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College of Engineering
Breazeale Nuclear Reactor

Area Code 814
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February 27, 1981

Mr. James R. Miller
Standardization and Special
Projects Branch
Division of Licensing
Nuclear Regulatory Commission
Washington, D.C. 20555

Docket No.: 50-5
NRC License: R-2

Subject: Initial problem when electric lights were substituted for a "tag-out" system on control panel

Dear Mr. Miller:

On February 17, 1981, 11:30 a.m., it was discovered that the electrical connections to four new panel lights, when activated, prevented the console switch from disconnecting power from the control rods. These new panel lights were connected the afternoon of February 16, 1981 and were installed to replace a "tag-out" system on the console control panel. The safety circuits and scrams were not affected by the panel light connections and all other aspects of the control system were operating normally.

Safety is of prime importance to the reactor operating staff of the Breazeale Nuclear Reactor, and our overall operational procedures are continually being reviewed and modifications made to improve the operational safety of the facility. On February 16, 1981 we had completed an additional safety modification to our facility which should not have involved any of our control or safety instrumentation. Four push button panel lights were installed at the console to inform the operator when 1) the core screen for the reactor was removed, 2) when source is removed from the core, 3) when the beam port plug is removed and 4) when a person is on the roof of the reactor facility. It was initially decided to have the panel lights turned on or off by the console power switch. The electronics technician studied the schematic diagram for the console and determined that a transformer supplying power to the reactor enunciator lights would not affect the operation of the control system, if the new panel lights were also connected to this transformer. After installing the system, it was checked and appeared to work satisfactorily.

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S
1/1

The reactor was shut down before the panel light installation was completed on February 16, 1981 and not operated until the next morning. On February 17, 1981, after the morning operation was completed, the reactor operator turned the key switch to the off position and alertly noted that the pulse rod air power supply did not shut off. After notifying reactor management, the panel light wiring connections were studied. It was then determined

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that the lights were actually connected across the key switch thus by-passing the switch through the light bulbs. However, when the power switch to the console was turned off, all control rods would be scrammed and the system could not operate until the console key switch was used again to reset the scram systems. At no time was the system left unattended with the key switch in the off position and the console power on. It is standard procedure to turn the power to the console off when the console switch is turned off.

The panel lights are now connected to a separate power supply and the system checked to operate satisfactorily.

Sincerely,

S. H. Levine, Director
Breazeale Nuclear Reactor
Professor of Nuclear Engineering

SHL:r

cc: R. G. Cunningham
I. B. McMaster
N. J. Palladino
F. J. Remick
W. F. Witzig

Card groups 7 and 8 are self-explanatory. The average boron microscopic cross sections for the fast, epithermal, and thermal groups are specified in card group 9. These cross-sections were obtained for a typical TRIGA flux spectrum.

Card group 10 gives the moderator (water) density in gm/cc. Card group 11 consist of ten cards because ten burnup steps are analyzed. Since the TRIGA reactor does not use soluble boron posion, the entries are all zero.

In the more general case where burnable boron is in the core, the equivalent soluble boron (poison) is placed in the moderator (water). The volume fractions of water in the various regions are specified in card group 12 to handle the more general case. In the example for the TRIGA core it is zero everywhere.

Card groups 13 and 14 are optional and need to be included only if these options are use'. In this case the poison search option is not used, and the card group 14 [illegible] ot included. Immediately after card group 13, the ADD decks from MUGDET, a[illegible] ositioned followed by a card with /*.

8.2 Analyzing a PWR (TMI-1)

The Three Mile Island Unit 1 (TMI-1) reactor has been selected for analysis. It is probably one of the more difficult PWR cores to analyze because the reactor operates with control rods fully and partially inserted into the core, and the initial core incorporates burnable boron. The TMI-1, is a 2535 MWt PWR operating on the east shore of the Susquehanna River in Dauphin County, Pennsylvani (near Harrisburg, Pa.).

The TMI-1 fuel assemblies consist of a 15 x 15 array of pins occupying an area 8.52 in. x 8.52 in. Of the 225 pins, 208 are fuel rods, the central pin is for a neutron sensitive instrument, and the other 16 pins are for control or left unused to be filled with the reactor coolant water. The fuel assemblies themselves are spaced on a pitch of 8.587 in. having a thin slab of water surrounding each fuel assembly. Eight grid plates per fuel assembly are used to hold the pins in position and they are spaced vertically every 16 inches. A top view of a fuel assembly is shown schematically in Fig. 8-4. The dimensions and material compositions of each of the different cell types are given in Fig. 8-5. The core thermal hydraulic design data are given in Table 8-4.

At startup, the cycle 1 core consists of 177 assemblies of which 56 are 2.06 w/o, 60 are 3.05 w/o, and 61 are 2.74 w/o enriched. Several of the 2.747 and 3.05 w/o assemblies are provided with burnable posion pins in the form of B_4C in Al_2O_3 to control the cycle 1 excess reactivity and flatten the power distribution. Figure 8-6 gives a 1/8 core map showing the cycle 1 loading pattern. Fully inserted control rods are in assemblies in positions 1 and 20, and partial height control rods are inserted in position 18. The type of fuel assembly in each location is as indicated in Fig. 8-6.

