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HFBR POWER CALCULATIONS FOR HIGHER ^{235}U CONTENT (351 gm) FUEL ASSEMBLIES (SUMMARY OF RESULTS)

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HFBR POWER CALCULATIONS FOR HIGHER ^{235}U CONTENT (351 GRAM) FUEL ASSEMBLIES (SUMMARY OF RESULTS)

INTRODUCTION

SRL has calculated the three-dimensional power distributions, fuel burnup, and the equilibrium cycle length in the High Flux Beam Reactor (HFBR) at Brookhaven National Laboratory (BNL) for a new fuel assembly design. The new fuel is an 18 plate assembly containing 351 grams ^{235}U per assembly. It has been proposed as a replacement for the HFBR 315 gram assemblies in order to extend the HFBR cycle time. The power distributions will be part of an investigation of the feasibility of increasing reactor power by 50%.

This document presents only a summary of the results obtained from the calculations. The detailed results of the calculations are contained on computer printouts and data tapes that have been transmitted to BNL.

SUMMARY

The mean cycle time for the equilibrium core was calculated to be 14.33 days at a reactor operating power of 60 MW. HFBR fuel plate power densities were determined at the start of cycle for a fresh core (each assembly containing 351 grams ^{235}U) and for the start, middle, and end of cycle of the equilibrium core (only 1/4 of the assemblies freshly loaded). The maximum point-wise power densities, P(X,Y,Z), were located at the outer edge of the core at the core axial midplane. These power densities, relative to a core average of 1.0, were

Fresh core	start of cycle	3.596
Equilibrium core	start of cycle	3.161
Equilibrium core	middle of cycle	2.836
Equilibrium core	end of cycle	2.581

The maximum axially averaged plate power densities, relative to a core average of 1.0, were

Fresh core	start of cycle	1.885
Equilibrium core	start of cycle	1.974
Equilibrium core	middle of cycle	2.032
Equilibrium core	end of cycle	1.956

The maximum axially averaged fuel element power densities, relative to a core average of 1.0, were

Fresh core	start of cycle	1.186
Equilibrium core	start of cycle	1.224
Equilibrium core	middle of cycle	1.261
Equilibrium core	end of cycle	1.250

The fuel element burnup (total ^{235}U consumed) after four burnup cycles was between 42.5% and 47%, depending on the location of the fuel at the time of discharge. The localized fuel burnup is maximum at the top and bottom of the core, reaching 60% ^{235}U burnup.

The control rod positions above the axial midplane of the core were determined to be

	Rod Height (cm)	*Reactor Time (days @ 60 MW)*
Fresh 351 gram core	21.83	0.0
Equilibrium core	28.36	0.0
" "	34.08	1.0
" "	39.88	4.0
" "	43.11	6.67
" "	45.78	8.67
" "	51.88	11.33
" "	60.96	14.33

An auxilliary calculation was performed to determine the shutdown margin of the fresh 351 gram core with the eight upper control rods fully inserted and the eight lower rods fully withdrawn. Under these conditions, the eigenvalue calculated in three-dimensional (X,Y,Z) geometry was 0.8211.

DISCUSSION

Background

The Brookhaven HFBR is a research reactor designed to produce high intensity neutron beams for experimental purposes. The core design and control system reflect this purpose. The reactor has a small core surrounded by a very large moderator-reflector region. The reflector contains many beam tubes positioned to extract thermal and fast fluxes for neutron experiments. Figure 1 shows the main features of the HFBR, and Figure 2 illustrates the plate type design of the 28 fuel boxes that comprise the core. The thermal neutron flux peaks in the reflector region and is severely depressed

in the interior of the core. This behavior is shown in Figure 3, which shows the thermal and epithermal fluxes of a north-south traverse through the core center.

The HFBR is controlled by upper and lower control rod blades, located outside the core. They control the core by suppressing the thermal flux in the upper and lower reflector regions. There are eight upper control blades and eight lower blades, which are normally above and below the active core region when the reactor is critical. The location of the control rod blades (at critical) minimizes the flux depression in the vicinity of the neutron beam extraction tubes. The control blades are shown in Figure 2, and their axial movement is shown in Figure 4.

The HFBR operates at a reactor power of 40 MW. It has operated in a two-cycle mode where each cycle is initiated by the loading of 14 fresh fuel assemblies in the 14 inner fuel positions, with 14 partially burned fuel assemblies in the outer core positions. The cycle terminates when the control rods are fully out. The HFBR presently operates in a four-cycle mode, in which seven fresh fuel assemblies are added at the start of each cycle to the core center region while the seven assemblies with the highest burnup are removed. Because of the steep flux gradients within a fuel assembly, the plates in the fuel assemblies do not burn-up uniformly during a single cycle. Consequently, BNL has adopted a fuel shuffling plan to yield approximately uniform burnup of an assembly after it has completed four cycles in the reactor.

At present, the HFBR is operating with a ^{235}U content of 315 grams per assembly and a cycle time of $\sim$17 days at 40 MW. BNL is considering replacing the 315 gram assemblies by 351 gram assemblies in order to extend the cycle time at 40 MW and determine the feasibility of raising reactor power to 60 MW. To determine whether the new fuel will be able to perform satisfactorily during operation, the power density in the fuel plates and the local burnup in the fuel must be known. BNL has requested that SRL perform the necessary calculations for this determination in accordance with the general plans and procedures developed in reference 1 and summarized in reference 2.

Review of the Calculational Procedure

The general calculational procedure required to obtain the HFBR power densities for the 351 gram ^{235}U assemblies is shown Figure 5. The basic procedures were detailed in Reference 1.

These included

- Developing the average five group (Table 1) cross sections to represent the fuel elements, moderator, core and axial extent, beam tubes, reflector regions and control rods. This was done using integral transport theory (RAHAB).

- Performing the HFBR fuel plate burnup calculations using integral transport theory to obtain microscopic cross sections for isotopes in the HFBR fuel.

- Correlating the five group microscopic cross sections as a function of the ^{235}U burnup (CRAB).

- Performing the burnup calculations using the three-dimensional burnup code REX, which solves the direct depletion equations in the fuel portion of the HFBR reactor. The half reactor problem is solved under the assumption of axial symmetry. The homogenized isotopic contents in a quarter-fuel element were calculated at each of five axial layers for seven discrete times in the burnup cycle.

- Comparing the fuel isotopic contents, control rod elevations, and the cycle lengths of two consecutive burnup cycles to determine if an equilibrium cycle has been established. The control rod elevations at discrete times in the reactor cycle and the cycle length are variables used to match a "control rod calibration curve" for the REX code. Equilibrium is established when the core contents do not change between two cycles that have the same rod elevations and cycle lengths.

- Developing transport theory correction factors by intercomparison of two-dimensional diffusion theory (2D-ORTHOGRIM) with two-dimensional S_N transport theory (TWOTRAN).

- Solving for the three-dimensional (X,Y,Z) diffusion theory flux (3D-ORTHOGRIM) in the quarter reactor. Axial symmetry is assumed, and the fuel rotation plan provides 180° symmetry in the (X,Y) plane.

- Applying the transport theory correction factors to the three-dimensional diffusion theory flux.

- Interpolating the region-wise three-dimensional transport corrected flux to the fine mesh structure dictated by the design of the fuel elements. The interpolated flux is used to calculate the total power density of the fuel, the plate power densities, and the point power densities (HFBREDIT).

Fuel Rotation Plan

The fuel rotation plan chosen for the HFBR 351 gram ^{235}U assemblies is shown in Figure 6, where the letter designations A through G indicate seven distinct fuel types that are charged at the same time; and the numeral designation indicates the number of irradiation cycles the fuel type has undergone. The fuel rotation plan provides reflective symmetry through the center of fuel type A, so that there are only four fuel element types with unique burnup and power histories. The rotation plan also provides uniform burnup of the four corners of the fuel element after the completion of four reactor cycles. The fuel rotation plan (Figure 6) can be superposed on the HFBR Edit Model shown in Figure 7, to obtain the cross reference list in Table 2.

The "fresh core" contains 351 gram ^{235}U assemblies in all 28 fuel positions at the start of operation. As ^{235}U burns up, the control rods are withdrawn from the core to maintain criticality. When the rods have reached the maximum withdrawal (60.96 cm above and below the axial midplane) the reactor will be shut down and the seven fuel assemblies with the highest burnup will be discharged. The high burnup assemblies are designated A4 through G4 (Figure 6) and are located on the outer portion of the core. Assemblies designated A3 through G3 will be moved to the A4 through G4 positions. Similarly, assemblies A2 through G2 will be moved to A3 through G3; and A1 through G1 will be moved to A2 through G2. Finally, seven fresh fuel assemblies will be loaded in locations A1 through G1. After loading the seven fresh fuel elements, sufficient reactivity is available to initiate the next burnup cycle.

After a sufficient number of burnup cycles, an "equilibrium core" is established. The core is in equilibrium when

a. The control rod positions (at critical) between two burnup cycles are the same,

b. The isotopic concentrations between two burnup cycles are the same, and

c. The cycle lengths between two consecutive cycles are the same.

Reactor Burnup Calculations

The HFBR burnup calculations were done using the REX burnup code, a three-dimensional reactor depletion calculation in hexagonal geometry. The geometric model of the HFBR is illustrated in Figure 8, which also shows the fuel designations. Each physical

fuel assembly is represented by four contiguous hex regions. Each hex has a separate material composition for the five axial levels above the midplane of the core. The base material numbers (the first axial level in the fuel) are shown in Figure 9. The homogenized isotopic contents in these regions are calculated by solving the direct depletion equations in these regions at seven discrete times in the burnup cycle. The 180° symmetry in the (X,Z) plane is absent in the REX burnup model. Thus, the burnup calculations were performed in 360° symmetry. The isotopic contents at the end of a burnup cycle were averaged about an "averaging plane" (shown in Figure 7) to simulate the true 180° symmetry.

The control rod cross sections for the REX burnup model were determined in the previous study of the 315 gram HFBR assemblies. This was done by comparing BNL measurements of critical rod height vs. exposure and the REX calculated eigenvalue at the critical rod height at the start of cycle. Absorption cross sections in the control rods were adjusted to force agreement between the measurement and calculation at the start of cycle. The same adjusted control cross sections for REX were also used in these calculations.

The measured critical rod heights and the REX k_{eff} calculations from the earlier study established a "REX calibration curve" shown as the dashed curve in Figure 10. The modeling errors in REX that were noted in the previous study were assumed to be present in this study. Hence, earlier k_{eff} calculations were matched as closely as possible. The absence of any experimental control rod data for the 351 gram core forced reliance on this calibration curve to determine the cycle length and critical rod positions for the equilibrium core. The final results obtained are shown as the solid line in Figure 10.

The burnup calculations were initiated by guessing the equilibrium core isotopic contents, cycle length, and critical rod positions at fixed times in the burnup cycles. An error in any of the above parameters would yield deviations from the REX calibration curve, and would require adjustments to cycle length and control rod heights; then another burnup calculation would be performed.

A number of constraints were used in matching the data for the 351 gram assembly core with the REX calibration curve:

a. The cycle would be terminated when the rods were fully out,

b. The REX k_{eff} had to be 1.0 at the start of the next cycle,

c. The REX k_{eff} had to match the calibration curve k_{eff} at the end of cycle,

d. The mid-cycle data should match the calibration curve well,

e. The final curve should be a reproduction of a curve from the previous burnup calculation without changing any parameters from the previous cycle,

f. The ^{235}U concentrations should change by less than 1% by quarter fuel element, and change by less than 2% along any axial mesh point.

All these constraints were met after eight complete burnup cycles. The final data for Figure 10 is listed in Table 3. The best estimate of the cycle time based on these burnup calculations is 14.33 days at a reactor power of 60 MW. This is ∿19% longer than for the 315 gram ^{235}U assemblies (on an equal power basis).

Burnup Results

The ^{235}U burnup for the four distinct types of fuel elements at the end of the equilibrium cycle are shown in Figures 10, 11, 12, and 13. The figures show the percent burnup (measured relative to the fresh 351 gram ^{235}U assemblies) as a function of axial distance above the core midplane. The burnup calculations were done for each quarter fuel element. Thus, at the end of the burnup cycle, each fuel element had four burnups for each of the five axial levels in the burnup calculations. The maximum and minimum burnups are plotted as burnup "bands" in Figures 11 through 14. A narrow band at the end of the burnup cycle indicates uniform ^{235}U contents within the fuel element at a given axial location.

The highest burnup occurs at the top (and bottom) of the core. This is due to the relatively high thermal fluxes in the upper (and lower) reflector regions, and the continuous exposure (over four cycles) of the tips of the fuel elements to these high fluxes. The maximum thermal flux occurs at the core edge at Z=0. But since a fuel element spends only half its lifetime (two cycles) near these high flux regions, it does not exhibit maximum burnup at the core midplane (Z=0).

The average burnups for the start and end of the equilibrium cycle are listed in Tables 4 and 5. The maximum burnup (averaged over the entire fuel element) will be 47% (in Fuel Type C, element F14), and the maximum local burnup (at the tip of the fuel element) will reach 60%. Table 6 shows the Z-averaged burnup by quarter element for the HFBR core with 351 gram fuel assemblies. The burnups vary from 9.1% to 17.3% per quarter element per cycle.

ORTHOGRIM Flux Calculation

The three-dimensional (X,Y,Z) diffusion theory code, ORTHOGRIM, was used to calculate the final flux levels for the HFBR. The ORTHOGRIM geometry provides an exact model of the homogenized fuel elements of the HFBR core. It also treats the beam tubes in the reflector region with more detail than the model used in the burnup calculations. The control blades are also represented in their exact geometry.

A map of the ORTHOGRIM geometry in the (X-Y) plane is shown in Figure 15; and the ORTHOGRIM geometry in the (X-Z) plane is shown in Figure 16. The ORTHOGRIM flux calculation was done for the quarter reactor using 62790 (70 × 39 × 23) fine mesh intervals and five energy groups. The flux mesh in the fuel elements was typically (7 × 7 × 11) = 539 points per half element. The exact ORTHOGRIM dimensions are listed in Appendix A.

The adjusted control rod cross sections used in ORTHOGRIM were the same as those used previously.[2] The rod cross sections had been adjusted to give eigenvalue and approximate flux shape agreement between two-dimensional diffusion theory using the adjusted rod cross sections and two-dimensional transport theory using the un-adjusted rod cross sections.

To improve the accuracy of the three-dimensional diffusion theory calculations, sets of transport correction factors were calculated. The transport correction factors were based on a pointwise comparison of two-dimensional transport theory fluxes and two-dimensional diffusion theory fluxes in the reactor core. These transport correction factors were used to scale the three-dimensional diffusion theory fluxes. A separate set of transport correction factors was used for each of the four ORTHOGRIM flux calculations that were done. The transport correction factors typically increased the relative fuel powers at the core-reflector interface by ∿3%.

HFBR Power Density Calculations

The detailed plate power densities were calculated by quadratic interpolation of the ORTHOGRIM power densities. The ORTHOGRIM power densities were derived from three-dimensional transport corrected group fluxes and from the REX macroscopic fission cross sections. These power densities were quadratically interpolated to get the detailed power densities in the fuel plates. The interpolation was confined to the physical boundaries of the fuel cell. First, the interpolation was done in the Y-direction, to obtain a nine-point (uniformly spaced) power shape for each X mesh interval. Then the nine-point power shapes were interpolated

in the X-direction to obtain 18 uniformly spaced X-points for each Y-level in the fuel. This was done for all axial levels within the fuel assemblies. Finally the power densities were normalized to a core average power density of 1.0. Typical power distributions obtained in this way are shown in Figure 17.

Figure 18 shows the plate numbering scheme we used and the Y-level or fractional elevation designation of the Y-mesh points within a plate. The plates are numbered 1 through 18, with plate 1 always facing north. The maximum Y-level (Y=9) within a plate always points toward the east. The minimum Z-level is located at the core midplane.

The power densities in the HFBR 351 gram fuel were calculated for four cases. These were

a. Fresh 351 gram assembly core, T=0.0 days @ 60 MW

b. Equilibrium core (start of cycle), T=0.0 days @ 60 MW

c. Equilibrium core (~middle of cycle), T=6.67 days @ 60 MW

d. Equilibrium core (end of cycle), T=14.33 days @ 60 MW

The different types of power densities calculated for each case are defined

1. $P(X,Y,Z)$ = point power density in plate X, at Y-level Y, at axial level Z

2. $P(X,Y)$ = axially averaged point power density = $\int P(X,Y,Z)\, dZ / \int dZ$

3. $P(X,Z)$ = plate power density in plate X, at axial level Z = $\int P(X,Y,Z)\, dY / \int dY$

4. $P(X)$ = axially averaged plate power density in plate X = $\int\int P(X,Y,Z)\, dZ/Z / \int\int dY dZ$

5. $P(Z)$ = fuel power density at axial level Z = $\int\int P(X,Y,Z)\, dX dY / \int\int dX dY$

6. P = axially averaged fuel power density = $\int\int\int P(X,Y,Z)\, dX dY dZ / \int\int\int dX dY dZ$

The axial average fuel powers, P, for all four cases are shown in Table 7. In all cases, fuel position F3 shows the highest average fuel power. Position F3 is occupied by Fuel Type C in the third cycle of operation in the equilibrium core. The fuel power history of Fuel Type C is shown in Figure 19 for three time steps

in each of its four cycles of operation. The figure shows both P and P(Z) plotted versus the Z-level index.*

The highest plate powers, P(X), in the HFBR fuel assemblies are shown in Table 8. The highest plate powers were always located in plate 1 or plate 18. The plate power history of Fuel Type C is traced in Figure 20, where both P(X) and P(X,Z) are shown for plates 1 and 18.

Figure 21 shows the point power history of Fuel Type C for the "hot corner" in plates 1 and 18. Both P(X,Y,Z) and its axial average, P(X,Y) are shown in the figure.

The plate power densities, P(X,Z), for the entire core (at the core midplane) are shown in Figures 22 through 25 for the fresh core and three times in the equilibrium core. Similarly, Figures 26 through 29 show the plate power densities at the top of the core. Finally, Figures 30 through 33 show the axially averaged plate power densities P(X) for four times in the fuel cycle.

The general behavior of the other types of fuel elements is similar to Fuel Type C. During the first two cycles of the fuel element's life, the element is located in the radial interior of the core, where the thermal fluxes are relatively low. Near the upper (and lower) reflector regions, high thermal fluxes yield high power densities at the top (and bottom) of the interior fuel elements. As the control rod banks are withdrawn during a cycle, the thermal flux increases in the upper reflector regions, thus increasing the power peaking at the top of the core. When the fuel element begins its third cycle, it is located at the core radial outer boundary where extremely high thermal fluxes produce a very high power peak in one of the corners of the fuel assembly. The location of the control rods at the start of the third cycle suppresses the thermal flux at the top of the core and produces a very large axial power density gradient in the outer fuel plate. As the control rods are withdrawn, the upper reflector thermal flux increases relative to the radial flux; and the power density becomes more uniform over the axial (Z) length of the fuel plate. This behavior is repeated for the fourth cycle, but because of the higher fuel burnup in the fourth cycle, the power densities are lower than in the third cycle.

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* Note that the Z-level index does not vary linearly with the Z dimension in Figures 19, 20, 21; however, the deviation from linearity is not too severe. Tables 10 and 11 contain the conversion between the Z-level index and the Z dimension.

Maximum Power Densities

The maximum power densities by fuel, by plate, and by point are summarized in Table 9. The maximum 200 point power densities for each of the cases studied are listed sequentially in Appendix B.

Uncertainty Analysis

An unambiguous assessment of the accuracy of the calculations of HFBR powers is not possible, since there are no measured data available with which to compare the results. Several contributions to the uncertainty of the computed powers can be estimated, however, based on approximations that were made in the computational procedure. The approximations that have been identified that contribute to this uncertainty are:

1. effects of energy group structure,
2. effects of spatial mesh structure,
3. effects of material mesh structure,
4. errors in eigenvalue calculations,
5. effects of transport-to-diffusion correction factors in the vertical plane,
6. use of diffusion theory in burnup calculations,
7. use of hexagonal geometry in burnup calculations.

This list is not comprehensive; for example, it excludes effects of approximations made in the definition of the physical model of the HFBR, such as homogenization of reflector components, and assumptions made regarding core symmetry. These approximations may result in some averaging of local power densities, and also may yield slight errors in radial and axial leakage. These effects are not readily estimable but are believed to be small.

The energy group structure used in the ORTHOGRIM calculations was selected after testing of alternate, more detailed structures. Tests involved comparison of thermal flux shapes using two-dimensional ORTHOGRIM calculations. Results of these tests indicated that use of the five-group structure yielded a mean difference of 1.5% in the thermal flux in the HFBR fuel, relative to a seven-group structure selected as a standard.

Similar tests of the spatial mesh structure used in ORTHOGRIM against finer mesh structures yielded a mean thermal flux difference of 0.12%.

The material mesh structure used in the burnup calculation is, by necessity, coarse. Hence, fuel burnup in plates near the core-reflector interface is underestimated. Use of a finer material mesh, if it had been possible, would have yielded a flatter radial power distribution than the one reported.

Uncertainties in the burnup procedure as measured by differences in REX eigenvalues from 1.0 at flux calculation times are believed to have little effect on the burned-up fuel concentrations. The uncertainty in peak powers resulting from such burnup errors is estimated to be less than 0.2%.

Uncertainties in the power shape as measured by differences in three-dimensional ORTHOGRIM eigenvalues from 1.0 are likely due to a misrepresentation of neutron leakage from the core. To the extent that this is true, the reported peak power densities should be conservative, since reported eigenvalues are generally slightly greater than 1.0.

Use of transport corrections to flux shapes in the horizontal plane removes much of the error inherent in diffusion theory treatment of the interface flux gradients. No transport correction to flux shapes in the axial direction was made. Some underestimation of power peaking at the top and bottom of the core should result. This should be less than corrections applied in the radial direction, since the diffusion properties of the top and bottom core reflectors approximate those of the core more closely than do properties of the radial reflector. Underestimates of local power densities at core top and bottom by 1 to 2% are possible, however.

Errors in point powers based on errors in point concentrations of ^{235}U (due to the REX limitation on mesh points in the burnup calculation) do not propagate through the burnup cycle. An error in a point concentration in a cycle will be partially compensated by an opposite error in the next cycle. The maximum error in point concentrations occurs when and where the ^{235}U concentrations of a quarter fuel element differ by the largest percentage. This occurs at the end of the third cycle and start of the fourth cycle for any fuel element. Linear extrapolation of the quarter fuel ^{235}U concentrations at the axial midplane to the corners of the fuel element at the end of cycle 3 show that the quarter fuel concentration is 9% higher than the concentration of the "hot corner" in that quarter fuel. But since the power and burnup rate are proportional to the concentration, flux, and cross section ($N\phi\sigma$), and since a reduced concentration at a fuel corner

leads to a higher flux at that corner, the error in ($N\phi\sigma$) will be less than 9%. The errors in the point concentrations, due to the limitations of the mesh structure, tend to be compensated by opposite errors in the flux, so that the errors in power or burnup rate are less than the errors in concentration. Peak powers in the outer fuel assemblies at the end of the fuel element's third cycle are estimated to be roughly 5% too high. At the start of the fourth cycle, peak power densities are estimated to be roughly 3% too low because of errors in point concentrations. At the end of the second and fourth cycles, as well as the start of the first and third cycles, peak powers are believed to be accurate to 1%.

Effects of these approximations on HFBR peak power densities are summarized in Table 12. All effects are indicated as uncertainties in the power density, although some effects are considered factors of conservatism.

REFERENCES

1. D. A. Sharp, *HFBR Power Calculations: A Program Document.* SRL Report DPST-74-455 (August 1974).

2. D. A. Sharp, *HFBR Power Calculations: Summary of Results.* SRL Report DPST-75-363 (July 1975).

TABLE 1

Five-Group Structure Used for HFBR Power Calculations

Group	Upper Energy, eV
1	10.0 (10^{+6})
2	0.82085 (10^{+6})
3	0.55308 (10^{4})
4	0.6325
5	0.0801604

Minimum energy = 0.6325 (10^{-6})

TABLE 2

HFBR Fuel Rotation Scheme for 4-Cycle Operation in the HFBR Edit Model

Fuel Type	Cycle Number 1		2		3		4
A	F2	→	F15	→	F16	→	F1
B	F12	→	F'5	→	F8	→	F'9
C	F13	→	F4	→	F3	→	F'14
D	F7	→	F10	→	F11	→	F'6
E	F'7	→	F'10	→	F'11	→	F6
F	F'13	→	F'4	→	F'3	→	F14
G	F'12	→	F5	→	F'8	→	F9

Note: Fuel types A, B, C and D are unique.

Fuel types G, F and E are mirror images of B, C and D respectively.

TABLE 3

HFBR Eigenvalues, Control Rod Elevations, and Time @ 60 MW Operating Power

	Rod Height[1] (cm)	Reactor Time (Days)	REX k_{eff}	ORTHOGRIM k_{eff}
Fresh 351 gm core	21.83	0.0	-	1.01138
Equilibrium core	28.36	0.0	1.00024	1.00494
	34.08	1.0	1.00422	-
	39.88	4.0	1.02508	-
	43.11	6.67	1.03074	1.02295
	45.78	8.67	1.03427	-
	51.88	11.33	1.04031	-
	60.96	14.33	1.03648	1.01905
Shut down margin of Upper Rod Bank Fresh Core	-15.24	0.0	-	0.82106

Note:

(1) Rod elevation relative to core mid-plane.

