0
	axial location 1 & 9	axial location 2 & 8	axial location 2 & 8	axial location 3 & 7
	(12.330GWD/MTU)	(14.041GWD/MTU)	(14.041GWD/MTU)	(18.006GWD/MTU)
u-234	7.2738E-06	7.1109E-06	7.1232E-06	6.7591E-06
u-235	7.4705E-04	7.1102E-04	7.1103E-04	6.3249E-04
u-236	6.3201E-05	6.9644E-05	6.9650E-05	8.3446E-05
u-238	2.1871E-02	2.1846E-02	2.1846E-02	2.1787E-02
pu-238	2.7907E-07	3.9483E-07	3.8525E-07	7.3356E-07
pu-239	9.3222E-05	1.0091E-04	1.0090E-04	1.1569E-04
pu-240	1.2872E-05	1.5353E-05	1.5346E-05	2.1172E-05
pu-241	5.1443E-06	7.9972E-06	6.5919E-06	1.2395E-05
pu-242	4.2866E-07	6.4265E-07	6.4265E-07	1.3567E-06
am-241	1.4636E-06	4.9180E-07	1.8893E-06	8.1377E-07
am-243	2.9083E-08	4.8610E-08	4.8592E-08	1.2893E-07
np-237	3.1096E-06	3.7238E-06	3.7316E-06	5.2803E-06
mo-95	1.8707E-05	2.0938E-05	2.1157E-05	2.6487E-05
tc-99	1.7929E-05	2.0293E-05	2.0292E-05	2.5652E-05
ru-101	1.5737E-05	1.7916E-05	1.7916E-05	2.2952E-05
rh-103	1.0201E-05	1.1560E-05	1.1563E-05	1.4624E-05
ag-109	7.9138E-07	9.7122E-07	9.7122E-07	1.4313E-06
cs-133	1.9651E-05	2.2231E-05	2.2231E-05	2.8069E-05
sm-147	4.2159E-06	1.9623E-06	4.6821E-06	2.5505E-06
sm-149	1.7444E-07	1.8004E-07	1.8004E-07	1.8905E-07
sm-150	3.7319E-06	4.3299E-06	4.3299E-06	5.7784E-06
sm-151	4.6240E-07	5.0124E-07	4.8603E-07	5.5238E-07
sm-152	1.6949E-06	1.9507E-06	1.9508E-06	2.5243E-06
nd-143	1.6076E-05	1.8019E-05	1.8019E-05	2.2270E-05
nd-145	1.1161E-05	1.2599E-05	1.2599E-05	1.5837E-05
eu-153	9.0062E-07	1.0833E-06	1.0833E-06	1.5474E-06
gd-155	5.4303E-08	1.7587E-08	6.3779E-08	2.4865E-08
o	4.6219E-02	4.6219E-02	4.6219E-02	4.6219E-02

Data set No. 46
4.5wt%U235, 30GWD/MTU
cooling time (yr)=5.0
axial location 3 & 7
(18.006GWD/MTU)

u-234	6.7821E-06
u-235	6.3251E-04
u-236	8.3455E-05
u-238	2.1787E-02
pu-238	7.1790E-07
pu-239	1.1568E-04
pu-240	2.1165E-05
pu-241	1.0217E-05
pu-242	1.3567E-06
am-241	2.9795E-06
am-243	1.2888E-07
np-237	5.2927E-06
mo-95	2.6703E-05
tc-99	2.5652E-05
ru-101	2.2952E-05
rh-103	1.4628E-05
ag-109	1.4313E-06
cs-133	2.8069E-05
sm-147	5.6683E-06
sm-149	1.8905E-07
sm-150	5.7784E-06
sm-151	5.3562E-07
sm-152	2.5244E-06
nd-143	2.2270E-05
nd-145	1.5837E-05
eu-153	1.5474E-06
gd-155	9.0177E-08
o	4.6219E-02