8.2.1 Sample Problem for a LEOPARD Calculation

Generate group constants with the LEOPARD code for the TMI-1 fuel assemblies

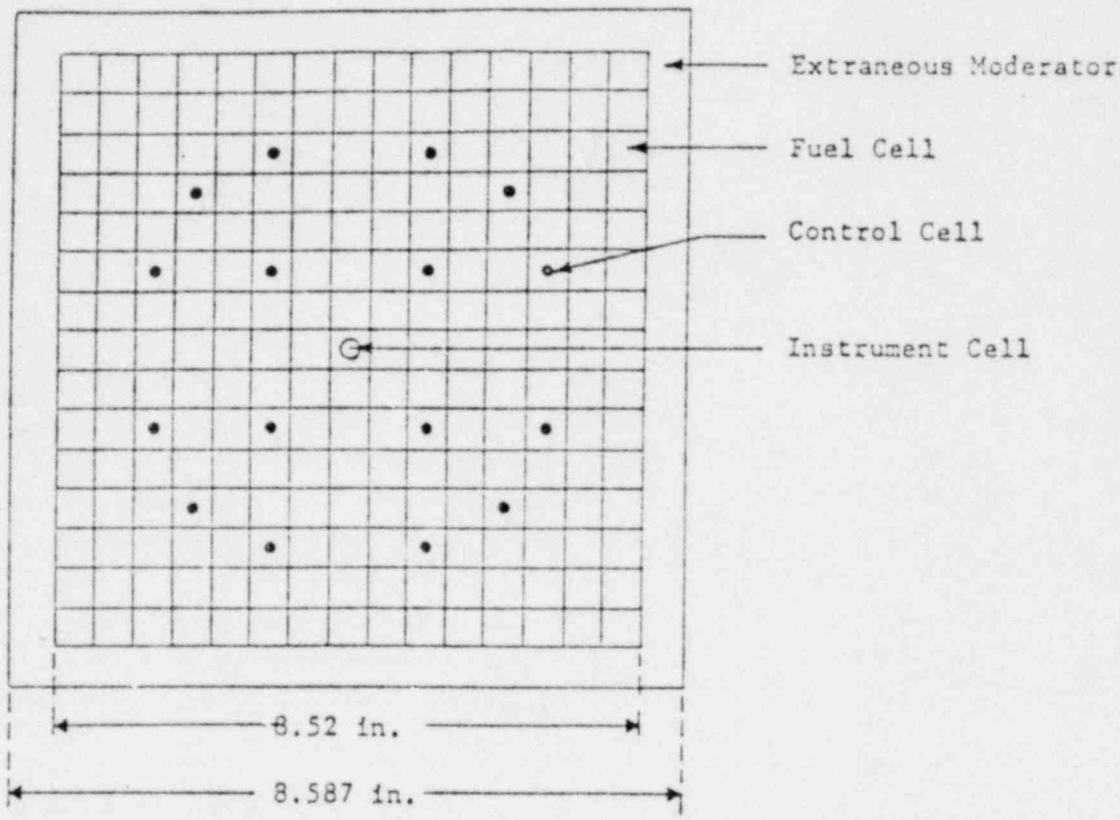


Figure 8-4 Assembly Map Showing Locations of Cell Types, Water Gap, and Dimensions