TABLE 4

Average ^{235}U Contents (Grams/Assembly)
Equilibrium Cycle

		F8 280 / 231 / 49	*F9* 231 / 187 / 44	←Start of cycle ←End of cycle ←Burnup per cycle	
	F6 235 / 194 / 41	*F7* 351 / 314 / 37	*F10* 314 / 281 / 33	*F11* 281 / 235 / 46	
F3 279 / 230 / 49	*F4* 313 / 279 / 34	*F5* 313 / 280 / 33	*F12* 351 / 313 / 38	*F13* 351 / 313 / 38	*F14* 230 / 186 / 44
F1 240 / 202 / 38	*F2* 351 / 314 / 37			*F15* 314 / 281 / 33	*F16* 281 / 240 / 41

CORE AVERAGE ^{235}U CONTENT

start of cycle	294 gm
end of cycle	254 gm
burnup/cycle	40 gm

AVERAGE ^{235}U CONTENT FOR DISCHARGED ASSEMBLIES

191 gm

TABLE 5

Average ^{235}U Burnup (Percent)

$$\left[\text{Burnup} = \frac{^{235}U \text{ consumed}}{351 \text{ grams}} \times 100\%\right]$$

		F8	*F9*		
		20.2	34.2		←Start of cycle (%)
		34.2	46.7		←End of cycle (%)
		14.0	12.5		←Burnup per cycle (%)
	F6	*F7*	*F10*	*F11*	
	33.0	0.0	10.5	19.9	
	44.7	10.5	19.9	33.0	
	11.7	10.5	9.4	13.1	
F3	*F4*	*F5*	*F12*	*F13*	*F14*
20.5	10.8	10.8	0.0	0.0	34.5
34.5	20.5	20.2	10.8	10.8	47.0
14.0	9.7	9.4	10.8	10.8	12.5
F1	*F2*			*F15*	*F16*
31.6	0.0			10.5	19.9
42.5	10.5			19.9	31.6
10.8	10.5			9.4	11.7

CORE AVERAGE BURNUP

Start of cycle	16.2%
End of cycle	27.6%
Burnup per cycle	11.4%

TABLE 6

Percent Burnup by Quarter Fuel

								F8		*F9*							
								20.0	20.5	33.2	30.1	Burnup start of cycle					
								37.9	35.5	46.8	46.8	Burnup end of cycle					
								17.9	15.0	13.6	16.7	Burnup per cycle					
								20.6	19.9	37.9	35.5						
								33.2	30.1	46.6	46.7						
								12.6	10.2	8.7	11.2						
				F6		*F7*		*F10*		*F11*							
				28.5	31.7	0	0	11.8	10.2	20.9	21.0						
				44.6	43.1	11.8	10.2	20.9	21.0	33.5	38.1						
				16.1	11.4	11.8	10.2	9.1	10.8	12.6	17.1						
				33.5	38.1	0	0	10.2	9.6	18.8	18.7						
				44.9	46.1	10.2	9.6	18.8	18.7	28.5	31.7						
				11.4	8.0	10.2	9.6	8.6	9.1	9.7	13.0						
F3		*F4*		*F5*		*F12*		*F13*		*F14*							
21.2	21.3	10.3	12.0	11.8	11.2	0	0	0	0	34.8	30.3						
39.1	34.0	21.2	21.3	20.6	19.9	10.2	10.1	10.3	12.0	46.1	46.8						
17.9	12.7	10.9	9.3	8.8	8.7	10.2	10.1	10.3	12.0	11.3	16.5						
19.7	19.9	10.3	10.6	10.2	10.1	0	0	0	0	39.1	34.0						
34.8	30.0	19.7	19.9	20.0	20.5	11.8	11.2	10.3	10.6	47.5	47.5						
15.1	10.1	9.4	9.6	9.8	10.4	11.8	11.2	10.3	10.6	8.4	13.5						
F1		*F2*						*F15*		*F16*							
29.5	33.7	0	0					10.1	10.9	19.9	19.9						
42.5	42.5	10.1	10.9					19.9	19.9	29.5	33.7						
13.0	8.8	10.1	10.9					9.8	9.0	9.6	13.8						

TABLE 7

Axially Averaged Fuel Power

$\left[P = \iiint P(X,Y,Z)dXdYdZ / \iiint dXdYdZ\right]$

		F8	*F9*			
		1.16104	1.16104	←Fresh 351 gm/assy core (t=0)		
		1.21363	1.07664	←Equilibrium core (t=0)		
		1.26337	1.11245	←Equilibrium core (t=6.67 days)		
		1.24734	1.09002	←Equilibrium core (t=14.67 days)		
	F6	*F7*	*F10*	*F11*		
	1.18390	.79228	.79228	1.18390		
	1.04172	.90376	.82486	1.16771		
	1.04776	.89289	.82969	1.17529		
	1.03093	.91360	.84072	1.16465		
F3	*F4*	*F5*	*F12*	*F13*	*F14*	
1.18573	.82583	.90892	.90892	.82583	1.18573	
1.22392	.84741	.88010	.96374	.92771	1.08208	
1.26083	.83895	.83828	.90603	.90463	1.10594	
1.24971	.85357	.83878	.91006	.92446	1.08813	
F1	*F2*			*F15*	*F16*	
1.03444	.85205			.85205	1.03444	
.91256	.93102			.84624	1.03804	
.92505	.89316			.82019	1.05150	
.92970	.90625			.82916	1.06232	

Note: Core Average Fuel Power = 1.0.

TABLE 8

Maximum Average Plate Power Density P(X)

$$\left[\begin{array}{l} P(X) = \iint P(X,Y,Z)\, dYdZ / \iint dYdZ \\ \text{where } X = \text{plate 1 or plate 18} \end{array}\right]$$

	F8	F9	
	1.62561	1.62561	Fresh 351 gm core
	1.72554	1.52929	Equilibrium core t=0
	1.79531	1.57697	Equilibrium core t=6.67 days
	1.73292	1.51090	Equilibrium core t=14.33 days

F6	F7	F10	F11
1.80065	.87499	.87499	1.80065
1.59578	1.04825	.93572	1.78198
1.60147	1.05330	.94816	1.79139
1.53912	1.07998	.96830	1.73477

F3	F4	F5	F12	F13	F14
1.88460	.87780	.93689	.93689	.8778	1.88460
1.97372	.94607	.89494	.99173	1.06658	1.76045
2.03200	.96628	.84724	.92887	1.07607	1.79504
1.95606	.99123	.84519	.93100	1.10985	1.71508

F1	F2	F15	F16
1.80749	1.04999	1.04999	1.80749
1.60735	1.11825	1.01443	1.79498
1.62678	1.05434	.996617	1.81535
1.59080	1.05548	.96283	1.78424

TABLE 9

Maximum HFBR Power Densities

Case Name	Case	Fuel	Plate	Y-Level	Z-Level	Power	Description
BASECASP	A	F3	All	All	All	1.18573	P
ORTH7	B	"	"	"	"	1.22392	Axially averaged
ORTH710	C	"	"	"	"	1.26083	Fuel power
ORTH722	D	"	"	"	"	1.24971	Density
	A	F3	1	All	All	1.88460	P(X)
	B	"	1	"	"	1.97372	Axially averaged
	C	"	1	"	"	2.03200	Plate power
	D	"	1	"	"	1.95606	Density
	A	F3	1	All	1	2.69381	P(X,Z)
	B	"	1	"	1	2.42324	Plate power
	C	"	1	"	1	2.18524	Density
	D	"	1	"	1	2.04199	
	A	F3	1	9	1	3.59618	P(X,Y,Z)
	B	"	1	9	1	3.16144	Point power
	C	"	1	9	1	2.82317	Density
	C	"	1	9	1	2.57892	

Note: (1) The word All is used to indicate an average over the X, Y or Z dimension.

(2) Because of 90° symmetry in CASE A (the fresh core) the power densities in (F3, plate 1) are equal to those in (F14, plate 18).

TABLE 10

Axial Fine Mesh for the Fresh Core

Z-level	Elevation above core midplane (cm)
1	0 to 4.445
2	4.445 to 7.62
3	7.62 to 10.795
4	10.795 to 13.7583
5	13.7583 to 16.7216
6	16.7216 to 19.685
7	19.685 to 21.83
8	21.83 to 23.3374
9	23.3374 to 24.8449
10	24.8449 to 26.3524
11	26.3524 to 27.7018
12	27.7018 to 29.0512

TABLE 11

Axial Fine Mesh for the Equilibrium Core

Z-level	Elevation above core midplane (cm)
1	0 to 4.445
2	4.445 to 7.62
3	7.62 to 10.795
4	10.795 to 13.7583
5	13.7583 to 16.7216
6	16.7216 to 19.685
7	19.685 to 21.83
8	21.83 to 24.0066
9	24.0066 to 26.1833
10	26.1833 to 28.3600
11	28.36 to 29.0512

TABLE 12

Uncertainties in Computed HFBR Power Densities Caused by Approximations in the Computational Procedure

Approximation	Uncertainty in Maximum HFBR Power Densities
ORTHOGRIM Energy Group Structure	1.5%
ORTHOGRIM Spatial Mesh Structure	0.1%
REX Material Mesh Structure	∿5%, end of 3rd cycle ∿3%, start of 2nd cycle ∿1%, end of 2nd & 4th cycles ∿1%, start of 3rd cycle
Eigenvalue Errors	
REX	0.2%
ORTHOGRIM	conservative
Transport - Diffusion Corrections	
- Vertical plane	1-2%, top of core

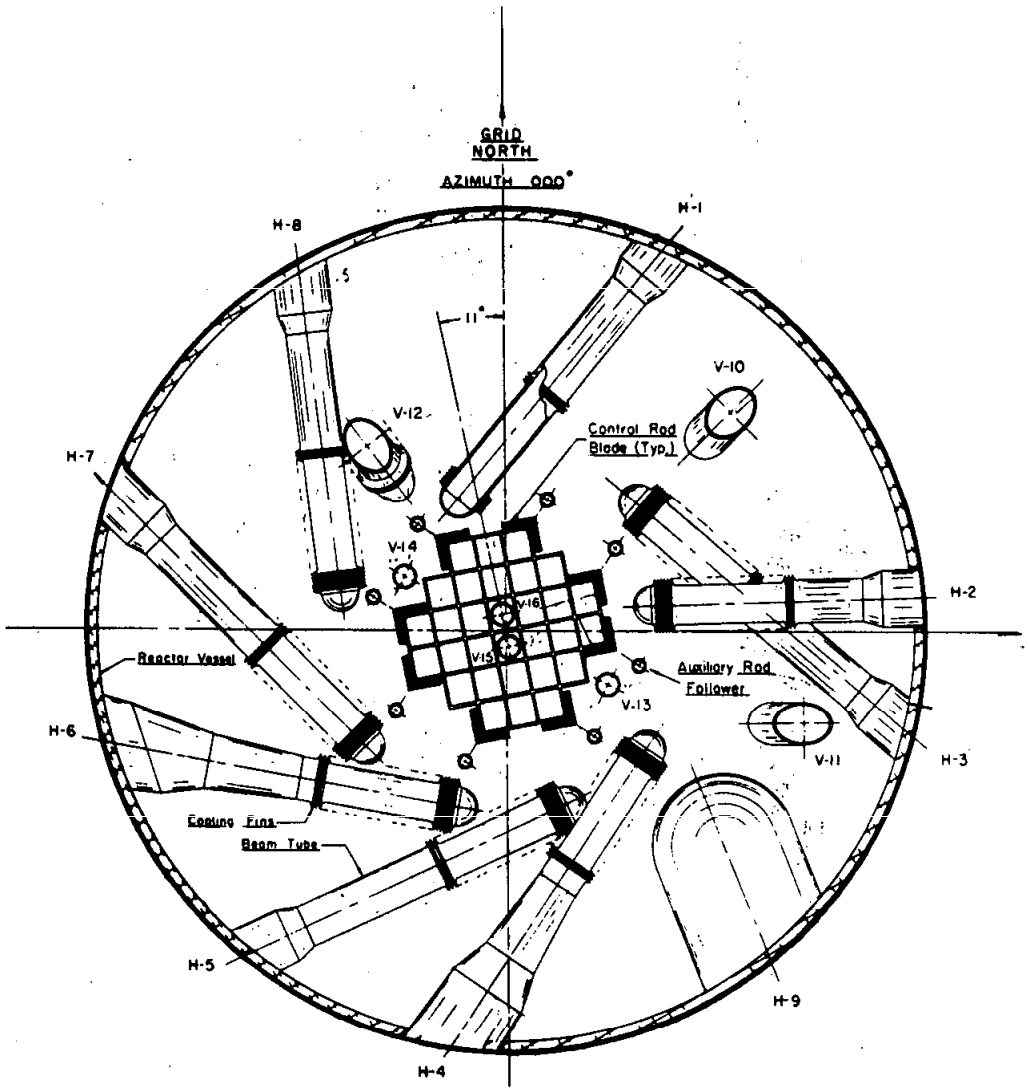


FIGURE 1. Cross Section of the HFBR Vessel

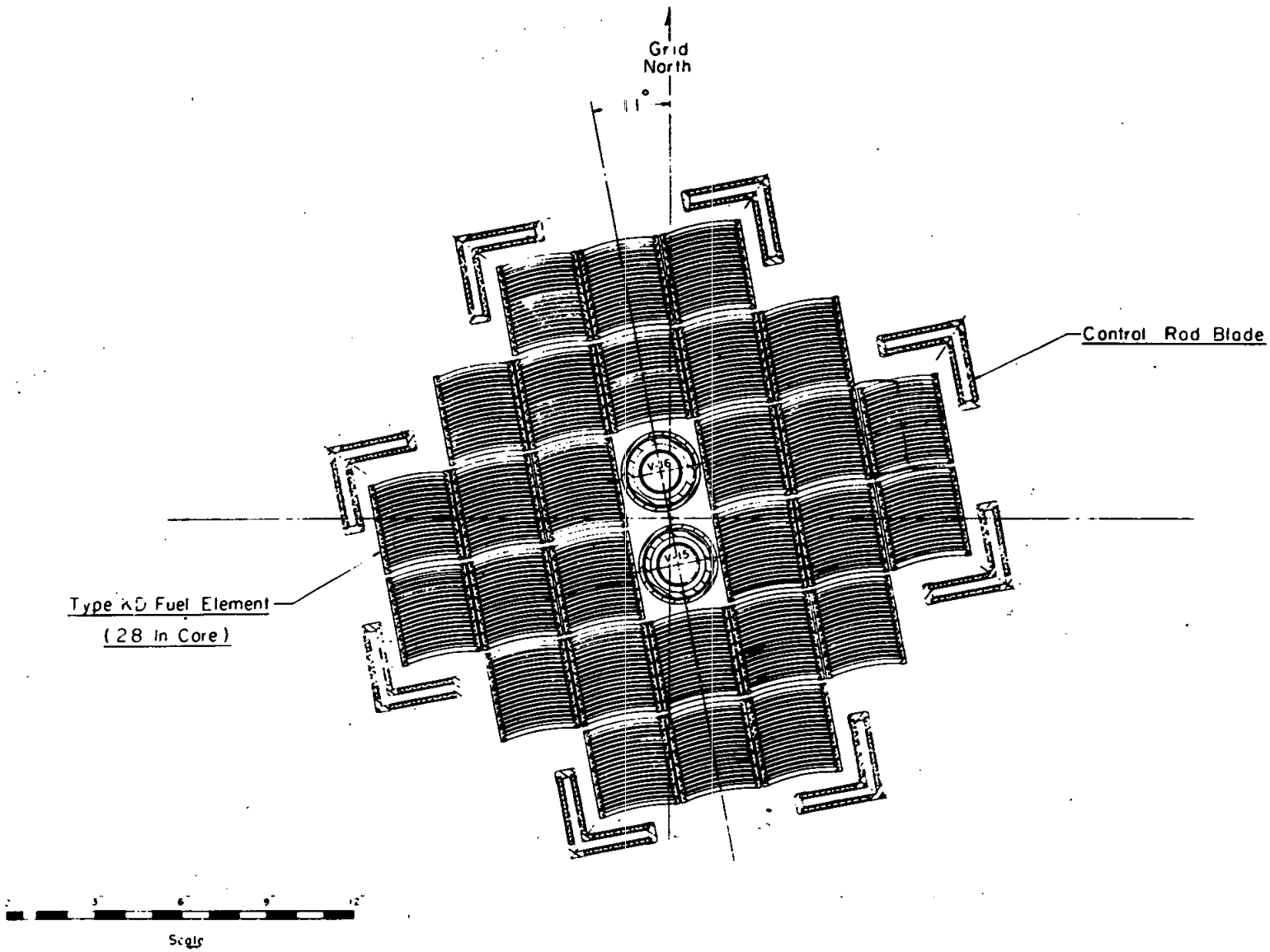


FIGURE 2. Cross Section of the HFBR Core

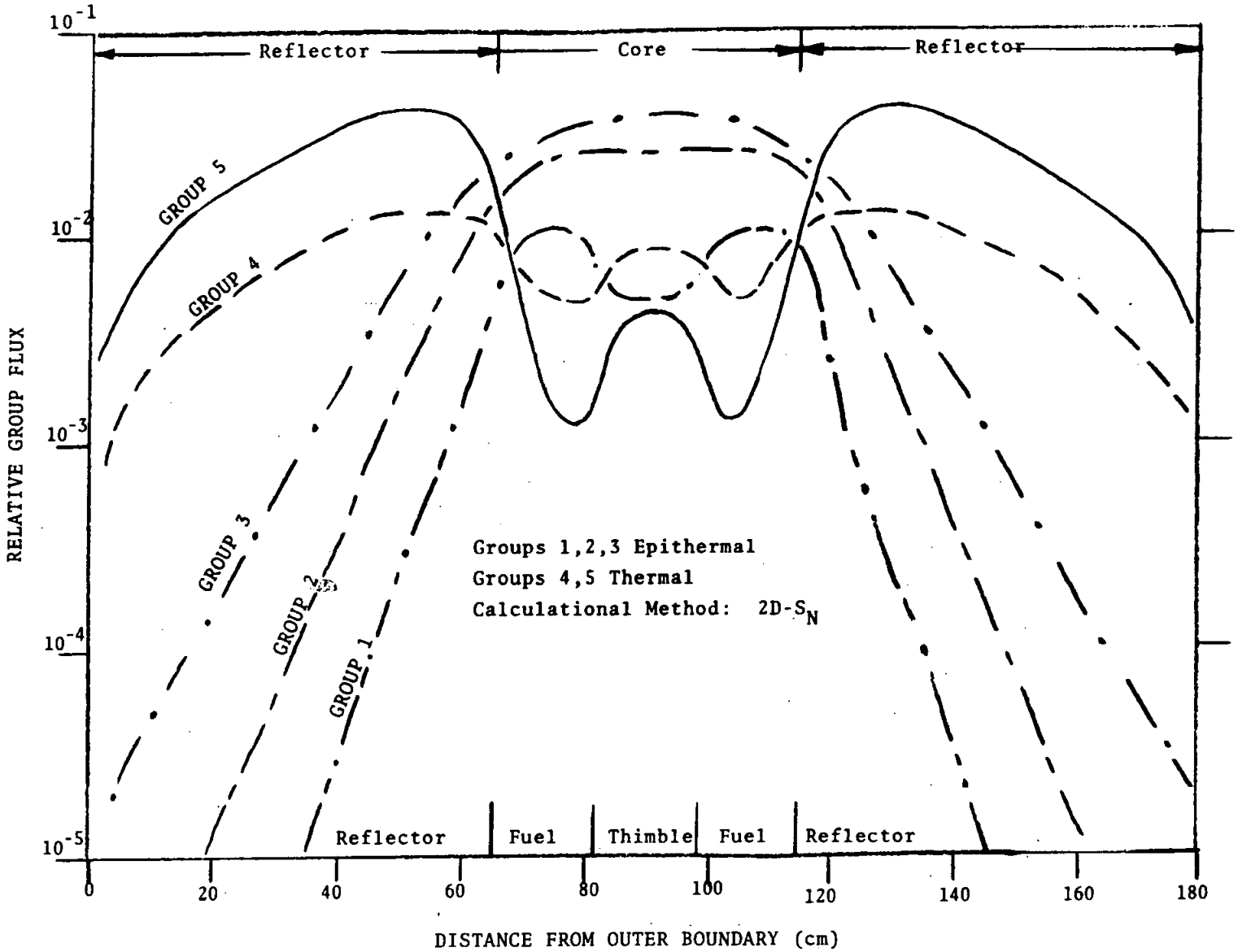


FIGURE 3. HFBR Core Centerline Group Fluxes (End of Equilibrium Cycle - 351 gram ^{235}U Assemblies)