Data set No. 47
4.5wt%U235, 30GWD/MTU
cooling time (yr)=1.0
axial location 4 & 6
(24.009GWD/MTU)

u-234	6.2417E-06
u-235	5.2583E-04
u-236	1.0149E-04
u-238	2.1693E-02
pu-238	1.5130E-06
pu-239	1.3159E-04
pu-240	2.9950E-05
pu-241	1.9338E-05
pu-242	3.0288E-06
am-241	1.3780E-06
am-243	3.9736E-07
np-237	7.8777E-06
mo-95	3.4552E-05
tc-99	3.3447E-05
ru-101	3.0530E-05
rh-103	1.8999E-05
ag-109	2.2210E-06
cs-133	3.6529E-05
sm-147	3.4066E-06
sm-149	1.9609E-07
sm-150	8.0419E-06
sm-151	6.1929E-07
sm-152	3.3453E-06
nd-143	2.8054E-05
nd-145	2.0493E-05
eu-153	2.3310E-06
gd-155	3.9606E-08
o	4.6219E-02

Data set No. 48
4.5wt%U235, 30GWD/MTU
cooling time (yr)=5.0
axial location 4 & 6
(24.009GWD/MTU)

u-234	6.2892E-06
u-235	5.2585E-04
u-236	1.0151E-04
u-238	2.1693E-02
pu-238	1.4854E-06
pu-239	1.3158E-04
pu-240	2.9945E-05
pu-241	1.5940E-05
pu-242	3.0288E-06
am-241	4.7561E-06
am-243	3.9721E-07
np-237	7.8978E-06
mo-95	3.4762E-05
tc-99	3.3447E-05
ru-101	3.0530E-05
rh-103	1.8999E-05
ag-109	2.2210E-06
cs-133	3.6529E-05
sm-147	6.9313E-06
sm-149	1.9609E-07
sm-150	8.0419E-06
sm-151	6.0050E-07
sm-152	3.3455E-06
nd-143	2.8054E-05
nd-145	2.0493E-05
eu-153	2.3310E-06
gd-155	1.4372E-07
o	4.6219E-02

Data set No. 49
4.5wt%U235, 30GWD/MTU
cooling time (yr)=1.0
axial location 5
(32.855GWD/MTU)

u-234	5.5185E-06
u-235	3.9296E-04
u-236	1.2236E-04
u-238	2.1547E-02
pu-238	3.3089E-06
pu-239	1.4511E-04
pu-240	4.2146E-05
pu-241	2.8801E-05
pu-242	6.7305E-06
am-241	2.2432E-06
am-243	1.2545E-06
np-237	1.1995E-05
mo-95	4.5717E-05
tc-99	4.4219E-05
ru-101	4.1575E-05
rh-103	2.4774E-05
ag-109	3.5242E-06
cs-133	4.8147E-05
sm-147	4.5297E-06
sm-149	1.9990E-07
sm-150	1.1326E-05
sm-151	7.0207E-07
sm-152	4.4607E-06
nd-143	3.5176E-05
nd-145	2.6836E-05
eu-153	3.5819E-06
gd-155	6.9558E-08
o	4.6219E-02

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Data set No. 50                Data set No. 51                Data set No. 52                Data set No. 53
4.5wt%U235, 30GWD/MTU          4.5wt%U235, 50GWD/MTU          4.5wt%U235, 50GWD/MTU          4.5wt%U235, 50GWD/MTU
cooling time (yr)=5.0          cooling time (yr)=1.0          cooling time (yr)=5.0          cooling time (yr)=1.0
axial location 5              axial location 1 & 9          axial location 1 & 9          axial location 2 & 8
(32.855GWD/MTU)               (21.565GWD/MTU)               (21.565GWD/MTU)               (24.023GWD/MTU)