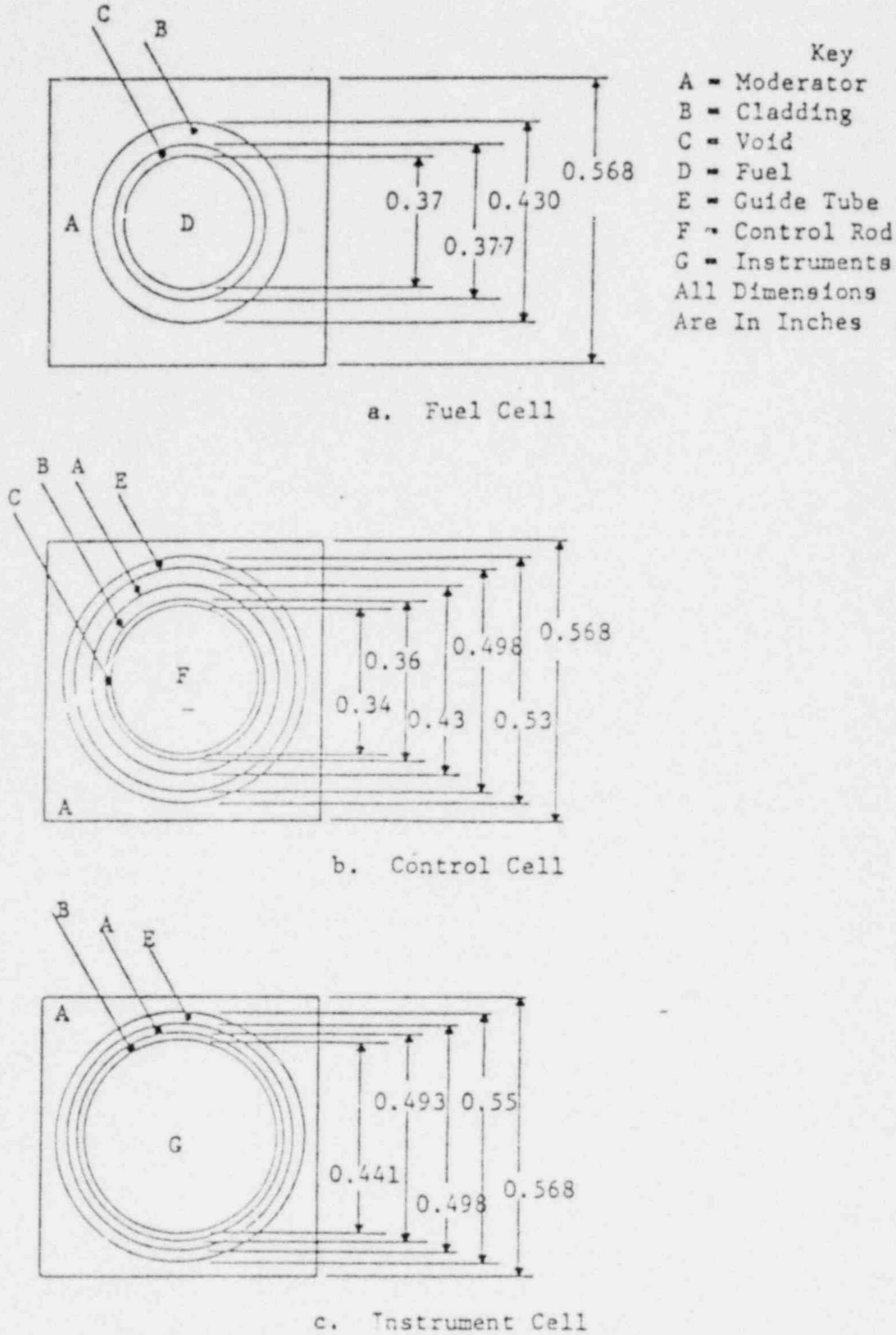


Figure 8-5 Cell Types

Table 8-4. Core Design, Thermal, and Hydraulic Data

Reactor	
Design Heat Output, MWt	2,535
Vessel Coolant Inlet Temperature, F	554
Vessel Coolant Outlet Temperature, F	603.8
Core Outlet Temperature, F	606.2
Core Operating Pressure, psig	2,185
Core and Fuel Assemblies	
Total No. of Fuel Assemblies in Core	177
No. of Fuel Rods per Fuel Assembly	208
No. of Control Rod Guide Tubes per Assembly	16
No. of In-Core Instr. Positions per Fuel Assembly	1
Fuel Rod Outside Diameter, in.	0.430
Cladding Thickness, in.	0.0265
Fuel Rod Pitch, in.	0.568
Fuel Assembly Pitch Spacing, in.	8.587
Unit Cell Metal/Water Ratio (Volume Basis)	0.82
Cladding Material	Zircaloy-4 (Cold Worked)
Fuel	
Material	UO_2
Form	Dished-End, Cylindrical Pellets
Pellet Diameter, in.	0.370
Active Length, in.	144
Density, % of theoretical	92.5
Heat Transfer and Fluid Flow at Design Power	
Total Heat Transfer Surface in Core, ft^2	49,734
Average Heat Flux, Btu/h-ft^2	171,470
Maximum Heat Flux, Btu/h-ft^2	534,440
Average Power Density in Core, kW/ℓ	83.39
Average Thermal Output, kW/ft of Fuel Rod	5.66
Maximum Thermal Output, kW/ft of Fuel Rod	17.63
Maximum Cladding Surface Temperature, F	654
Average Core Fuel Temperature, F	1,280
Maximum Fuel Central Temperature at Hot Spot, F	4,220
Total Reactor Coolant Flow, lb/h	131.32×10^6
Core Flow Area (Effective for Heat Transfer), ft^2	49.19
Core Coolant Average Velocity, fps	15.73
Coolant Outlet Temperature at Hot Channel, F	647.1
Power Distribution	
Maximum/Average Power Ratio, Radial x Local ($F\Delta h$ Nuclear)	1.78
Maximum/Average Power Ratio, Axial (F_z Nuclear)	1.70
Overall Power Ratio (F_q Nuclear)	3.03
Power Generated in Fuel and Cladding, %	97.3

Nuclear Design Data

Fuel Assembly Volume Fractions

Fuel	0.303
Moderator	0.580
Zircaloy	0.102
Stainless Steel	0.003
Void	0.012
	1.000

Total UO_2 (BOL, First Core)

Metric Tons	93.1

Core Dimensions, in.

Equivalent Diameter	128.9
Active Height	144.0

Unit Cell H_2O/U Atomic Ratio (Fuel Assembly)

Cold	2.88
Hot	2.06

Full-Power Lifetime, days

First Cycle	460
Each Succeeding Cycle	310

Fuel Irradiation, MWd/MTU

First Cycle Average	14,400
Succeeding Cycle Average	9,700

Fuel Loading, wt % 235U

Core Average First Cycle	2.62

Control Data

Control Rod Material	Ag-In-Cd
No. of Full-Length CRA's	61
No. of APSR's	8
Worth of 61 Full-Length CRA's ($\Delta k/k$)%	11.1
Control Rod Cladding Material	SS 304

1 B	2 E	3 A	4 D	5 A	6 D	7 G	8 G
	9 A	10 E	11 A	12 D	13 A	14 E	15 G
		16 A	17 C	18 I	19 D	20 H	21 G
			22 A	23 C	24 A	25 G	
				26 A	27 F	28 G	
					29 G		

W X	W: Position X: Assembly Type

A = 2.06 w/o
B = 2.747 w/o; Fully inserted control rod
C = 2.747 w/o; 0.047 gms Boron/in
D = 2.747 w/o; 0.054 gms Boron/in
E = 2.747 w/o; 0.062 gms Boron/in
F = 3.05 w/o; 0.054 gms Boron/in
G = 3.05 w/o
H = 3.05 w/o; Fully inserted control rod
I = 2.06 w/o; Partial control rod

Figure 8-6 One-Eighth Core Map Showing TMI Cycle 1 at BOC

a) 2.747 w/o U-235 with 500 ppm soluble boron

b) 2.06 w/o U-235 with 500 ppm soluble boron, and

c) pure water with 500 ppm soluble boron

The sample input data for a) and c) are given in Table 8-5; sample problem b) is identical to a), except in the seventh card the 0.02747 should be replaced by 0.0206. Referring to the code manual for LEOPARD input instructions, we note that the first card is a title card and the second is one for options. The third set of cards contain the composition description cards. LEOPARD assumes that a fuel cell consists of four regions as shown below.

A : extra region
B : moderator
C : clad
D : fuel

In the composition description cards the volumetric composition for each of the regions is specified. For the dimension of a fuel cell as shown in Fig. 8-5a, the calculation of volume fraction for the pellet, clad, and moderator region of the fuel cell is straight-forward, but the extra region includes the non-lattice part of the assembly. For example, the control cells, instrument cell, and extraneous moderator as shown in Fig. 8-4 and its volumetric composition is calculated in the following manner:

Extra Region Volumetric Composition

Total assembly area, T = $(8.587)^2$

= 73.74 in^2

Unit fuel cell area, U = 0.568 x 0.568

= 0.3226 in

Non-lattice area, NLV = T-(208 x U)

= 6.631 in^2

Non-lattice fraction, NLF = NLV/T

= 0.0899

Water area in the extraneous moderator region = T-(225 x U)

= 1.1462

As given in Fig. 8-5b and 8-5c the composition of the instrument cell and the control cell is as follows:

TABLE 8-5

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

LEOPARD SAMPLE PROBLEM 2.747W/O TMI FUEL ASSEMBLY
  1  0  1  0  0  1  1  1  0  0  0  0  1 00 00 00                       1
          99         1.0         0.0         0.0         0.0
           3         0.0       0.891         0.0     0.07455
         100         0.0         0.0         1.0     0.90421
         777
          18   -0.027470
          29        500.
         777
       1280.       1280.        650.        580.    0.000275         1.0
        .185        .215        .568         1.0         1.0       .0899
       2200.         0.0       0.925          0.          0.       0.625