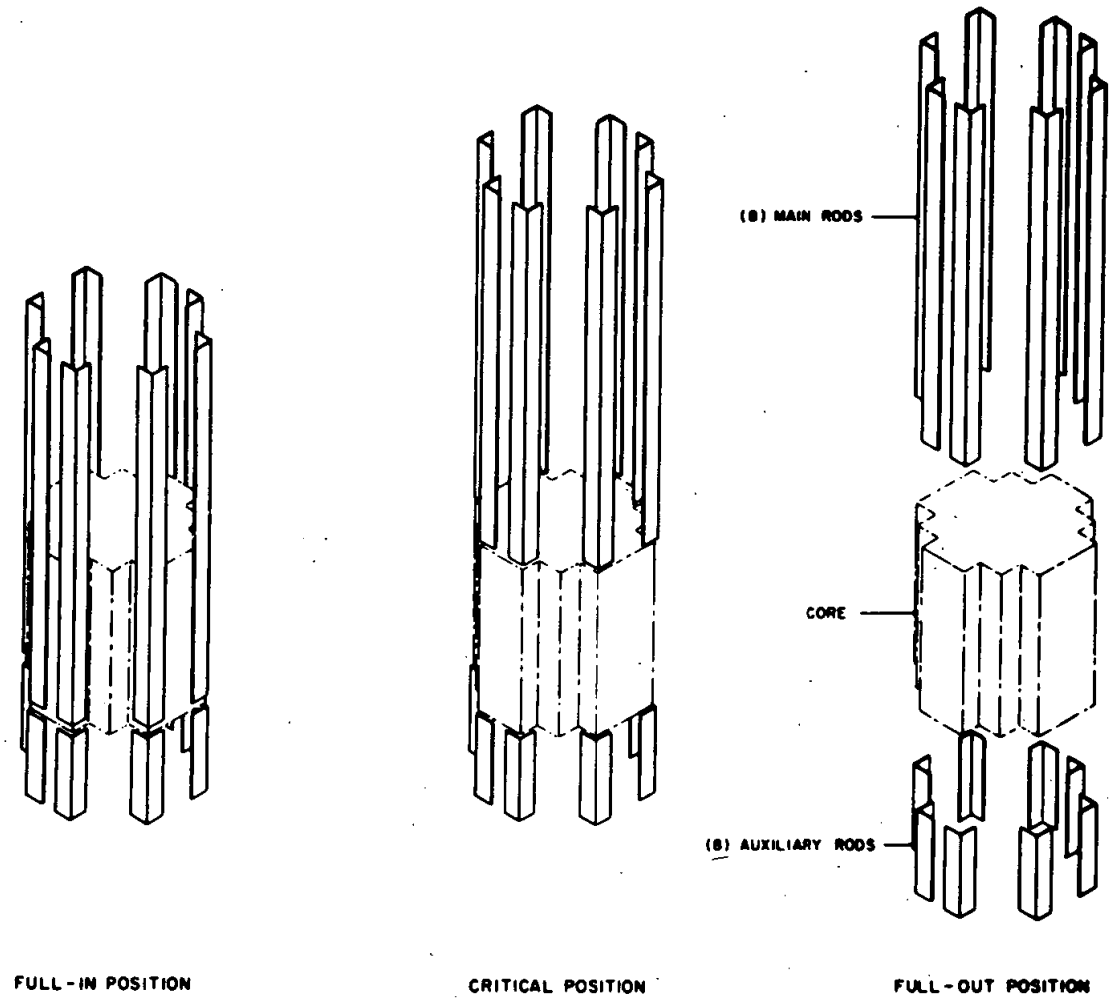


FIGURE 4. Axial Positions of HFBR Control Blades

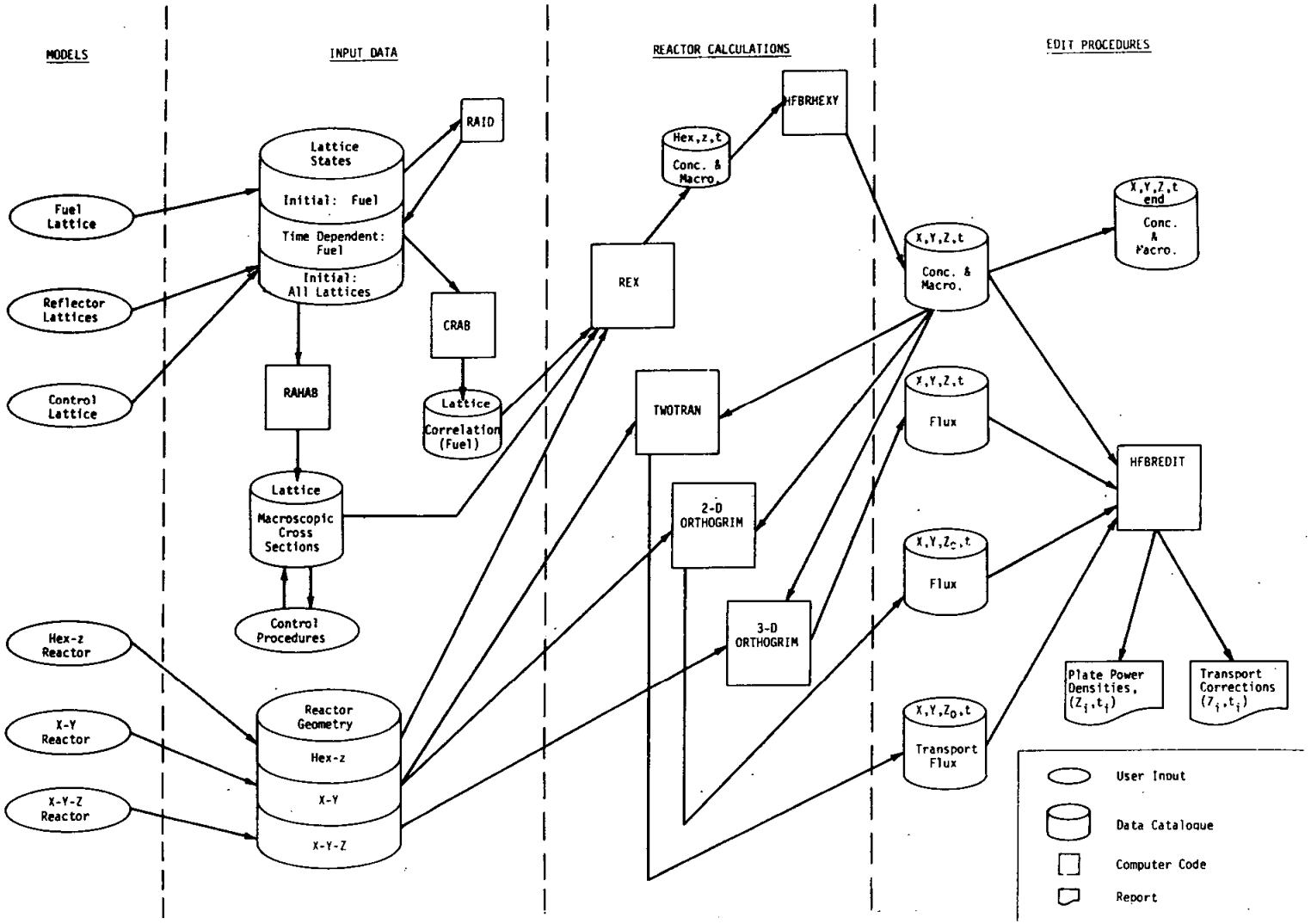
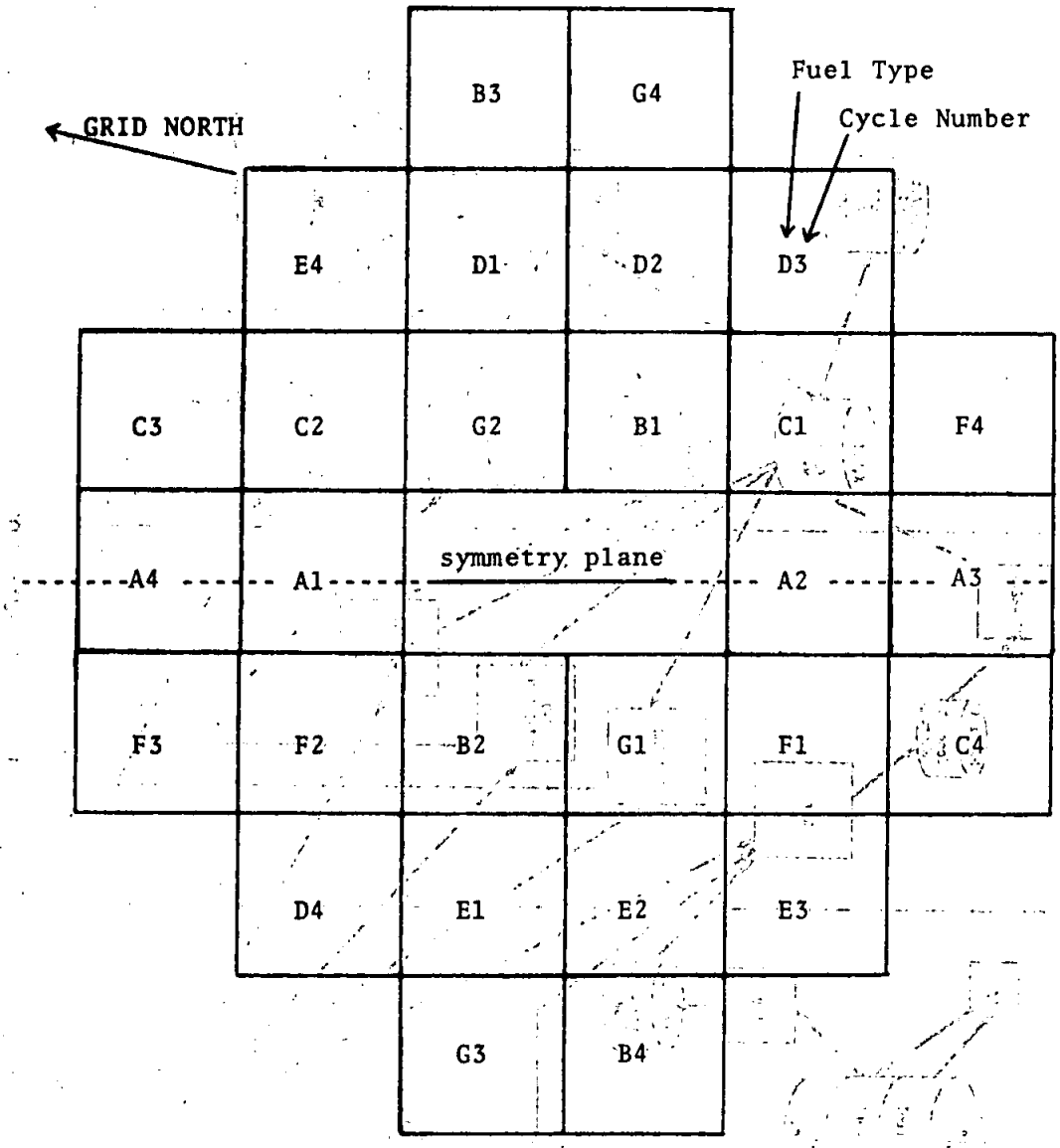


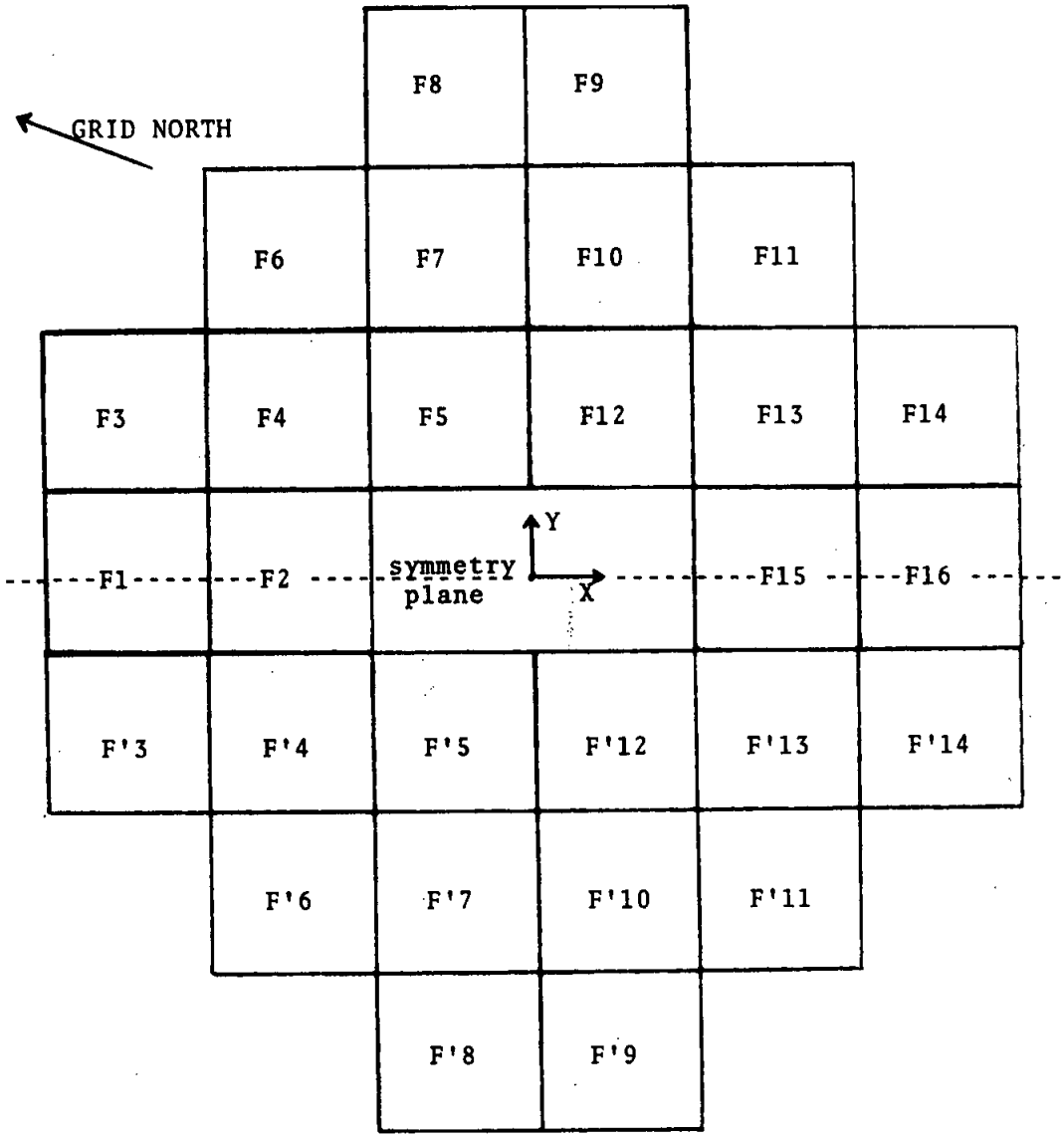
FIGURE 5. Calculational Procedure for HFBR



NOTE (1) The numeral designation after the fuel type is the cycle number of that fuel.

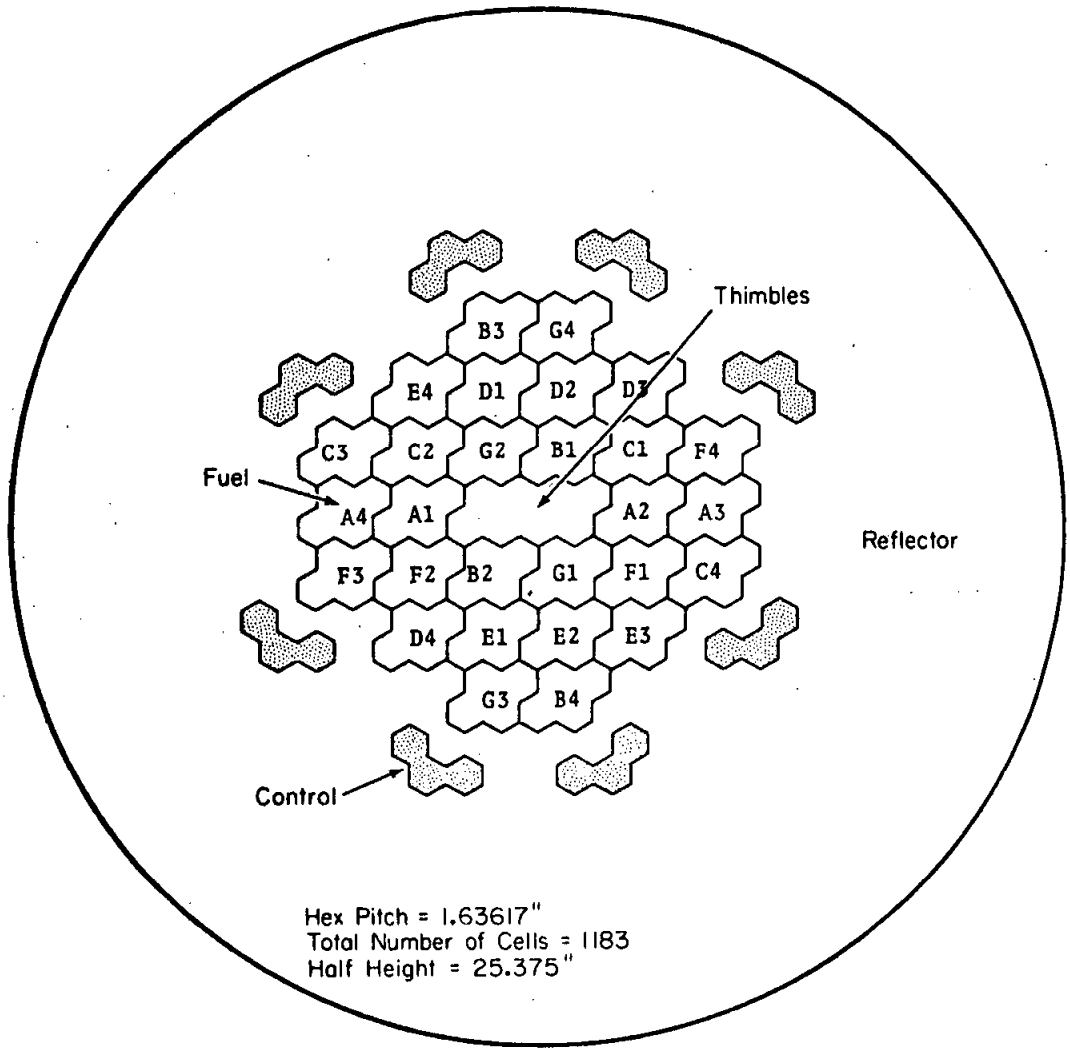
(2) A1, B1, C1, D1, E1, F1 and G1 are fresh 351 gm assembli

FIGURE 6. HFBR Fuel Rotation Scheme



Note: The primed fuel numbers are mirror images of the unprimed fuel numbers.

FIGURE 7. HFBR Edit Model at the (X,Y) Midplane Designating the Fuel Numbers



Unit cell area = 9.2736 in^2

Fuel unit cell half height = 11.4375 in

FIGURE 8. Fuel Rotation Plan in REX-HFBR Geometry

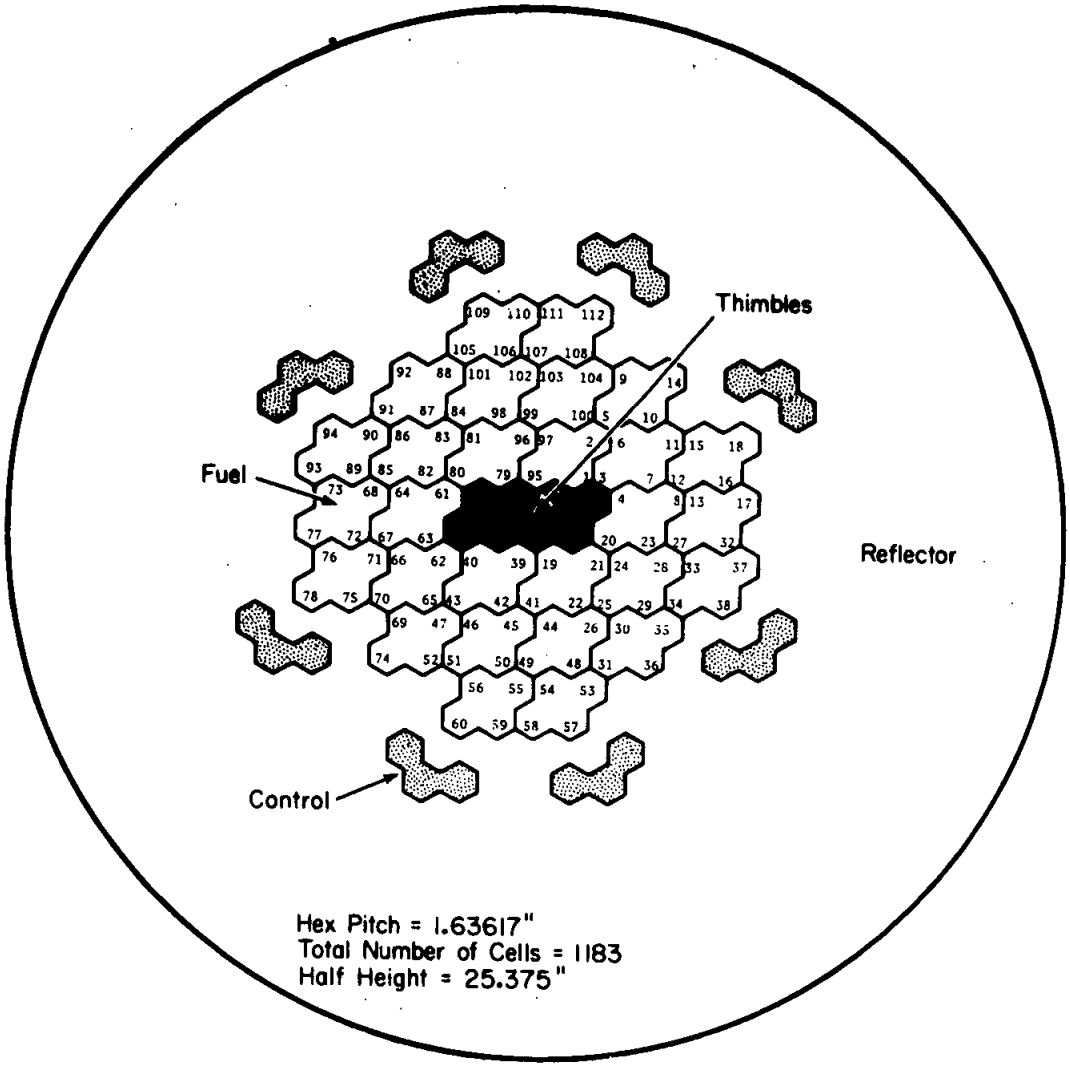


FIGURE 9. Base Material Numbers in REX-HFBR Geometry

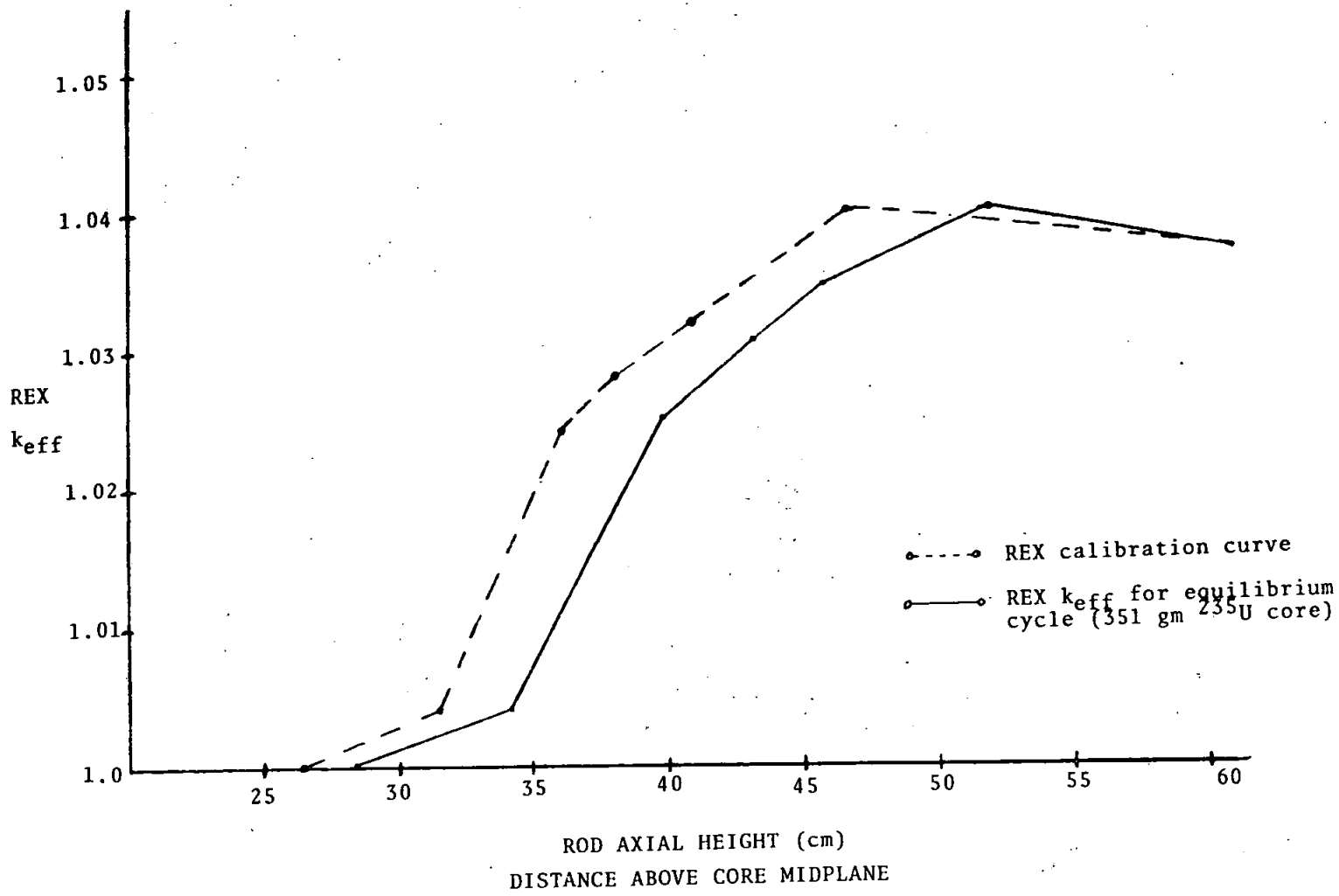


FIGURE 10. REX Calibration Curve

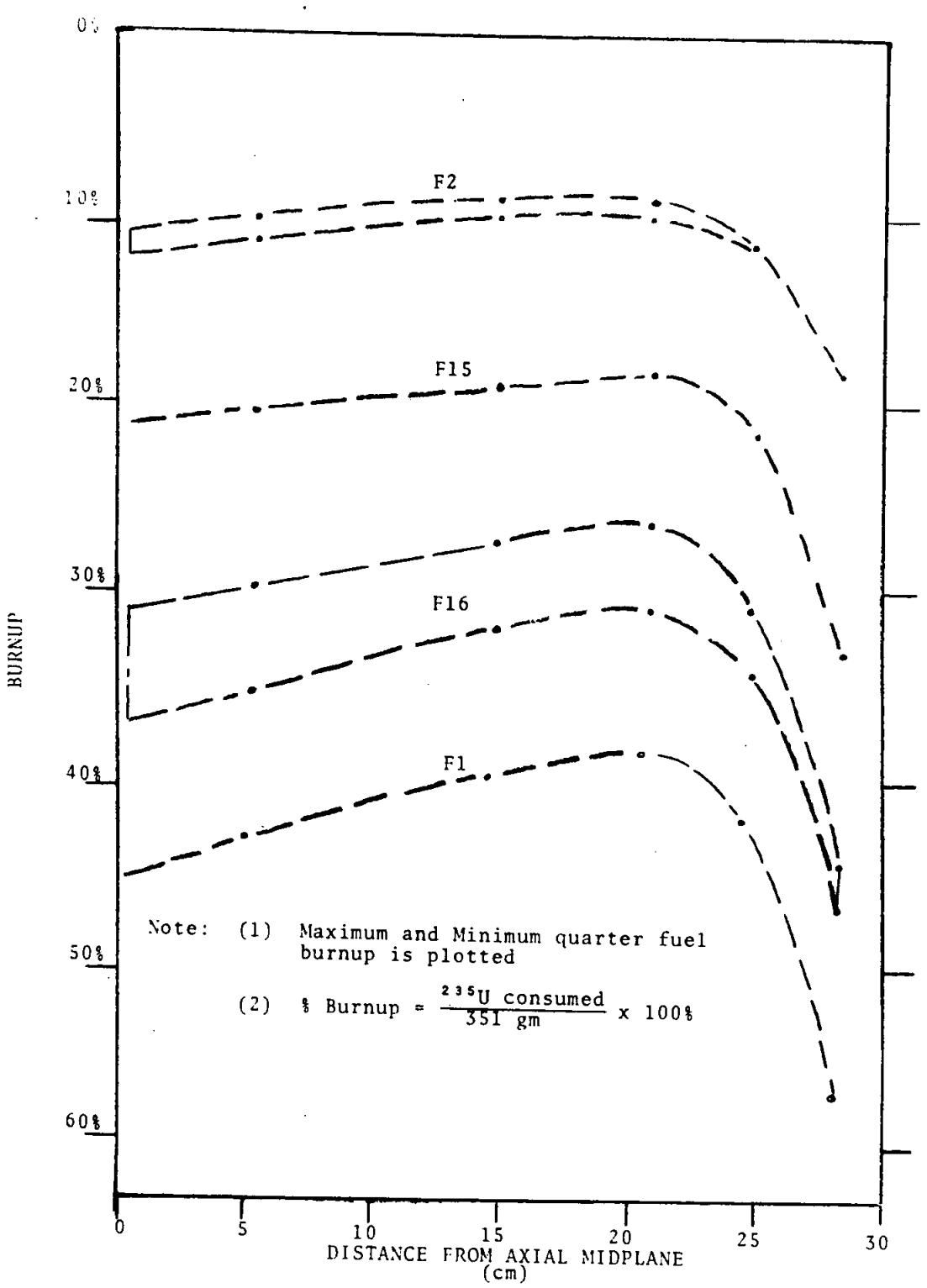


FIGURE 11. ^{235}U Burnup Versus Axial Distance (Fuel Type A)

