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APPENDIX A

FUEL DESIGN DATA AND GENERATION OF BROAD GROUP CROSS SECTIONS.

APPENDIX A

FUEL DESIGN DATA AND GENERATION OF BROAD GROUP CROSS SECTIONS

A.1 Fuel Rod and Fuel Follower Rod Design Data

The design of a standard UZrH fuel element for a TRIGA Mark III reactor is shown in Fig. 3.3 (reproduced from Ref. 10). The fuel data that were used in the calculations for this study are shown below:

	Fuel Rod		Fuel Follower Rod	
	cm	in.	cm	in.
Fuel OD	3.632	1.43	3.327	1.31
Central Hole OD	0.635	0.25	0.635	0.25
Clad Thickness	0.051	0.02	0.051	0.02
Fuel Length	38.1	15.0	38.1	15.0

UZr fuel and follower rods are manufactured with a central hole about 0.635 cm (0.25 in.) in diameter that facilitates uniform hydriding of the fuel. After hydriding, a Zr rod slightly smaller than 0.635 cm in diameter is inserted (not forced) into this hole. Many TRIGA fuel rods have a molybdenum disk (see Fig. A1) between the fuel and the bottom graphite reflector in order to separate the more dense UZrH fuel from the less dense graphite.

The fissile content of the fuel rods can be computed using the following formulae:

$$V_{UZrH} = \pi L\left[\left(\frac{D_o}{2}\right)^2 - \left(\frac{D_i}{2}\right)^2\right]$$

$$\rho_U = \frac{W_U}{0.177 - 0.125\ W_U}$$

$$g\ {}^{235}U = \epsilon \rho_U\ V_{UZrH}$$

$$\epsilon = 0.1979 \pm 0.0020$$

V_{UZrH} = Fuel Volume

D_o = Fuel Outer Diameter

D_i = Fuel Inner Diameter (Central Hole OD)

L = Fuel Length

ρ_U = U Density in UZrH

W_U = wt% of U in UZrH

ϵ = U enrichment

In a standard fuel rod with 8.5 wt% U, for example,

$$V_{UZrH} = \pi(38.1)\left[\left(\frac{3.632}{2}\right)^2 - \left(\frac{0.635}{2}\right)^2\right] = 382.67\ cm^3$$

$$\rho_U = \frac{0.085}{0.177 - 0.125(0.085)} = 0.5109\ g/cm^3$$

$$g\ {}^{235}U = (0.1979)(0.5109)(382.67) = 38.69\ g$$

Calculated fissile contents for the fuel and fuel follower rods with 8.5 wt% U and 20 wt% U are:

	g ^{235}U/Rod	
wt% U	Fuel Rod	Fuel Follower Rod
8.5	38.69	32.27
20	99.65	83.11

The rods with 20 wt% U also contain 0.53 wt% natural erbium as a burnable poison in the UZrH fuel meat. Natural erbium has an ^{166}Er abundance of 33.41 wt% and an ^{167}Er abundance of 22.93 wt%. Only ^{166}Er and ^{167}Er have been included in these calculations. Neutron absorption effects in the other stable erbium isotopes (^{162}Er, ^{164}Er, ^{168}Er, and ^{170}Er) have not been considered.

Additional fuel data that were used in the calculations are:

Graphite Reflectors (Top and Bottom)

Height : 8.763 cm (3.45 in.)

Graphite Density: 1.7 g/cm^3

Volume Fractions of Stainless Steel (SS 304) End Fittings

Top : L = 10.795 cm (4.25 in.) above graphite
60 vol% SS, 40 vol% H_2O

Bottom: L = 6.350 cm (2.5 in.) below graphite
60 vol% SS, 40 vol% H_2O

Stainless Steel Composition (Clad and End Fittings)

Type: SS 304 Density: 7.8264 g/cm^3

Component	wt%	Component Density, g/cm^3
Cr	20.1	7.19
^{55}Mn	1.695	7.43
Fe	68.44	7.87
Ni	9.765	8.90

A.2 The EPRI-CELL/RERTR Code

EPRI-CELL/RERTR is a one-dimensional integral transport code used at ANL to generate broad-group cross sections for subsequent use in diffusion theory calculations for all research and test reactors in the RERTR Program.

As input, EPRI-CELL/RERTR utilizes a 68-group fast GAM library and a 35-group slow THERMOS library. These cross section libraries were prepared using ENDF/B-IV data processed either through the XLACS2 module of the AMPX system or by the NJOY code[7] for the thermal library, and by the MC^2-II code for the fast library. The energy boundaries of the fast GAM and slow THERMOS fine-group libraries are shown in Tables A1 and A2.

For a specified cylindrical or slab cell geometry, EPRI-CELL/RERTR computes a fine-group neutron spectrum as a function of space, energy, and burnup. Broad-group cross sections result from collapsing the GAM/THERMOS fine-group cross sections over this spectrum. Considerable flexibility is available for choosing the number and energy boundaries of the broad groups. However, the values for the energy broundaries must be contained in Tables A1 and A2, and the boundary between the fast and thermal groups must be 1.855 eV at the present time. The energy boundaries of the 11 broad groups used in this study are shown in Table A3.

A.3 Core Cross Sections

In the diffusion theory calculations, the core was modeled as a hexagonal array containing a homogenized mixture of fuel rod materials and water. The center-to-center distance between the fuel rods or the lattice pitch was 4.3536 cm (1.714 in.).

The cross sections for each lattice position were calculated heterogeneously (fuel rod surrounded by water) using the EPRI-CELL/RERTR code and homogenized over the fuel cell. This means that the homogenized cross sections have values that represent a heterogeneous cell.

Since EPRI-CELL/RERTR is a one-dimensional code, each hexagonal lattice position was represented by a cylindrical unit cell whose dimensions were chosen to preserve the fuel rod material and water volume fractions. The radii of the cylindrical unit cells for the fuel rods and fuel rod followers are shown in Fig. A2 along with the various material volume fractions and atom densities.

To properly account for the periodic array of cylindrical unit cells, an analytic isotropic boundary condition was applied to the outer surface of the unit cell. A non-zero buckling of 3.37×10^{-2} cm^{-2} was used in the EPRI-CELL/RERTR code to approximately account for the effect of axial leakage on the broad-group microscopic cross sections. This axial buckling was computed for an extrapolation length of 8 cm. In retrospect, a value of 6 cm would have been more accurate, but would have had very little effect on the microscopic cross sections. Dancoff factors, which account for the shadowing effect of one fuel rod on another, were calculated by Sauer's method.[8] Values of D that were computed for the fuel rods and fuel follower rods were 0.1939 and 0.1132, respectively.

Table A1. Group Structure of the Fast GAM Library

Group Number	Upper Energy of Group (eV)	Group Number	Upper Energy of Group (eV)	Group Number	Upper Energy of Group (eV)
1	1.0000 E+7	24	3.1824 E+4	47	1.0130 E+2
2	7.7880 E+6	25	2.4788 E+4	48	7.8893 E+2
3	6.0653 E+6	26	1.9309 E+4	49	6.1442 E+2
4	4.7237 E+6	27	1.5034 E+4	50	4.7851 E+1
5	3.6788 E+6	28	1.1709 E+4	51	3.7267 E+1
6	2.8650 E+6	29	9.1188 E+3	52	2.9023 E+1
7	2.2313 E+6	30	7.1018 E+3	53	2.2603 E+1
8	1.7377 E+6	31	5.5308 E+3	54	1.7604 E+1
9	1.3534 E+6	32	4.3074 E+3	55	1.3710 E+1
10	1.0540 E+6	33	3.3546 E+3	56	1.0677 E+1
11	8.2085 E+5	34	2.6126 E+3	57	8.3153
12	6.3928 E+5	35	2.0347 E+3	58	6.4760
13	4.9787 E+5	36	1.5846 E+3	59	5.0435
14	3.8774 E+5	37	1.2341 E+3	60	3.9279
15	3.0197 E+5	38	9.6112 E+2	61	3.0590
16	2.3518 E+5	39	7.4852 E+2	62	2.3824
17	1.8316 E+5	40	5.8295 E+2	63	1.8550
18	1.4264 E+5	41	4.5400 E+2	64	1.4450
19	1.1109 E+5	42	3.5358 E+2	65	1.1254
20	8.6517 E+4	43	2.7536 E+2	66	8.7643 E-1
21	6.7380 E+4	44	2.1445 E+2	67	6.8256 E-1
22	5.2475 E+4	45	1.6702 E+2	68	5.3458 E-1
23	4.0868 E+4	46	1.8109 E+2	69	4.1400 E-1

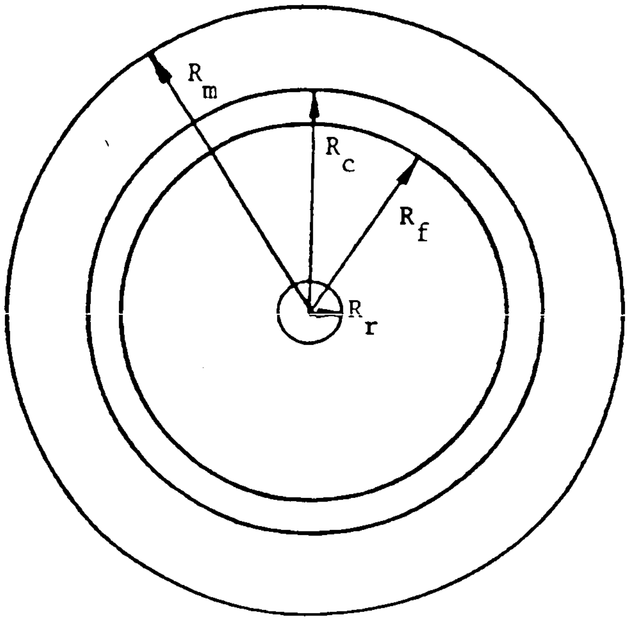
Table A2. Group Structure of the Slow THERMOS Library

Group Number	Lower Energy of Group (eV)	Group Number	Lower Energy of Group (eV)	Group Number	Lower Energy of Group (eV)
1	1.0000 E-5	13	2.2770 E-1	25	1.0137
2	2.2770 E-3	14	2.5104 E-1	26	1.0428
3	6.3250 E-3	15	2.7053 E-1	27	1.0525
4	1.2397 E-2	16	2.9075 E-1	28	1.0624
5	2.0493 E-2	17	3.0113 E-1	29	1.0722
6	3.0613 E-2	18	3.2064 E-1	30	1.0987
7	4.2757 E-2	19	3.5768 E-1	31	1.1664
8	5.6925 E-2	20	4.1704 E-1	32	1.3079
9	8.1972 E-2	21	5.0326 E-1	33	1.4575
10	1.1157 E-1	22	6.2493 E-1	34	1.5950
11	1.4573 E-1	23	7.8211 E-1	35	1.7262
12	1.8444 E-1	24	9.5070 E-1	36	1.8550

Table 3A. Broad Group Structure

Group Number	Upper Energy of Group (eV)	Group Number	Upper Energy of Group (eV)	Group Number	Upper Energy of Group (eV)
1	1.0000 E+7	5	5.5308 E+3	9	0.4170
2	8.2085 E+5	6	1.8550	10	0.1457
3	6.3928 E+5	7	1.1664	11	0.0569
4	9.1188 E+3	8	0.6249		

Fig. A2. Unit Cell Description Used in EPRI-CELL/RERTR to Generate Broad-Group Microscopic Cross Sections.



Region	Standard Fuel Rod: Radii, cm	Standard Fuel Rod: Volume Fraction	Fuel Follower Rod: Radii, cm	Fuel Follower Rod: Volume Fraction
Zr Rod	R_r 0.3175	0.0193	R_r 0.3175	0.0193
Fuel	R_f 1.8161	0.6120	R_f 1.6637	0.5105
Clad	R_c 1.8669	0.0358	R_c 1.7145	0.0328
Moderator	R_m 2.2858	0.3329	R_m 2.2858	0.4374

		Atom Density, atoms/cm^3 x 10^{-24}		
Region	Isotope	8.5 w/o U Fuel Rod	20 w/o U Fuel Rod	8.5 w/o U Fuel Follower
Fuel*	^{235}U	2.51201-4	6.46858-4	2.49683-4
	^{238}U	1.00527-3	2.58864-3	9.99195-4
	Zr	3.59031-2	3.42319-2	3.65164-2
	H	5.53465-2	4.93804-2	5.50120-2
	^{166}Er	-	4.06673-5	-
	^{167}Er	-	2.79230-5	-
Clad	Cr	1.67405-2	1.67405-2	1.67405-2
	Ni	8.91586-3	8.91586-3	8.91586-3
	Fe	5.80895-2	5.80895-2	5.80895-2
	^{55}Mn	1.38070-3	1.38070-3	1.38070-3
Moderator	H	6.68610-2	6.68610-2	6.68610-2
	O	3.34305-2	3.34305-2	3.34305-2

*0.635 cm Zr rod was homogenized with the active fuel

A.4 Reflector Cross Sections

Cross sections were computed for four separate reflector regions: (1) the radial light water reflector, (2) a region representing the reactor tank and water, (3) top and bottom regions representing the aluminum and water beyond the SS end fittings, and (4) a region representing the stainless steel end fittings, water, graphite, and aluminum. The cross sections for item (3) were also used for the various aluminum plus water regions inside the core. This is the correct choice because the neutron spectrum in these regions inside the core is very similar to the neutron spectrum in the light water reflector.

Cross sections for each reflector were computed by adding an additional region 8.7 cm thick to the unit cells shown in Fig. A2 and collapsing the cross sections using only the fine-group fluxes over the 8.7 cm thick region.

APPENDIX B

VERTICAL CROSS SECTION OF TRR-1/M1 COMPUTER MODEL SHOWING DIMENSIONS AND VOLUME FRACTIONS

A vertical cross section of the computer model for the TRR-1/M1 is shown in Fig. B1. Volume fractions for the various regions of the core are provided in Table B1 with descriptions in Table B2.

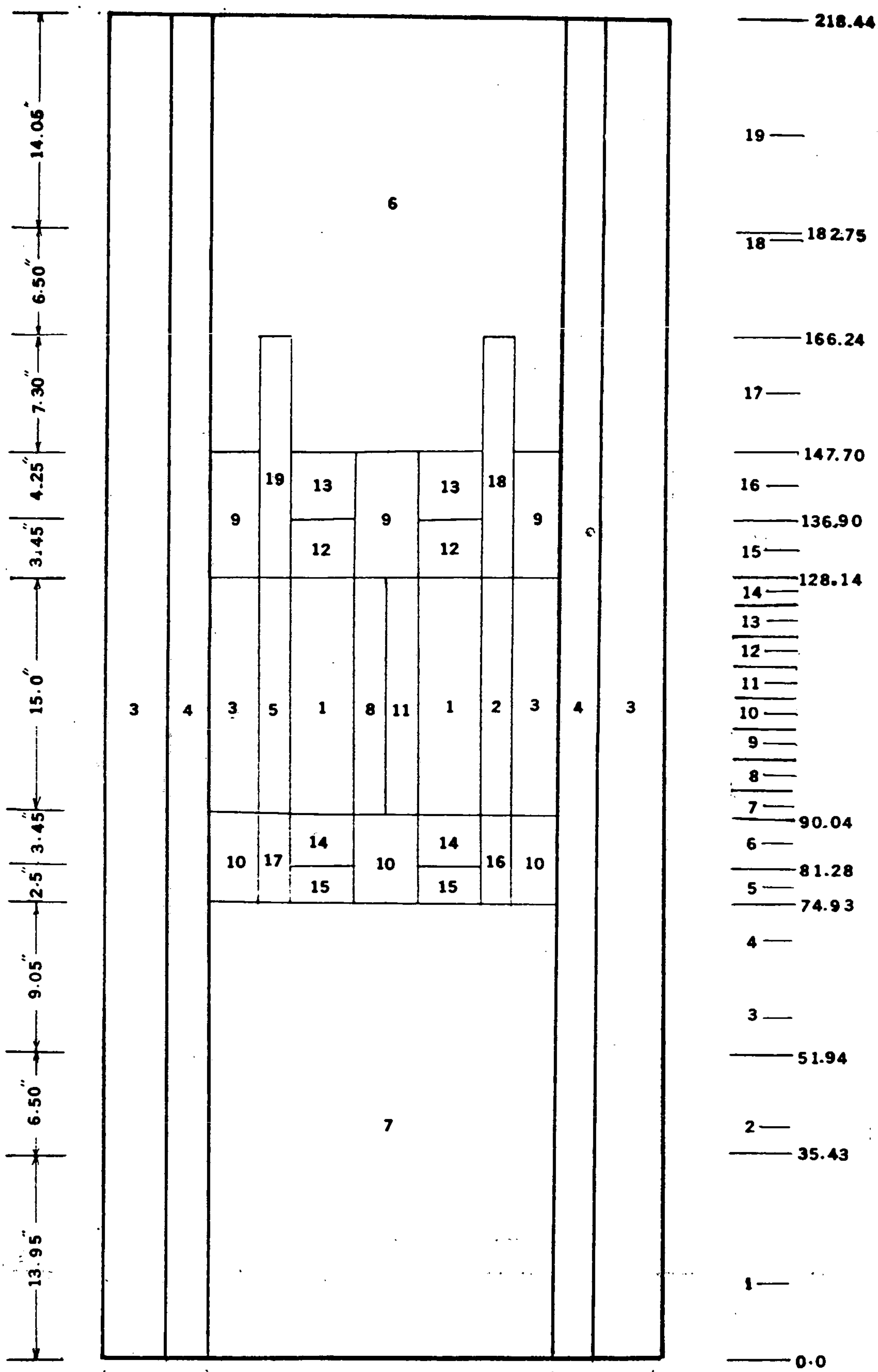


Fig. B1 Vertical Cross Section of Computer Model

Table B1. Volume Fractions of Materials in the Various Regions Shown in Fig. B1 Region Descriptions Are Provided in Table B2.