LEOPARD SAMPLE PROBLEM PURE WATER
  1  0  1  0  0  1  1  1  0  0  0  0  1  0  0  0
         100         1.0         1.0         1.0
         777
          29        500.
         777
        580.        580.        580.        580.    0.000275
       0.185       0.215       0.568         1.0         1.0         0.0
       2200.         0.0         0.0         0.0         0.0       0.625
```

Instrument cell:

$$G \text{ Central void area} = \frac{\pi}{4}(0.441)^2$$

$$= 0.1528 \text{ in}^2$$

$$B \text{ Cladding (Zr-4)} = 0.03814 \text{ in}^2$$

$$E \text{ Guide tube (Zr-4)} = 0.0428 \text{ in}^2$$

$$A \text{ Water} = 0.08893 \text{ in}^2$$

Control cell:

$$F \text{ Central region area} = 0.09079 \text{ in}^2$$

$$C \text{ Void} = 0.010995 \text{ in}^2$$

$$B \text{ Cladding} = 0.04343 \text{ in}^2$$

$$E \text{ Guide tube (Zr-4)} = 0.02584 \text{ in}^2$$

$$A \text{ Water} = 0.15257 \text{ in}^2$$

In the absence of control rods the regions F, C, and B are filled with water moderator. Thus the composition of the extra region is

$$Zr - 4 = 16 \times 0.02584 + 0.0428 + 0.03814,$$

$$= 0.49438 \text{ in}^2,$$

$$\text{Void} = 0.15274 \text{ in}^2,$$

$$\text{Water} = 16 \times 0.29778 + 0.08893 + 1.1462,$$

$$= 5.9996 \text{ in}^2.$$

The extra region volume fractions are, therefore,

$$Zr\text{-}4 = 0.07455,$$

$$\text{Void} = 0.02303,$$

$$\text{Water} = 0.9024.$$

Thus the volumetric composition data for the TMI fuel assembly are

a. Pellet 100 % UO_2

b. Clad & Void 89.1% Zr-4, 10.9% void

c. Moderator 100% H_2O

d. Extra 90.241% H_2O, 7.455% Zr-4, 2.3% Void

The next set of cards specifies the trace element compositions. In the given problem the trace elements are U-235 and boron-10. Since U-235 is 2.747 w/o enriched, the enrichment is given as -0.02747. This set of cards is followed by the design parameters of the reactor core. All the design data needed for the problem are tabulated in Table 8-4. The buckling of the core is obtained as follows:

Buckling

The reactor core is considered as a cylinder of

equivalent diameter D = 128.9 inch

height H = 12 feet

It is further assumed that the reactor has δ reflector savings in the axial direction and similar reflector savings in the radial direction. The buckling is then given by

$$B^2 = \left(\frac{\pi}{H+2\delta}\right)^2 + \left(\frac{2.405}{R+\delta}\right)^2 ,$$

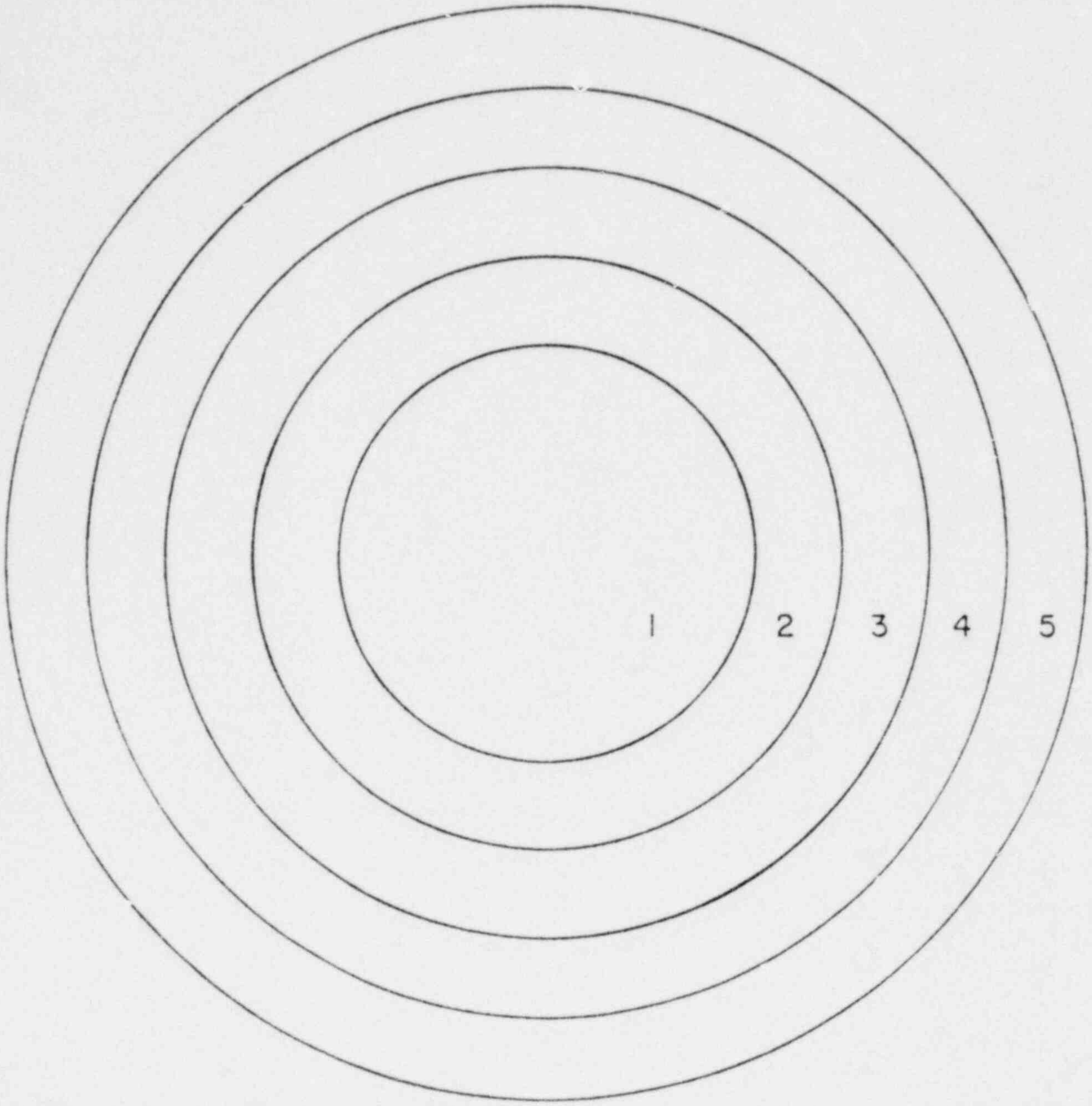
where R is the equivalent radius of the core and δ is the reflector savings. For a typical PWR core, δ is nearly 5 cm. Thus

$$B^2 = 0.000275 \text{ cm}^{-2}$$

The last set of cards in LEOPARD is for the burnout calculation which is not needed for this problem because no depletion analysis is required.

8.2.2 Sample Problem Using the FOG Code

The FOG code is used to analyze a cylindrical core having the same number of fuel assemblies, 177, as the TMI-1 core. Only two different types of fuel assemblies make up the core - the 2.06 w/o U-235 fuel and the 2.747 w/o U-235 fuel. The inner part of the core contains the equivalent of 89 fuel assemblies 2.06 w/o and the outer core contains the equivalent of 88 fuel assemblies 2.747 w/o. The core is surrounded with 30 cm of water reflector as shown in Fig. 8-7.