u-234    5.6227E-06           u-234    6.4500E-06           u-234    6.4862E-06           u-234    6.2405E-06
u-235    3.9298E-04           u-235    5.6755E-04           u-235    5.6757E-04           u-235    5.2560E-04
u-236    1.2238E-04           u-236    9.4545E-05           u-236    9.4556E-05           u-236    1.0153E-04
u-238    2.1547E-02           u-238    2.1732E-02           u-238    2.1732E-02           u-238    2.1693E-02
pu-238   3.2553E-06           pu-238   1.1544E-06           pu-238   1.1322E-06           pu-238   1.5152E-06
pu-239   1.4509E-04           pu-239   1.2592E-04           pu-239   1.2591E-04           pu-239   1.3162E-04
pu-240   4.2164E-05           pu-240   2.6401E-05           pu-240   2.6395E-05           pu-240   2.9970E-05
pu-241   2.3740E-05           pu-241   1.6516E-05           pu-241   1.3614E-05           pu-241   1.9354E-05
pu-242   6.7305E-06           pu-242   2.2623E-06           pu-242   2.2623E-06           pu-242   3.0335E-06
am-241   7.2733E-06           am-241   1.1411E-06           am-241   4.0266E-06           am-241   1.3794E-06
am-243   1.2540E-06           am-243   2.6232E-07           am-243   2.6222E-07           am-243   3.9824E-07
np-237   1.2026E-05           np-237   6.7920E-06           np-237   6.8089E-06           np-237   7.8840E-06
mo-95    4.5919E-05           mo-95    3.1317E-05           mo-95    3.1530E-05           mo-95    3.4570E-05
tc-99    4.4219E-05           tc-99    3.0320E-05           tc-99    3.0319E-05           tc-99    3.3465E-05
ru-101   4.1575E-05           ru-101   2.7452E-05           ru-101   2.7452E-05           ru-101   3.0548E-05
rh-103   2.4779E-05           rh-103   1.7256E-05           rh-103   1.7260E-05           rh-103   1.9004E-05
ag-109   3.5242E-06           ag-109   1.8879E-06           ag-109   1.8879E-06           ag-109   2.2230E-06
cs-133   4.8147E-05           cs-133   3.3140E-05           cs-133   3.3140E-05           cs-133   3.6549E-05
sm-147   8.3505E-06           sm-147   3.0651E-06           sm-147   6.4488E-06           sm-147   3.4086E-06
sm-149   1.9990E-07           sm-149   1.9390E-07           sm-149   1.9390E-07           sm-149   1.9611E-07
sm-150   1.1326E-05           sm-150   7.1174E-06           sm-150   7.1174E-06           sm-150   8.0472E-06
sm-151   6.8077E-07           sm-151   5.9331E-07           sm-151   5.7531E-07           sm-151   6.1943E-07
sm-152   4.4610E-06           sm-152   3.0176E-06           sm-152   3.0178E-06           sm-152   3.3471E-06
nd-143   3.5176E-05           nd-143   2.5793E-05           nd-143   2.5793E-05           nd-143   2.8067E-05
nd-145   2.6836E-05           nd-145   1.8633E-05           nd-145   1.8633E-05           nd-145   2.0504E-05