Region	Name	Volume Fraction
1	FUEL1 (8.5 wt% U) or FUEL2 (20 wt% U)	
	Meat	0.63125
	Clad	0.03581
	H_2O	0.33294
2	FUEL3 (8.5 wt% U) FUEL FOLLOWER	
	Meat	0.52975
	Clad	0.03285
	H_2O	0.43740
3	H2OREF	
	H_2O	1.0000
4	TANK	
	Al	0.15986
	H_2O	0.84014
5	TR	
	Al	0.15743
	H_2O	0.40248
	(Void	0.44009)
6	AXH2OT	
	Al	0.00926
	H_2O	0.98210
	(Void	0.00864)
7	AXH2OB	
	Al	0.03485
	H_2O	0.96270
	(Void	0.00245)
8	CT	
	Al	0.14852
	H_2O	0.30542
	(Void	0.54606)
9	AXREFT	
	Al	0.05429
	H_2O	0.91688
	(Void	0.02883)
10	AXREFB	
	Al	0.21577
	Graphite	0.02953
	H_2O	0.74356
	(Void	0.01114)
11	DET	
	Al	0.18927
	Graphite	0.24117
	H_2O	0.32838
	(Void	0.24118)
12	FETI	
	SS	0.03581
	Graphite	0.56261
	H_2O	0.40158
13	FETO	
	SS	0.40024
	Al	0.07186
	H_2O	0.52789
14	FEBI	
	SS	0.03581
	Graphite	0.55712
	H_2O	0.40158
	Mo	0.00549
15	FEBO	
	SS	0.40024
	Al	0.48781
	H_2O	0.11195
16	FFB	
	SS	0.03285
	Al	0.05134
	H_2O	0.38606
	(Void	0.52976)
17	TRB	
	Al	0.22159
	H_2O	0.19901
	(Void	0.57940)
18	CNTL1	
	SS	0.03285
	B_4C	0.52975
	H_2O	0.43740
19	CNTL2	
	Al	0.04210
	B_4C	0.43714
	H_2O	0.52076

1.6 Table B2 Description of Regions in Table B1.

Region	Name	Description
1	FUEL1	Fuel cell with 8.5 wt%U (See App. A)
1	FUEL2	Fuel cell with 20 wt % U (See App. A)
2	FUEL3	Fuel Follower Cell with 8.5 wt % U (See App.A)
3	H2OREF	Light Water Reflector (Pool Water)
4	TANK	Homogenized Reactor Tank and Water Tank OD = 22.0 in., ID = 21.5 in.
5	TR	Transient Rod with "Air Follower". Transient Rod is B_4C (2.52 g/cm^3) with Al cladding and fuel follower geometry. It moves in an Al guide tube with OD = 1.50 in., ID = 1.37 in. Air replaces fuel in follower section. Other control rods are B_4C clad with SS 304 and have UZrH fuel followers.
6	AXH2OT	Top axial reflector containing the water at the top of reactor core inside the tank, four aluminum connecting rods, instrumented fuel element structures having the same OD = 0.75 in. (Approx.), ID = 0.50 in.(Approx.) and Central Thimble with OD=1.5 in., ID = 1.33 in. (not included the portion of neutron absorber in control rods) and ignored a very small amount of other materials that may contain in this region.
7	AXH2OB	Bottom axial reflector, similar compositions to region NO. 9 , located at the bottom of reflector inside the tank. The volume fractions of this region depend upon the number of fuel elements loaded in the core.
8	CT	Central Thimble, an aluminum tube in the portion of fuel active length having OD=1.5 in., ID = 1.33 in.

Region	Name	Description
9	AXREFT	Top axial reflector, containing water at the top of fuel elements upper part of container of three neutron detectors with OD = 1.475 in (Approx.),ID = 1.25 in (Approx.) upper part of Central Thimble. (see region No.8) The volume fractions of this region are slightly differrent from core to core (core No. 1-4) and the same in core No. 5-12 depend upon the number of fuel element loaded in the core.
10	AXREFB	Bottom axial reflector, similar compositions to region No. 9. and volume fractions depend upon the number of fuel elements loaded in the core.
11	DET	Three detectors are in the position D-6, E-8, and E-19 . They are aluminum container in each detector with OD = 1.475 in., ID = 1.25 in., 50 % void in the upper part and 50 % graphite in the lower part
12	FETI	The top of each fuel element is designed to this region, it is graphite reflector(20 % porosity) having the same diameters as fuel element, OD = 1.47 in., ID = 1.43 in., Length = 3.45 in and SS-304 cladding with 0.02 in thickness.
13	FETO	Top-end fitting of fuel elements (stainless steel), top grid plate (hole dimeter = 1.5 in.) and water.
14	FEBI	Graphite reflector (same dimensions in the lower part of fuel elements including molybdenum disk between the fuel meat and graphite reflector (disk diameter = 1.43 in, and 0.03 in. thickness).

Region	Name	Description
15	FEBO	Fuel element bottom part and outer side is stainless steel bottom -end fitting, lower grid plate and water.
16	FFB	The lower part of four Fuel Follower Control Rods, containing air (void) which located at: D-1 for Safety rod D-10 for Regulating rod D-13 for Shim 1 rod D-16 for Shim 2 rod All rods have OD = 1.31 in. Wall thickness = 0.02 in.(SS-304) Length = 6.5 in.
17	TRB	The transient control rod follower is air (Void) with OD = 1.25 in.and wall thickness = 0.028 in.(Aluminum)
18	CNTL1	The boron carbide neutron absorber (solid form) in the upper part of lour fuel follower control rods with diameter of 1.31 in.and wall thickness 0.02 in.(stainless steel).
19	CNTL2	The boron carbide neutron absorber (solid form) in the upper part of the Transient Control rod with diameter of 1.25 in. (aluminum).
20	IIT	(not shown) In-core Iradiation tubes had been installed in core No 3 at the position of G-5, G-6, G-32 and G-33 for isotope productions. The OD = 1.475 in.(Approx.) and ID = 1.225 in.(Approx.)

APPENDIX C

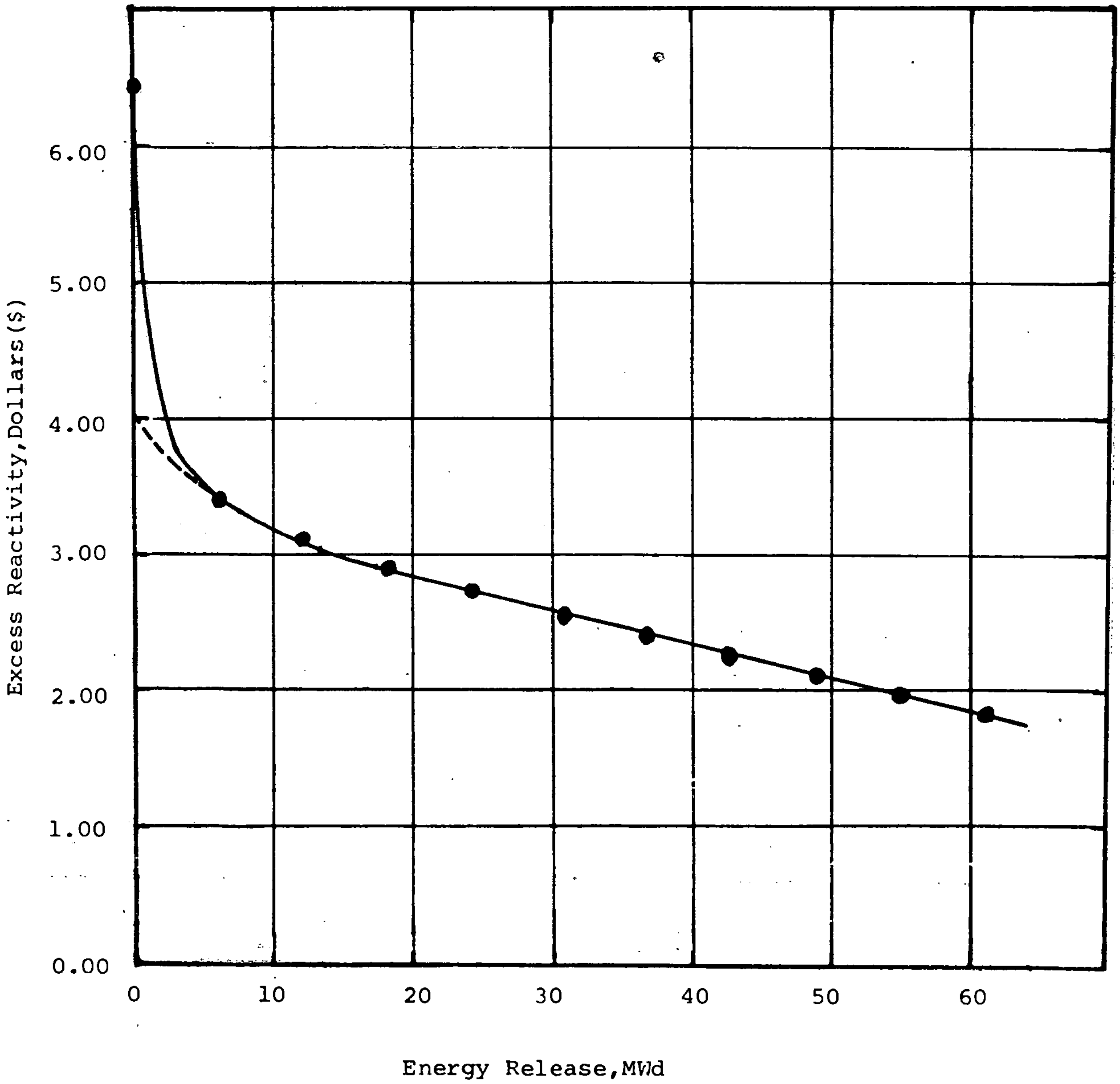
BURNUP HISTORY DATA
FOR CORE NO.'s 1-4

Fig C1 TRR-1/M1 CORE No.1

Calculated Reactivity Rundown Data

(All Rods out, cold core, No xe At BOC)

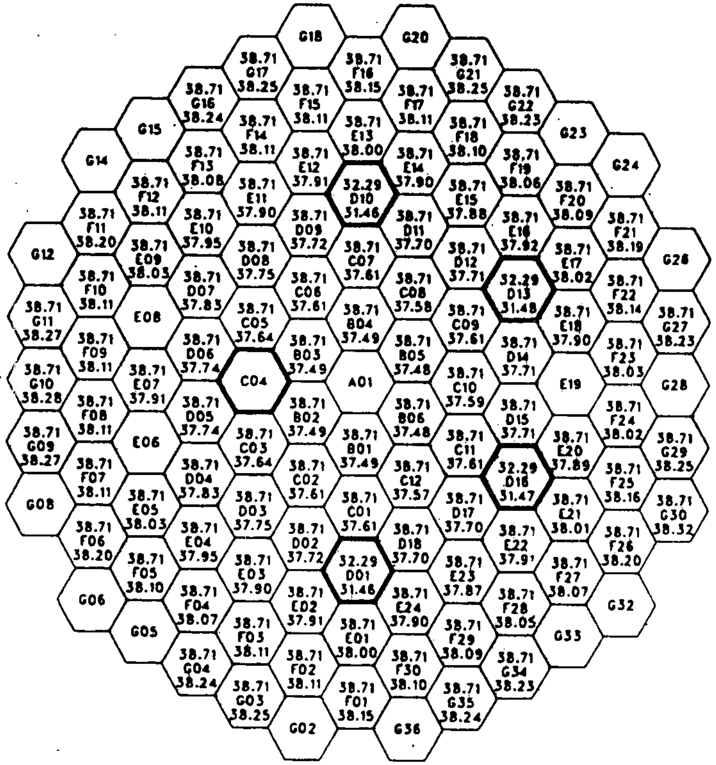
Energy Release, MWd	k_{eff}	Excess React., %δk/k,	($)
0.0	1.04703	4.492	(6.417)
6.122	1.02436	2.378	(3.397)
12.244	1.02239	2.190	(3.129)
18.366	1.02074	2.032	(2.903)
24.488	1.01932	1.895	(2.707)
30.610	1.01806	1.774	(2.534)
36.732	1.01694	1.666	(2.380)
42.854	1.01590	1.565	(2.236)
48.976	1.01486	1.464	(2.091)
55.098	1.01393	1.374	(1.963)
61.220	1.01304	1.287	(1.839)



TRR-1/M1 CORE No.1

^{235}U Loadings, g

BOC (Top) and EOC (Bottom)



Total ^{235}U Content at BOC : 3844.87 g

Total ^{235}U Content at EOC : 3768.24 g

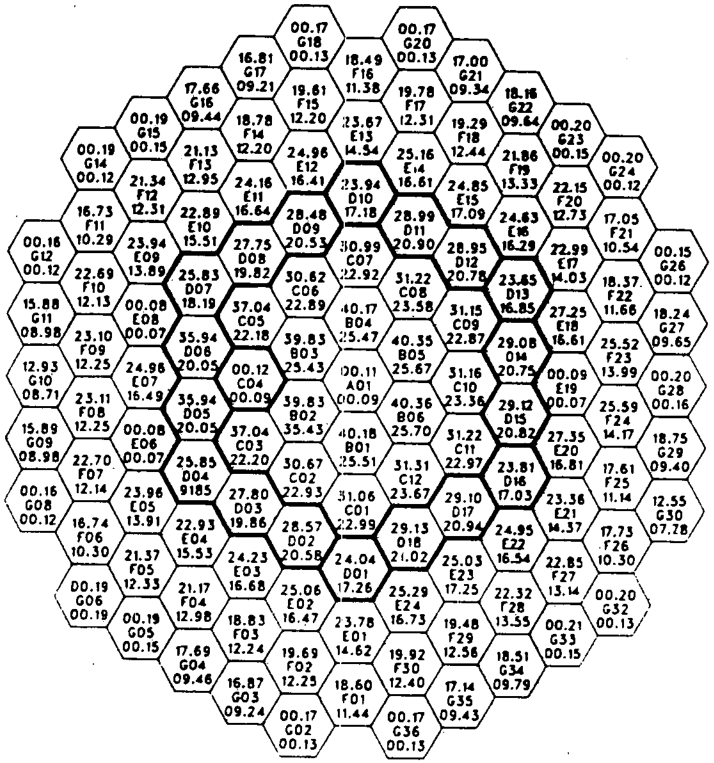
Average ^{235}U Burnup : 1.2517 g/MWd

No. of 8.5 wt %U elements : 100

No. of 20 wt. %U elements : -

BOC Power Densities, W/cm^3

Peak (Top) and Average (Bottom)