1 : 2.06 w/o Fuel Assemblies (45)
2 : 2.06 w/o Fuel Assemblies (44)
3 : 2.747 w/o Fuel Assemblies (44)
4 : 2.747 w/o Fuel Assemblies (44)
5 : Water

Fig. 8-7 Cylindrical Core for FOG Calculation

The core can be considered to be a cylindrical, two fuel region core of the TMI-1 design. The purpose of the analysis is to obtain the core k_{eff} and the normalized power for four regions of the core; the first inner region has 45 fuel assemblies, and the three other regions each have 44 fuel assemblies as shown in Fig. 8-7. Group constants found in Section 8.2.1 are used as input for the FOG problem as shown in Table 8-6. Again one should refer to the FOG code manual to understand and follow the data in Table 8-6.

The first card is a title card and the next five cards make up the option set of cards. The third card set consists of the floating point data which includes the design parameters and the macroscopic cross-sections. The first card in this set is the flux convergence criterion chosen. The second and third card gives the region widths which are obtained as follows:

Each fuel assembly area A = 8.587 x 8.587

= 73.736 in^2

Region 1 area = 45A

= 3318.14 in^2

Equivalent Region 1 radius = 82.569 cm,

which is the width of inner region 1. Similarly the widths for the regions 2, 3, and 4 are obtained which are 33.55 cm, 25.23 cm, and 21.78 cm, respectively. A width of 30 cm is used for the water reflector, region 5.

The axial buckling is $B_z^2 = (\frac{\pi}{H+2\delta})^2 = .0000699\ cm^{-2}$; the initial source guess, and the values of χ for the fast and thermal group are specified in the next three cards.

The last set of cards input the macroscopic cross sections as obtained from the LEOPARD runs.

8.2.3 Sample Problem Using the EXTERMINATOR-2 Code

The EXT-2 computer code is used to analyze the simple core configuration of Fig. 8-8. Figure 8-8 is a "square" core configuration (1/4 core) image of the cylindricized core analyzed in Section 8.2.2. In this case, the X-Y geometry option of EXT-2 is used to analyze the four region core of Fig. 8-8. Figure 8-8 also shows the mesh intervals used in the sample problem. The input data used to solve this problem with the EXT-2 computer code are given in Table 8-7.

Again one must refer to the EXT-2 code manual for the detailed input instruction. The first card is the title card and the second card is the option card. The third card is the specification card and the inputs for this card are self-explanatory. It is assumed that all the neutrons are born in the fast group. Thus the input in column 1-8 of the fission spectrum card 9 is 1.0. The fifth card set inputs the buckling. For this problem, buckling is assumed group independent, therefore, there is only one entry. The calculation of buckling

TABLE 8-6

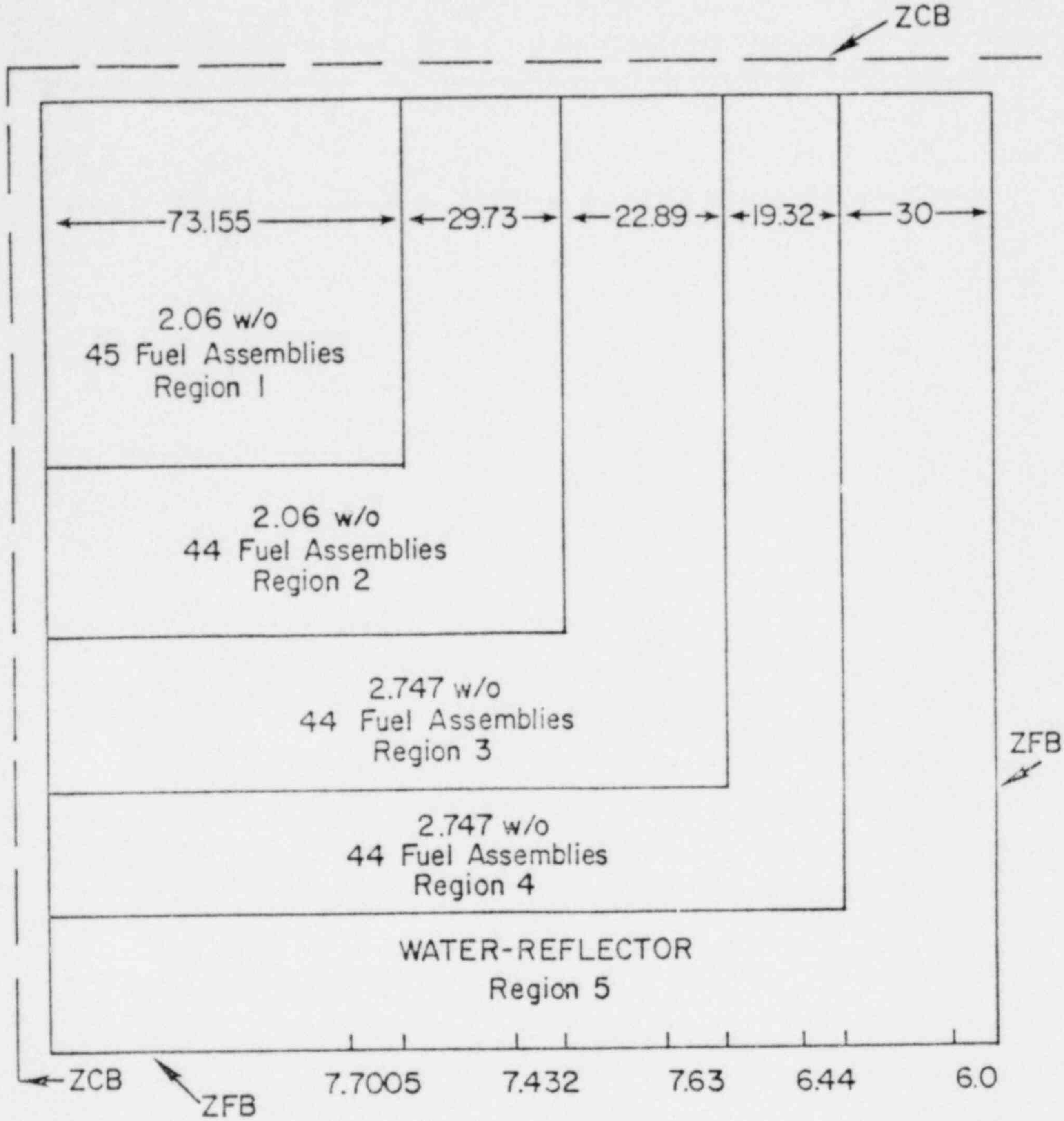
```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