eu-153   3.5819E-06           eu-153   2.0026E-06           eu-153   2.0026E-06           eu-153   2.3329E-06
gd-155   2.5275E-07           gd-155   3.3040E-08           gd-155   1.1986E-07           gd-155   3.9645E-08
o        4.6219E-02           o        4.6219E-02           o        4.6219E-02           o        4.6219E-02
```

Data set No. 54
4.5wt%U235, 50GWD/MTU
cooling time (yr)=5.0
axial location 2 & 8
(24.023GWD/MTU)

u-234	6.2881E-06
u-235	5.2562E-04
u-236	1.0155E-04
u-238	2.1693E-02
pu-238	1.4876E-06
pu-239	1.3161E-04
pu-240	2.9965E-05
pu-241	1.5953E-05
pu-242	3.0335E-06
am-241	4.7603E-06
am-243	3.9809E-07
np-237	7.9041E-06
mo-95	3.4781E-05
tc-99	3.3465E-05
ru-101	3.0548E-05
rh-103	1.9008E-05
ag-109	2.2230E-06
cs-133	3.6549E-05
sm-147	6.9339E-06
sm-149	1.9611E-07
sm-150	8.0472E-06
sm-151	6.0064E-07
sm-152	3.3473E-06
nd-143	2.8067E-05
nd-145	2.0504E-05
eu-153	2.3329E-06
gd-155	1.4386E-07
o	4.6219E-02

Data set No. 55
4.5wt%U235, 50GWD/MTU
cooling time (yr)=1.0
axial location 3 & 7
(30.580GWD/MTU)

u-234	5.6995E-06
u-235	4.2453E-04
u-236	1.1761E-04
u-238	2.1585E-02
pu-238	2.7719E-06
pu-239	1.4250E-04
pu-240	3.9132E-05
pu-241	2.6524E-05
pu-242	5.6472E-06
am-241	2.0253E-06
am-243	9.7389E-07
np-237	1.0920E-05
mo-95	4.2926E-05
tc-99	4.1532E-05
ru-101	3.8751E-05
rh-103	2.3367E-05
ag-109	3.1774E-06
cs-133	4.5257E-05
sm-147	4.2601E-06
sm-149	1.9936E-07
sm-150	1.0496E-05
sm-151	6.8230E-07
sm-152	4.1841E-06
nd-143	3.3502E-05
nd-145	2.5263E-05
eu-153	3.2545E-06
gd-155	6.0994E-08
o	4.6219E-02

Data set No. 56
4.5wt%U235, 50GWD/MTU
cooling time (yr)=5.0
axial location 3 & 7
(30.580GWD/MTU)

u-234	5.7868E-06
u-235	4.2455E-04
u-236	1.1763E-04
u-238	2.1585E-02
pu-238	2.7262E-06
pu-239	1.4249E-04
pu-240	3.9140E-05
pu-241	2.1863E-05
pu-242	5.6472E-06
am-241	6.6579E-06
am-243	9.7353E-07
np-237	1.0948E-05
mo-95	4.3130E-05
tc-99	4.1531E-05
ru-101	3.8751E-05
rh-103	2.3371E-05
ag-109	3.1774E-06
cs-133	4.5257E-05
sm-147	8.0315E-06
sm-149	1.9936E-07
sm-150	1.0496E-05
sm-151	6.6160E-07
sm-152	4.1844E-06
nd-143	3.3502E-05
nd-145	2.5263E-05
eu-153	3.2546E-06
gd-155	2.2155E-07
o	4.6219E-02

Data set No. 57
4.5wt%U235, 50GWD/MTU
cooling time (yr)=1.0
axial location 4 & 6
(40.424GWD/MTU)

u-234	4.9433E-06
u-235	3.0000E-04
u-236	1.3532E-04
u-238	2.1413E-02
pu-238	5.4525E-06
pu-239	1.5066E-04
pu-240	5.1412E-05
pu-241	3.5395E-05
pu-242	1.0893E-05
am-241	2.9059E-06
am-243	2.5117E-06
np-237	1.5563E-05
mo-95	5.4612E-05
tc-99	5.2747E-05
ru-101	5.0881E-05
rh-103	2.9052E-05
ag-109	4.7134E-06
cs-133	5.7263E-05
sm-147	5.3175E-06
sm-149	1.9993E-07
sm-150	1.3997E-05
sm-151	7.6073E-07
sm-152	5.3313E-06
nd-143	3.9984E-05
nd-145	3.1783E-05
eu-153	4.6704E-06
gd-155	1.0133E-07
o	4.6219E-02