Peak Power Density : 40.36 W/cm^3 in B6

Average Power Density

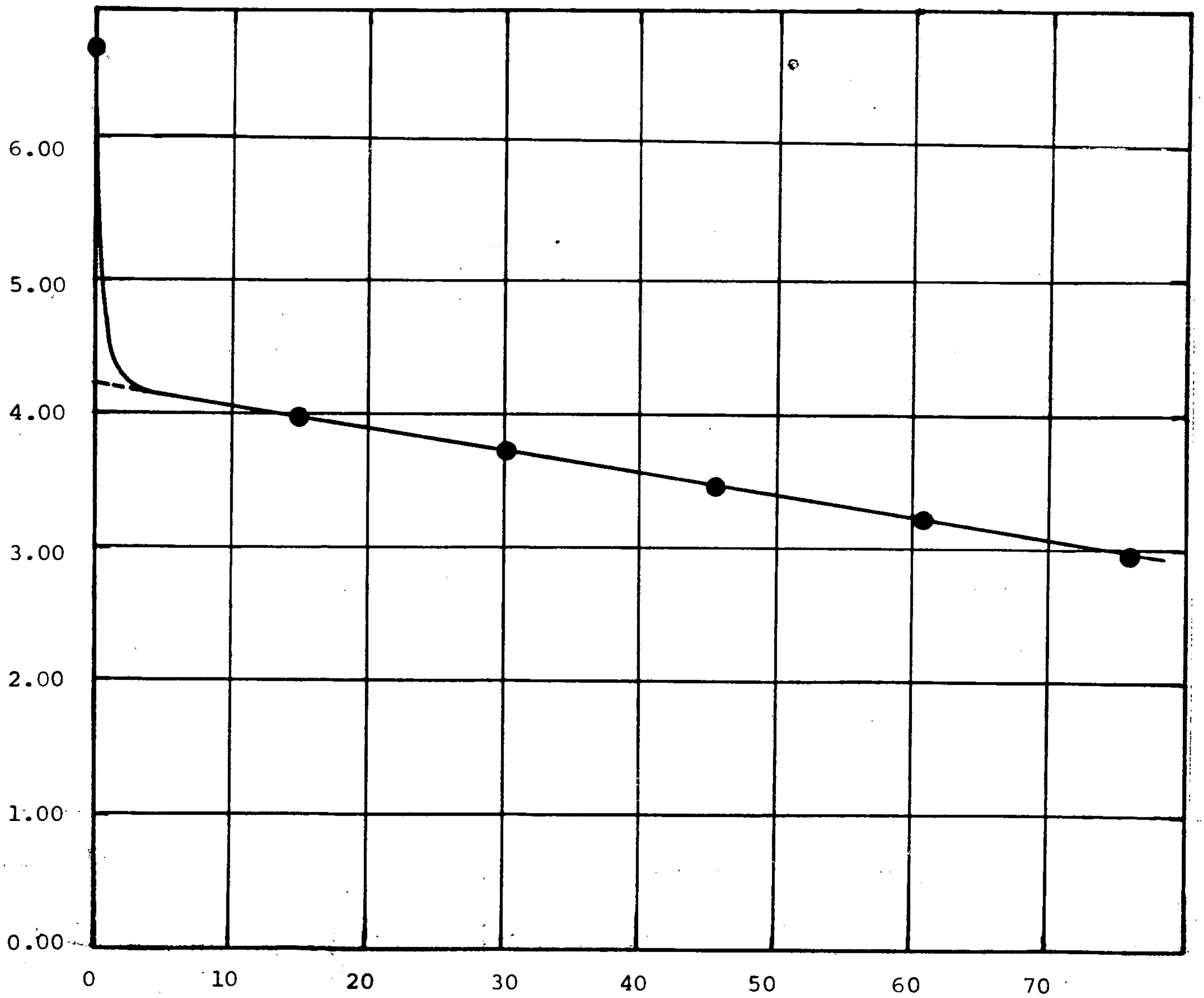
in Fuelled Regions : 15.85 W/cm^3

Fig. C2 Core No. 1 ^{235}U loading and power densities

Fig C3 TRR-1/M1 CORE No.2

Calculated Reactivity Rundown Data

Energy Release, MWd	k_{eff}	Excess React., %δk/k ,	($)
0.0	1.04936	4.704	(6.720)
15.266	1.02835	2.757	(3.939)
30.532	1.02641	2.573	(3.676)
45.798	1.02462	2.403	(3.433)
61.064	1.02291	2.240	(3.200)
76.330	1.02137	2.092	(2.989)

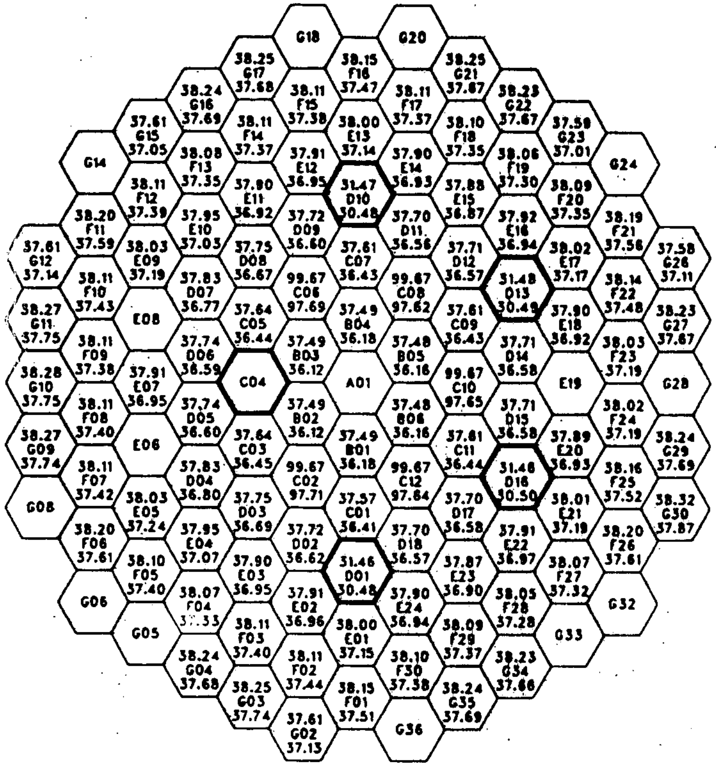


Energy Release, MWd

TRR-1/M1 CORE No.2

^{235}U Loadings, g

BOC (Top) and EOC (Bottom)



Total ^{235}U Content at BOC : 4266.99 g

Total ^{235}U Content at EOC : 4171.30 g

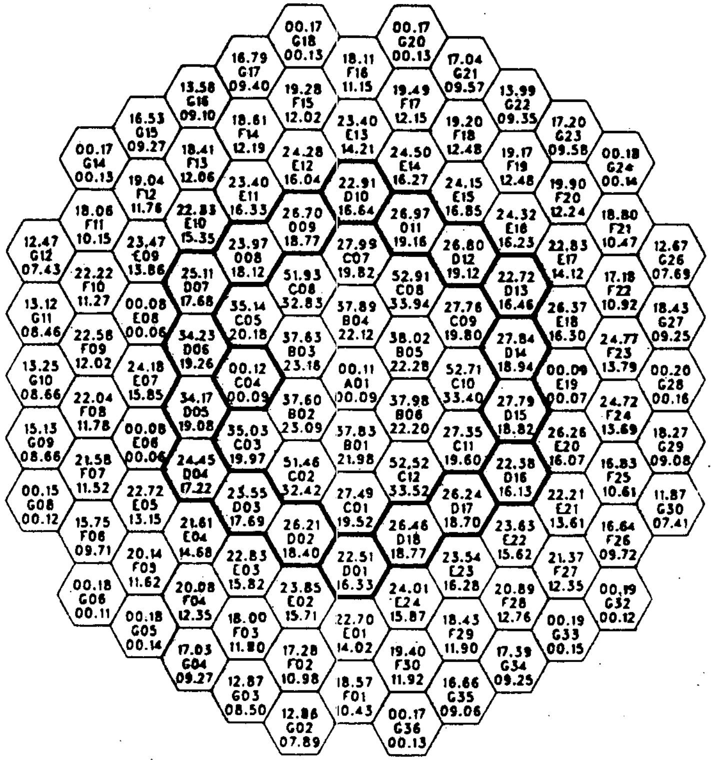
Average ^{235}U Burnup : 1.2484 g/MWd

No. of 8.5 wt. %U elements: 100

No. of 20 wt. %U elements : 5

BOC Power Densities, W/cm^3

Peak (Top) and Average (Bottom)



Peak Power Density : 52.91 W/cm^3 in C8

Average Power Density

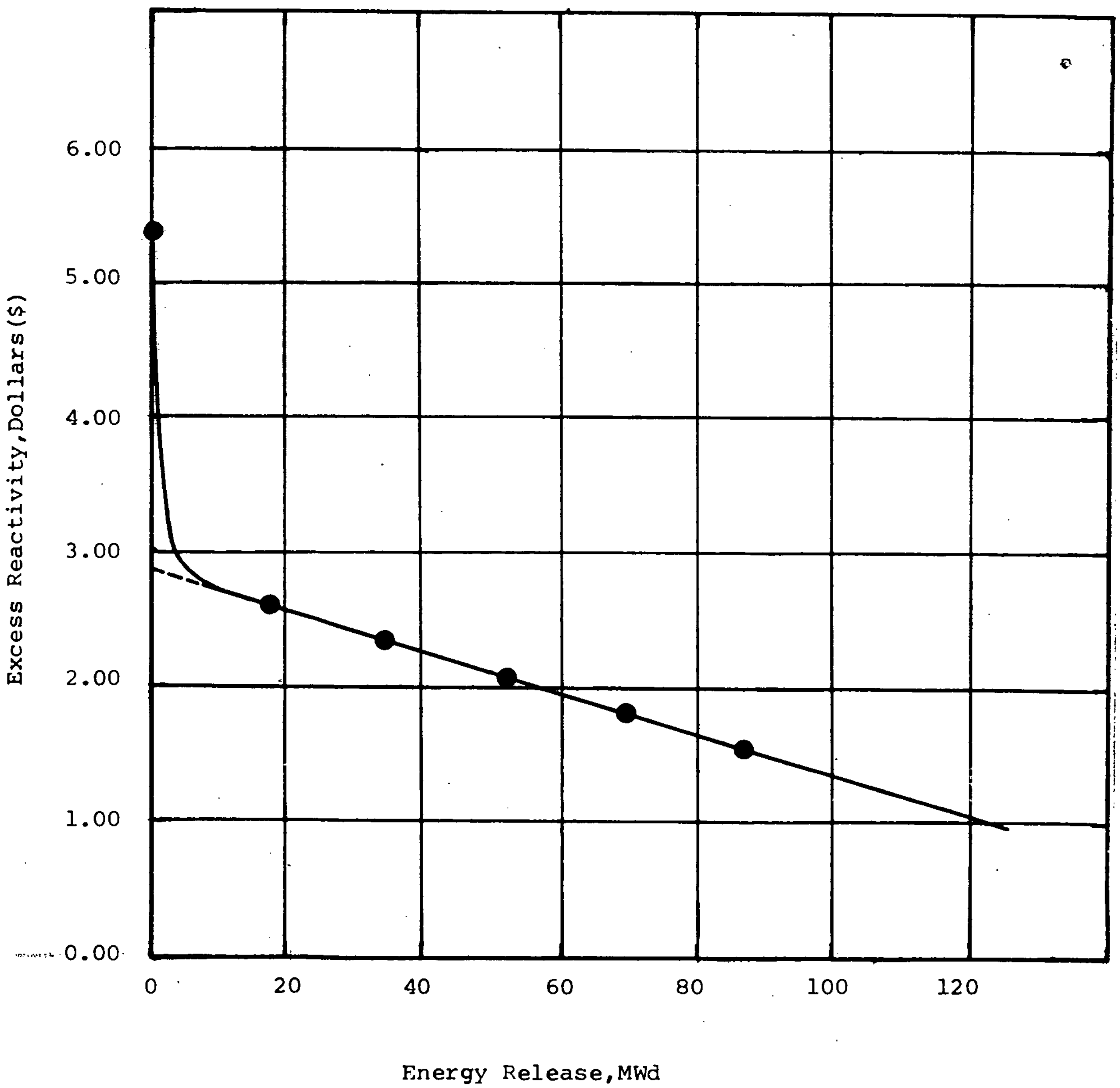
in Fuelled Region : 15.09 W/cm^3

Fig. C4 Core No.2 ^{235}U loading and power densities

Fig C5 TRR-1/M1 CORE No.3

Calculated Reactivity Rundown Data

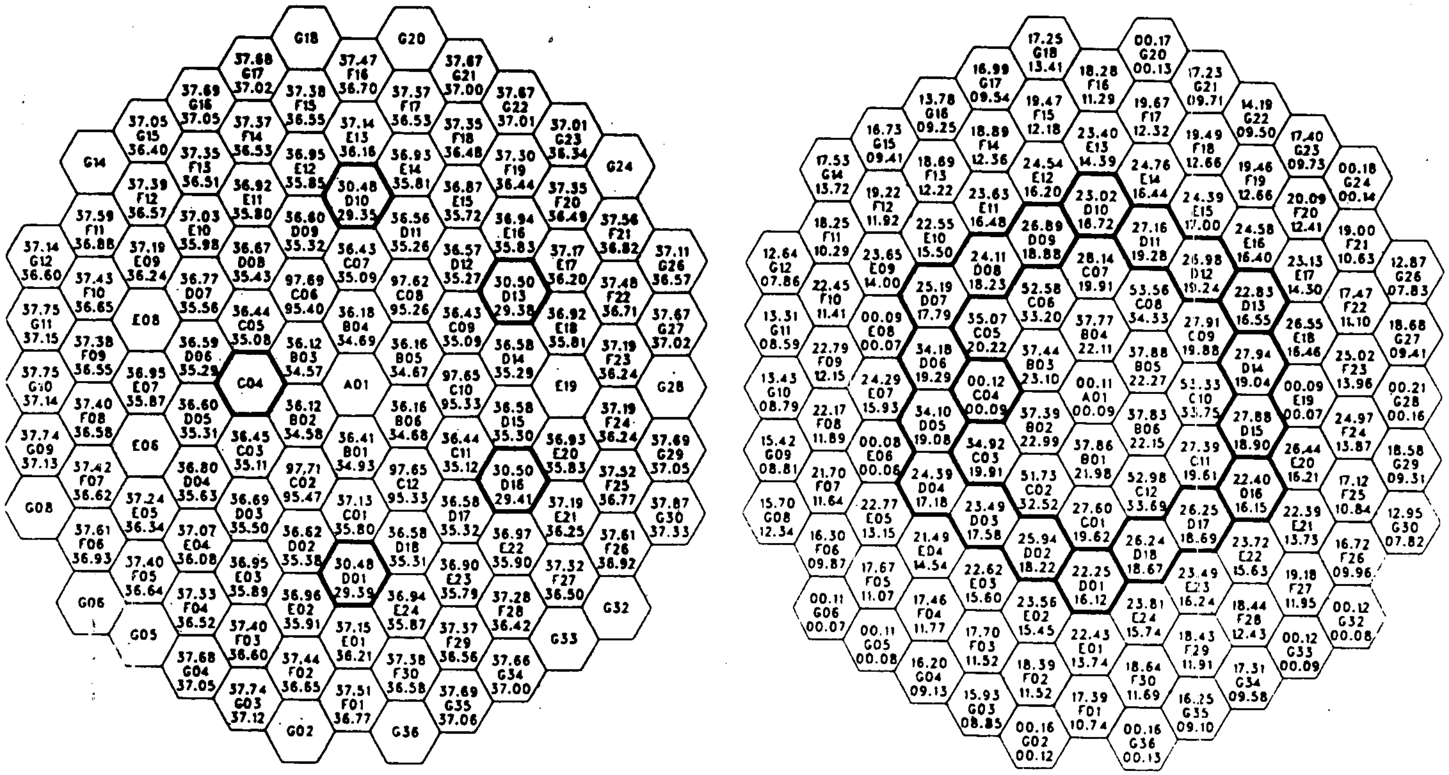
Energy Release, MWd	k_{eff}	Excess React., %δk/k,	($)
0.0	1.03928	3.780	(5.400)
17.398	1.01864	1.830	(2.614)
34.796	1.01668	1.641	(2.344)
52.194	1.01477	1.456	(2.080)
69.592	1.01287	1.271	(1.816)
86.990	1.01111	1.099	(1.570)



TRR-1/M1 CORE No.3

^{235}U Loadings, g
BOC (Top) and EOC (Bottom)

BOC Power Densities, W/cm^3
Peak (Top) and Average (Bottom)



Total ^{235}U Content at BOC : 4135.12 g
Total ^{235}U Content at EOC : 4027.06 g
Average ^{235}U Burnup : 1.2422 g/MWd
No. of 8.5 wt. %U elements : 99
No. of 20 wt. %U elements : 5