1  *****   FOG SAMPLE PROBLEM
           1           2           2           0           0           1
           7           5          30          20          20          20
          12          10
          63           2
1        150         100
           1      0.0001
           7         0.0      82.569       33.55       25.83       21.76
          12        30.0
          50   .00004238
          90         1.0         1.0         1.0         1.0         0.0
         395         1.0         0.0
         600.1705102E-01.1705102E-01.1636849E-01.1636849E-01.3483288E-01
         800.5133592E-02.5133592E-02.6023671E-02.6023671E-02         0.0
         840.9646618E-01.9646618E-01.1236645E-00.1236645E-00         0.0
        1000.8520111E-02.8520111E-02.8939676E-02.8939676E-02.7916659E-03
        1040.6694770E-01.6694770E-01.7954031E-01.7954031E-01.1925360E-01
        1200   1.4566450   1.4566450   1.4501448   1.4501448   1.8578272
1       1240    .3890600    .3890600    .3885857    .3885857    .2804990
```

TABLE 8-7

```
          1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

EXTERMINATOR SAMPLE PROBLEM
 1 1 1 1 1 1                                                         2
300 26 26  2  3     3  1           1 1       .0001   1.0E12
     1.0      0.0
.0000424      -
7.7005 11 7.432 15  7.63 18  6.44 21   6.0 26
7.7005 11 7.432 15  7.63 18  6.44 21   6.0 26
  3  1 26  1 26      2  1 21  1 21       1  1 15  1 15
    1   11.4566441 0.01705102 .00852011 .00513359
      0.0       1.0
    1    2 .38905996 0.0       .06694770 .09646618
      0.0       0.0
    2   11.4501448  .01636849 .00893968 .00602367
      0.0       1.0
    2    2 .3885857  0.0       .07954031 .1236645
      0.0       0.0
    3   11.8578272  .03483288 .00079167 0.0
      0.0       1.0
    3    2 .2804990  0.0       .01925360 0.0
      0.0       0.0
```



ZFB = Zero Flux Boundary
ZCB = Zero Current Boundary

Fig. 8-8 Sample Problem with Square Core is shown in problem 8.2.2 (above). The next set of cards is the mesh specification cards. In quarter core symmetry, the ZCB (see Fig. 8-8) at the center is a half mesh width outside of the core boundary. To account for this, the mesh width for region 1 is found as follows:

Region 1 width = 73.155 cm

Mesh intevals in Region 1 = 9.5

$$\text{Mesh width for Region 1} = \frac{73.155}{9.5}$$

$$= 7.7005 \text{ cm}$$

The composition specification is given in card group 7. The last set of cards contains the macroscopic data cards. The macroscopic cross-sections are obtained from the LEOPARD runs of problem 8.2.1 (above).

8.2.4 Sample Problem Using the PFMP

In this problem the TMI-1 core is depleted with the PFMP following the actual core operational history. At the beginning of the first reactor cycle, the core requires 10 separate LEOPARD runs to describe the different regions in the core as shown in Fig. 8-6 and presented in Table 8-8. A fully inserted control rod is initially in core position 20 (actually a bank of 8 control rods). At a BU of 7931 MWd/MTU, these rods are withdrawn from the core and control rods are inserted into core positions 7 and 26. At a BU of 13,360 MWd/MTU all control rods are fully withdrawn from the core. The control rod schedule is given in Table 8-9. A special partial height control rod for controlling the axial power distribution is inserted into core position 18 and remains in the core for the full reactor cycle.

The first task is to generate group constants as a function of exposure or burnup for each of the 10 different core regions using the boron let down schedule given in Fig. 8-9. The three control rod changes made during the first reactor cycle requires a three step process for generating group constants for those fuel regions in which the control rods were moved*. Table 8-10 through 8-19 lists the input data for all 10 different regions. As explained in Section 4, the PSU LEOPARD input sightly modifies the standard LEOPARD input. In column 66 of the second card, there is a 4 which is a flag that PSU LEOPARD is being activated. All curve fitting will be performed with a polynomial of degree four unless the number of steps justifies automatic lowering of this number. The analysis of the 3 steps of the 1st cycle is given below.

Step 1, Cycle 1 (from BOC (0 MWd/MTU) to 7931 MWd/MTU).

From the core map of Cycle 1 (Fig. 8-6), note that nine (9) different types of fuel assemblies are used in the core. In addition, the core is

---

*A new improved model of the PFMP does not require the three step process. The new model was not completed in time to be included as part of this chapter.

Table 8-8. Composition of the Various Core Regions.

ADD ID	Description
550	Water-reflector
551	2.06 w/o fuel assembly
553	2.747 w/o; 0.047 gms boron/in
554	2.747 w/o; 0.054 gms boron/in
555	2.747 w/o; 0.062 gms boron/in
556	3.05 w/o fuel assembly
557	3.05 w/o; 0.054 gms boron/in