```
Data set No. 58
4.5wt%U235, 50GWD/MTU
cooling time (yr)=5.0
axial location 4 & 6
(40.424GWD/MTU)

u-234    5.1152E-06
u-235    3.0002E-04
u-236    1.3534E-04
u-238    2.1413E-02
pu-238   5.3656E-06
pu-239   1.5064E-04
pu-240   5.1484E-05
pu-241   2.9175E-05
pu-242   1.0893E-05
am-241   9.0866E-06
am-243   2.5108E-06
np-237   1.5602E-05
mo-95    5.4806E-05
tc-99    5.2746E-05
ru-101   5.0881E-05
rh-103   2.9057E-05
ag-109   4.7134E-06
cs-133   5.7263E-05
sm-147   9.2075E-06
sm-149   1.9993E-07
sm-150   1.3997E-05
sm-151   7.3765E-07
sm-152   5.3316E-06
nd-143   3.9984E-05
nd-145   3.1783E-05
eu-153   4.6705E-06
gd-155   3.6871E-07
o        4.6219E-02
```

```
Data set No. 59
4.5wt%U235, 50GWD/MTU
cooling time (yr)=1.0
axial location 5
(54.605GWD/MTU)

u-234    3.9925E-06
u-235    1.7106E-04
u-236    1.4895E-04
u-238    2.1142E-02
pu-238   1.0655E-05
pu-239   1.5301E-04
pu-240   6.5224E-05
pu-241   4.3713E-05
pu-242   2.0303E-05
am-241   3.7731E-06
am-243   6.1573E-06
np-237   2.1757E-05
mo-95    6.9709E-05
tc-99    6.6976E-05
ru-101   6.7875E-05
rh-103   3.5401E-05
ag-109   6.9836E-06
cs-133   7.2263E-05
sm-147   6.3252E-06
sm-149   1.9259E-07
sm-150   1.8627E-05
sm-151   8.4338E-07
sm-152   6.7635E-06
nd-143   4.5992E-05
nd-145   3.9892E-05
eu-153   6.5857E-06
gd-155   1.6688E-07
o        4.6219E-02
```

```
Data set No. 60
4.5wt%U235, 50GWD/MTU
cooling time (yr)=5.0
axial location 5
(54.605GWD/MTU)