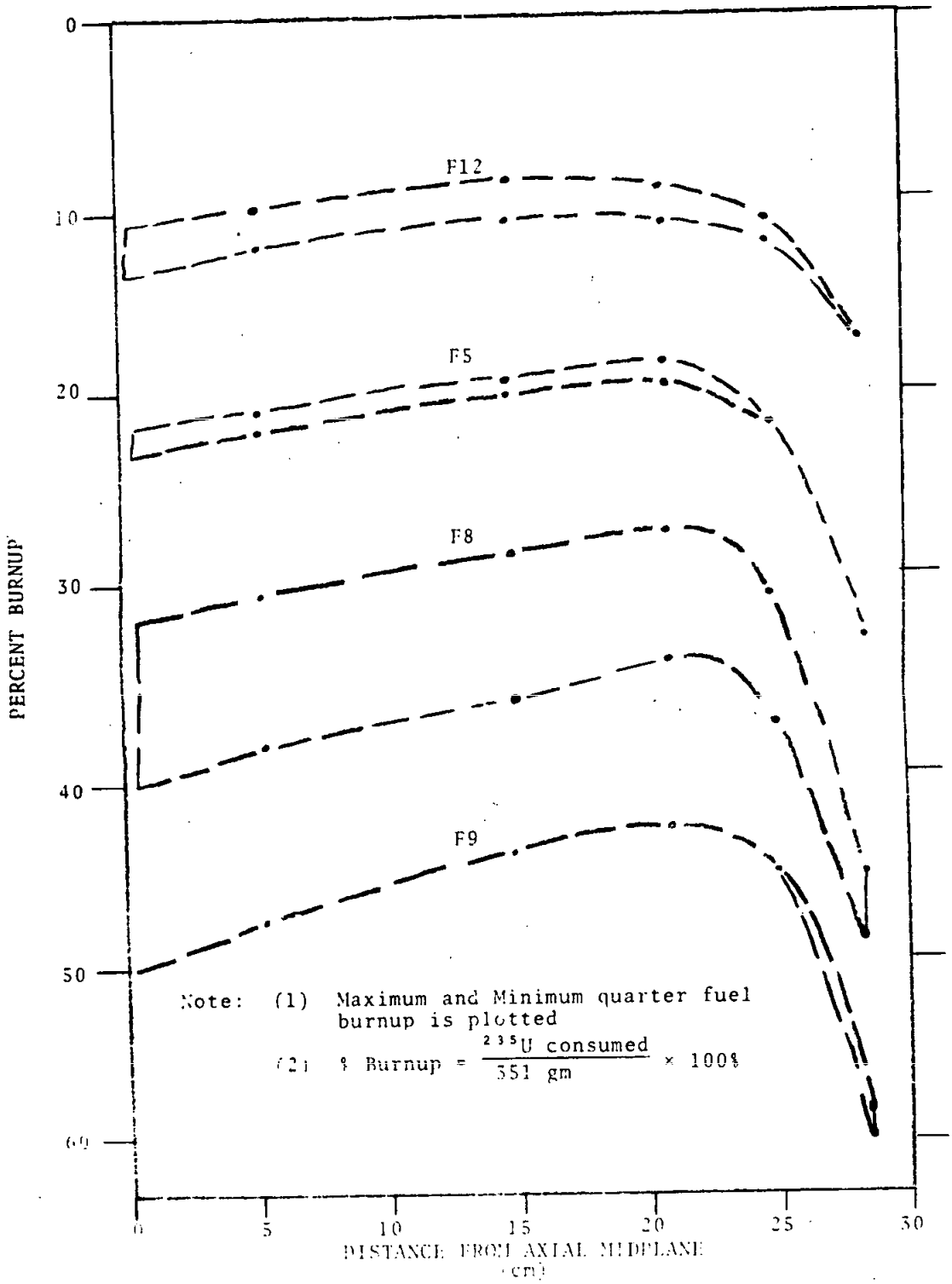


FIGURE 12. ^{235}U Burnup Versus Axial Distance (Fuel Type B)

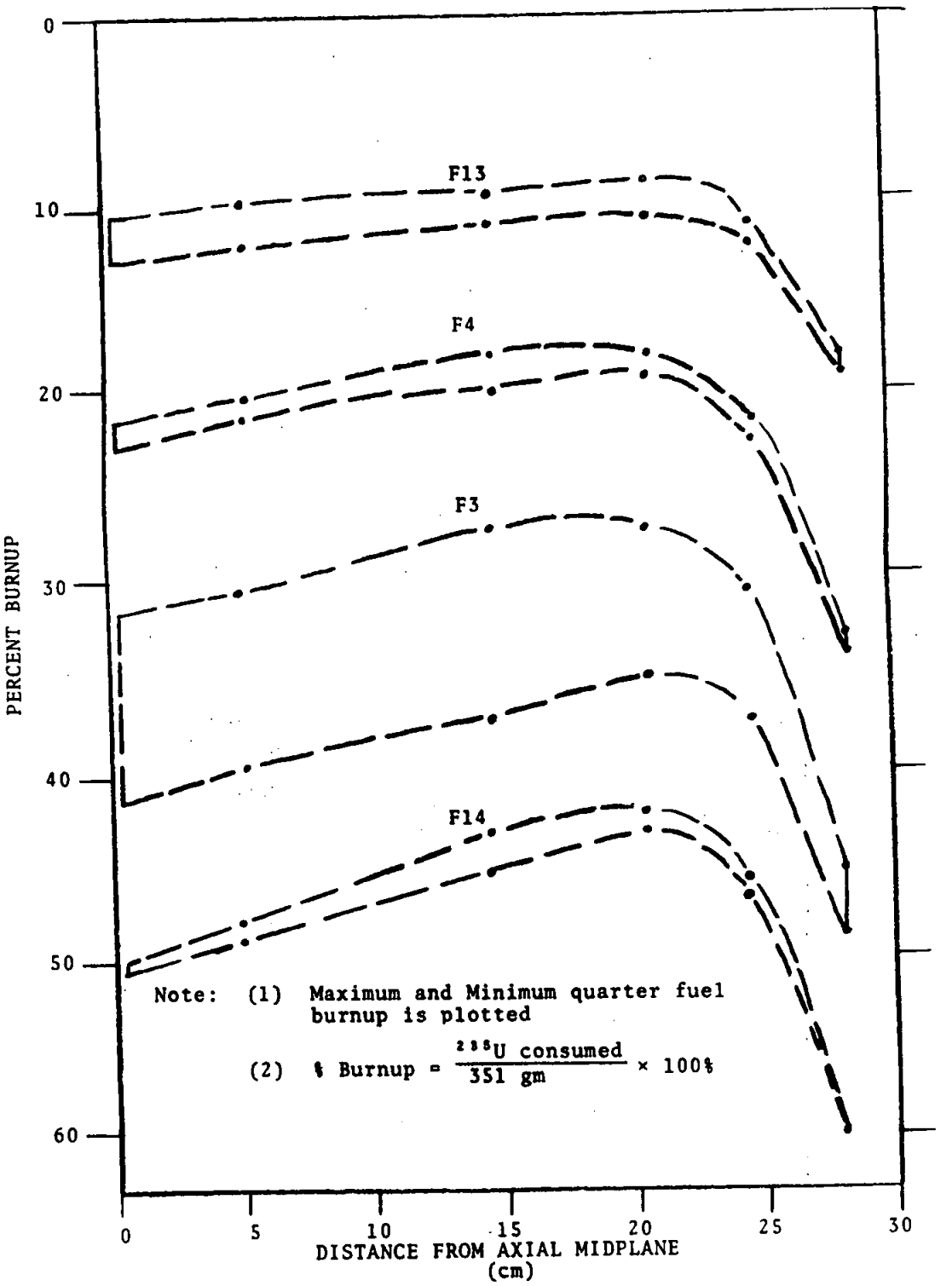


FIGURE 13. ^{235}U Burnup Versus Axial Distance (Fuel Type C)

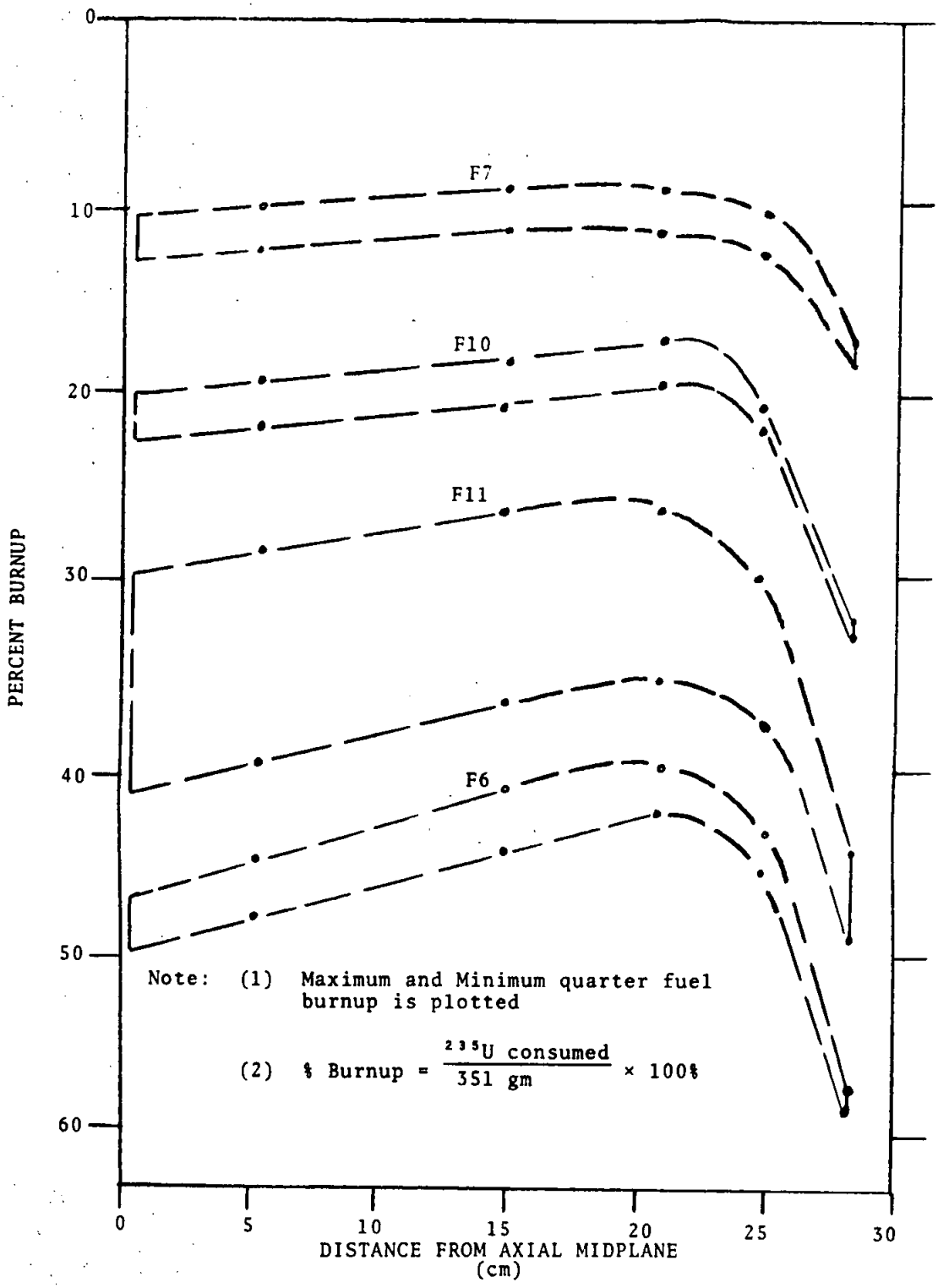


FIGURE 14. ^{235}U Burnup Versus Axial Distance (Fuel Type D)

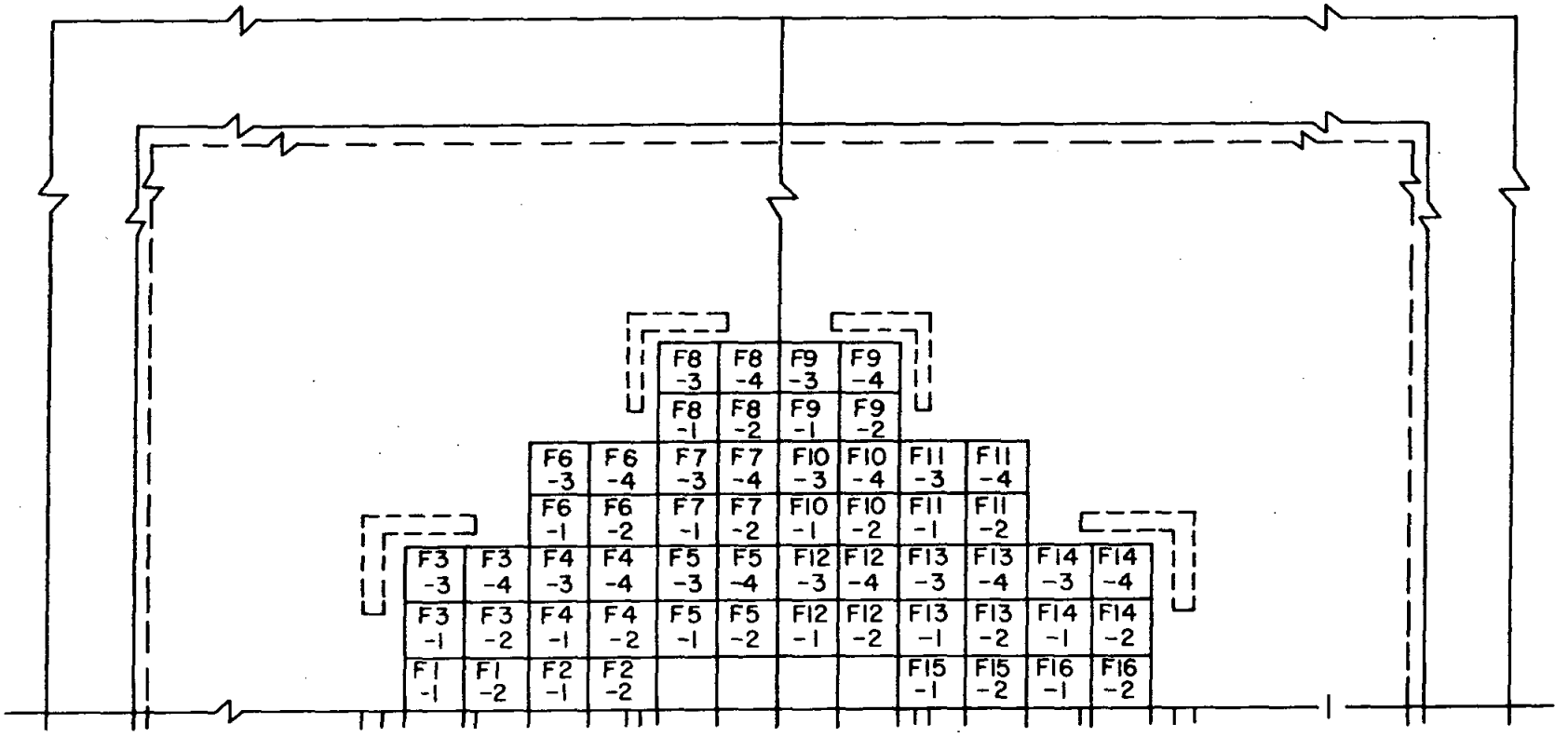
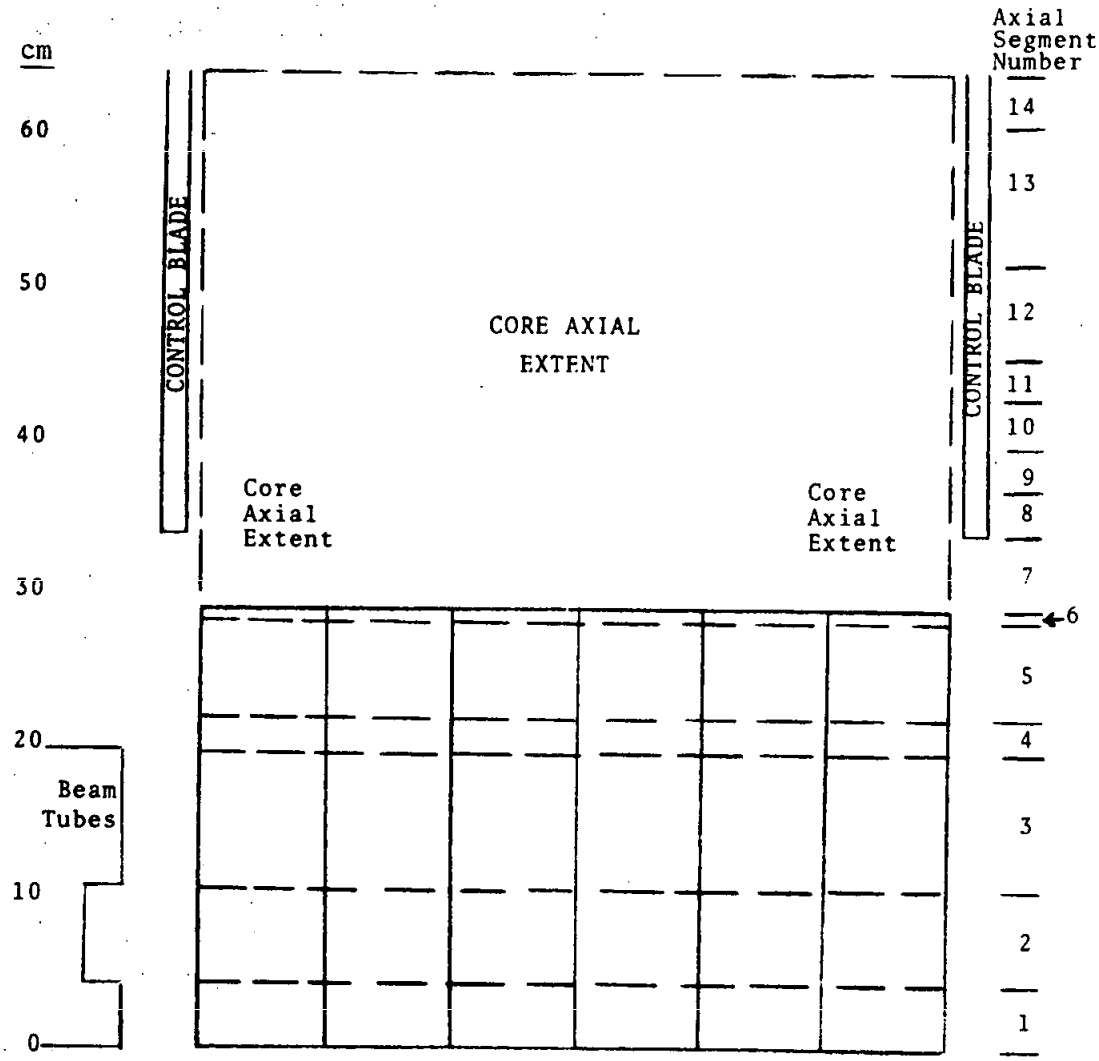


FIGURE 15. ORTHOGRIM - Material Mesh in the (X,Y) Plane



Segment	Cm above Core Midplane	Sub-intervals
1	4.445	1
2	10.745	2
3	19.685	3
4	21.83	1
5	28.36	3
6	29.0512	1
7	34.0808	2
8	36.9794	1
9	39.878	2
10	43.1133	2
11	45.78	1
12	51.8763	1
13	60.96	2
14	64.4523	1

FIGURE 16. ORTHOGRIM - HFBR Axial Mesh

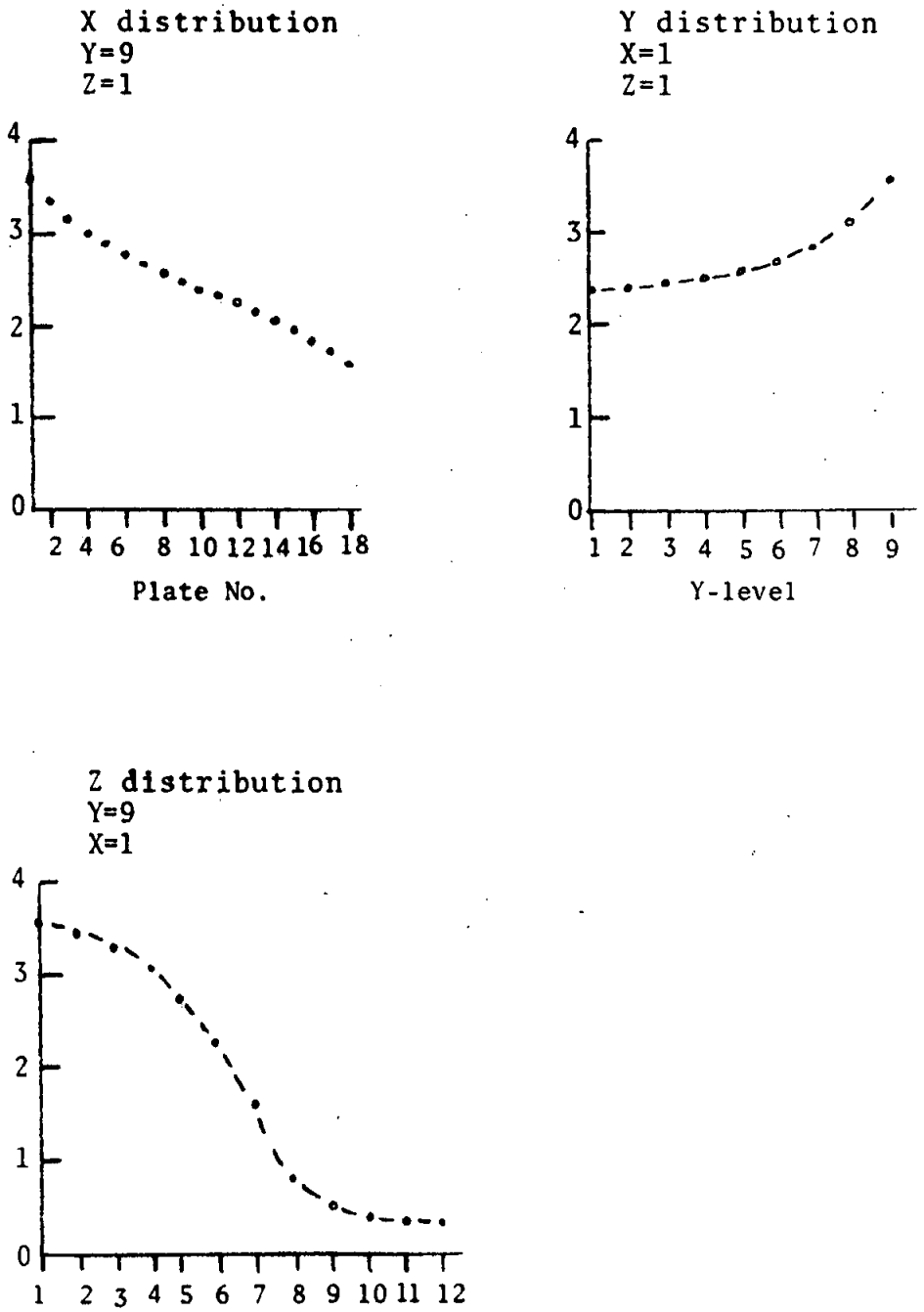
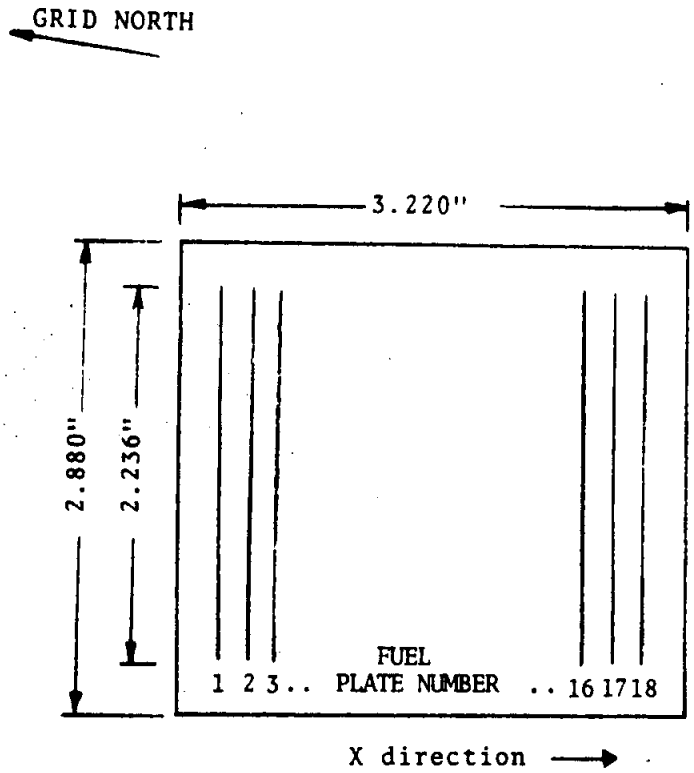


FIGURE 17. Point Power Density Distributions P(X,Y,Z)
Fuel F3 Fresh Core, T=0



Fractional Elevation	Y-Level
1	9
7/8	8
3/4	7
5/8	6
1/2	5
3/8	4
1/4	3
1/8	2
0	1

FIGURE 18. Designation of Plate Numbers and Y Elevations in the HFBR 351 Gram Fuel Cell