561	2.06 w/o; partial control rod
562	2.747 w/o; fully inserted control rod
566	3.05 w/o; fully inserted control rod

Table 8-9. Burnable Boron Depletion Data

Step #	Step Length (MWd/MTU)	.062 gm/in Burnable Boron (PPM)	.054 gm/in Burnable Boron (PPM)	.047 gm/in Burnable Boron (PPM)
1	25	1195	1101	1007
2	25	1191	1098	1006
3	25	1188	1096	1005
4	25	1186	1093	1004
5	.01	1182	1089	1002
6	100	1182	1089	1002
7	150	1170	1082	983
8	150	1160	1080	970
9	.01	1140	1058	960
10	500	1140	1058	960
11	1000	1100	1005	908
12	2000	995	900	810
13	2000	780	678	506
14	2000	570	481	440
15	2000	421	360	309
16	2000	306	260	206
17	2400	202	170	111
18	2000	106	101	40
19	2000	60	60	30
20	.01	50	50	20

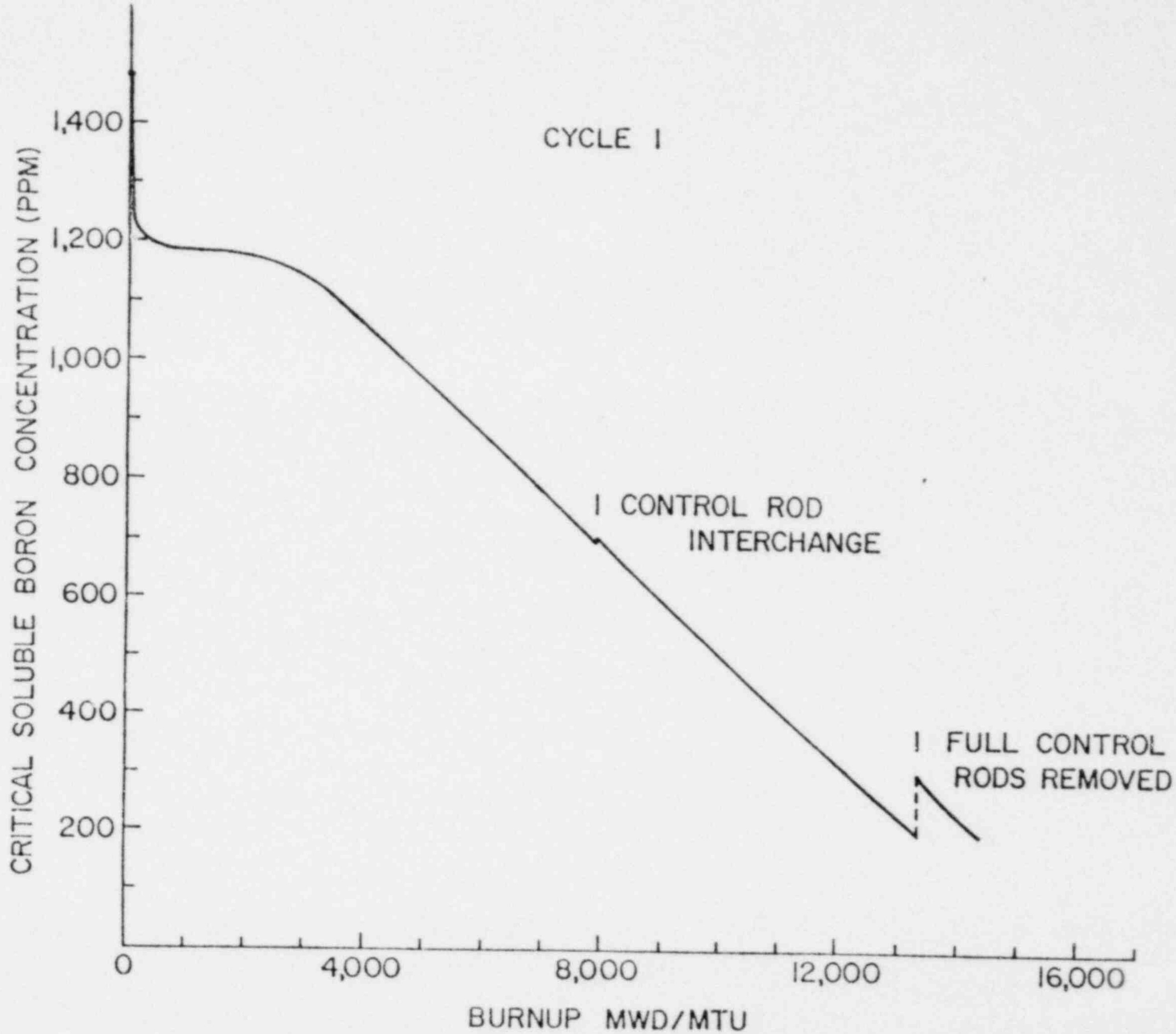


Fig. 8-9 Boron Let Down Schedule for TI-Unit 1, Cycle 1

surrounded with a water reflector. In order to represent all of these different materials in the core, PSU-LEOPARD is run for each of them and ADDs defining their cross-sections with burnup are obtained. Table 8-8 contains the description of each of these materials and the ADD numbers used for them.

As discussed in Chapter 4, section 3, in PSU-LEOPARD the control rods and burnable boron are simulated as ppm boron concentration in the moderator based on the equations derived in Section 4.3. Given below is the calculation for 0.047 gms/in burnable boron.

<u>0.047 gm/in - Burnable Boron</u>

For $\overline{\phi}_4 = \overline{\phi}_M$ Eq. (4-191) reduces to

$$N_{BW}^{\ H} = \frac{16 N_B^{\ H}\, V_{cell}\, k}{(V_W^{\ 4} + V_W^{\ M})} ,$$

$$= \frac{16 g\, N_B\, A_p\, k}{V_W}$$

where

$$k = \frac{\overline{\phi}_{BC}}{\overline{\phi}_M} ,$$

$$= .968$$

Substituting in Eq. (4-192B) yields

$$PPMBB = \frac{16 g\, N_B A_p\, k}{V_W \cdot \rho_{H_2O}\, N_a} \cdot W_B \times 10^6 .$$

for 0.047 gm/in burnable boron,

$g = 0.58,$

$N_B = 1.75994 \times 10^{21}\ \frac{\text{B atoms}}{\text{cm}^3}$,

$W_B = 10.811,$

$A_p = 0.585754\ \text{cm}^2,$

$V_W = 247.4\ \text{cm}^2,$

$$PPMBB = \frac{16(.58)(1.75994 \times 10^{21})(0.585754)(.968)(10.811)(10^6)}{(247.4)(.667)(.6023 \times 10^{24})} ,$$

$= 1007.$

Similarly for 0.054 gms/in and 0.062 gms/in the equivalent soluble boron in ppm is, respectively, 1101 and 1195.

Full control rod = 3000 ppm

Partial Control rod = 700 ppm

0.047 gms Boron/in = 1007 ppm

0.054 gms Boron/in = 1101 ppm

0.062 gms Boron/in = 1195 ppm

Further since the burnable boron depletes with burnup, a depletion calculation as discussed in Chapter 4 needs to be made. Table 8-9 gives such depletion data.

Table 8-10 through 8-19 list the input for PSU-LEOPARD to obtain the ADDs listed in Table 8-8. Once all the ADDs are obtained, SCAR for the step 1 of cycle 1 can now be run. Table 8-20 lists the input for PSU-SCAR for step 1.

To prepare the input cards for PSU-SCAR, one must refer to the PFMP manual. The first card is the title card. The second card (AL) is the allocate data card. The next set of data classes can be entered in any order. In Table 8-20, in the third card (ST), depletion step lengths are input. The fourth card (BL) inputs the boron letdown schedule and the fifth lists the printing options. The next two cards (MA) input the material composition identification by ADD numbers. The actual burnups of the assemblies at the beginning of step 1 are input in card (CB). The axial buckling B_z^2 is input in the next card identified as BU. The axial buckling is obtained as follows:

$$B_z^2 = \left(\frac{\pi}{H+2\delta}\right)^2,$$

where H is the height of the core including the reflector savings in the axial direction.

H = height of the core

= 12 ft

= 365.76 cm

δ = reflector saving

= 5 cm

$H+2\delta$ = 365.76 + 10

= 375.76 cm

$$B_z^2 = \left(\frac{\pi}{H+2\delta}\right)^2 = 6.99 \times 10^{-5}\ \text{cm}^{-2}$$

TABLE 8-10

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

TMI WATER REFLECTOR ADD 550
  1  0  1  0  0  1  1  0  0  0  0  0  1  1  0  0                 4
         100         .70         .70         .70
         304         .30         .30        .30
         777
          29     1490.
         777
        554.        554.        554.        554.    0.000279        1.00
       0.185       0.215       1.136                               0.0
      2199.7                   0.925
1.          80.2
           1          0.       1490.                    -550
           2          0.       1350.
           3          0.       1200.
           4          0.       1100.
           5          0.       1000.
           6          0.        900.
           7          0.        800.
           8          0.        700.
           9          0.        600.
          10          0.        500.
          11          0.        400.
          12          0.        300.
          13          0.        200.
          14          0.        100.
          15          0.          0.
         777
```