u-234    4.3280E-06
u-235    1.7108E-04
u-236    1.4897E-04
u-238    2.1142E-02
pu-238   1.0471E-05
pu-239   1.5300E-04
pu-240   6.5540E-05
pu-241   3.6032E-05
pu-242   2.0303E-05
am-241   1.1405E-05
am-243   6.1550E-06
np-237   2.1806E-05
mo-95    6.9892E-05
tc-99    6.6975E-05
ru-101   6.7875E-05
rh-103   3.5406E-05
ag-109   6.9836E-06
cs-133   7.2263E-05
sm-147   1.0106E-05
sm-149   1.9259E-07
sm-150   1.8627E-05
sm-151   8.1779E-07
sm-152   6.7637E-06
nd-143   4.5992E-05
nd-145   3.9892E-05
eu-153   6.5858E-06
gd-155   6.0862E-07
o        4.6219E-02
```

Appendix B

Burnup Profiles
(10, 30, 40 and 50 GWd/t)


Prepared by Dr. A. Santamarina
and
Dr. P. Albarede

EOC1

El of Cycle 1 ; $\overline{BU}$ = 8610 MwD/t
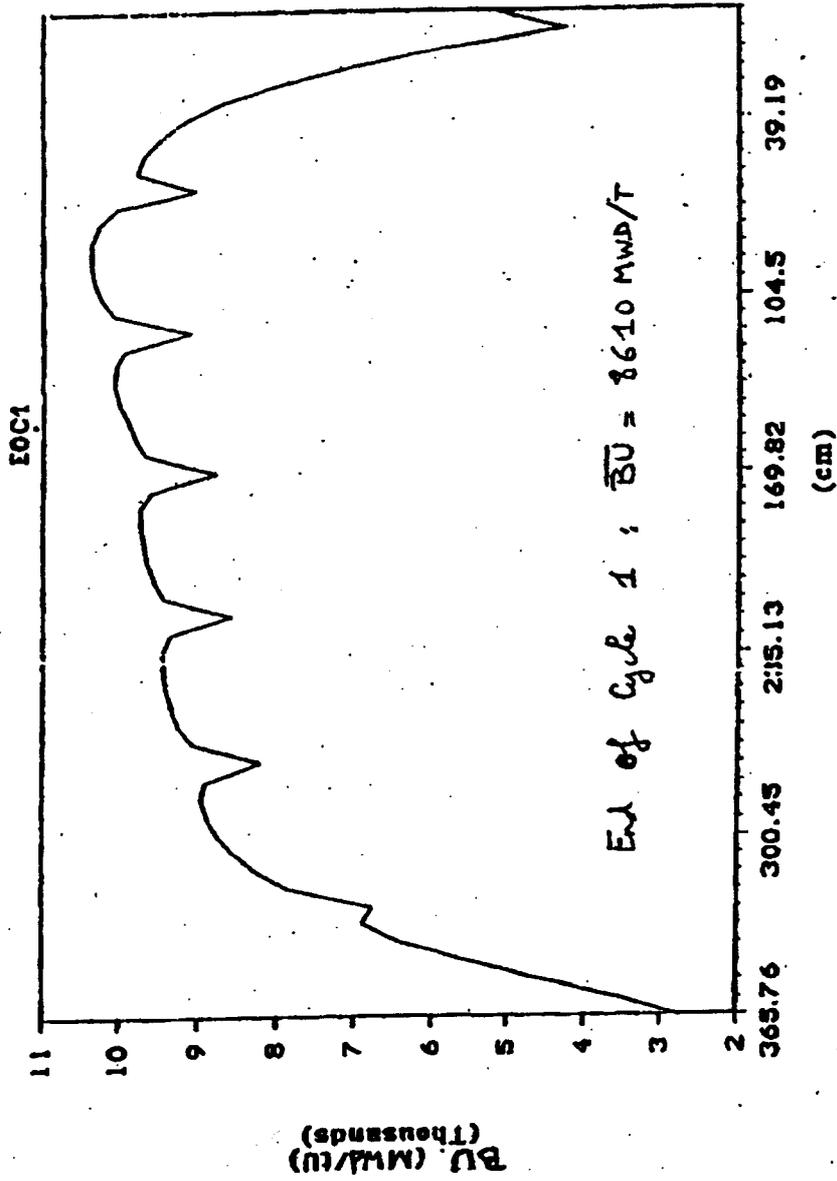
Fig. B.1 Burnup Profile for 10 GWd/t case

EOC3

End of Cycle 3 : $\overline{BU} = 36{,}910$ MWd/t

BU (MWd/tu)
(Thousands)

42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12

365.76 300.45 235.13 169.82 104.5 39.19

(cm)
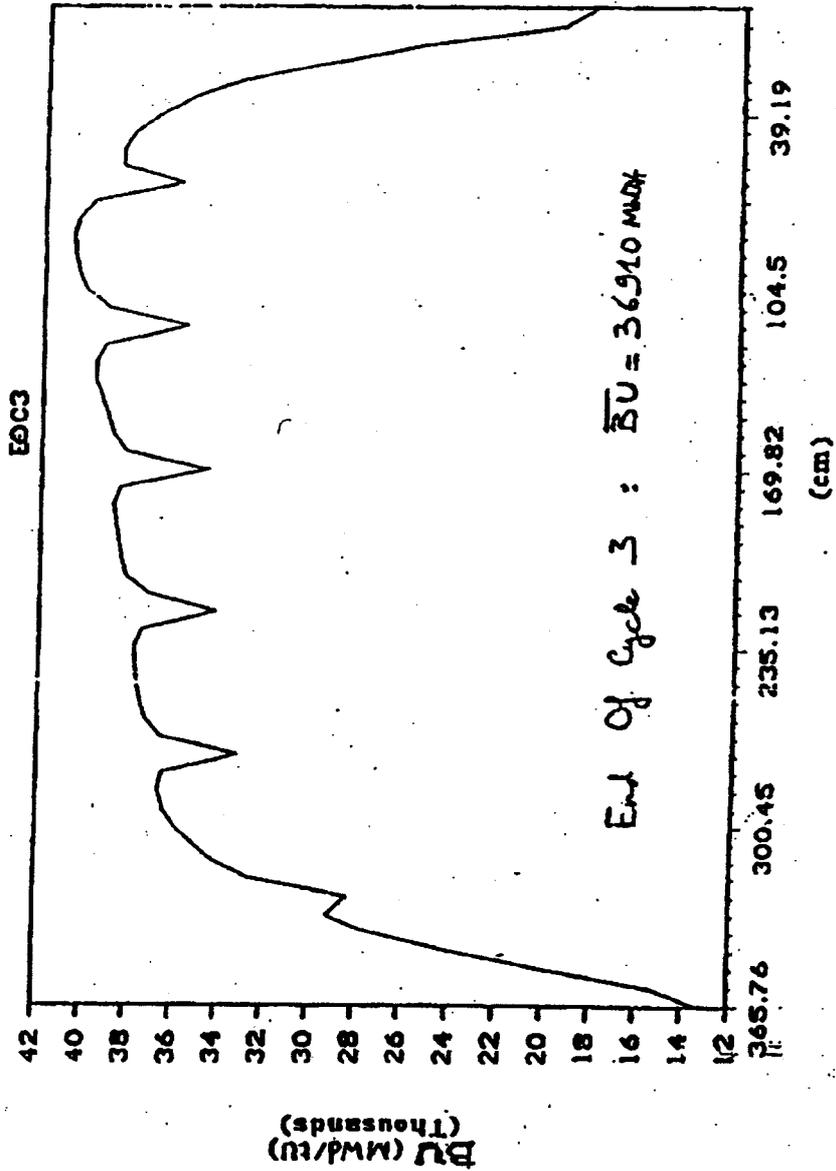
Fig. B.2 Burnup Profile for 30 and 40 GWd/t cases

EOC3

EOC4

End Of Cycle 4 : $\overline{BU} = 48380\ MwD/T$

(cm)

BU (MWd/cu)
(Thousands)

60 55 50 45 40 35 30 25 20 15

39.19 104.5 169.82 235.13 300.45 365.76
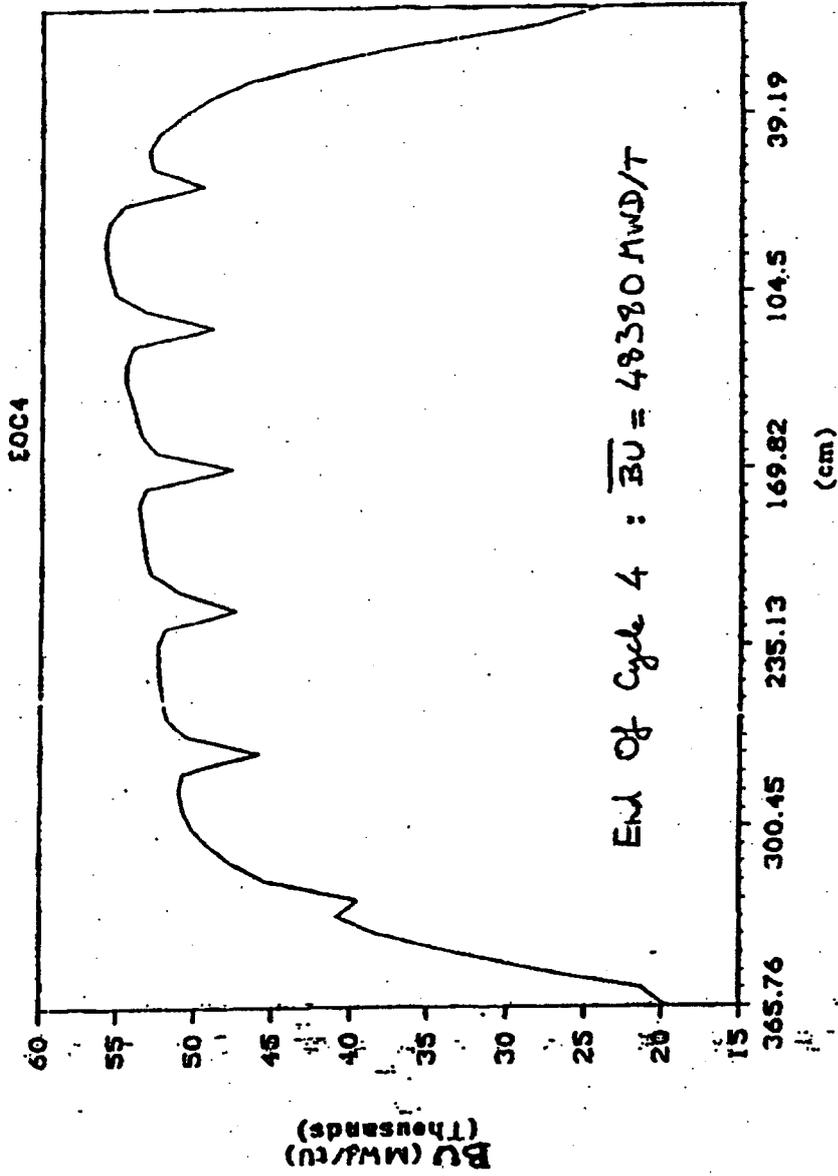
Fig. B.3 Burnup Profile for 50 GWd/t case