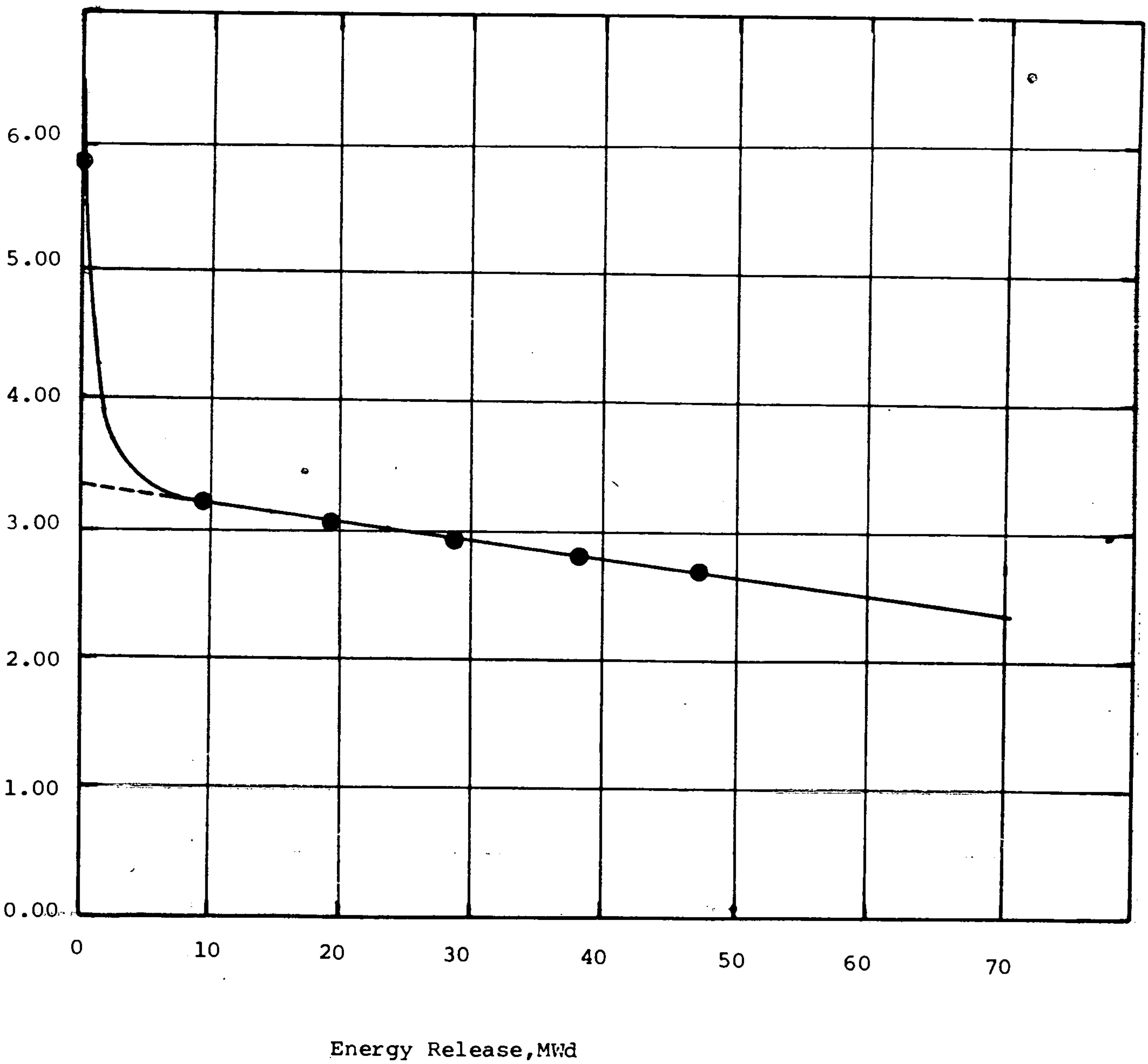
Peak Power Density : 53.56 W/cm^3 in C8
Average Power Density
in Fuelled Regions : 15.24 W/cm^3

Fig. C6 Core No. 3 ^{235}U loading and power densities

Fig C7 TRR-1/M1 CORE No.4

Calculated Reactivity Rundown Data

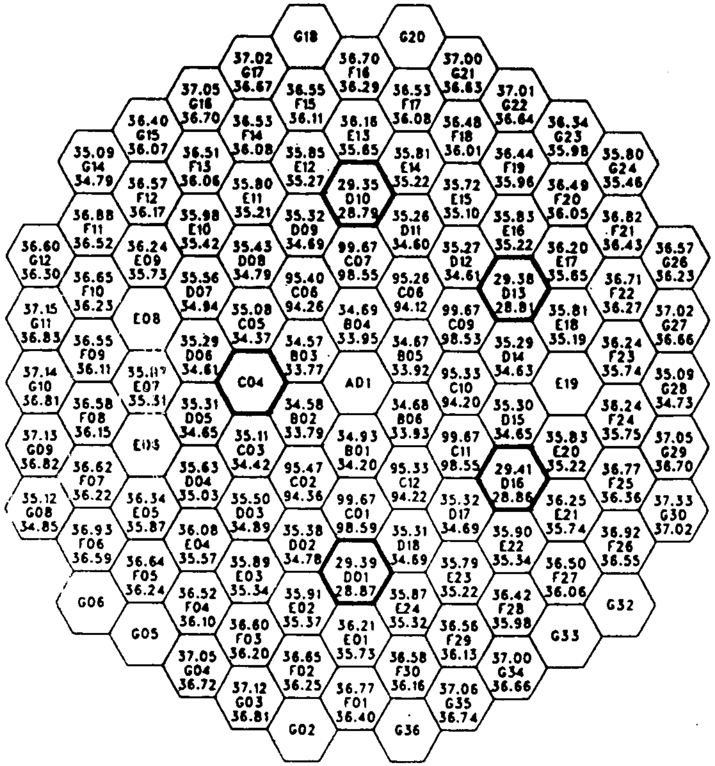
Energy Release, MWd	k_{eff}	Excess React., %δk/k,	($)
0.0	1.04223	4.052	5.789
9.490	1.02317	2.265	3.236
18.980	1.02212	2.164	3.091
28.470	1.02111	2.067	2.953
37.960	1.02015	1.975	2.821
47.450	1.01925	1.889	2.699



TRR-1/M1 CORE No. 4

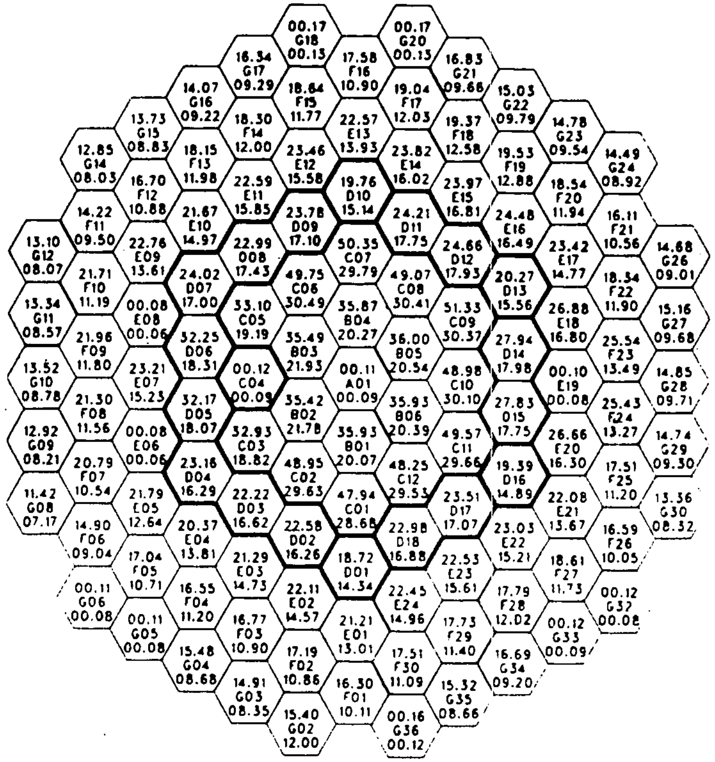
^{235}U Loadings, g

BOC (Top) and EOC (Bottom)



BOC Power Densities, W/cm^3

Peak (Top) and Average (Bottom)



Total ^{235}U Content at BOC : 4425.74 g

Total ^{235}U Content at EOC : 4366.90 g

Average ^{235}U Burnup : 1.2400 g/MWd

No. of 8.5 wt %U elements : 99

No. of 20 wt %U elements : 9

Peak Power Density : 51.33 W/cm^3 in C9

Average Power Density

in Fuelled Regions : 14.67 W/cm^3

Fig. C8 Core No. 4 ^{235}U loading and power densities

APPENDIX D

TRR-1 /M1 LOADING LIST

FOR CORE NO.'S 1-5

TRR-1/M1 Loading List
for Core No.'s 1-5

I.D.	Core 1	Core 2	Core 3	Core 4	Core 5
8558	F21	F21	F21	F21	F21
8559	E22	E22	E22	E22	E22
8560	G21	G21	G21	G21	G21
8561	E10	E10	E10	E10	E10
8562	E11	E11	E11	E11	E11
8563	E15	E15	E15	E15	C6
8564	D8	D8	D8	D8	E15
8565	E23	E23	E23	E23	E23
8566	F2	F2	F2	F2	F2
8567	E2	E2	E2	E2	F8
8568	D17	D17	D17	D17	E5
8569	D15	D15	D15	D15	G18
8570	D14	D14	D14	D14	G36
8571	F7	F7	F7	F7	B2
8572	D18	D18	D18	D18	E17
8573	D3	D3	D3	D3	E21
8574	F18	F18	F18	F18	B4
8575	E14	E14	E14	E14	E14
8576	F13	F13	F13	F13	F13
8577	F29	F29	F29	F29	F29
8578	F6	F6	F6	F6	F6
8579	F25	F25	F25	F25	F25
8580	F14	F14	F14	F14	F14
8581	C1	G2	C1	G24	G24

TRR-1/M1 Loading List (continued)
for Core No.'s 1-5

I.D.	Core 1	Core 2	Core 3	Core 4	Core 5
8582	C2	G15	G15	G15	G15
8583	B4	B4	B4	B4	F18
8584	B5	B5	B5	B5	E7
8585	F3	F3	F3	F3	F3
8586	F16	F16	F16	F16	F16
8587	F15	F15	F15	F15	F15
8588	F4	F4	F4	F4	F4
8589	F9	F9	F9	F9	B3
8590	B6	B6	B6	B6	G26
8591	C10	G23	G23	G23	G23
8592	E7	E7	E7	E7	E7
8593	F11	F11	F11	F11	F11
8594	D9	D9	D9	D9	E9
8595	E1	E1	E1	E1	C3
8596	E9	E9	E9	E9	C2
8597	D4	D4	D4	D4	E2
8598	C5	C5	C5	C5	G20
8599	C7	C7	C7	G14	G14
8600	G35	G35	G35	G35	G35
8601	G4	G4	G4	G4	G4
8602	E20	E20	E20	E20	E20
8603	C3	C3	C3	C3	G2
8604	C9	C9	C9	G28	G28
8605	D6	D6	D6	D6	E13

TRR-1/M1 Loading List (continued)
for Core No.'s 1-5

I.D.	Core 1	Core 2	Core 3	Core 4	Core 5
8606	F26	F26	F26	F26	F26
8607	E3	E3	E3	E3	C5
8608	D11	D11	D11	D11	E16
8609	B3	B3	B3	B3	F9
8610	G22	G22	G22	G22	G22
8611	E16	E16	E16	E16	C12
8612	E18	E18	E18	E18	E18
8613	F1	F1	F1	F1	F1
8614	F27	F27	F27	F27	F27
8615	G9	G9	G9	G9	G9
8616	G10	G10	G10	G10	G10
8617	F23	F23	F23	F23	F23
8618	G11	G11	G11	G11	G11
8619	F19	F19	F19	F19	F19
8620	G34	G34	G34	G34	G34
8621	E21	E21	E21	E21	C10
8622	E12	E12	E12	E12	C7
8623	D7	D7	D7	D7	E3
8624	E4	E4	E4	E4	C11
8625	G3	G3	G3	G3	G3
8626	F10	F10	F10	F10	F10
8627	G17	G17	G17	G17	G17
8628	E13	E13	E13	E13	C1
8629	F28	F28	F28	F28	F28

TRR-1/M1 Loading List (continued)
for Core No.'s 1-5

I.D.	Core 1	Core 2	Core 3	Core 4	Core 5
8630	C8	G26	G26	G26	B6
8631	D2	D2	D2	D2	E1
8632	D12	D12	D12	D12	E4
8633	C11	C11	C11	G8	G8
8634	C6	G12	G12	G12	G12
8635	D5	D5	D5	D5	E12
8636	G30	G30	G30	G30	G30
8637	F17	F17	F17	F17	F17
8638	F20	F20	F20	F20	F20
8639	G29	G29	G29	G29	G29
8640	F8	F8	F8	F8	B5
8641(a)	B2	B2	B2	B2	-
8642	G27	G27	G27	G27	G27
8643	G16	G16	G16	G16	G16
8644	F30	F30	F30	F30	F30
8645	E24	E24	E24	E24	E24
8646	F12	F12	F12	F12	F12
8647	F22	F22	F22	F22	F22
8648	F5	F5	F5	F5	F5
8649	E5	E5	E5	E5	C9
8650	E17	E17	E17	E17	C8
8651	F24	F24	F24	F24	F24
8652(TC1)	C12	C1	B1	B1	B1
8653(TC2)	B1	B1	-	-	-

TRR–1/M1 Loading List (continued)
for Core No.'s 1–5

I.D.	Core 1	Core 2	Core 3	Core 4	Core 5
9219	-	C12	C12	C12	D17
9220	-	-	-	C1	D2
9221	-	-	-	C7	D11
9222	-	C2	C2	C2	D4
9223	-	C10	C10	C10	D3
9224	-	C8	C8	C8	D12
9225	-	-	-	C9	D14
9226	-	-	-	C11	D15
9227 (TC3)	-	-	-	-	-
9228 (TC4)	-	C6	C6	C6	D8
9860	-	-	-	-	D7
9862	-	-	-	-	D5
9865	-	-	-	-	D9
9866	-	-	-	-	D18
9868	-	-	-	-	D6
8264	D1*	D1	D1	D1	D1
8265	D10*	D10	D10	D10	D10
8266	D13*	D13	D13	D13	D13
8267	D16*	D16	D16	D16	D16
Total	100	105	104	108	112

* D1 = Safety Rod

D10 = Regulating Rod

D13 = Shim Rod 1

D16 = Shim Rod 2

(a) = Fuel element I.D. # 8641 stored in rack III-3

TC1 = Instrumented 8.5 wt. % U fuel element, loaded in B1

TC2 = Fuel element I.D. # 8653 was discharged due to the rupture of cladding and emitted fission products.