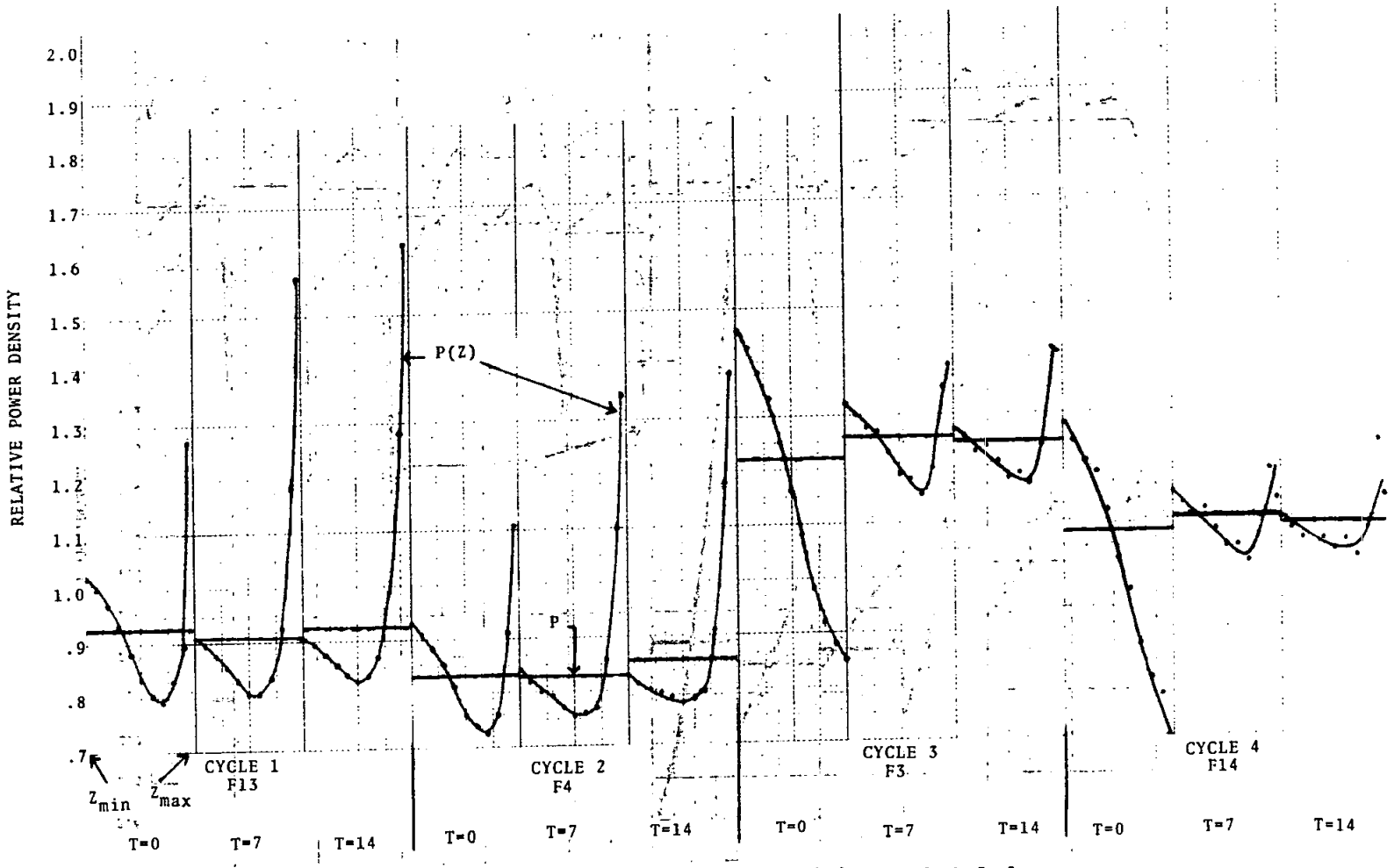


FIGURE 19. Fuel Power Density P(Z) and Axial Average Fuel Power Density $P = \int P(Z)dZ/\Delta Z$

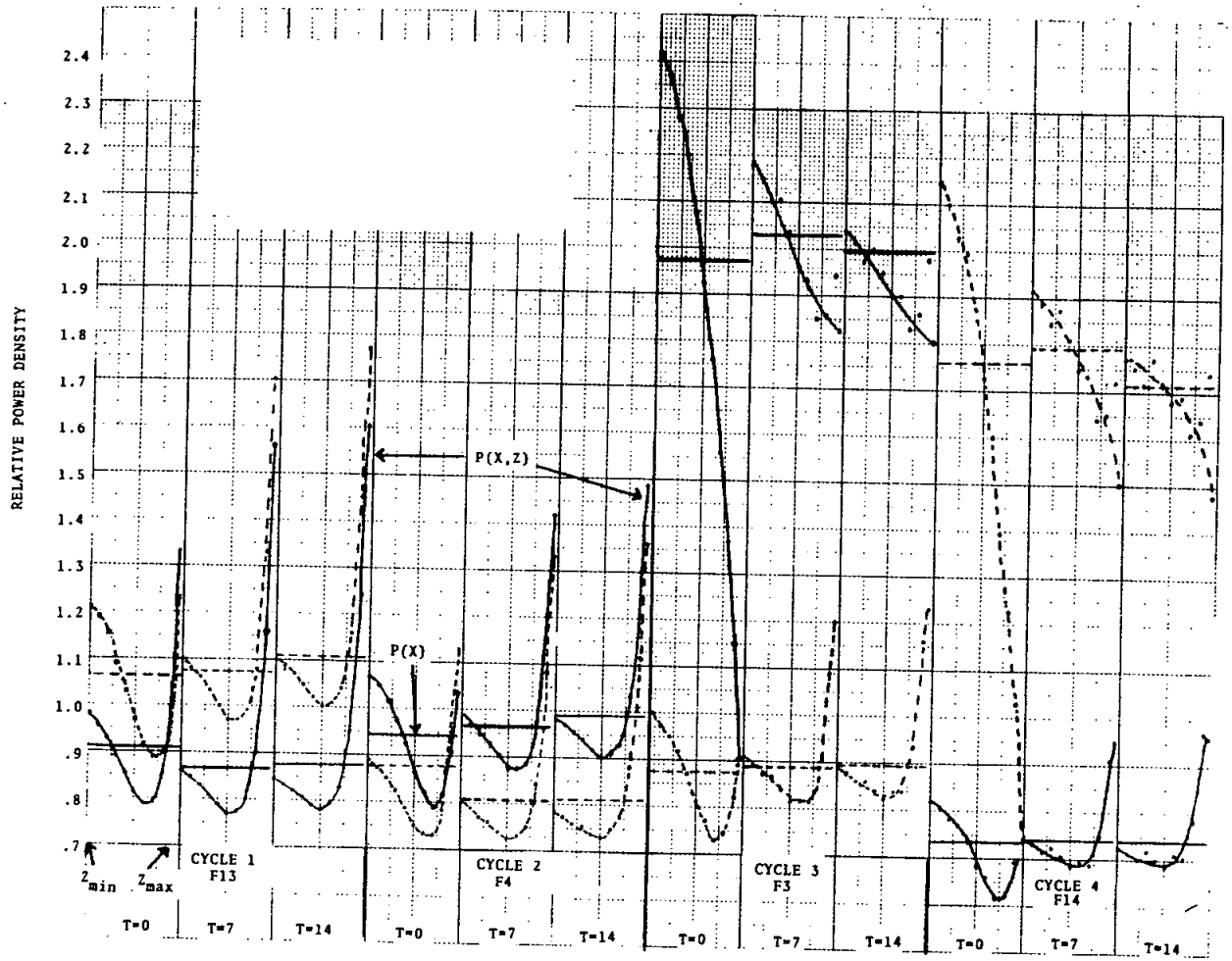


FIGURE 20. Plate Power Density P(X,Z) and Axial Average Plate Power Density $P(X) = \int P(X,Z)dZ/\Delta Z$

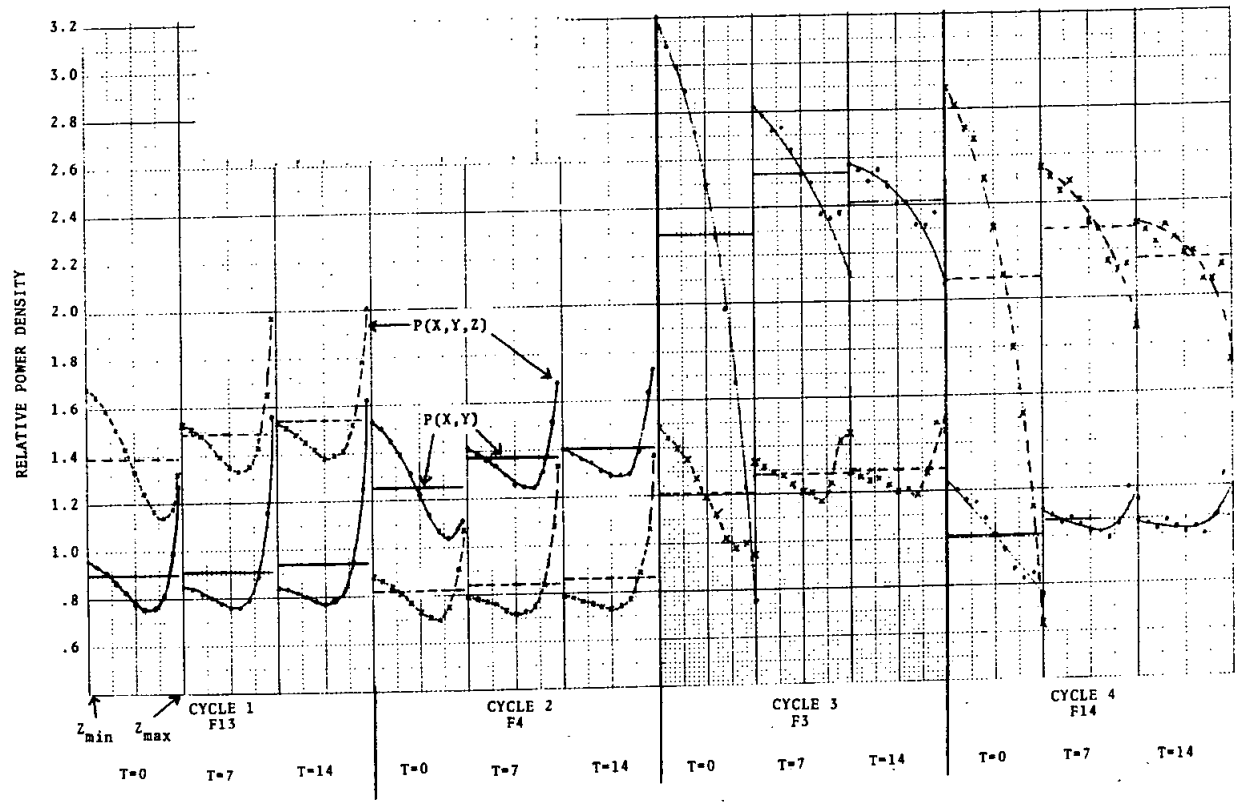


FIGURE 21. Point Power Density P(X,Y,Z) and Axial Average Point Power Density $P(X,Y) = \int P(X,Y,Z)dZ/\Delta Z$

CASE=BASECASP PLATE POWER DENSITIES, AVERAGED FROM Z= 0.0 CM. TO Z= 4.4450 CM.

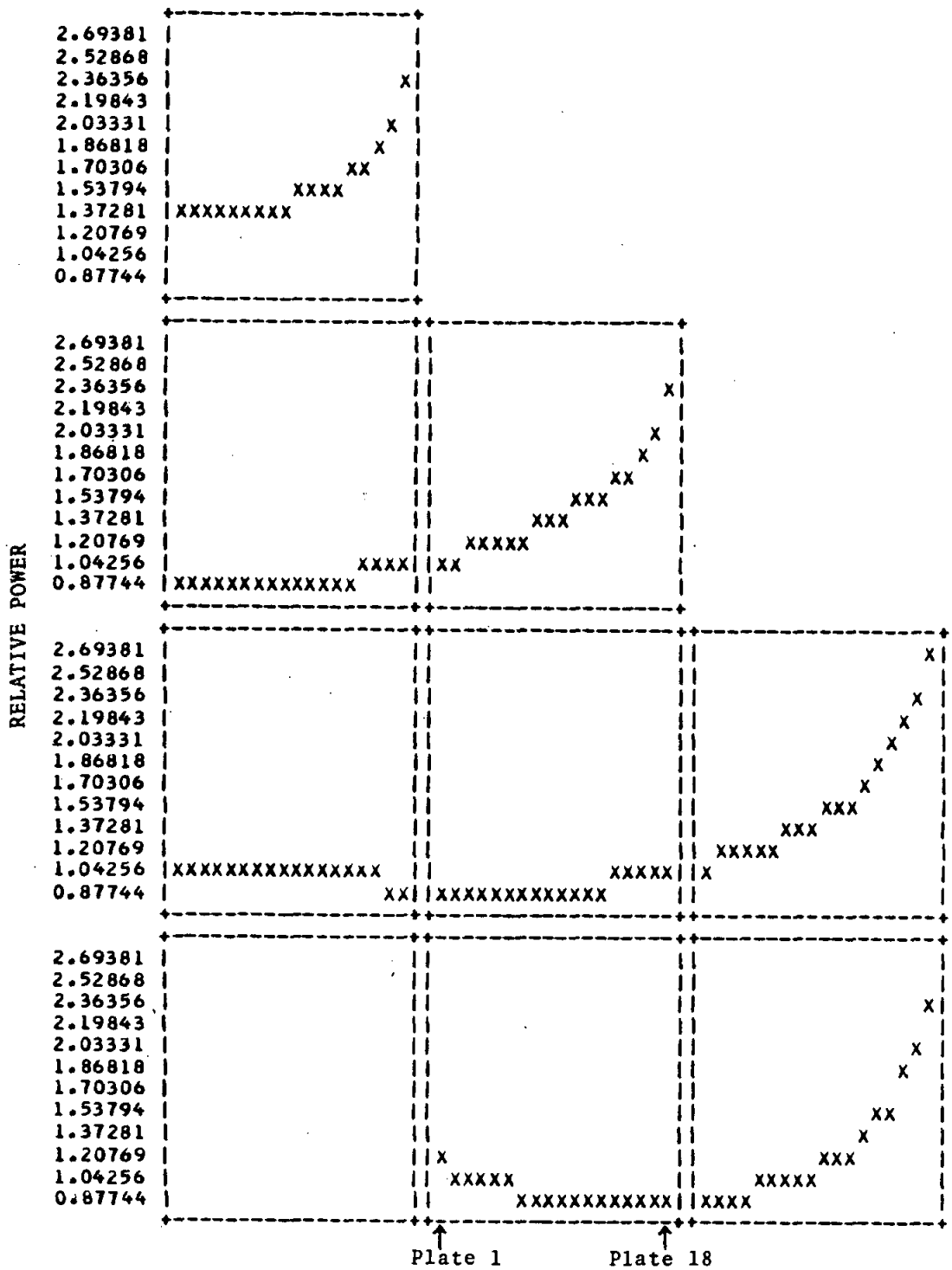


FIGURE 22. Fresh Core T = 0 @ 60 MW

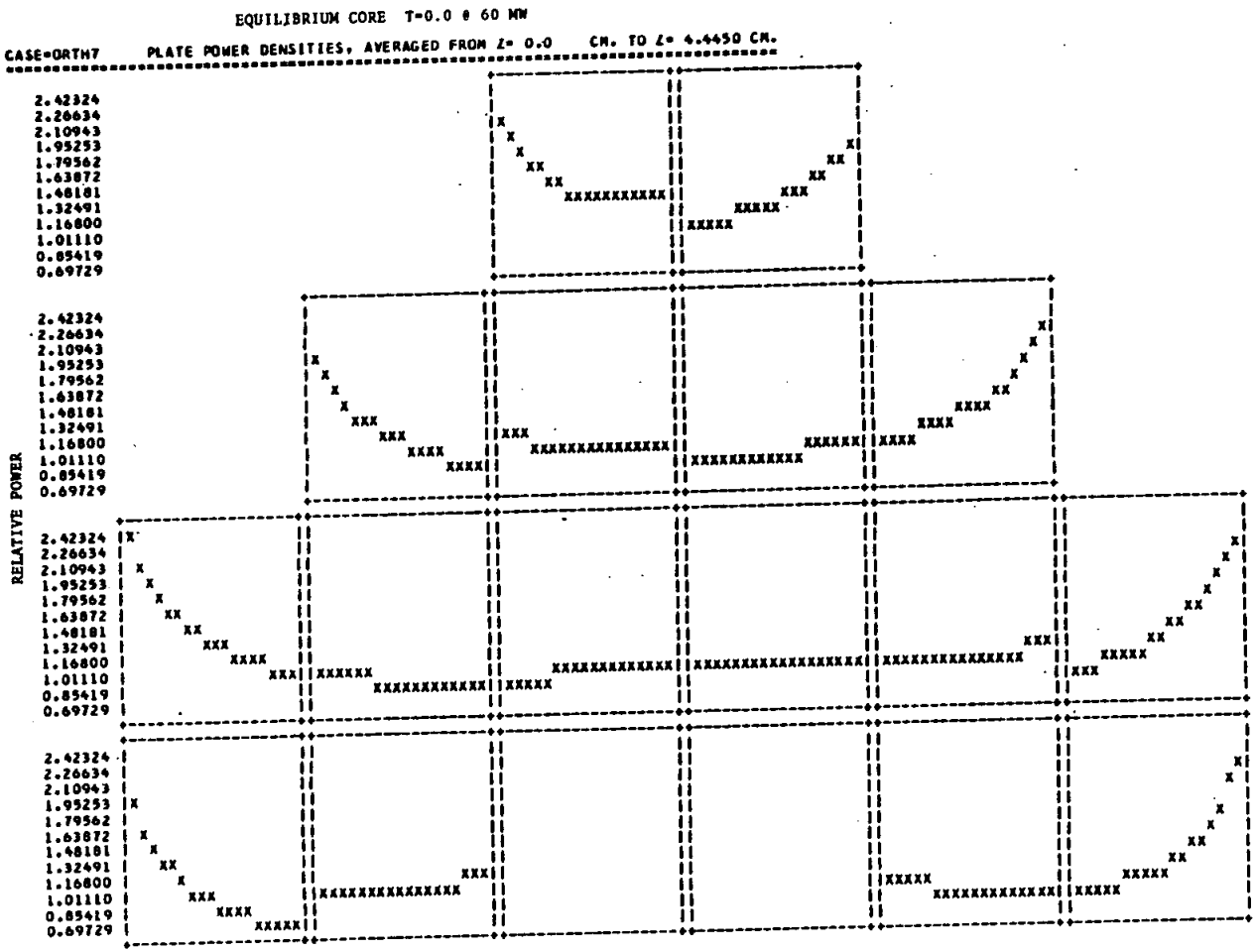

EQUILIBRIUM CORE T=0.0 @ 60 MW
CASE=ORTH7 PLATE POWER DENSITIES, AVERAGED FROM Z= 0.0 CM. TO Z= 4.4450 CM.
RELATIVE POWER
2.42324
2.26634
2.10943
1.95253
1.79562
1.63872
1.48181
1.32491
1.16800
1.01110
0.85419
0.69729

FIGURE 23

EQUILIBRIUM CORE, T=6.67 DAYS @ 60 MW

CASE=OPT+710 PLATE POWER DENSITIES, AVERAGED FROM Z= 0.0 CM. TO Z= 4.4450 CM.

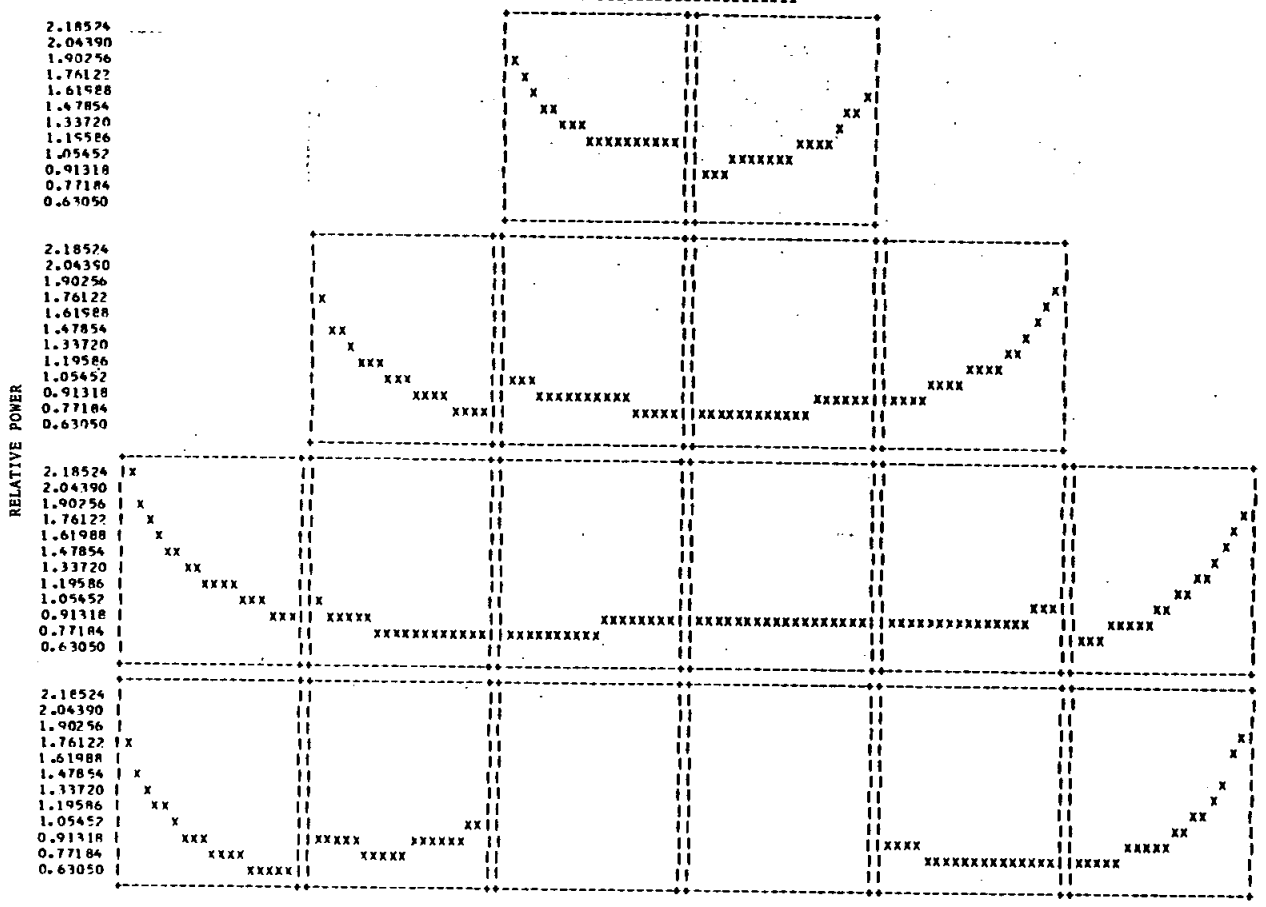


FIGURE 24

EQUILIBRIUM CORE, T=14.33 DAYS @ 60 MW

CASE=ORTH722 PLATE POWER DENSITIES, AVERAGED FROM Z= 0.0 CM. TO Z= 4.4450 CM.

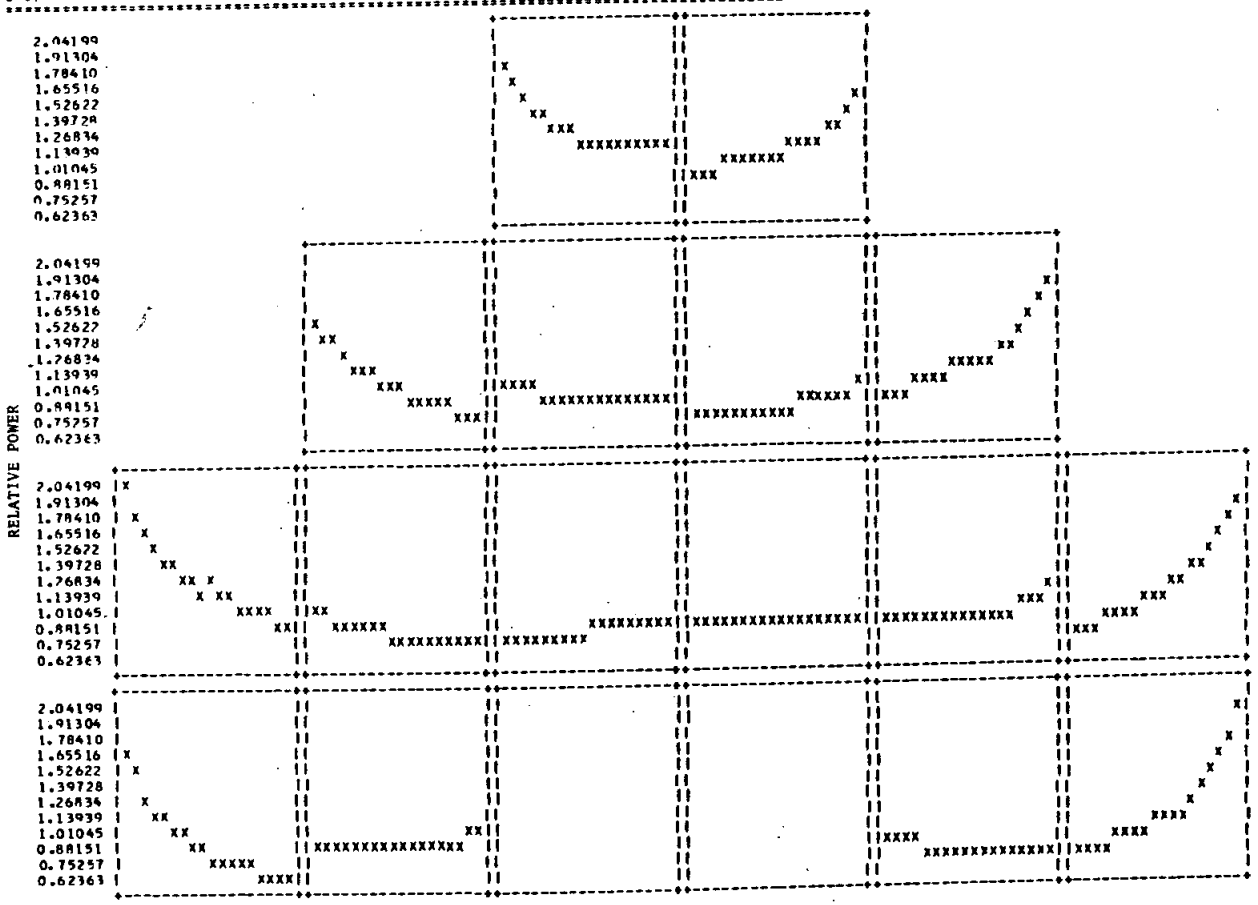


FIGURE 25

FRESH CORE, T=0.0 @ 60 MW

CASE=BASECASP PLATE POWER DENSITIES, AVERAGED FROM Z=27.7018 CM. TO Z=29.0512 CM.