TC3 = Instrumented 20 wt. % U fuel element, stored in rack III-5

TC4 = Instrumented 20 wt .% U fuel element, loaded in D8

APPENDIX E

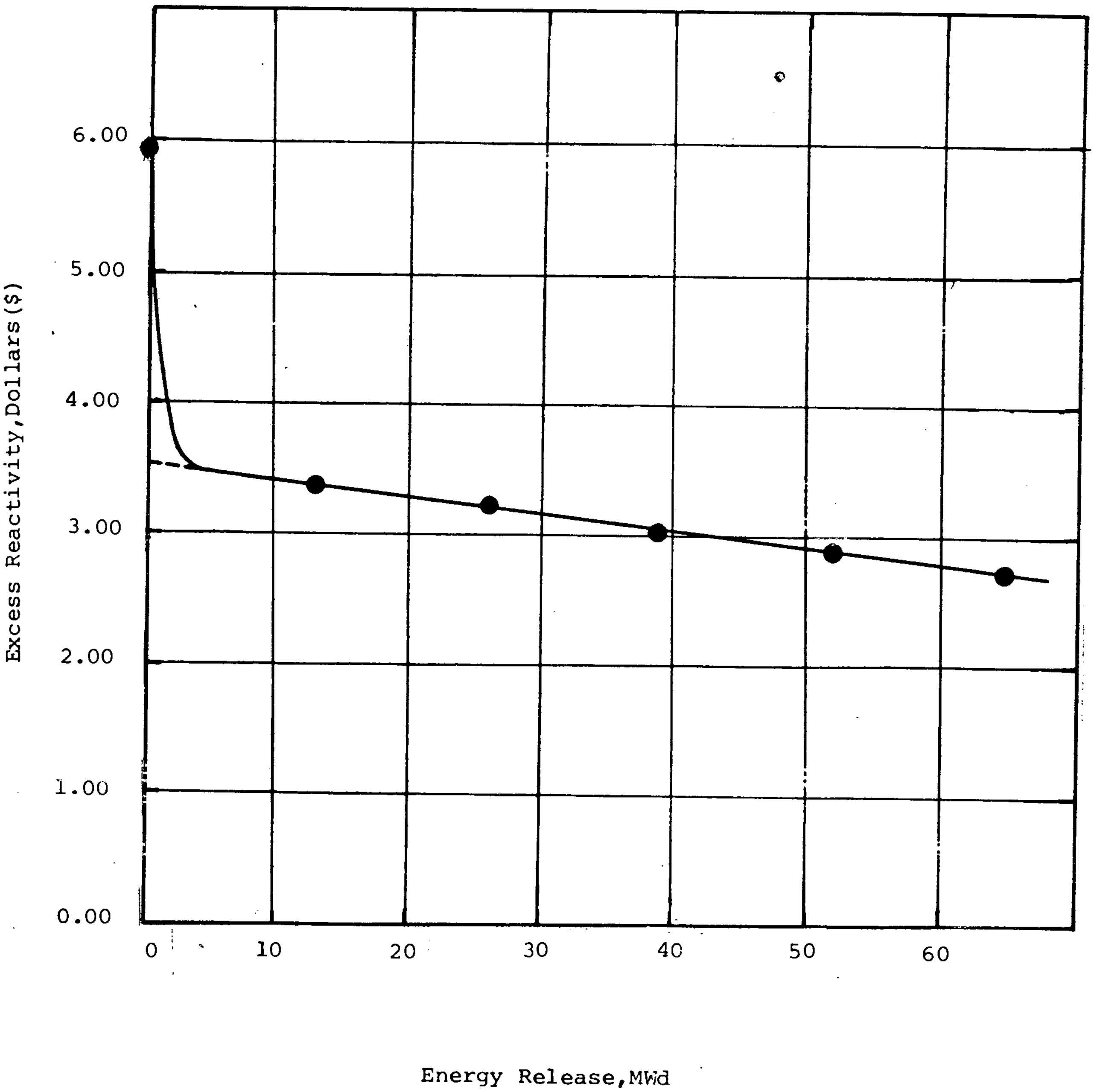
TRR-1/M1

Calculated Reactivity Rundown for Potential Core No 's 6-12

Fig E1 POTENTIAL TRR-1/M1 CORE No.6

Calculated Reactivity Rundown Data

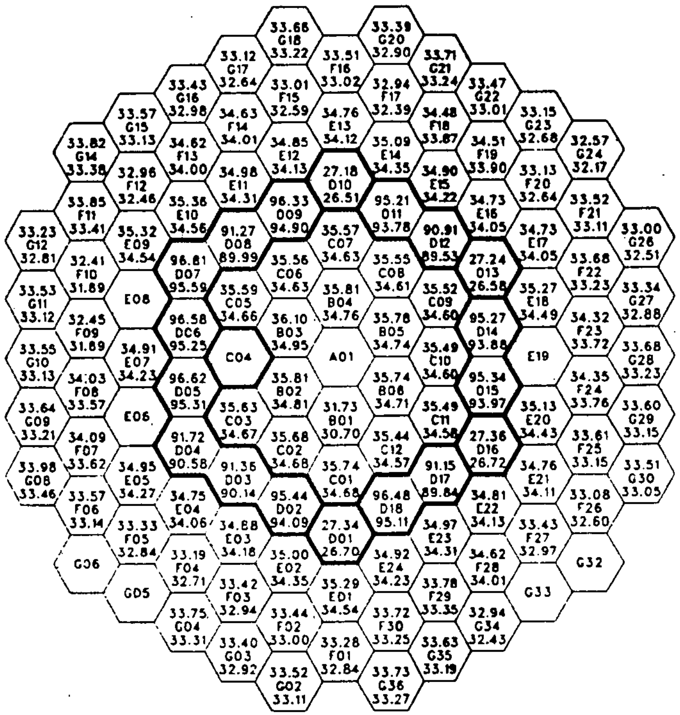
Energy Release, MWd	k_{eff}	Excess React., %δk/k	($)
0.0	1.04296	4.119	5.884
12.88	1.02420	2.363	3.376
25.76	1.02297	2.245	3.207
38.64	1.02176	2.130	3.043
51.52	1.02057	2.015	2.879
64.40	1.01943	1.906	2.723



TRR-1/M1 CORE No.6

^{235}U Loadings, g

BOC (Top) and EOC (Bottom)



Total ^{235}U Content at BOC : 4644.91 g

Total ^{235}U Content at EOC : 4565.58 g

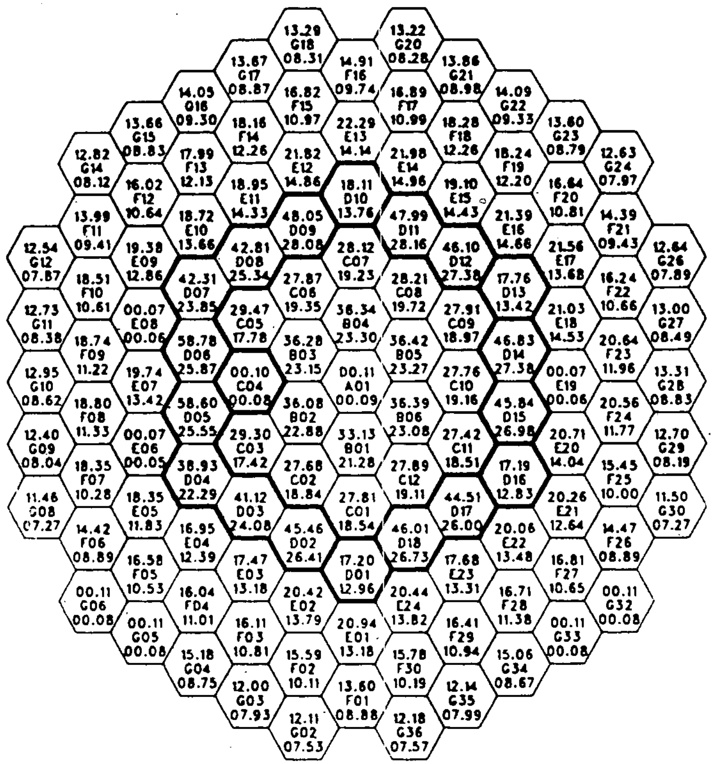
Average ^{235}U Burnup : 1.2319 g/MWd

No. of 8.5 wt %U elements : 98

No. of 20 wt %U elements : 14

BOC Power Densities, W/cm^3

Peak (Top) and average (Bottom)



Peak Power Density : 58.78 W/cm^3

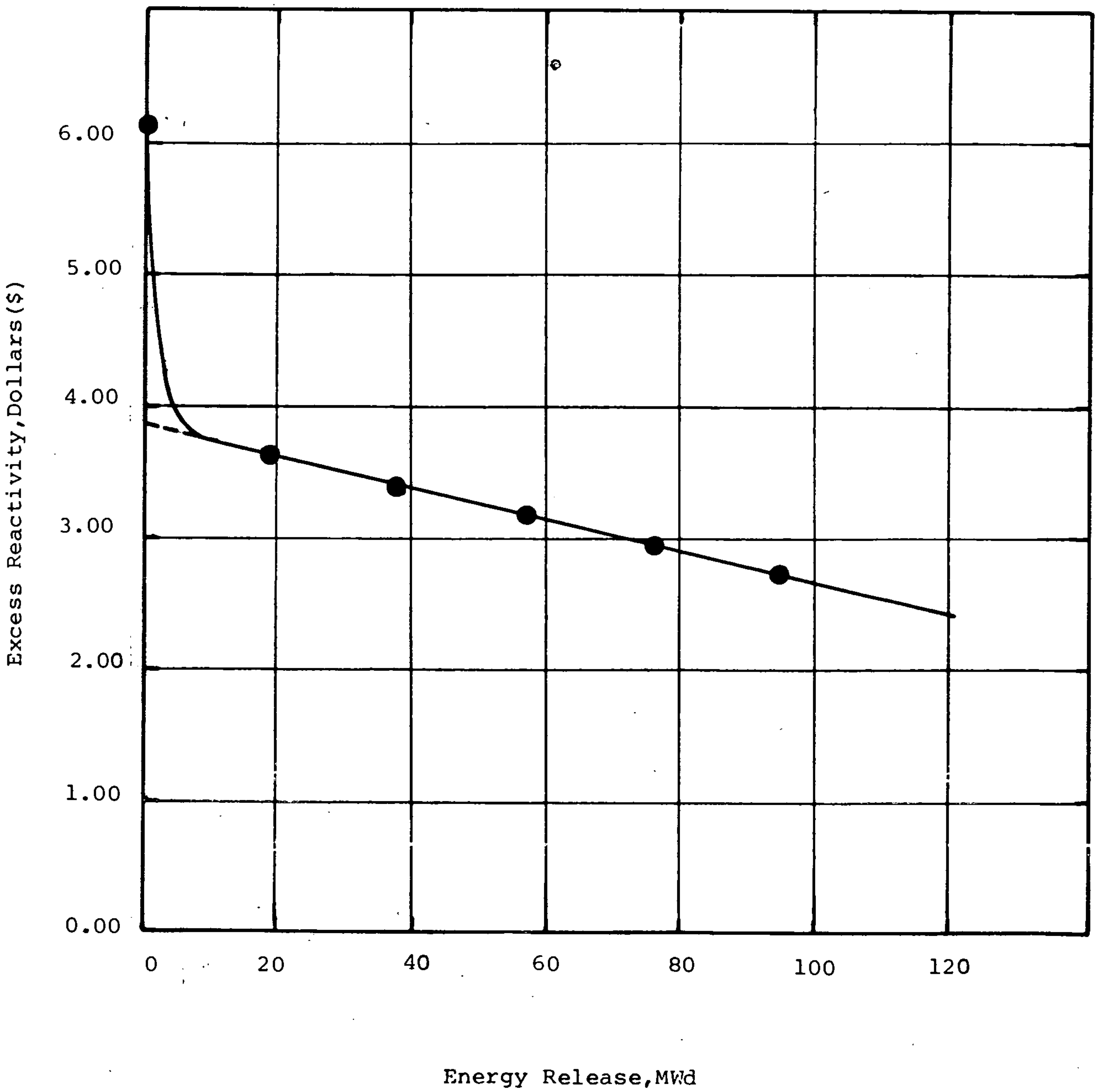
Average Power Density in Fuelled Regions : 14.15 W/cm^3

Fig. E2 Core No.6 ^{235}U loading and power densities

Fig E3 POTENTIAL TRR-1/M1 CORE No.7

Calculated Reactivity Rundown Data

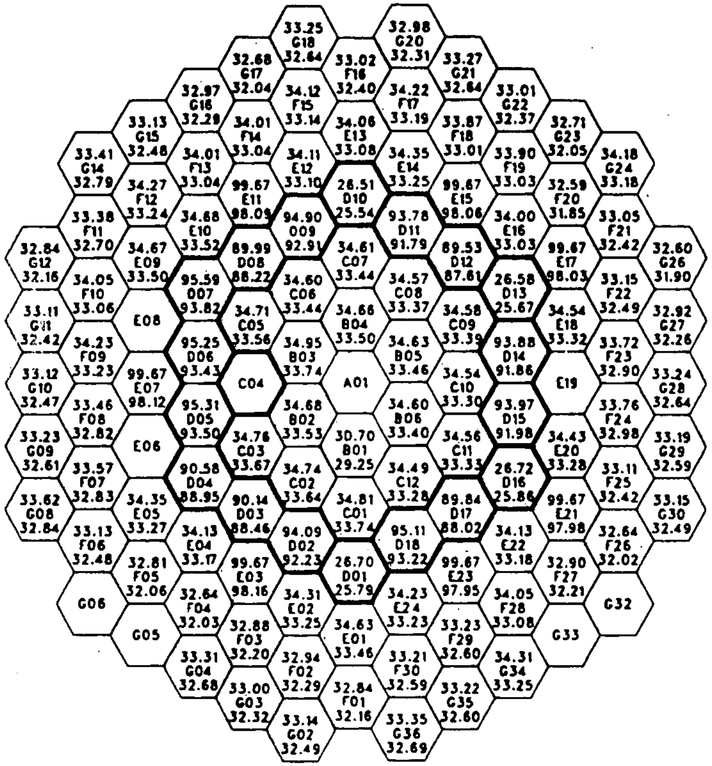
Energy Release, MWd	k_{eff}	Excess React., %δk/k,	($)
0.0	1.04490	4.297	6.139
19.0	1.02615	2.548	3.640
38.0	1.02435	2.377	3.396
57.0	1.02263	2.213	3.161
76.0	1.02096	2.053	2.933
95.0	1.01941	1.904	2.720



TRR-1/M1 CORE No.7

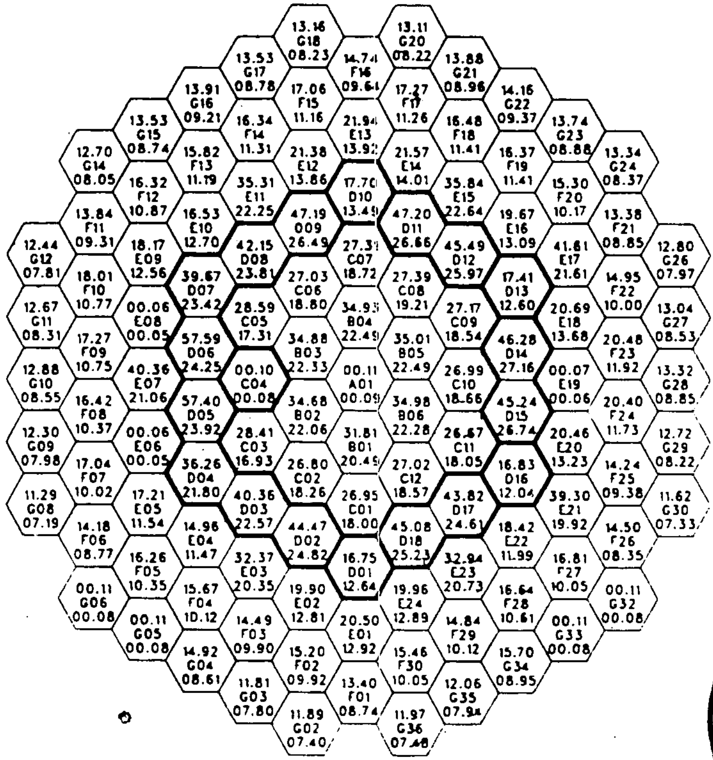
^{235}U Loadings, g

BOC (Top) and EOC (Bottom)



BOC Power Densities, W/cm^3

Peak (Top) and Average (Bottom)



Total ^{235}U Content at BOC : 5037.52 g

Total ^{235}U Content at EOC : 4920.56 g

Average ^{235}U Burnup : 1.2311 g/MWd

No. of 8.5 wt. %U elements : 91

No. of 20 wt. %U elements : 21

Peak Power Density : 57.59 W/cm^3 in D6

Average Power Density

in Fuelled Regions : 14.15 W/cm^3

Fig. E4 Core No.7 ^{235}U loading and power densities

Fig E5 POTENTIAL TRR-1/M1 CORE No.8

Calculated Reactivity Rundown Data

Energy Release, MWd	k_{eff}	Excess React., %δk/k ,	($)
0.0	1.04408	4.222	6.031
19.866	1.02606	2.540	3.629
39.732	1.02429	2.372	3.389
59.598	1.02263	2.213	3.161
79.464	1.02103	2.059	2.941
99.330	1.01955	1.918	2.740

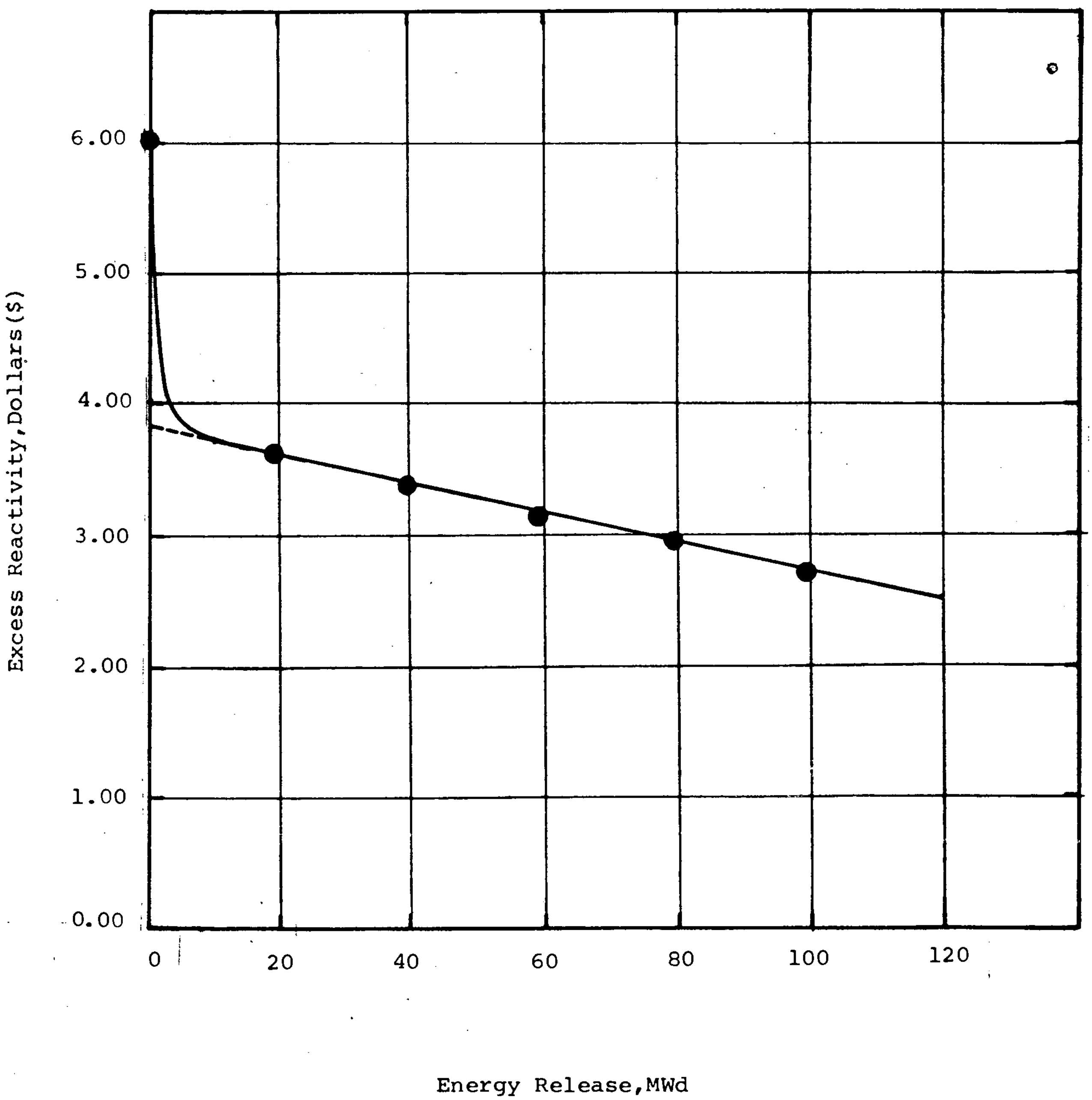
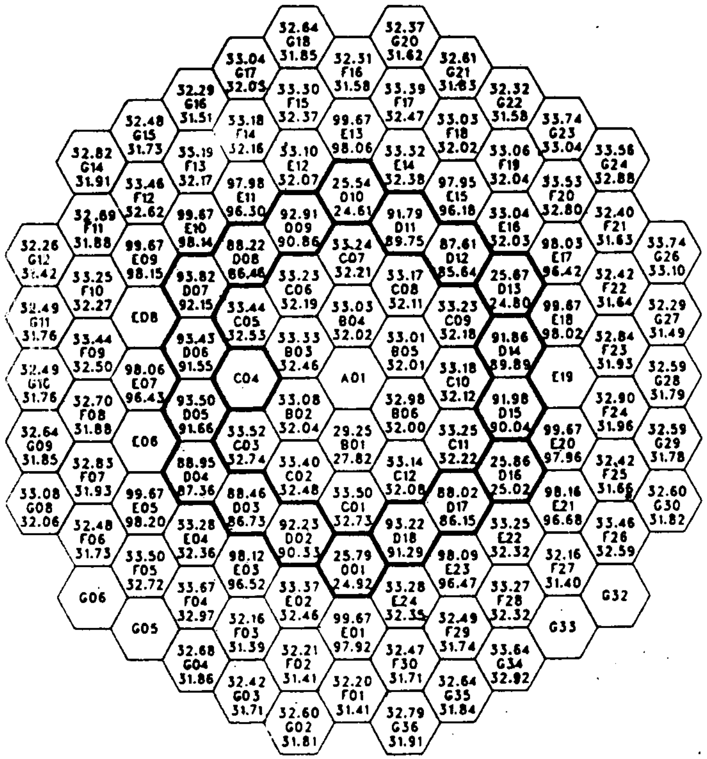


Fig TRR-1/M1 CORE No.8

^{235}U Loadings, g

BOC (Top) and EOC (Bottom)



Total ^{235}U Content at BOC : 5394.30 g

Total ^{235}U Content at EOC : 5272.18 g

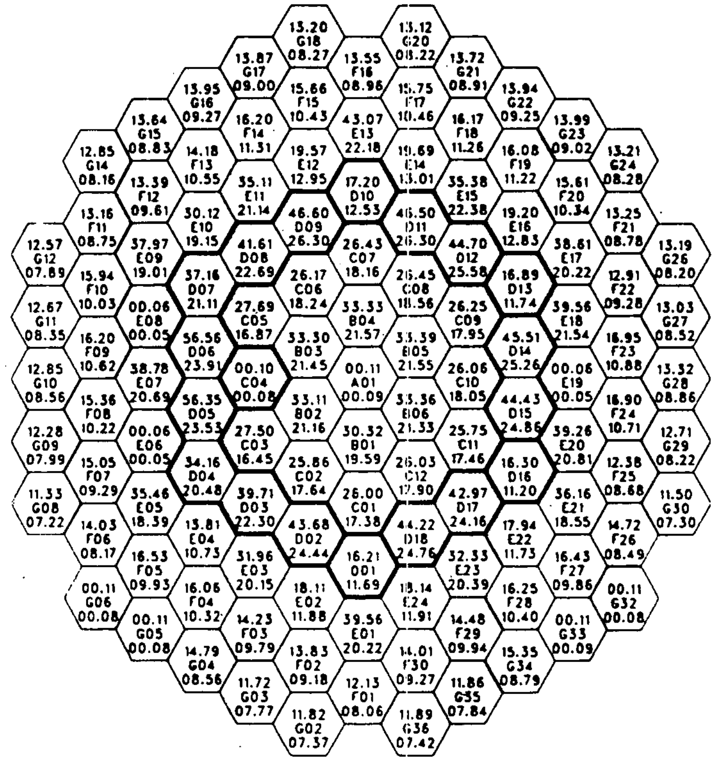
Average ^{235}U Burnup : 1.2286 g/MWd

No. of 8.5 wt. %U elements : 84

No. of 20 wt. %U elements : 28

BOC Power Densities, W/cm^3

Peak (Top) and Average (Bottom)



Peak Power Density : 56.56 W/cm^3

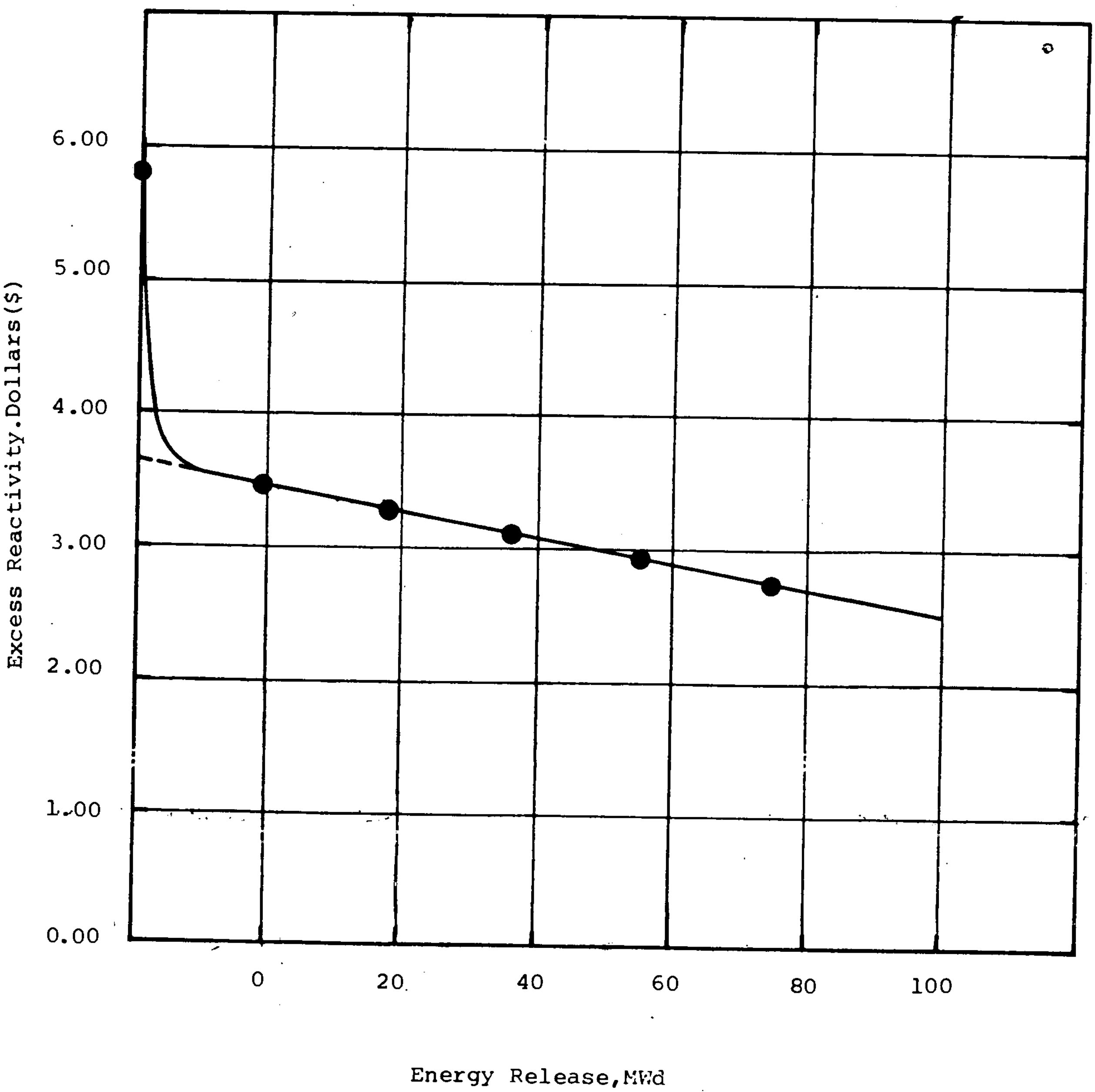
Average Power Density in Fuelled Regions : 14.15 W/cm^3

Fig. E6 Core No.8 ^{235}U loading and power densities

Fig E7 POTENTIAL TRR-1/M1 CORE No.9

Calculated Reactivity Rundown Data

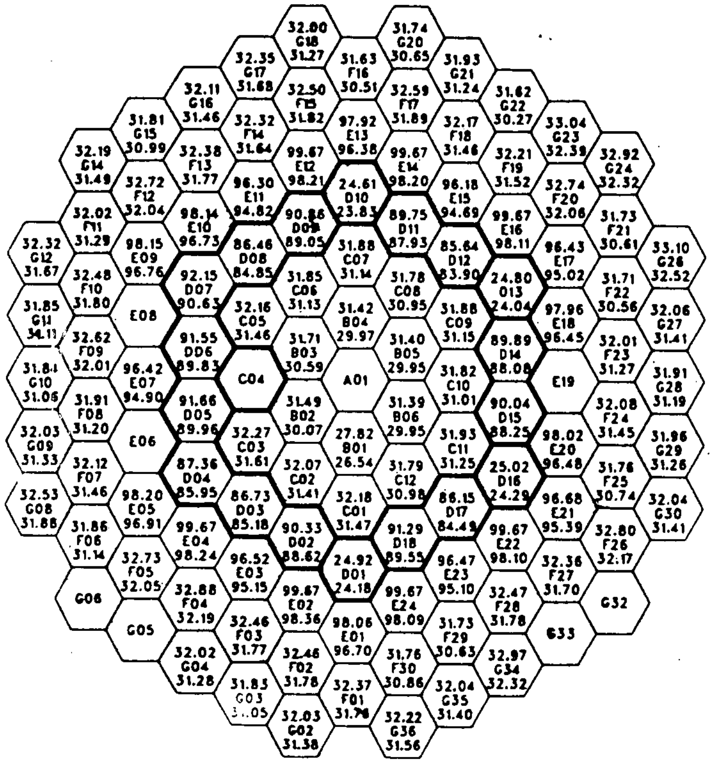
Energy Release, MWd	k_{eff}	Excess React., %δk/k ,	($)
0.0	1.04224	4.053	5.790
18.678	1.02498	2.437	3.481
37.356	1.02348	2.294	3.277
56.034	1.02205	2.157	3.081
74.712	1.02066	2.024	2.891
93.39	1.01942	1.905	2.721



TRR-1/M1 CORE No.9

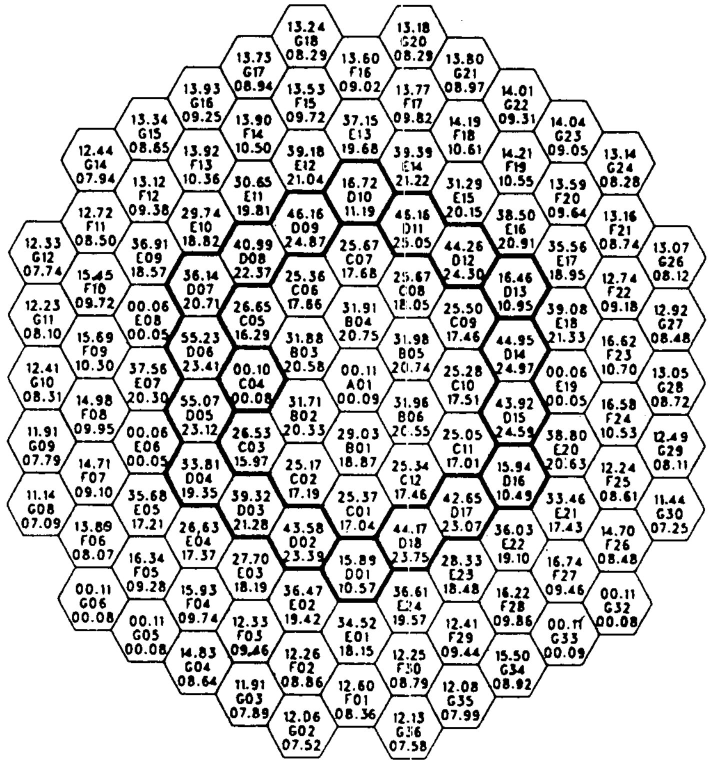
^{235}U Loadings, g

BOC (Top) and EOC (Bottom)



BOC Power Densities, W/cm^3

Peak (Top) and Average (Bottom)