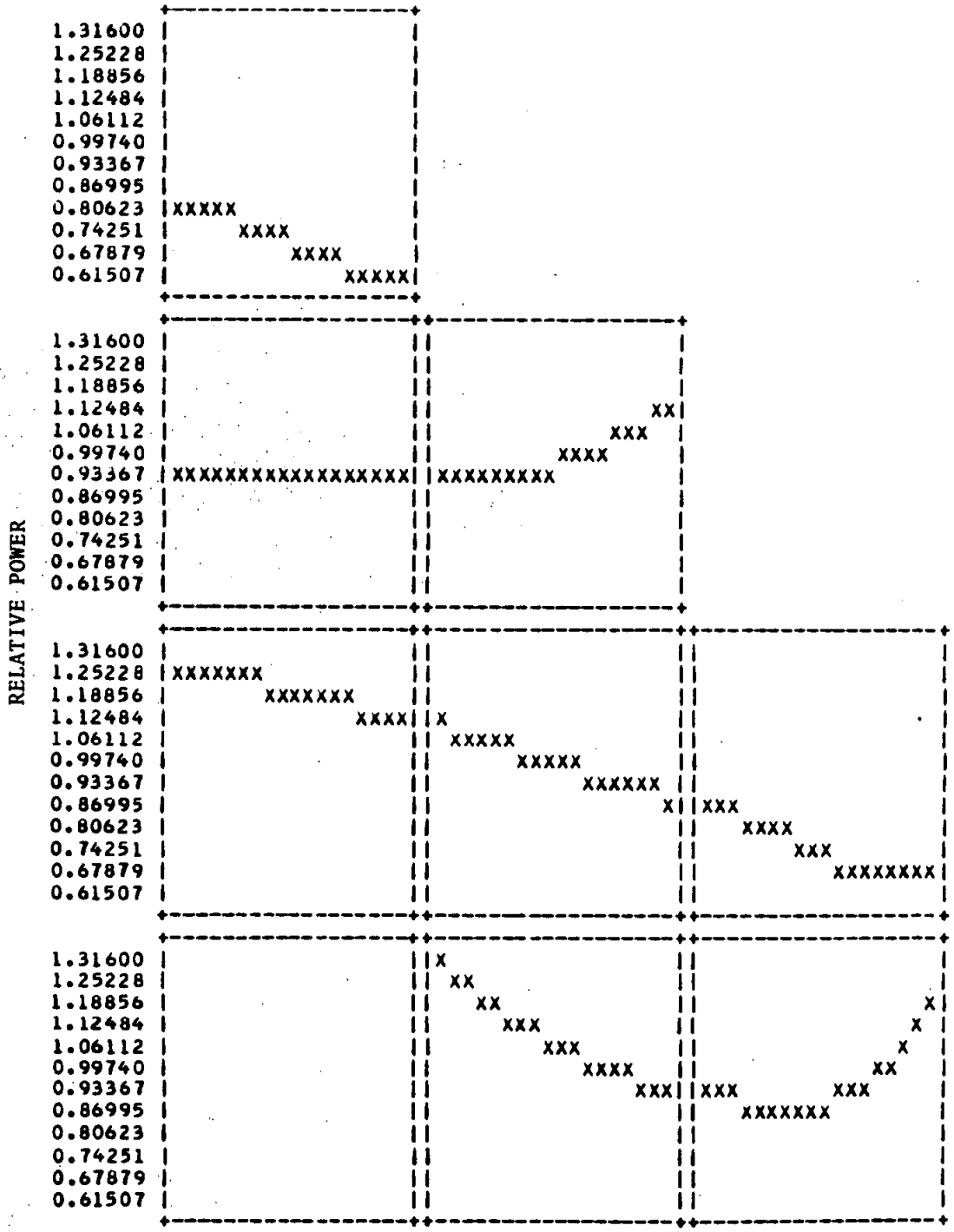


FIGURE 26

EQUILIBRIUM CORE, T=0.0 @ 60 MW

CASE=ORTH7 PLATE POWER DENSITIES, AVERAGED FROM Z=28.3600 CM. TO Z=29.0512 CM.

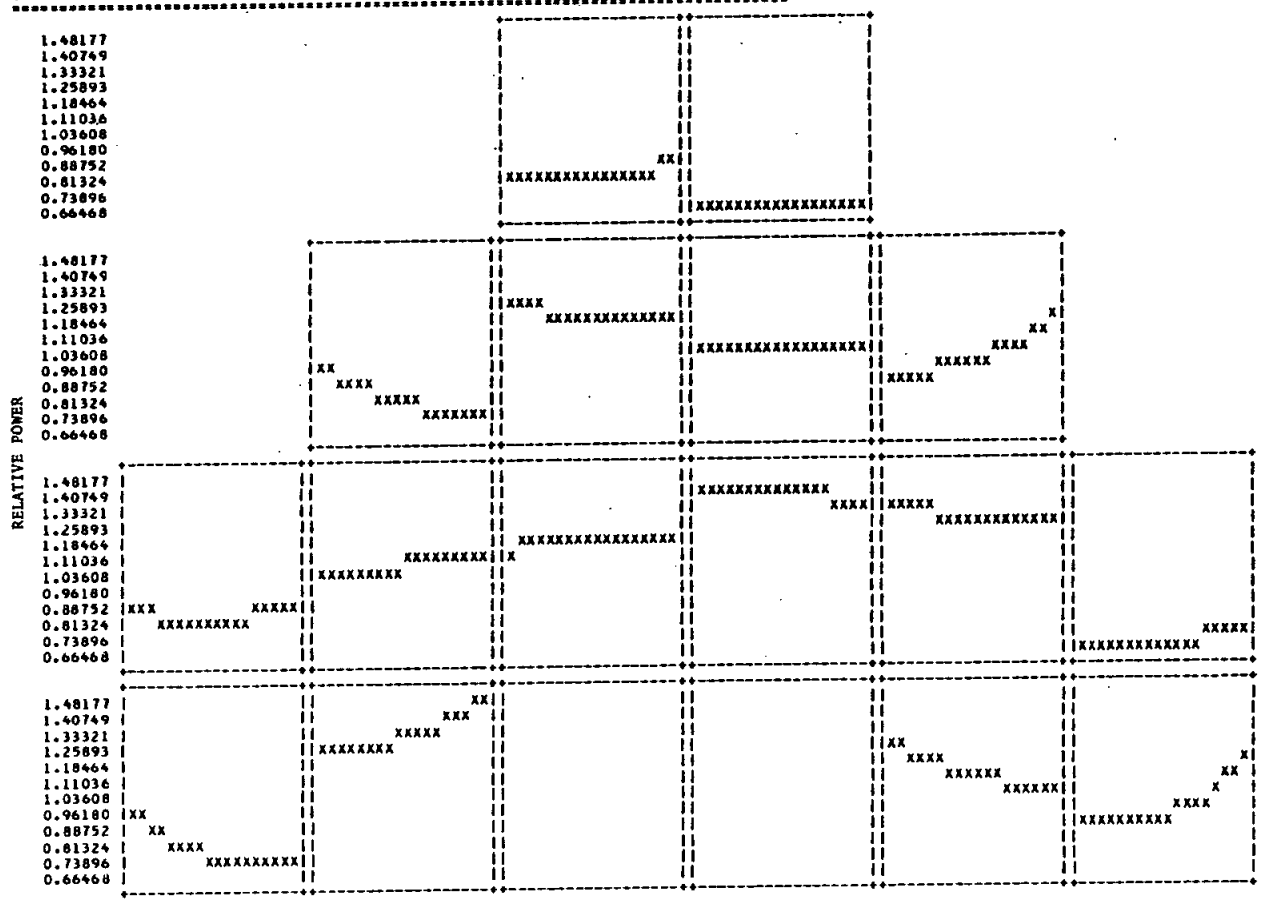


FIGURE 27

EQUILIBRIUM CORE, T=6.67 DAYS @ 60 MW

CASE=ORTH710 PLATE POWER DENSITIES, AVERAGED FROM Z=28.3600 CM. TO Z=29.0512 CM.

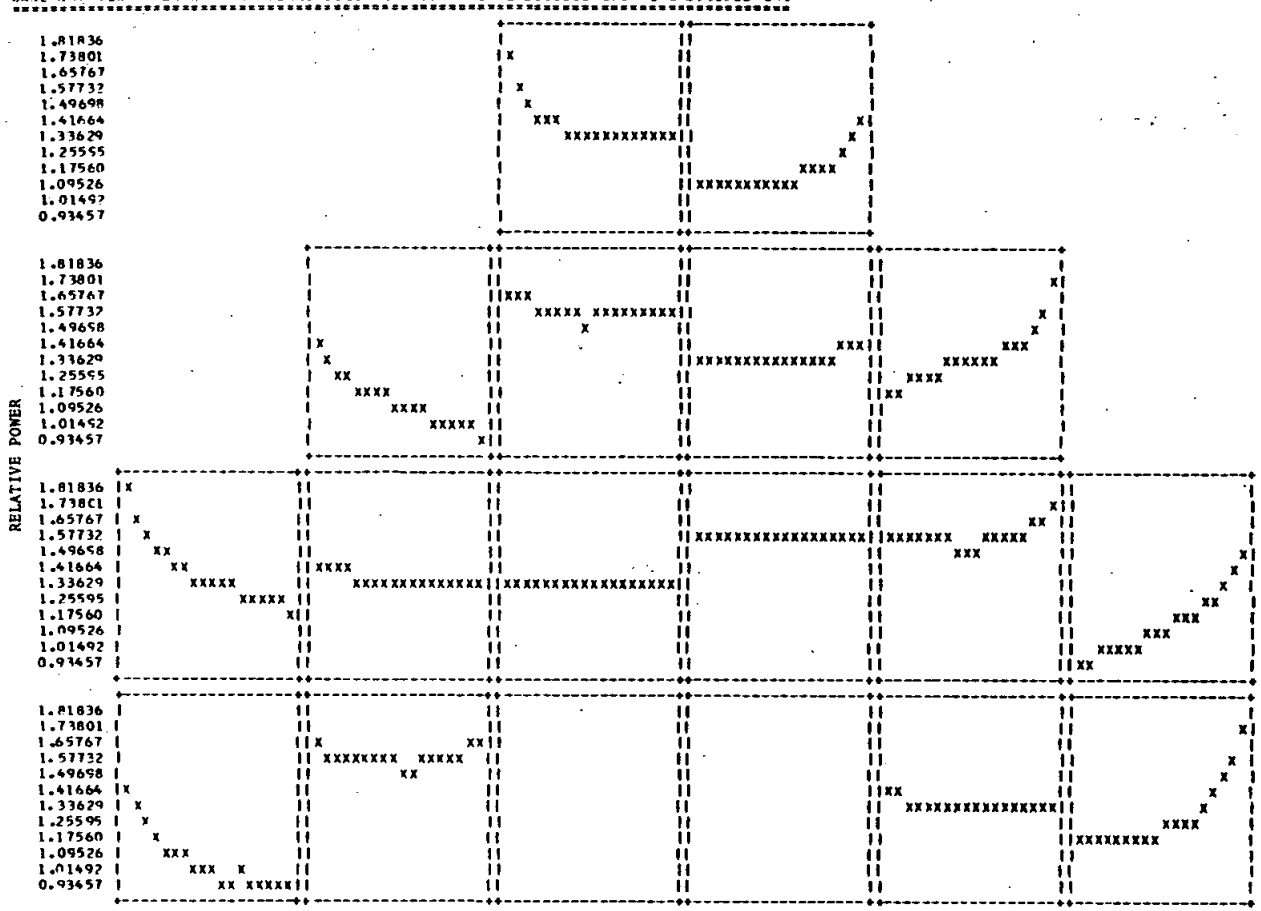


FIGURE 28

EQUILIBRIUM CORE, T=14.33 DAYS @ 60 MW

CASE=ORTH722 PLATE POWER DENSITIES, AVERAGED FROM Z=28.3600 CM. TO Z=29.0512 CM.

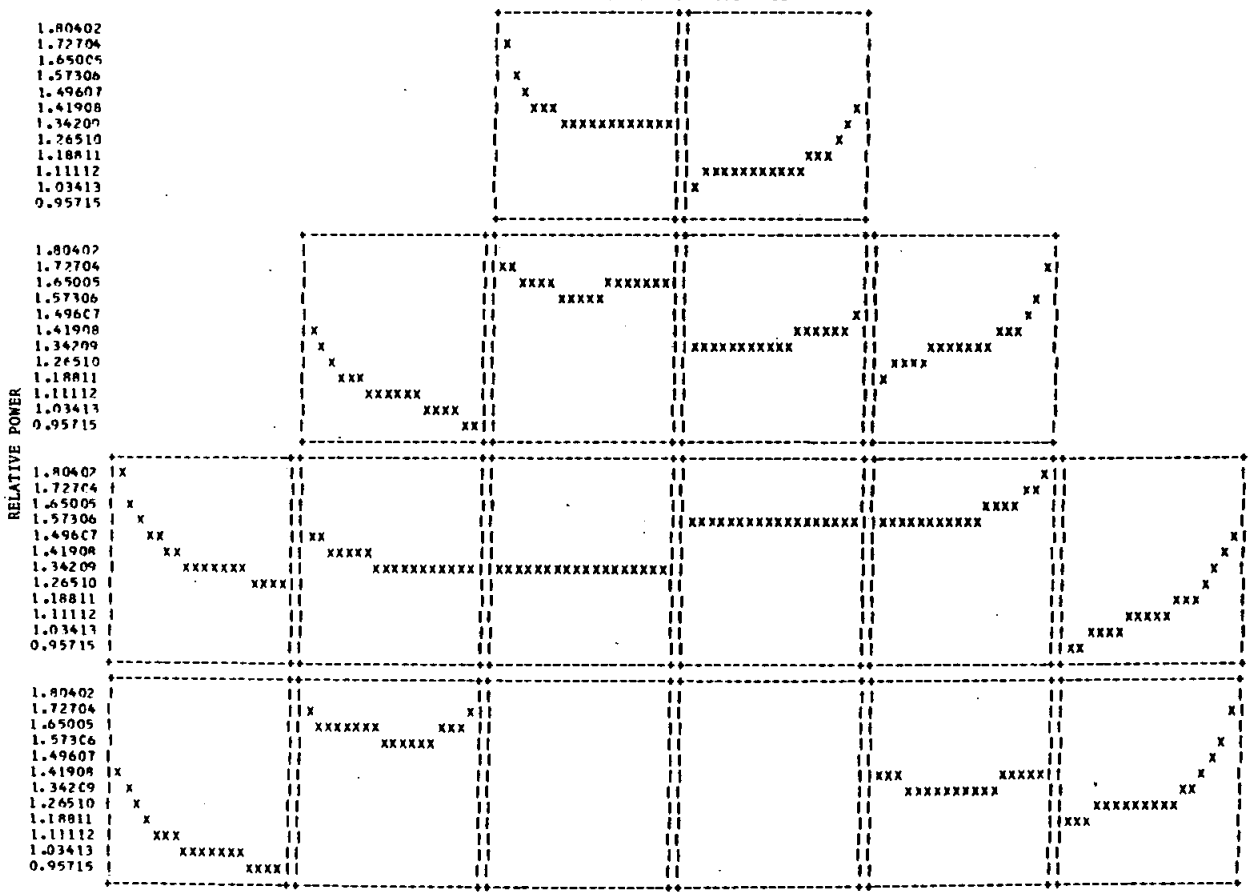


FIGURE 29

FRESH CORE, T=0 @ 60 MW

CASE=BASECASP PLATE POWER DENSITIES, AVERAGED FROM Z= 0.0 CM. TO Z=29.0512 CM.

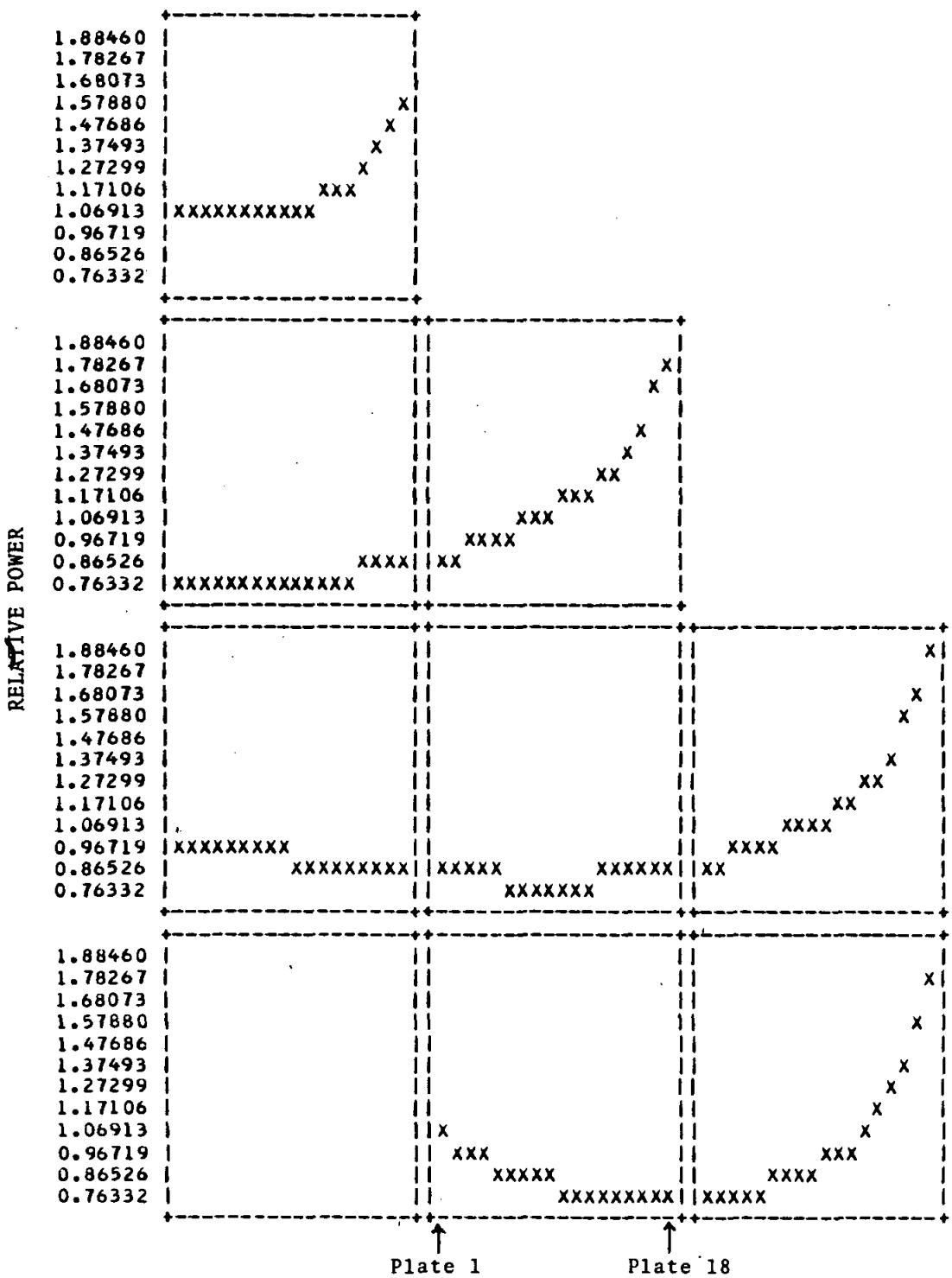


FIGURE 30

EQUILIBRIUM CORE, T=0 @ 60 MW

CASE=ORTH7 PLATE POWER DENSITIES, AVERAGED FROM Z= 0.0 CM. TO Z=29.0512 CM.

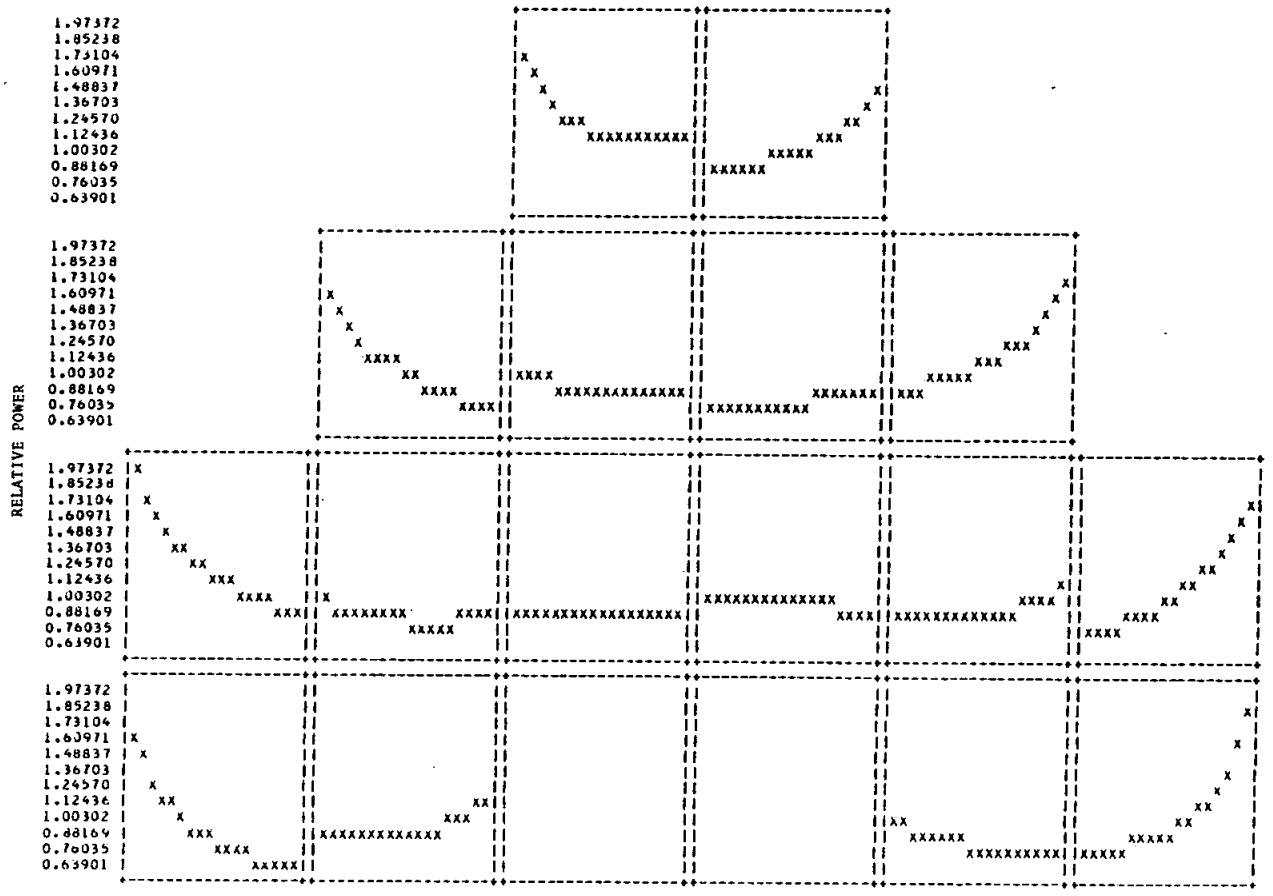


FIGURE 31

EQUILIBRIUM CORE, T=6.67 DAYS @ 60 MW

CASE=ORTH710 PLATE POWER DENSITIES, AVERAGED FROM Z= 0.0 CM. TO Z=29.0512 CM.