Total ^{235}U Content at BOC : 5749.06 g

TOtal ^{235}U Content at EOC : 5634.36 g

Average ^{235}U Burnup : 1.2283 g/MWd

No. of 8.5 wt. %U elements : 77

No. of 20 wt. %U elements : 35

Peak Power Density : 55.23 W/cm^3 in D6

Average Power Density

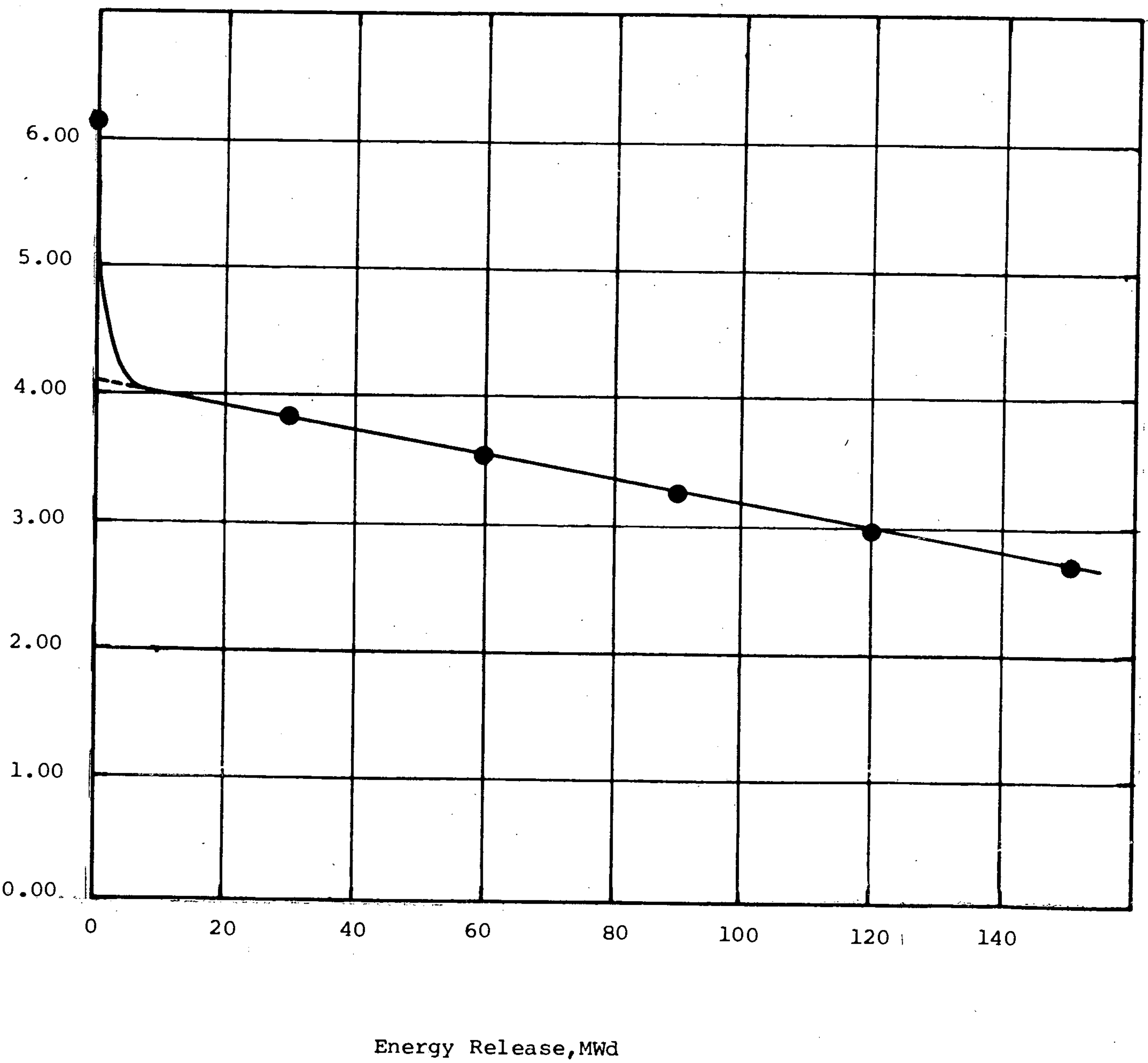
in Fuelled Regions : 14.15 W/cm^3

Fig. E 8 Core No. 9 ^{235}U loading and power densities

Fig E9 POTENTIAL TRR-1/M1 CORE No.10

Calculated Reactivity Rundown Data

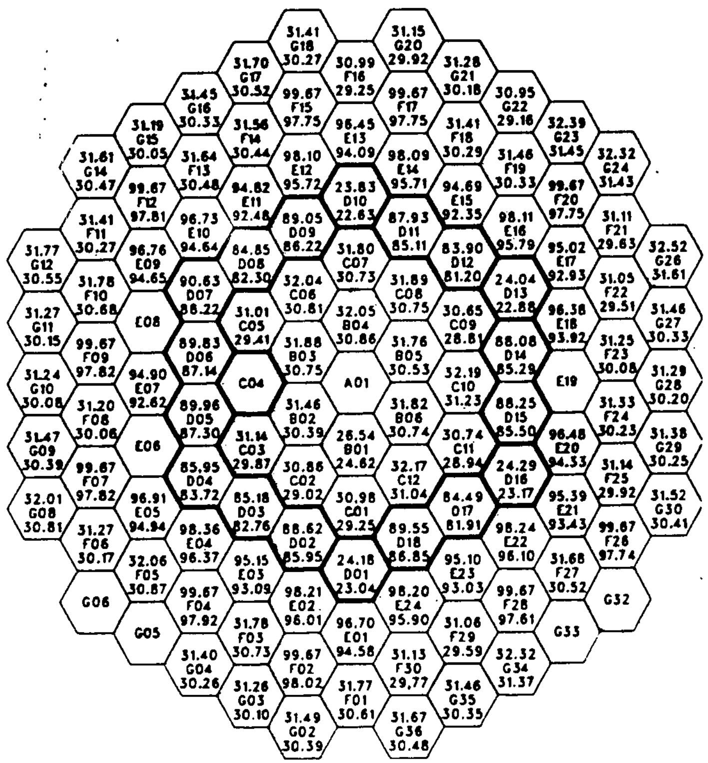
Energy Release, MWd	k_{eff}	Excess React., %δk/k,	($)
0.0	1.04483	4.291	6.130
29.9	1.02754	2.680	3.829
59.8	1.02538	2.475	3.536
89.7	1.02331	2.278	3.254
119.6	1.02130	2.086	2.980
149.5	1.01945	1.908	2.756



TRR-1/M1 CORE No.10

^{235}U Loadings, g

BOC (Top) and EOC (Bottom)



Total ^{235}U Content at BOC : 6327.92 g

Total ^{235}U Content at EOC : 6144.39 g

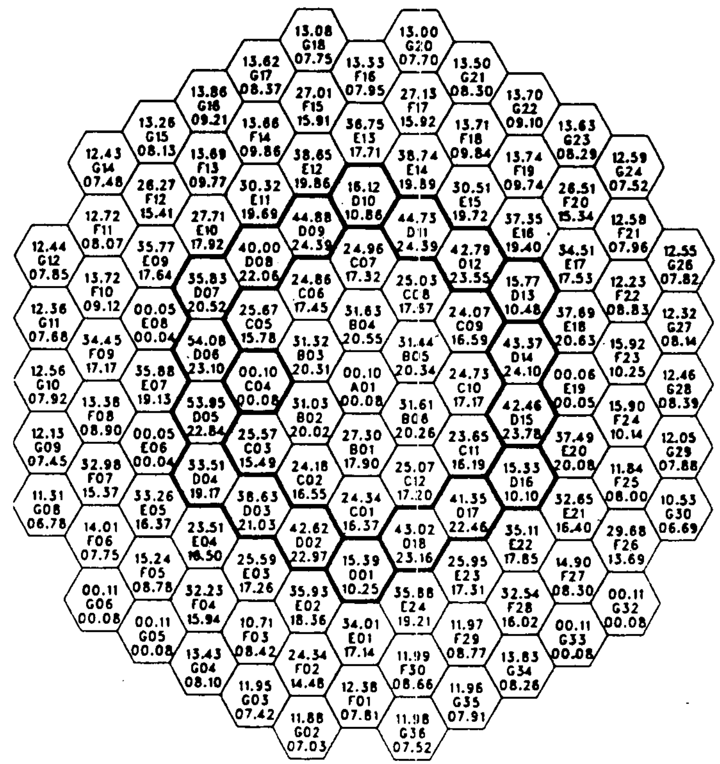
Average ^{235}U Burnup : 1.2276 g/MWd

No. of 8.5 wt. %U elements : 67

No. of 20 wt. %U elements : 45

BOC Power Densities, W/cm^3

Peak (Top) and Average (Bottom)



Peak Power Density : 54.08 W/cm^3 in D6

Average Power Density

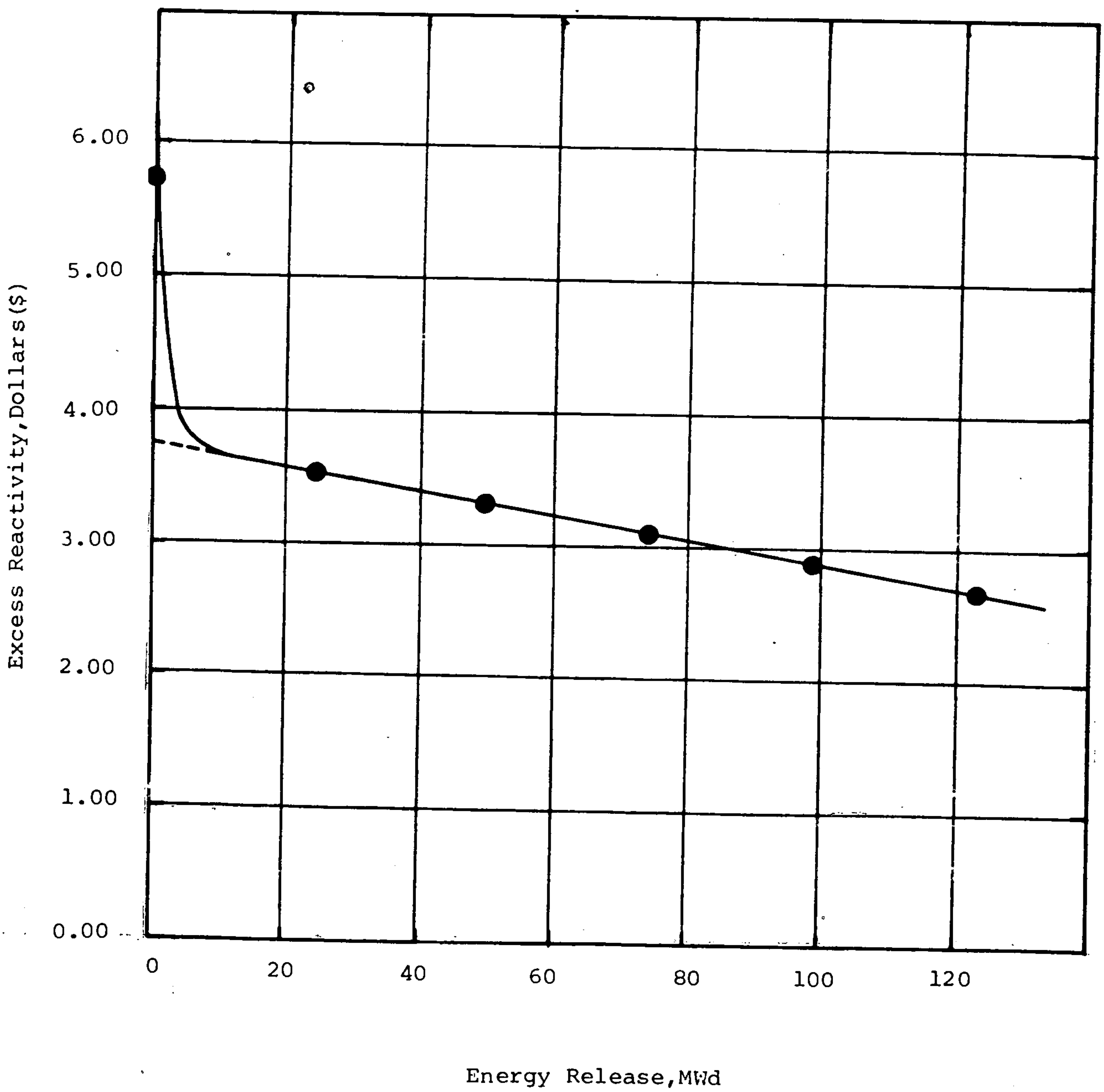
in Fuelled Regions : 14.15 W/cm^3

Fig. E10 Core No.10 U loading and power densities

Fig E11 POTENTIAL TRR-1/M1 CORE No. 11

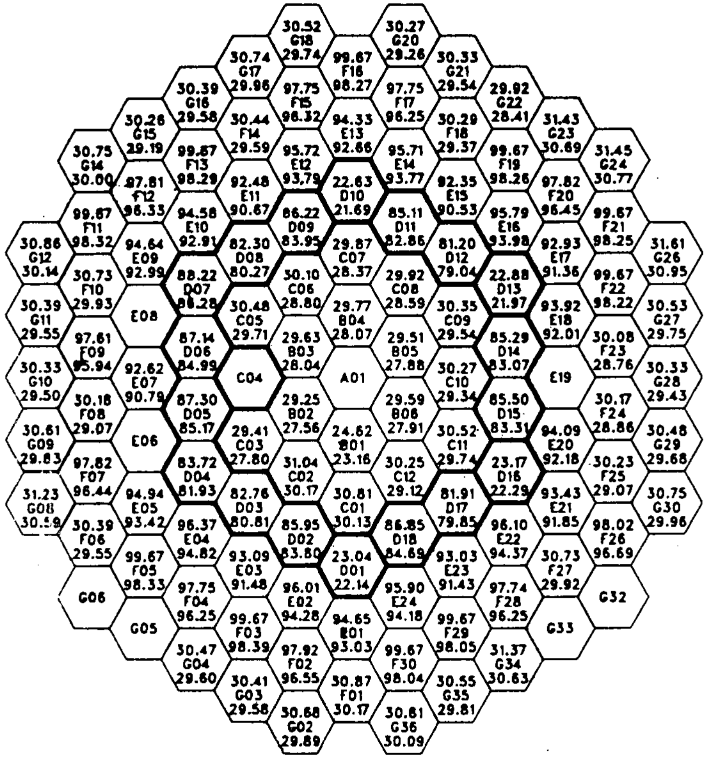
Calculated Reactivity Rundown Data

Energy Release, MWd	k_{eff}	Excess React., %δk/k,	($)
0.0	1.04169	4.002	5.717
24.58	1.02549	2.486	3.551
49.16	1.02385	2.329	3.327
73.74	1.02225	2.177	3.110
98.32	1.02070	2.028	2.897
122.90	1.01926	1.890	2.700



^{235}U Loadings, g

BOC (Top) and EOC (Bottom)



Total ^{235}U Content at BOC : 6845.38 g

Total ^{235}U Content at EOC : 6694.67 g

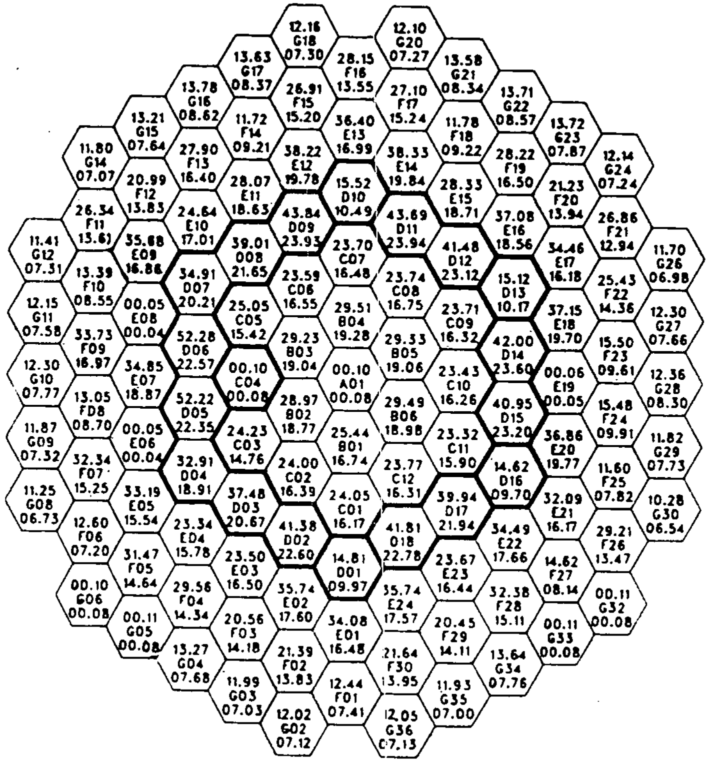
Average ^{235}U Burnup : 1.2263 g/MWd

No. of 8.5 wt. %U elements : 57

No. of 20 wt. %U elements : 55

BOC Power Densities, W/cm^3

Peak (Top) and Average (Bottom)



Peak Power Density : 52.28 W/cm^3 in D6

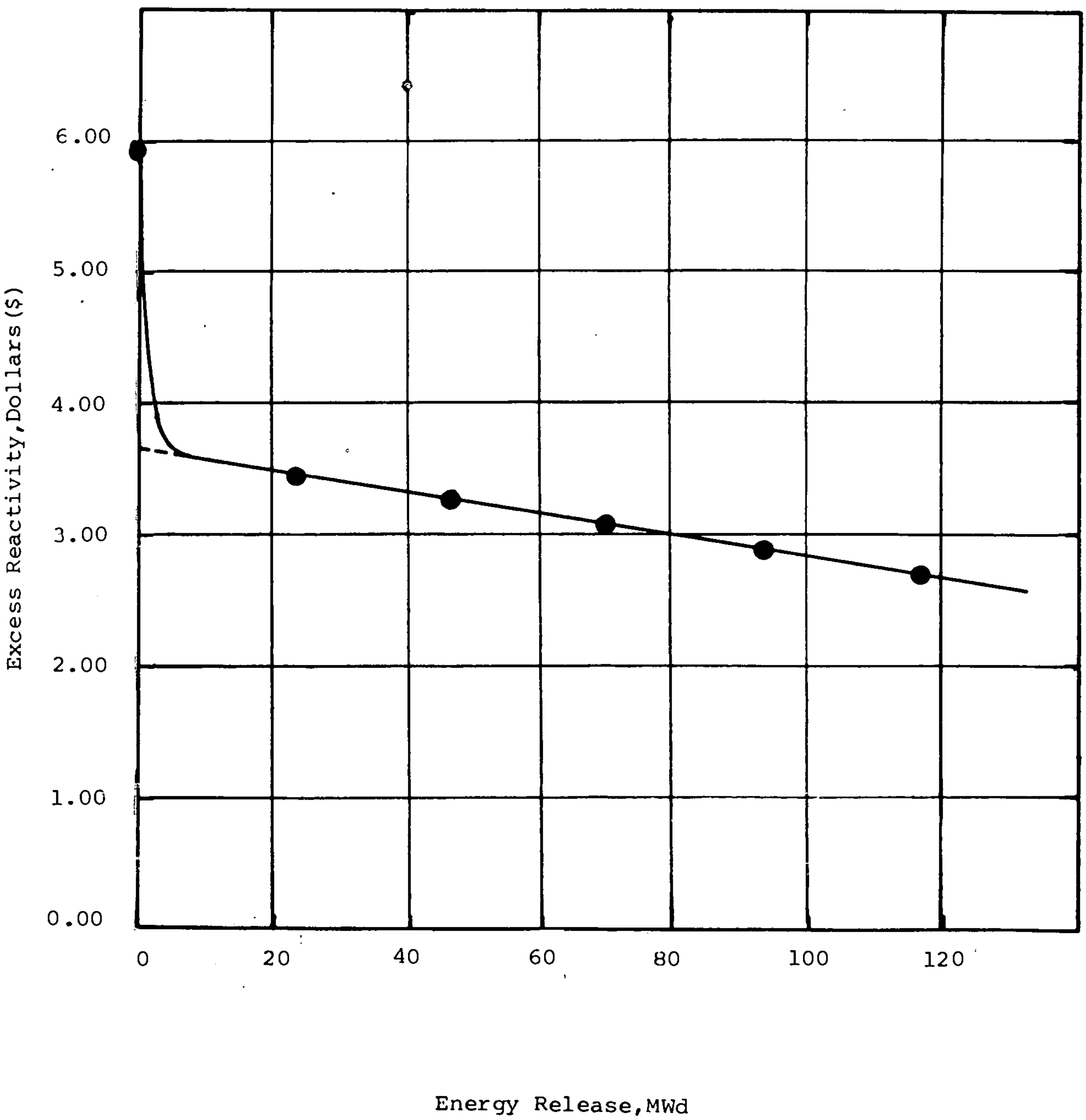
Average Power Density in Fuelled Regions : 14.15 W/cm^3

Fig. E 12 Core No.11 ^{235}U loading and power densities

Fig E13 POTENTIAL TRR-1/M1 CORE No.12

Calculated Reactivity Rundown Data

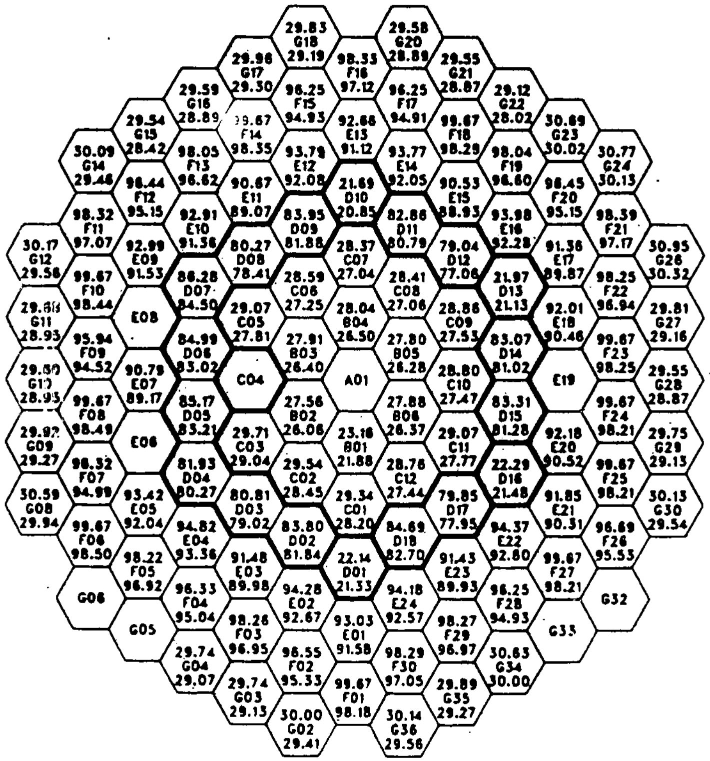
Energy Release, MWd	k_{eff}	Excess React., %δk/k	Excess React., ($)
0.0	1.04310	4.132	5.903
23.30	1.02488	2.428	3.469
46.60	1.02344	2.291	3.273
69.90	1.02204	2.157	3.081
93.20	1.02068	2.026	2.894
116.50	1.01939	1.903	2.719



TRR-1/M1 CORE No.12

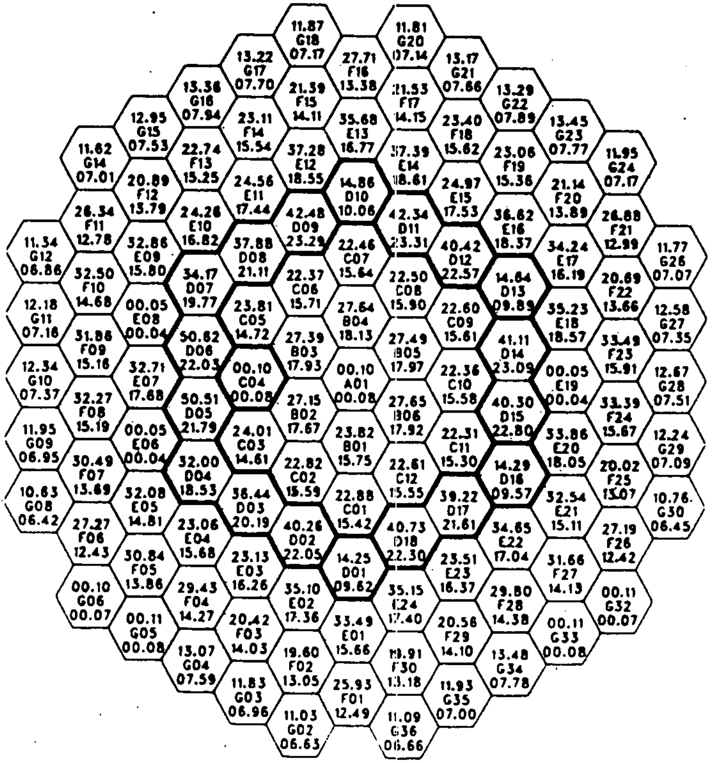
^{235}U Loadings, g

BOC (Top) and EOC (Bottom)



BOC Power Densities, W/cm^3

Peak (Top) and Average (Bottom)



Total ^{235}U Content at BOC	:	7396.90 g
Total ^{235}U Content at EOC	:	7254.05g
Average ^{235}U Burnup	:	1.2262 g/MWd
No. of 8.5 wt. %U elements	:	47
No. of 20 wt. %U elements	:	65

Peak Power Density	:	50.62 W/cm^3 in D6
Average Power Density in Fuelled Regions	:	14.15 W/cm^3

Fig E 14 Core No.12 ^{235}U loading and power densities

APPENDIX F

LOADING LIST

FOR CORE NO "S 6-12

The following list was obtained by using the result of substantial burnup calculations as described at the beginning of this study. These schemes had been made very carefully to assure they can be used effectively for the TRR-1/M1 Core Management Program.

TRR-1/M1 Loading List

for Core No.'S 6-12

I.D.	Core.6	Core.7	Core.8	Core.9	Core.10	Core.11	COre.12
8558	E18	E18	F20	F20	B4	B4	B4
8559	F29	F29	F29	F29	F29	Discharged	
8560	C9	C9	C9	C9	C9	Discharged	
8561	F11	F11	F11	F11	F11	C5	C5
8562	G15	G15	G15	G15	G15	G15	G15
8563	G34	Discharged					
8564	G23	G23	Discharged				
8565	F22	F22	F22	F22	F22	Out	
8566	E2	E2	E2	F2	B6	B6	B6
8567	F8	F8	F8	F8	F8	F8	Out
8568	F5	F5	Out				
8569	G18	G18	G18	G18	G18	G18	G18
8570	G36	G36	G36	G36	G36	G36	G36
8571	G9	G9	G9	G9	G9	G9	G9
8572	F20	F20	Discharged				
8573	F27	F27	F27	Discharged			
8574	G3	G3	G3	G3	G3	G3	G3
8575	F16	F16	F16	F16	F16	Discharged	
8576	F13	F13	F13	F13	F13	C11	C11
8577	E22	E22	E22	F27	F27	F27	Out
8578	C10	C10	C10	C10	Discharged		
8579	E20	E20	F26	F26	C10	C10	C10
8580	F14	F14	F14	F14	F14	F14	Out
8581	F18	F18	F18	F18	F18	F18	Out

TRR-1/M1 Loading List (Continued)

for Core No.'S 6-12

I.D.	Core.6	Core.7	Core.8	Core.9	Core.10	Core.11	Core.12
8582	E11	F12	F12	F12	C6	C6	C6
8583	G24	Discharged					
8584	F10	Discharged					
8585	E3	F17	F17	F17	C8	C8	C8
8586	E14	E14	E14	G12	G12	G12	G12
8587	E13	E13	G17	G17	G17	G17	G17
8588	E4	E4	E4	F3	F3	C1	C1
8589	G30	G30	G30	G30	G30	G30	G30
8590	G26	G26	Discharged				
8591	E15	G24	G24	G24	G24	G24	G24
8592	F7	F7	F7	F7	B2	B2	B2
8593	E10	E10	G23	G23	G23	G23	G23
8594	G12	G12	G12	Discharged			
8595	G4	G4	G4	G4	G4	G4	G4
8596	G29	G29	G29	G29	G29	G29	G29
8597	F2	F2	F2	Discharged			
8598	G20	G20	G20	G20	G20	G20	G20
8599	G14	G14	G14	G14	G14	G14	G14
8600	B6	B6	B6	B6	Discharged		
8601	C3	C3	C3	C3	C3	C3	Discharged
8602	F25	F25	F25	F25	F25	F25	Discharged
8603	G2	G2	G2	G2	G2	G2	G2
8604	G28	G28	G28	G28	G28	G28	G28
8605	F15	Discharged					

TRR-1/M1 Loading List (Continued)

for Core No.'S 6-12

I.D.	Core.6	Core.7	Core.8	Core.9	Core.10	Core.11	Core.12
8606	C12	C12	C12	C12	—— Discharged ——		
8607	G27	G27	G27	—— Discharged ——			
8608	F17	—— Discharged ——					
8609	F9	—— Discharged					
8610	C11	C11	C11	C11	C11	—— Discharged ——	
8611	F26	F26	—— Discharged ——				
8612	F21	F21	F21	F21	—— Discharged ——		
8613	E1	E1	F4	F4	C12	C12	C12
8614	E21	F15	F15	F15	C7	C7	C7
8615	B2	B2	B2	B2	—— Discharged ——		
8616	C1	C1	C1	C1	C1	—— Discharged ——	
8617	F23	F23	F23	F23	F23	F23	Discharged
8618	B5	B5	B5	B5	—— Discharged ——		
8619	F19	F19	F19	F19	F19	C9	C9
8620	C6	C6	C6	C6	—— Discharged ——		
8621	F6	F6	F6	F6	F6	F6	C3
8622	G17	G17	—— Discharged ——				
8623	F3	F3	F3	—— Discharged ——			
8624	G22	G22	G22	G22	G22	G22	G22
8625	B4	B4	B4	B4	—— Discharged ——		
8626	E7	F9	F9	F9	B3	B3	B3
8627	C7	C7	C7	C7	—— Discharged ——		
8628	G10	G10	G10	G10	G10	G10	G10
8629	F28	F28	F28	F28	B5	B5	B5
8630	G35	G35	G35	G35	G35	G35	G35

TRR-1/M1 Loading List (Continued)
for Core No.'S 6-12

I.D.	Core.6	Core.7	Core.8	Core.9	Core.10	Core.11	Core.12
8631	F1	F1	F1	—	Discharged	—	—
8632	F4	F4	Discharged	—	—	—	—
8633	G8	G8	G8	G8	G8	G8	G8
8634	E9	E9	G26	G26	G26	G26	G26
8635	F12	Discharged	—	—	—	—	—
8636	B3	B3	B3	B3	Discharged	—	—
8637	E16	E16	E16	G27	G27	G27	G27
8638	E17	F10	F10	F10	F10	F10	Discharged
8639	C2	C2	C2	C2	C2	Discharged	—
8640	G11	G11	G11	G11	G11	G11	G11
8641 (a)	—	—	—	—	—	—	—
8642	C5	C5	C5	C5	C5	Discharged	—
8643	C8	C8	C8	C8	Discharged	—	—
8644	E24	E24	E24	F1	F1	F1	Discharged
8645	F30	F30	F30	F30	F30	Discharged	—
8646	E12	E12	E12	G16	G16	G16	G16
8647	E23	G34	G34	G34	G34	G34	G34
8648	E5	E5	F5	F5	F5	C2	C2
8649	G21	G21	G21	G21	G21	G21	G21
8650	G16	G16	G16	Discharged	—	—	—
8651	F24	F24	F24	F24	F24	F24	Discharged
8652 (TC1)	B1	B1	B1	B1	B1	B1	B1
8653 (TC2)	—	—	—	—	—	—	—
9219	D17	D17	D17	D17	D17	D17	D17
9220	D2	D2	D2	D2	D2	D2	D2

TRR-1/M1 Loading List (Continued)
for Core No.'s 6-12

I.D.	Core.6	Core.7	Core.8	Core.9	Core.10	Core.11	Core.12
9221	D11	D11	D11	D11	D11	D11	D11
9222	D4	D4	D11	D11	D11	D11	D11
9223	D3	D3	D3	D3	D3	D3	D3
9224	D12	D12	D12	D12	D12	D12	D12
9225	D14	D14	D14	D14	D14	D14	D14
9226	D15	D15	D15	D15	D15	D15	D15
9227(TC3)							
9228(TC4)	D8	D8	D8	D8	D8	D8	D8
9860	D7	D7	D7	D7	D7	D7	D7
9862	D5	D5	D5	D5	D5	D5	D5
9865	D9	D9	D9	D9	D9	D9	D9
9866	D18	D18	D18	D18	D18	D18	D18
9868	D6	D6	D6	D6	D6	D6	D6
8264	D1*	D1	D1	D1	D1	D1	D1
8265	D10*	D10	D10	D10	D10	D10	D10
8266	D13*	D13	D13	D13	D13	D13	D13
8267	D16*	D16	D16	D16	D16	D16	D16

TRR-1/M1 Loading List (Continued)
for Core No.'S 6-12

I.D.	Core.6	Core.7	Core.8	Core.9	Core.10	Core.11	Core.12
7 Fresh 20 wt.%U	–	E3	E3	E3	E3	E3	E3
	–	E7	E7	E7	E7	E7	E7
	–	E11	E11	E11	E11	E11	E11
	–	E15	E15	E15	E15	E15	E15
	–	E17	E17	E17	E17	E17	E17
	–	E21	E21	E21	E21	E21	E21
	–	E23	E23	E23	E23	E23	E23
7 Fresh 20 wt.%U	–	–	E1	E1	E1	E1	E1
	–	–	E5	E5	E5	E5	E5
	–	–	E9	E9	E9	E9	E9
	–	–	E10	E10	E10	E10	E10
	–	–	E13	E13	E13	E13	E13
	–	–	E18	E18	E18	E18	E18
	–	–	E20	E20	E20	E20	E20
7 Fresh 20 wt.%U	–	–	–	E2	E2	E2	E2
	–	–	–	E4	E4	E4	E4
	–	–	–	E12	E12	E12	E12
	–	–	–	E14	E14	E14	E14
	–	–	–	E16	E16	E16	E16
	–	–	–	E22	E22	E22	E22
	–	–	–	E24	E24	E24	E24
10 Fresh 20 wt.%U	–	–	–	–	F2	F2	F2
	–	–	–	–	F4	F4	F4
	–	–	–	–	F7	F7	F7
	–	–	–	–	F9	F9	F9
	–	–	–	–	F12	F12	F12

TRR-1/M1 Loading List (Continued)

for Core No.'S 6-12

I.D.	Core.6	Core.7	Core.8	Core.9	Core.10	Core.11	Core.12
	–	–	–	–	F15	F15	F15
	–	–	–	–	F17	F17	F17
	–	–	–	–	F20	F20	F20
	–	–	–	–	F26	F26	F26
	–	–	–	–	F28	F28	F28
10 Fresh 20 wt.%U	–	–	–	–	–	F3	F3
	–	–	–	–	–	F5	F5
	–	–	–	–	–	F11	F11
	–	–	–	–	–	F13	F13
	–	–	–	–	–	F16	F16
	–	–	–	–	–	F19	F19
	–	–	–	–	–	F21	F21
	–	–	–	–	–	F22	F22
	–	–	–	–	–	F29	F29
	–	–	–	–	–	F30	F30
10 Fresh 20 wt.%U	–	–	–	–	–	–	F1
	–	–	–	–	–	–	F6
	–	–	–	–	–	–	F8
	–	–	–	–	–	–	F10
	–	–	–	–	–	–	F14
	–	–	–	–	–	–	F18
	–	–	–	–	–	–	F23
	–	–	–	–	–	–	F24
	–	–	–	–	–	–	F25
	–	–	–	–	–	–	F27
Tatal	112	112	112	112	112	112	112

Note * D1	=	SAFETY ROD
D10	=	REGULATING ROD
D13	=	SHIM 1 ROD
D16	=	SHIM 2 ROD
(a)	=	Fuel element I.D # 8641 stored in rack III-3
TC1	=	Instrumented 8.5 wt.%U fuel element, loaded in B1
TC2	=	Fuel element I.D # 8653 was discharged due to the rupture of cladding and emitted fission products.
TC3	=	Instrumented 20 wt.%U fuel element, stored in rack III-5
TC4	=	Instrumented 20 wt.%U fuel element, loaded in D8

VITA

Mr. Yuthapong Busamongkol was born in Kalasin, on February 11, 1949. He was graduated in Electrical and Electronic Engineering from Institute of Technology and Vocational Education, Bangkok. Certificated in Nuclear Technology, Chulalongkorn University in 1980. He has been employed at the Office of Atomic Energy for Peace since 1976.

In 1984 he was awarded the IAEA fellowship in the field of Reactor Operations and Fault Tree Analysis to minimize reactor downtime, at the Radiation Center, Oregon State University for one year.

Now his position is Nuclear electronic Engineer and Reactor Supurvisor.