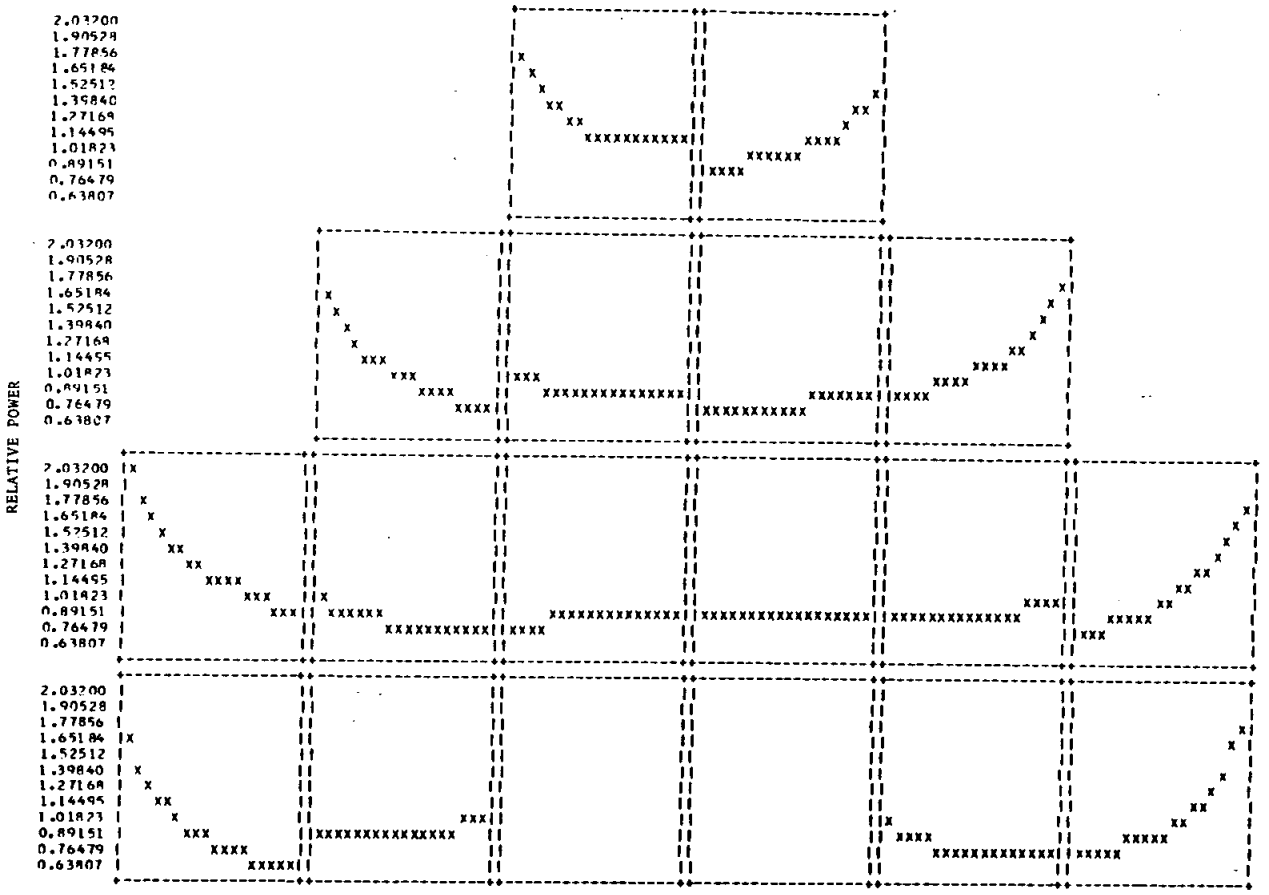


FIGURE 32

EQUILIBRIUM CORE, T=14.33 DAYS @ 60 MW

CASE=OPTH722 PLATE POWER DENSITIES, AVERAGED FROM Z= 0.0 CM. TO Z=29.0512 CM.

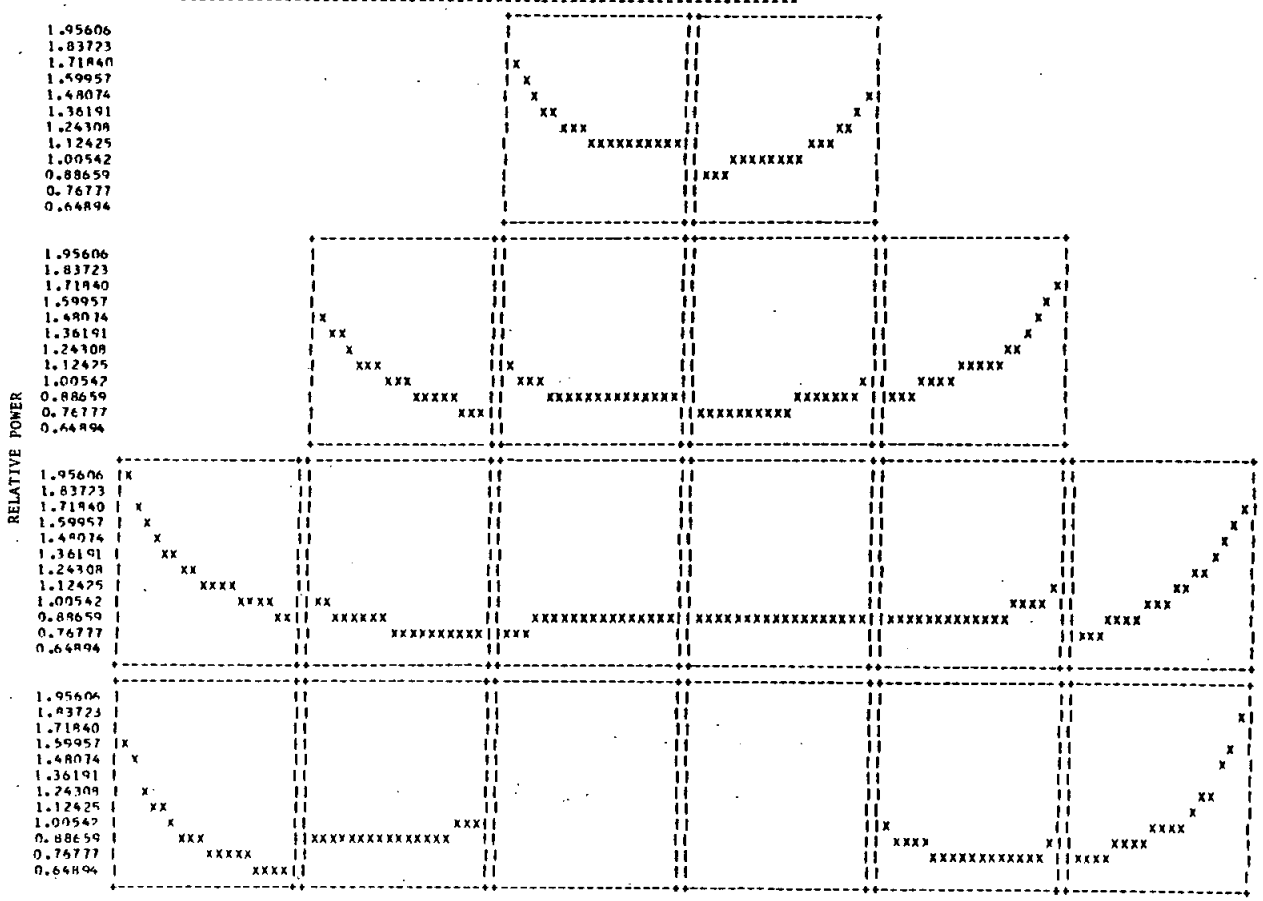


FIGURE 33

APPENDIX A

ORTHOGRIM Flux Mesh for HFBR
351 Gram Assemblies

X FLUX MESH

PNT	D(OUTER)	D(AVERG)	THICKNES				
1	8.4455	4.2227	8.4455	36	92.5446	91.5222	2.0447
2	16.8910	12.6682	8.4455	37	94.5893	93.5669	2.0447
3	25.0698	20.9804	8.1788	38	95.6116	95.1004	1.0223
4	33.2485	29.1591	8.1787	39	96.6340	96.1228	1.0223
5	41.4273	37.3379	8.1788	40	97.6563	97.1451	1.0223
6	49.6061	45.5167	8.1788	41	98.6786	98.1675	1.0223
7	53.6955	51.6508	4.0894	42	100.3728	99.5257	1.6942
8	57.7849	55.7402	4.0894	43	101.2683	100.8206	0.8955
9	59.8296	58.8072	2.0447	44	102.1638	101.7161	0.8955
10	61.8743	60.8519	2.0447	45	102.7678	102.4658	0.6040
11	62.9974	62.4358	1.1231	46	103.7903	103.2791	1.0225
12	63.8991	63.4482	0.9017	47	104.8128	104.3016	1.0225
13	64.8008	64.3499	0.9017	48	105.8353	105.3241	1.0225
14	65.9637	65.3822	1.1629	49	106.8578	106.3465	1.0225
15	66.9860	66.4748	1.0223	50	108.5658	107.7118	1.7080
16	68.0083	67.4972	1.0223	51	110.2738	109.4198	1.7080
17	69.0307	68.5195	1.0223	52	110.9468	110.6103	0.6730
18	70.0530	69.5418	1.0223	53	111.9690	111.4579	1.0222
19	70.7263	70.3896	0.6733	54	112.9913	112.4801	1.0222
20	72.4343	71.5803	1.7081	55	114.0135	113.5024	1.0222
21	74.1424	73.2883	1.7081	56	115.0358	114.5246	1.0222
22	75.1647	74.6536	1.0224	57	116.1988	115.6173	1.1630
23	76.1871	75.6759	1.0224	58	117.1008	116.6497	0.9020
24	77.2095	76.6983	1.0224	59	118.0027	117.5517	0.9020
25	78.2319	77.7207	1.0224	60	119.1257	118.5642	1.1230
26	78.8364	78.5341	0.6045	61	121.1702	120.1480	2.0445
27	79.7317	79.2840	0.8953	62	123.2147	122.1925	2.0445
28	80.6270	80.1794	0.8953	63	127.3037	125.2592	4.0890
29	82.3212	81.4741	1.6941	64	131.3937	129.3486	4.0900
30	83.3435	82.8323	1.0223	65	139.5727	135.4832	8.1790
31	84.3658	83.8547	1.0223	66	147.7507	143.6616	8.1780
32	85.3882	84.8770	1.0223	67	155.9297	151.8402	8.1790
33	86.4105	85.8993	1.0223	68	164.1087	160.0192	8.1790
34	88.4552	87.4328	2.0447	69	172.5542	168.3314	8.4455
35	90.4999	89.4775	2.0447	70	180.9997	176.7770	8.4455

ORTHOGRIM FLUX MESH

Y Flux Mesh

PNT	D(OUTER)	D(AVERG)	THICKNES
1	1.8288	0.9144	1.8288
2	3.6576	2.7432	1.8288
3	4.9720	4.3148	1.3145
4	6.2865	5.6293	1.3145
5	7.3152	6.8008	1.0287
6	8.2296	7.7724	0.9144
7	9.1440	8.6868	0.9144
8	10.0584	9.6012	0.9144
9	10.9728	10.5156	0.9144
10	12.2123	11.5925	1.2355
11	13.1140	12.6631	0.9017
12	14.0157	13.5648	0.9017
13	14.6304	14.3230	0.6147
14	15.5448	15.0876	0.9144
15	16.4592	16.0020	0.9144
16	17.3736	16.9164	0.9144
17	18.2880	17.8308	0.9144
18	19.5757	18.9318	1.2877
19	20.8634	20.2195	1.2877
20	21.9455	21.4044	1.0821
21	22.8599	22.4027	0.9144
22	23.7743	23.3171	0.9144
23	24.6887	24.2315	0.9144
24	25.6031	25.1459	0.9144
25	26.7893	26.1962	1.1862
26	27.6910	27.2401	0.9017
27	28.5927	28.1418	0.9017
28	29.2608	28.9267	0.6681
29	31.0896	30.1752	1.8288
30	32.9184	32.0040	1.8288
31	36.5759	34.7471	3.6576
32	40.2336	38.4047	3.6576
33	47.5488	43.8911	7.3152
34	54.8640	51.2063	7.3152
35	62.1792	58.5215	7.3152
36	69.4943	65.8367	7.3152
37	76.8095	73.1519	7.3152
38	83.6547	80.2321	6.8452
39	90.4999	87.0773	6.8452

Z Flux Mesh

PNT	D(OUTER)	D(AVERG)	THICKNES
1	4.4450	2.2225	4.4450
2	7.6200	6.0325	3.1750
3	10.7950	9.2075	3.1750
4	13.7583	12.2767	2.9633
5	16.7216	15.2400	2.9633
6	19.6850	18.2033	2.9633
7	21.8300	20.7575	2.1450
8	24.0066	22.9183	2.1767
9	26.1833	25.0950	2.1767
10	28.3600	27.2716	2.1767
11	29.0512	28.7056	0.6912
12	31.5660	30.3086	2.5148
13	34.0808	32.8234	2.5148
14	36.9794	35.5301	2.8986
15	38.4286	37.7040	1.4493
16	39.8779	39.1533	1.4493
17	41.4956	40.6868	1.6176
18	43.1132	42.3044	1.6176
19	45.7799	44.4466	2.6667
20	51.8762	48.8281	6.0963
21	56.4181	54.1472	4.5418
22	60.9599	58.6890	4.5418
23	64.4523	62.7061	3.4924

APPENDIX B

Maximum Point Power Densities P(X,Y,Z)

CASE	CASENAME	CASE DESCRIPTION
A	BASECASP	Fresh 351 gm core t = 0.0 @ 60 MW
B	ORTH7	Equilibrium core t=0.0 @ 60 MW
C	ORTH710	Equilibrium core t=6.67 days @ 60 MW
D	ORTH722	Equilibrium core t=14.33 days @ 60 MW

CASE = BASECASP MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F14	3	2	18	9	1	3.59618	1
F11	2	3	18	9	1	3.53130	2
F9	1	4	18	9	1	3.51745	3
F14	3	2	18	9	2	3.48305	4
F11	2	3	18	9	2	3.42158	5
F9	1	4	18	9	2	3.40376	6
F14	3	2	17	9	1	3.39580	7
F9	1	4	17	9	1	3.34090	8
F11	2	3	17	9	1	3.33499	9
F14	3	2	18	9	3	3.31767	10
F14	3	2	17	9	2	3.28892	11
F11	2	3	18	9	3	3.26420	12
F9	1	4	18	9	3	3.23760	13
F9	1	4	17	9	2	3.23285	14
F11	2	3	17	9	2	3.23129	15
F14	3	2	16	9	1	3.19675	16
F9	1	4	16	9	1	3.17143	17
F11	2	3	16	9	1	3.14487	18
F14	3	2	18	8	1	3.13699	19
F14	3	2	17	9	3	3.13268	20
F14	3	2	16	9	2	3.09612	21
F11	2	3	17	9	3	3.08250	22
F14	3	2	18	9	4	3.08022	23
F9	1	4	17	9	3	3.07493	24
F9	1	4	16	9	2	3.06884	25
F11	2	3	18	9	4	3.04744	26
F11	2	3	16	9	2	3.04708	27
F11	2	3	18	8	1	3.04262	28
F14	3	2	18	8	2	3.03852	29
F9	1	4	18	8	1	3.02904	30
F9	1	4	15	9	1	3.02490	31
F14	3	2	15	9	1	3.01841	32
F9	1	4	18	9	4	2.99946	33
F11	2	3	15	9	1	2.97685	34
F14	3	2	16	9	3	2.94903	35
F11	2	3	18	8	2	2.94827	36
F9	1	4	14	9	1	2.93538	37
F9	1	4	18	8	2	2.93123	38
F9	1	4	15	9	2	2.92706	39
F14	3	2	15	9	2	2.92342	40
F9	1	4	16	9	3	2.91893	41
F14	3	2	17	9	4	2.90834	42
F11	2	3	16	9	3	2.90672	43
F14	3	2	14	9	1	2.90444	44
F14	3	2	18	8	3	2.89462	45
F11	2	3	15	9	2	2.88432	46
F11	2	3	17	9	4	2.87737	47
F14	3	2	18	7	1	2.86775	48
F14	3	2	17	8	1	2.86191	49
F9	1	4	13	9	1	2.85204	50

CASE = BASECASP MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F9	1	4	17	9	4	2.84866	51
F11	2	3	14	9	1	2.84329	52
F9	1	4	14	9	2	2.84044	53
F14	3	2	14	9	2	2.81309	54
F11	2	3	18	8	3	2.81291	55
F14	3	2	13	9	1	2.78970	56
F9	1	4	18	8	3	2.78828	57
F14	3	2	15	9	3	2.78461	58
F9	1	4	15	9	3	2.78415	59
F9	1	4	12	9	1	2.78187	60
F11	2	3	18	9	5	2.77970	61
F14	3	2	18	7	2	2.77804	62
F11	2	3	17	8	1	2.77784	63
F9	1	4	17	8	1	2.77668	64
F14	3	2	17	8	2	2.77208	65
F9	1	4	13	9	2	2.75983	66
F14	3	2	18	9	5	2.75976	67
F11	2	3	13	9	1	2.75797	68
F11	2	3	14	9	2	2.75493	69
F11	2	3	15	9	3	2.75145	70
F14	3	2	16	9	4	2.73790	71
F9	1	4	11	9	1	2.72990	72
F11	2	3	18	7	1	2.72762	73
F11	2	3	16	9	4	2.71307	74
F9	1	4	15	9	4	2.70429	75
F14	3	2	13	9	2	2.70205	76
F9	1	4	14	9	3	2.70184	77
F14	3	2	18	6	1	2.69868	78
F9	1	4	18	7	1	2.69600	79
F9	1	4	12	9	2	2.69197	80
F11	2	3	17	8	2	2.69177	81
F14	3	2	18	8	4	2.68806	82
F9	1	4	17	8	2	2.68702	83
F14	3	2	12	9	1	2.68485	84
F9	1	4	10	9	1	2.68142	85
F9	1	4	18	9	5	2.67978	86
F14	3	2	14	9	3	2.67966	87
F11	2	3	13	9	2	2.67224	88
F11	2	3	12	9	1	2.65819	89
F14	3	2	18	7	3	2.64704	90
F11	2	3	18	7	2	2.64325	91
F9	1	4	9	9	1	2.64184	92
F9	1	4	11	9	2	2.64173	93
F14	3	2	17	8	3	2.64081	94
F11	2	3	14	9	3	2.62801	95
F11	2	3	18	8	4	2.62635	96
F14	3	2	16	8	1	2.62557	97
F9	1	4	13	9	3	2.62529	98
F11	2	3	17	9	5	2.62355	99
F14	3	2	18	6	2	2.61464	100

CASE = BASECASP MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F9	1	4	8	9	1	2.61171	101
F9	1	4	18	7	2	2.60917	102
F14	3	2	17	9	5	2.60561	103
F14	3	2	12	9	2	2.60062	104
F14	3	2	11	9	1	2.59800	105
F9	1	4	10	9	2	2.59487	106
F9	1	4	7	9	1	2.58897	107
F14	3	2	15	9	4	2.58546	108
F9	1	4	18	8	4	2.58338	109
F14	3	2	18	5	1	2.58241	110
F9	1	4	15	9	4	2.57973	111
F11	2	3	12	9	2	2.57558	112
F14	3	2	13	9	3	2.57410	113
F11	2	3	11	9	1	2.57146	114
F11	2	3	17	8	3	2.56828	115
F11	2	3	15	9	4	2.56802	116
F9	1	4	16	8	1	2.56713	117
F9	1	4	6	9	1	2.56543	118
F14	3	2	17	7	1	2.56326	119
F9	1	4	12	9	3	2.56088	120
F9	1	4	9	9	2	2.55663	121
F9	1	4	17	8	3	2.55601	122
F11	2	3	16	8	1	2.55415	123
F11	2	3	13	9	3	2.54903	124
F9	1	4	5	9	1	2.54665	125
F9	1	4	17	9	5	2.54519	126
F14	3	2	16	8	2	2.54318	127
F9	1	4	4	9	1	2.53279	128
F9	1	4	8	9	2	2.52753	129
F9	1	4	3	9	1	2.52396	130
F11	2	3	18	7	3	2.52214	131
F9	1	4	1	9	1	2.52169	132
F9	1	4	2	9	1	2.52025	133
F14	3	2	11	9	2	2.51665	134
F9	1	4	11	9	3	2.51326	135
F14	3	2	10	9	1	2.50912	136
F9	1	4	7	9	2	2.50557	137
F14	3	2	18	4	1	2.50512	138
F9	1	4	14	9	4	2.50384	139
F14	3	2	18	5	2	2.50242	140
F11	2	3	18	6	1	2.49849	141
F11	2	3	10	9	1	2.49297	142
F14	3	2	18	6	3	2.49210	143
F11	2	3	11	9	2	2.49156	144
F14	3	2	14	9	4	2.48841	145
F9	1	4	16	8	2	2.48426	146
F14	3	2	17	7	2	2.48311	147
F9	1	4	6	9	2	2.48284	148
F9	1	4	18	7	3	2.48233	149
F14	3	2	12	9	3	2.47775	150

CASE = BASECASP MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F9	1	4	18	6	1	2.47739	151
F11	2	3	16	8	2	2.47510	152
F11	2	3	16	9	5	2.47311	153
F9	1	4	10	9	3	2.46885	154
F9	1	4	5	9	2	2.46471	155
F14	3	2	18	7	4	2.45935	156
F11	2	3	18	9	6	2.45767	157
F11	2	3	12	9	3	2.45681	158
F14	3	2	16	9	5	2.45315	159
F11	2	3	14	9	4	2.45264	160
F14	3	2	17	8	4	2.45240	161
F9	1	4	4	9	2	2.45134	162
F14	3	2	18	3	1	2.44533	163
F9	1	4	3	9	2	2.44283	164
F11	2	3	17	7	1	2.44205	165
F9	1	4	1	9	2	2.44067	166
F9	1	4	2	9	2	2.43926	167
F14	3	2	15	8	1	2.43390	168
F9	1	4	13	9	4	2.43337	169
F9	1	4	9	9	3	2.43266	170
F14	3	2	10	9	2	2.43073	171
F14	3	2	9	9	1	2.42804	172
F14	3	2	18	4	2	2.42798	173
F14	3	2	16	8	3	2.42281	174
F11	2	3	18	6	2	2.42144	175
F9	1	4	17	7	1	2.41690	176
F9	1	4	16	9	5	2.41688	177
F11	2	3	10	9	2	2.41555	178
F11	2	3	9	9	1	2.41390	179
F14	3	2	18	8	5	2.40949	180
F9	1	4	8	9	3	2.40516	181
F9	1	4	15	8	1	2.40381	182
F14	3	2	18	2	1	2.40167	183
F14	3	2	11	9	3	2.39808	184
F11	2	3	17	8	4	2.39805	185
F9	1	4	18	6	2	2.39795	186
F11	2	3	18	8	5	2.39558	187
F14	3	2	13	9	4	2.39091	188
F14	3	2	17	6	1	2.38805	189
F14	3	2	18	5	3	2.38605	190
F9	1	4	7	9	3	2.38445	191
F11	2	3	13	9	4	2.37856	192
F11	2	3	11	9	3	2.37663	193
F11	2	3	15	8	1	2.37526	194
F14	3	2	18	1	1	2.37501	195
F9	1	4	12	9	4	2.37422	196
F14	3	2	18	3	2	2.37050	197
F9	1	4	17	8	4	2.36831	198
F11	2	3	17	7	2	2.36667	199
F14	3	2	17	7	3	2.36608	200

CASE = CRTH7 MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F3	1	2	1	9	1	3.16144	1
F8	1	4	1	9	1	3.15997	2
F11	4	3	18	9	1	3.11085	3
F3	1	2	1	9	2	3.08921	4
F8	1	4	1	9	2	3.08652	5
F11	4	3	18	9	2	3.03937	6
F8	1	4	2	9	1	3.01053	7
F3	1	2	2	9	1	2.99486	8
F3	1	2	1	9	3	2.98574	9
F8	1	4	1	9	3	2.98133	10
F11	4	3	17	9	1	2.94767	11
F8	1	4	2	9	2	2.94049	12
F11	4	3	18	9	3	2.93743	13
F3	1	2	2	9	2	2.92637	14
F3	1	2	1	9	4	2.89956	15
F8	1	4	1	9	4	2.88272	16
F14	6	2	18	9	1	2.88076	17
F11	4	3	17	9	2	2.87990	18
F8	1	4	3	9	1	2.86796	19
F6	1	3	1	9	1	2.86456	20
F11	4	3	18	9	4	2.85600	21
F8	1	4	2	9	3	2.84014	22
F3	1	2	3	9	1	2.83087	23
F9	2	4	18	9	1	2.83061	24
F3	1	2	2	9	3	2.82822	25
F14	6	2	18	9	2	2.81465	26
F8	1	4	3	9	2	2.80119	27
F6	1	3	1	9	2	2.79508	28
F11	4	3	16	9	1	2.79000	29
F3	1	2	1	8	1	2.78404	30
F11	4	3	17	9	3	2.78217	31
F3	1	2	3	9	2	2.76607	32
F9	2	4	18	9	2	2.76445	33
F3	1	2	2	9	4	2.74612	34
F8	1	4	2	9	4	2.74578	35
F8	1	4	4	9	1	2.74452	36
F8	1	4	1	8	1	2.74446	37
F14	6	2	17	9	1	2.73145	38
F11	4	3	16	9	2	2.72582	39
F3	1	2	1	9	5	2.72222	40
F3	1	2	1	8	2	2.72043	41
F14	6	2	18	9	3	2.71970	42
F6	1	3	2	9	1	2.71652	43
F11	4	3	17	9	4	2.70549	44
F8	1	4	3	9	3	2.70547	45
F11	4	3	18	8	1	2.70501	46
F6	1	3	1	9	3	2.70493	47
F8	1	4	1	9	5	2.70274	48
F9	2	4	17	9	1	2.70029	49
F11	4	3	18	9	5	2.68548	50

CASE = ORTH7 MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F3	1	2	4	9	1	2.68346	51
F8	1	4	1	8	2	2.68062	52
F8	1	4	4	9	2	2.68058	53
F3	1	2	3	9	3	2.67316	54
F9	2	4	18	9	3	2.66941	55
F14	6	2	17	9	2	2.66868	56
F14	6	2	18	9	4	2.66846	57
F8	1	4	5	9	1	2.66706	58
F6	1	3	2	9	2	2.65400	59
F6	1	3	1	9	4	2.65115	60
F11	4	3	15	9	1	2.64988	61
F11	4	3	18	8	2	2.64286	62
F9	2	4	17	9	2	2.63711	63
F11	4	3	16	9	3	2.63416	64
F3	1	2	1	8	3	2.62918	65
F3	1	2	4	9	2	2.62198	66
F9	2	4	18	9	4	2.61557	67
F8	1	4	3	9	4	2.61512	68
F8	1	4	5	9	2	2.60488	69
F8	1	4	6	9	1	2.59538	70
F3	1	2	3	9	4	2.59502	71
F8	1	4	1	8	3	2.58911	72
F11	4	3	15	9	2	2.58890	73
F8	1	4	4	9	3	2.58888	74
F14	6	2	16	9	1	2.58715	75
F3	1	2	5	9	1	2.58505	76
F14	6	2	17	9	3	2.57848	77
F9	2	4	16	9	1	2.57833	78
F3	1	2	2	9	5	2.57814	79
F6	1	3	3	9	1	2.57523	80
F8	1	4	2	9	5	2.57424	81
F6	1	3	2	9	3	2.56460	82
F11	4	3	16	9	4	2.56012	83
F3	1	2	2	8	1	2.55781	84
F3	1	2	1	7	1	2.55647	85
F11	4	3	18	8	3	2.55409	86
F3	1	2	1	8	4	2.55207	87
F14	6	2	18	8	1	2.55162	88
F9	2	4	17	9	3	2.54627	89
F11	4	3	17	9	5	2.54387	90
F11	4	3	14	9	1	2.53682	91
F8	1	4	7	9	1	2.53515	92
F8	1	4	6	9	2	2.53483	93
F3	1	2	4	9	3	2.53378	94
F8	1	4	2	8	1	2.53210	95
F14	6	2	17	9	4	2.52929	96
F14	6	2	16	9	2	2.52763	97
F3	1	2	5	9	2	2.52579	98
F9	2	4	16	9	2	2.51795	99
F6	1	3	3	9	2	2.51592	100

CASE = ORTH7 MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F8	1	4	5	9	3	2.51568	101
F6	1	3	2	9	4	2.51301	102
F14	6	2	18	9	5	2.50447	103
F3	1	2	1	9	6	2.50365	104
F6	1	3	1	8	1	2.50324	105
F8	1	4	1	8	4	2.50237	106
F8	1	4	4	9	4	2.50203	107
F11	4	3	15	9	3	2.50175	108
F3	1	2	2	8	2	2.49931	109
F3	1	2	1	7	2	2.49808	110
F9	2	4	17	9	4	2.49425	111
F14	6	2	18	8	2	2.49301	112
F6	1	3	1	9	5	2.49287	113
F8	1	4	8	9	1	2.49123	114
F11	4	3	17	8	1	2.48718	115
F3	1	2	6	9	1	2.48662	116
F11	4	3	18	9	6	2.48364	117
F11	4	3	18	8	4	2.48198	118
F8	1	4	1	9	6	2.48094	119
F11	4	3	14	9	2	2.47841	120
F9	2	4	18	8	1	2.47660	121
F8	1	4	7	9	2	2.47597	122
F9	2	4	15	9	1	2.47318	123
F8	1	4	2	8	2	2.47316	124
F11	4	3	13	9	1	2.46174	125
F3	1	2	4	9	4	2.45924	126
F14	6	2	15	9	1	2.45800	127
F8	1	4	1	7	1	2.45501	128
F8	1	4	3	9	5	2.45171	129
F9	2	4	18	9	5	2.45129	130
F6	1	3	4	9	1	2.45001	131
F8	1	4	9	9	1	2.44806	132
F8	1	4	6	9	3	2.44794	133
F6	1	3	1	8	2	2.44564	134
F14	6	2	16	9	3	2.44201	135
F3	1	2	5	9	3	2.44076	136
F11	4	3	18	7	1	2.43632	137
F3	1	2	3	9	5	2.43631	138
F8	1	4	8	9	2	2.43305	139
F8	1	4	5	9	4	2.43114	140
F6	1	3	3	9	3	2.43105	141
F9	2	4	16	9	3	2.43103	142
F11	4	3	15	9	4	2.43100	143
F11	4	3	17	8	2	2.43002	144
F3	1	2	6	9	2	2.42959	145
F9	2	4	18	8	2	2.41864	146
F3	1	2	2	8	3	2.41533	147
F9	2	4	15	9	2	2.41521	148
F3	1	2	1	7	3	2.41423	149
F8	1	4	10	9	1	2.41138	150

CASE = ORTH7 MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F3	1	2	1	6	1	2.40956	151
F14	6	2	18	8	3	2.40865	152
F11	4	3	16	9	5	2.40716	153
F11	4	3	13	9	2	2.40503	154
F9	2	4	14	9	1	2.40462	155
F14	6	2	15	9	2	2.40139	156
F8	1	4	1	7	2	2.39788	157
F3	1	2	7	9	1	2.39617	158
F3	1	2	1	8	5	2.39617	159
F11	4	3	14	9	3	2.39490	160
F14	6	2	16	9	4	2.39466	161
F6	1	3	4	9	2	2.39356	162
F8	1	4	7	9	3	2.39103	163
F8	1	4	9	9	2	2.39085	164
F8	1	4	2	8	3	2.38860	165
F8	1	4	11	9	1	2.38170	166
F6	1	3	3	9	4	2.38148	167
F9	2	4	16	9	4	2.38063	168
F11	4	3	18	7	2	2.38036	169
F11	4	3	12	9	1	2.37563	170
F14	6	2	17	9	5	2.37378	171
F3	1	2	2	9	6	2.37147	172
F14	6	2	14	9	1	2.36909	173
F3	1	2	5	9	4	2.36886	174
F8	1	4	6	9	4	2.36554	175
F6	1	3	1	8	3	2.36319	176
F8	1	4	2	9	6	2.36317	177
F6	1	3	2	9	5	2.36287	178
F3	1	2	3	8	1	2.36228	179
F14	6	2	18	8	4	2.36146	180
F8	1	4	12	9	1	2.35850	181
F8	1	4	10	9	2	2.35499	182
F8	1	4	3	8	1	2.35486	183
F3	1	2	1	6	2	2.35456	184
F14	6	2	17	8	1	2.35410	185
F11	4	3	17	9	6	2.35275	186
F14	6	2	18	7	1	2.35103	187
F8	1	4	8	9	3	2.34952	188
F11	4	3	17	8	3	2.34829	189
F9	2	4	14	9	2	2.34821	190
F6	1	3	5	9	1	2.34794	191
F3	1	2	6	9	3	2.34773	192
F8	1	4	1	8	5	2.34631	193
F8	1	4	4	9	5	2.34570	194
F3	1	2	2	8	4	2.34364	195
F3	1	2	1	7	4	2.34292	196
F9	2	4	13	9	1	2.34150	197
F3	1	2	7	9	2	2.34120	198
F8	1	4	13	9	1	2.33887	199
F9	2	4	17	9	5	2.33743	200

CASE = CRTH710 MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F8	1	4	1	9	1	2.83619	1
F3	1	2	1	9	1	2.82317	2
F8	1	4	1	9	2	2.79423	3
F3	1	2	1	9	2	2.78141	4
F11	4	3	18	9	1	2.76774	5
F8	1	4	1	9	3	2.73510	6
F8	1	4	1	9	4	2.73463	7
F3	1	2	1	9	4	2.73158	8
F11	4	3	18	9	2	2.72665	9
F3	1	2	1	9	3	2.72251	10
F8	1	4	2	9	1	2.70334	11
F11	4	3	18	9	4	2.67873	12
F3	1	2	2	9	1	2.67356	13
F11	4	3	18	9	3	2.66885	14
F8	1	4	2	9	2	2.66329	15
F8	1	4	1	9	5	2.64404	16
F3	1	2	1	9	5	2.64109	17
F3	1	2	2	9	2	2.63392	18
F11	4	3	17	9	1	2.62201	19
F8	1	4	2	9	3	2.60677	20
F8	1	4	2	9	4	2.60565	21
F11	4	3	18	9	5	2.59075	22
F3	1	2	2	9	4	2.58586	23
F11	4	3	17	9	2	2.58302	24
F3	1	2	2	9	3	2.57797	25
F8	1	4	3	9	1	2.57683	26
F6	1	3	1	9	1	2.54730	27
F8	1	4	1	9	6	2.54697	28
F14	6	2	18	9	1	2.54602	29
F3	1	2	1	9	6	2.54414	30
F8	1	4	3	9	2	2.53859	31
F11	4	3	17	9	4	2.53672	32
F11	4	3	17	9	3	2.52813	33
F3	1	2	3	9	1	2.52674	34
F8	1	4	2	9	5	2.51928	35
F9	2	4	18	9	1	2.51531	36
F6	1	3	1	9	2	2.50935	37
F14	6	2	18	9	2	2.50821	38
F3	1	2	1	9	7	2.50048	39
F3	1	2	2	9	5	2.50025	40
F11	4	3	18	9	6	2.49763	41
F8	1	4	1	9	7	2.49687	42
F14	6	2	18	9	4	2.49199	43
F3	1	2	1	8	1	2.49054	44
F3	1	2	3	9	2	2.48918	45
F6	1	3	1	9	4	2.48675	46
F8	1	4	3	9	3	2.48455	47
F8	1	4	3	9	4	2.48274	48
F11	4	3	16	9	1	2.48134	49
F9	2	4	18	9	2	2.47787	50

CASE = CRTH710 MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F8	1	4	4	9	1	2.46709	51
F8	1	4	1	8	1	2.46548	52
F9	2	4	18	9	4	2.46096	53
F11	4	3	18	9	7	2.45901	54
F6	1	3	1	9	3	2.45587	55
F14	6	2	18	9	3	2.45466	56
F3	1	2	1	8	2	2.45358	57
F11	4	3	17	9	5	2.45344	58
F11	4	3	16	9	2	2.44436	59
F3	1	2	3	9	4	2.44271	60
F3	1	2	3	9	3	2.43609	61
F8	1	4	4	9	2	2.43042	62
F8	1	4	1	8	2	2.42881	63
F8	1	4	2	9	6	2.42715	64
F9	2	4	18	9	3	2.42484	65
F6	1	3	2	9	1	2.41519	66
F14	6	2	17	9	1	2.41375	67
F14	6	2	18	9	5	2.40917	68
F3	1	2	2	9	6	2.40913	69
F11	4	3	18	8	1	2.40751	70
F3	1	2	1	8	4	2.40708	71
F6	1	3	1	9	5	2.40499	72
F3	1	2	1	8	3	2.40125	73
F9	2	4	17	9	1	2.40089	74
F8	1	4	3	9	5	2.40037	75
F11	4	3	16	9	4	2.39959	76
F8	1	4	5	9	1	2.39705	77
F3	1	2	4	9	1	2.39439	78
F11	4	3	16	9	3	2.39223	79
F8	1	4	2	9	7	2.38036	80
F6	1	3	2	9	2	2.37914	81
F9	2	4	18	9	5	2.37902	82
F3	1	2	1	9	8	2.37858	83
F8	1	4	4	9	3	2.37852	84
F14	6	2	17	9	2	2.37780	85
F3	1	2	1	9	10	2.37741	86
F8	1	4	1	8	3	2.37698	87
F8	1	4	4	9	4	2.37613	88
F8	1	4	1	8	4	2.37445	89
F8	1	4	1	9	10	2.37318	90
F8	1	4	1	9	8	2.37205	91
F11	4	3	18	8	2	2.37162	92
F3	1	2	2	9	7	2.36939	93
F11	4	3	18	9	10	2.36701	94
F11	4	3	17	9	6	2.36586	95
F9	2	4	17	9	2	2.36507	96
F3	1	2	3	9	5	2.36187	97
F14	6	2	17	9	4	2.36139	98
F8	1	4	5	9	2	2.36138	99
F3	1	2	4	9	2	2.35870	100

CASE = ORTH710 MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F6	1	3	2	9	4	2.35675	101
F11	4	3	15	9	1	2.35598	102
F3	1	2	1	9	9	2.35054	103
F9	2	4	17	9	4	2.34790	104
F8	1	4	1	9	9	2.34490	105
F11	4	3	18	9	8	2.34432	106
F8	1	4	6	9	1	2.33233	107
F11	4	3	17	9	7	2.33071	108
F6	1	3	2	9	3	2.32826	109
F11	4	3	18	8	4	2.32734	110
F3	1	2	1	8	5	2.32716	111
F14	6	2	17	9	3	2.32683	112
F11	4	3	18	9	9	2.32619	113
F14	6	2	18	9	6	2.32105	114
F11	4	3	18	8	3	2.32097	115
F11	4	3	16	9	5	2.32082	116
F11	4	3	15	9	2	2.32080	117
F6	1	3	1	9	6	2.31908	118
F9	2	4	17	9	3	2.31427	119
F3	1	2	4	9	4	2.31367	120
F8	1	4	3	9	6	2.31291	121
F8	1	4	5	9	3	2.31083	122
F8	1	4	5	9	4	2.30827	123
F3	1	2	4	9	3	2.30816	124
F3	1	2	5	9	1	2.30400	125
F8	1	4	6	9	2	2.29759	126
F8	1	4	4	9	5	2.29721	127
F8	1	4	1	8	5	2.29580	128
F9	2	4	15	9	1	2.29388	129
F9	2	4	18	9	6	2.29193	130
F3	1	2	2	8	1	2.29108	131
F14	6	2	18	9	7	2.28978	132
F6	1	3	3	9	1	2.28941	133
F6	1	3	1	9	7	2.28896	134
F3	1	2	1	7	1	2.28730	135
F14	6	2	16	9	1	2.28613	136
F14	6	2	17	9	5	2.28292	137
F8	1	4	2	9	10	2.28035	138
F8	1	4	2	8	1	2.27965	139
F6	1	3	2	9	5	2.27928	140
F8	1	4	7	9	1	2.27780	141
F11	4	3	15	9	4	2.27744	142
F3	1	2	3	9	6	2.27648	143
F3	1	2	2	9	10	2.27517	144
F11	4	3	15	9	3	2.27112	145
F9	2	4	17	9	5	2.26964	146
F3	1	2	5	9	2	2.26958	147
F8	1	4	3	9	7	2.26928	148
F11	4	3	17	9	10	2.26538	149
F8	1	4	2	9	8	2.26369	150

CASE = ORTH710 MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F9	2	4	18	9	7	2.26157	151
F14	6	2	18	8	1	2.25964	152
F9	2	4	16	9	2	2.25959	153
F3	1	2	2	9	8	2.25711	154
F3	1	2	2	8	2	2.25699	155
F6	1	3	3	9	2	2.25516	156
F11	4	3	14	9	1	2.25412	157
F3	1	2	1	7	2	2.25326	158
F14	6	2	16	9	2	2.25199	159
F11	4	3	18	8	5	2.25086	160
F8	1	4	6	9	3	2.24828	161
F8	1	4	2	8	2	2.24568	162
F8	1	4	6	9	4	2.24555	163
F8	1	4	7	9	2	2.24382	164
F3	1	2	1	8	6	2.24238	165
F8	1	4	2	9	9	2.24236	166
F9	2	4	16	9	4	2.24204	167
F3	1	2	3	9	7	2.24068	168
F11	4	3	16	9	6	2.23856	169
F3	1	2	4	9	5	2.23714	170
F3	1	2	2	9	9	2.23661	171
F8	1	4	8	9	1	2.23621	172
F14	6	2	16	9	4	2.23520	173
F6	1	3	3	9	4	2.23286	174
F8	1	4	5	9	5	2.23158	175
F6	1	3	1	8	1	2.22723	176
F14	6	2	18	8	2	2.22595	177
F3	1	2	5	9	4	2.22587	178
F11	4	3	17	9	8	2.22507	179
F3	1	2	5	9	3	2.22080	180
F11	4	3	14	9	2	2.22038	181
F11	4	3	17	8	1	2.21620	182
F8	1	4	4	9	6	2.21382	183
F3	1	2	6	9	1	2.21379	184
F11	4	3	17	9	9	2.21371	185
F8	1	4	1	8	6	2.21283	186
F3	1	2	2	8	4	2.21267	187
F9	2	4	16	9	3	2.21084	188
F3	1	2	1	7	4	2.20912	189
F3	1	2	2	8	3	2.20859	190
F14	6	2	18	8	4	2.20852	191
F11	4	3	15	9	7	2.20682	192
F6	1	3	3	9	3	2.20673	193
F3	1	2	1	8	7	2.20565	194
F3	1	2	1	7	3	2.20491	195
F14	6	2	16	9	3	2.20346	196
F8	1	4	1	7	1	2.20338	197
F8	1	4	8	9	2	2.20282	198
F11	4	3	15	9	5	2.20269	199
F9	2	4	18	8	1	2.20227	200

CASE = ORTH722 MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F8	1	4	1	9	1	2.58143	1
F3	1	2	1	9	1	2.57892	2
F3	1	2	1	9	4	2.55292	3
F8	1	4	1	9	2	2.54837	4
F8	1	4	1	9	4	2.54639	5
F3	1	2	1	9	2	2.54575	6
F11	4	3	18	9	1	2.53329	7
F11	4	3	18	9	4	2.50681	8
F8	1	4	1	9	3	2.50176	9
F11	4	3	18	9	2	2.50067	10
F3	1	2	1	9	3	2.49893	11
F3	1	2	1	9	5	2.48316	12
F8	1	4	1	9	5	2.47732	13
F8	1	4	2	9	1	2.46495	14
F11	4	3	18	9	3	2.45485	15
F3	1	2	2	9	1	2.44607	16
F11	4	3	18	9	5	2.43947	17
F8	1	4	2	9	2	2.43332	18
F8	1	4	2	9	4	2.43036	19
F3	1	2	2	9	4	2.42019	20
F3	1	2	2	9	2	2.41451	21
F3	1	2	1	9	7	2.41261	22
F3	1	2	1	9	6	2.41257	23
F8	1	4	1	9	6	2.40769	24
F11	4	3	17	9	1	2.40352	25
F8	1	4	1	9	7	2.40223	26
F8	1	4	2	9	3	2.38862	27
F3	1	2	1	9	10	2.37998	28
F11	4	3	17	9	4	2.37721	29
F11	4	3	18	9	7	2.37574	30
F8	1	4	1	9	10	2.37392	31
F11	4	3	18	9	10	2.37277	32
F11	4	3	18	9	6	2.37269	33
F11	4	3	17	9	2	2.37248	34
F3	1	2	2	9	3	2.36988	35
F8	1	4	2	9	5	2.36438	36
F8	1	4	3	9	1	2.35471	37
F3	1	2	2	9	5	2.35410	38
F11	4	3	17	9	3	2.32881	39
F8	1	4	3	9	2	2.32442	40
F8	1	4	3	9	4	2.32046	41
F3	1	2	3	9	1	2.31663	42
F6	1	3	1	9	1	2.31514	43
F3	1	2	1	9	9	2.31503	44
F14	6	2	18	9	4	2.31455	45
F11	4	3	17	9	5	2.31338	46
F8	1	3	1	9	4	2.31297	47
F3	1	2	1	9	8	2.31040	48
F14	6	2	18	9	1	2.30764	49
F8	1	4	1	9	9	2.30548	50

CASE = CRTH722 MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F8	1	4	1	9	8	2.29846	51
F8	1	4	2	9	6	2.29831	52
F8	1	4	2	9	7	2.29409	53
F11	4	3	18	9	9	2.29335	54
F3	1	2	3	9	4	2.29074	55
F3	1	2	1	8	1	2.29041	56
F3	1	2	2	9	7	2.28963	57
F3	1	2	2	9	6	2.28791	58
F3	1	2	3	9	2	2.28663	59
F8	1	4	2	9	10	2.28570	60
F6	1	3	1	9	2	2.28519	61
F3	1	2	2	9	10	2.28211	62
F8	1	4	3	9	3	2.28151	63
F11	4	3	16	9	1	2.27874	64
F11	4	3	18	9	8	2.27842	65
F14	6	2	18	9	2	2.27783	66
F9	2	4	18	9	4	2.27568	67
F11	4	3	17	9	10	2.27510	68
F9	2	4	18	9	1	2.26950	69
F3	1	2	1	8	4	2.26401	70
F3	1	2	1	8	2	2.26080	71
F8	1	4	1	8	1	2.25944	72
F8	1	4	4	9	1	2.25888	73
F8	1	4	3	9	5	2.25735	74
F11	4	3	17	9	7	2.25512	75
F11	4	3	16	9	4	2.25256	76
F14	6	2	18	9	5	2.25111	77
F6	1	3	1	9	5	2.25081	78
F11	4	3	17	9	6	2.25071	79
F11	4	3	16	9	2	2.24923	80
F3	1	2	3	9	3	2.24412	81
F6	1	3	1	9	3	2.24304	82
F9	2	4	18	9	2	2.24022	83
F14	6	2	18	9	3	2.23556	84
F8	1	4	1	8	2	2.23028	85
F8	1	4	4	9	2	2.22576	86
F3	1	2	3	9	5	2.22820	87
F8	1	4	1	8	4	2.22529	88
F8	1	4	4	9	4	2.22493	89
F3	1	2	1	8	3	2.21874	90
F11	4	3	18	8	1	2.21713	91
F9	2	4	18	9	5	2.21365	92
F8	1	4	2	9	9	2.20897	93
F11	4	3	16	9	3	2.20760	94
F3	1	2	2	9	9	2.20688	95
F8	1	4	3	9	10	2.20338	96
F3	1	2	1	8	5	2.20188	97
F3	1	2	4	9	1	2.19955	98
F9	2	4	18	9	3	2.19873	99
F6	1	3	2	9	1	2.19856	100

CASE = CRTH722 MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F6	1	3	1	9	7	2.19829	101
F8	1	4	2	9	8	2.19745	102
F14	6	2	17	9	4	2.19674	103
F14	6	2	18	9	7	2.19673	104
F3	1	2	2	9	8	2.19605	105
F6	1	4	5	9	1	2.19577	106
F6	1	3	2	9	4	2.19529	107
F8	1	4	3	9	6	2.19464	108
F11	4	3	16	9	5	2.19206	109
F8	1	4	3	9	7	2.19161	110
F14	6	2	17	9	1	2.19152	111
F11	4	3	18	8	4	2.19058	112
F6	1	3	1	9	6	2.18975	113
F6	1	4	1	8	3	2.18895	114
F3	1	2	3	9	10	2.18894	115
F11	4	3	18	8	2	2.18835	116
F6	1	4	4	9	3	2.18838	117
F14	6	2	18	9	6	2.18751	118
F11	4	3	17	9	9	2.18631	119
F11	4	3	16	9	10	2.18297	120
F9	2	4	17	9	4	2.17496	121
F3	1	2	4	9	4	2.17372	122
F3	1	2	4	9	2	2.17100	123
F9	2	4	17	9	1	2.17034	124
F6	1	3	2	9	2	2.17005	125
F3	1	2	3	9	7	2.16976	126
F8	1	4	5	9	2	2.16740	127
F11	4	3	15	9	1	2.16716	128
F3	1	2	3	9	6	2.16631	129
F11	4	3	17	9	8	2.16595	130
F8	1	4	1	8	5	2.16487	131
F8	1	4	4	9	5	2.16433	132
F14	6	2	17	9	2	2.16311	133
F6	1	4	5	9	4	2.16224	134
F9	2	4	18	9	7	2.16211	135
F6	1	3	1	9	10	2.15825	136
F3	1	2	1	8	10	2.15397	137
F9	2	4	18	9	6	2.15173	138
F11	4	3	18	8	3	2.14779	139
F9	2	4	17	9	2	2.14226	140
F3	1	2	1	8	7	2.14176	141
F11	4	3	15	9	4	2.14114	142
F3	1	2	1	8	6	2.14000	143
F11	4	3	16	9	7	2.13912	144
F11	4	3	15	9	2	2.13900	145
F8	1	4	6	9	1	2.13772	146
F14	6	2	17	9	5	2.13653	147
F6	1	3	2	9	5	2.13630	148
F8	1	4	4	9	10	2.13353	149
F11	4	3	16	9	6	2.13333	150

CASE = ORTF722 MAXIMUM POINT POWER DENSITIES

FUEL	POSITION	ROW	PLATE	Y-LEVEL	Z-LEVEL	POWER	INDEX
F8	1	4	1	8	10	2.13299	151
F11	4	3	18	8	5	2.13164	152
F14	6	2	18	9	10	2.13105	153
F3	1	2	4	9	3	2.13037	154
F6	1	3	2	9	3	2.12980	155
F11	4	3	18	8	10	2.12892	156
F8	1	4	5	9	3	2.12703	157
F14	6	2	17	9	3	2.12271	158
F8	1	4	3	9	9	2.11796	159
F3	1	2	2	8	1	2.11706	160
F3	1	2	5	9	1	2.11674	161
F9	2	4	17	9	5	2.11558	162
F3	1	2	4	9	5	2.11440	163
F3	1	2	1	7	1	2.11010	164
F8	1	4	6	9	2	2.11004	165
F9	2	4	18	9	10	2.10754	166
F3	1	2	4	9	10	2.10737	167
F8	1	4	1	8	6	2.10542	168
F8	1	4	6	9	4	2.10458	169
F8	1	4	4	9	6	2.10455	170
F8	1	4	1	8	7	2.10394	171
F8	1	4	5	9	5	2.10332	172
F11	4	3	15	9	10	2.10308	173
F8	1	4	4	9	7	2.10268	174
F9	2	4	17	9	3	2.10237	175
F3	1	2	3	9	9	2.10236	176
F8	1	4	3	9	8	2.10187	177
F8	1	4	2	8	1	2.09576	178
F11	4	3	15	9	3	2.09919	179
F3	1	2	5	9	4	2.09127	180
F3	1	2	2	8	4	2.09065	181
F8	1	4	5	9	10	2.09051	182
F3	1	2	2	8	2	2.08958	183
F3	1	2	5	9	2	2.08914	184
F8	1	4	7	9	1	2.08863	185
F6	1	3	2	9	7	2.08863	186
F6	1	3	3	9	1	2.08789	187
F6	1	3	1	9	9	2.08767	188
F14	6	2	17	9	7	2.08722	189
F3	1	2	3	9	8	2.08494	190
F11	4	3	16	9	9	2.08404	191
F3	1	2	1	7	4	2.08382	192
F11	4	3	15	9	5	2.08364	193
F6	1	3	3	9	4	2.08349	194
F14	6	2	16	9	4	2.08348	195
F3	1	2	1	7	2	2.08269	196
F9	2	4	16	9	4	2.08109	197
F11	4	3	18	8	7	2.08004	198
F14	6	2	16	9	1	2.08003	199
F8	1	4	1	9	11	2.07911	200