TABLE 8-11

```
          1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

2.06 W/O FUEL ASSEMBLY ADD 551
 1  0  1  0  0  1  1  0  0  0  0  0  1  1  0  0                   4
          099 1.
          003            .891                   .07455
          100                       1.          .90421
          777
           18 -.0206
           29 1490.
          777
        1280.       1280.     650.      580.     .000279  1.00
   .185         .215     .568      1.           1.        .08992
 2200.     0.            .925      .925         .925      .625
    1.       82.2
            1      -25.     1490.                     -551
            2      -25.     1400.
            3      -25.     1310.
            4      -25.     1220.
            5      -.01     1210.
            6      -100.    1210.                        2
            7      -150.    1200.
            8      -150.    1190.
            9      -.01     1180.
           10      -500.    1180.                        3
           11      -1000.   1170.
           12      -2000.   1060.
           13      -2000.   1050.
           14      -2000.    930.
           15      -2000.    710.
           16      -2000.    500.
           17      -2400.    325.
           18      -2000.    200.
           19      -2000.    100.
           20      -.01       50.
          777
```

TABLE 8-12

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

2.747 W/O 0.047 GMS BORON/IN ADD 553
  1  0  1  0  0  1  1  0  0  0  0  1  1  0  0  0                 4
          99         1.0
           3                    .891                   .1794
         100                                 1.0       .5520
           9                                           .1498
           4                                         .001202
           2                                          .01344
         777
          18 -.02747
          29 2497.
         777
       1280.        1280.     650.       580.      .000279 1.00
    .185       .215     .568        1.          1.          .08992
 2200.       0.         .925        .925        .925        .625
    1.      82.2
           1      -25.        1490.      1007.          -553
           2      -25.        1400.      1006.
           3      -25.        1310.      1005.
           4      -25.        1220.      1004.
           5      -.01        1210.      1002.
           6      -100.       1210.      1002.             2
           7      -150.       1200.      983.
           8      -150.       1190.      970.
           9      -.01        1180.      960.
          10      -500.       1180.      960.              3
          11      -1000.      1170.      908.
          12      -2000.      1060.      810.
          13      -2000.      1050.      606.
          14      -2000.       930.      440.
          15      -2000.       710.      309.
          16      -2000.       500.      206.
          17      -2400.       325.      111.
          18      -2000.       200.      40.
          19      -2000.       100.      30.
          20      -.01          50.      20.
         777
```

TABLE 8-13

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

2.747 W/O 0.054 GMS BORON/IN ADD 554
  1  0  1  0  0  1  1  0  0  0  0  0  1  1  0  0                 4
         99         1.0
          3                    .891                   .1794
        100                                 1.0       .5520
          9                                           .1494
          4                                         .001374
          2                                          .01341
        777
         18 -.02747
         29 2591.
        777
       1280.       1280.      650.       580.     .000279   1.00
   .185        .215     .568        1.          1.          .08992
 2200.      0.          .925        .925        .925        .625
    1.      82.2
          1      -25.        1490.      1101.          -554
          2      -25.        1400.      1098.
          3      -25.        1310.      1096.
          4      -25.        1220.      1093.
          5      -.01        1210.      1089.
          6      -100.       1210.      1089.             2
          7      -150.       1200.      1080.
          8      -150.       1190.      1072.
          9      -.01        1180.      1058.
         10      -500.       1180.      1058.             3
         11      -1000.      1170.      1005.
         12      -2000.      1060.      900.
         13      -2000.      1050.      678.
         14      -2000.       930.      481.
         15      -2000.       710.      360.
         16      -2000.       500.      260.
         17      -2400.       325.      170.
         18      -2000.       200.      101.
         19      -2000.       100.      60.
         20      -.01          50.      50.
        777
```

TABLE 8-14

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

2.747 W/O 0.062 GMS BORON/IN ADD 555
  1  0  1  0  0  1  1  0  0  0  0  1  1  0  0                    4
          99         1.0
           3                       .891                    .1794
         100                                 1.0        .5520
           9                                            .1491
           4                                          .001579
           2                                           .01338
         777
          18 -.02747
          29 2685.
         777
       1280.        1280.     650.       580.     .000279   1.00
   .185        .215     .568        1.          1.          .08992
 2200.      0.          .925        .925        .925        .625
    1.      82.2
           1      -25.          1490.     1195.           -555
           2      -25.          1400.     1191.
           3      -25.          1310.     1188.
           4      -25.          1220.     1186.
           5      -.01          1210.     1182.
           6      -100.         1210.     1182.              2
           7      -150.         1200.     1170.
           8      -150.         1190.     1160.
           9      -.01          1180.     1140.
          10      -500.         1180.     1140.              3
          11      -1000.        1170.     1100.
          12      -2000.        1060.     995.
          13      -2000.        1050.     780.
          14      -2000.         930.     570.
          15      -2000.         710.     421.
          16      -2000.         500.     306.
          17      -2400.         325.     202.
          18      -2000.         200.     106.
          19      -2000.         100.     60.
          20      -.01            50.     50.
         777
```

TABLE 8-15

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

3.05 W/O FUEL ASSEMBLY ADD 556
  1  0  1  0  0  1  1  0  0  0  0  0  1  1  0  0                 4
         099 1.
         003            .891                    .07455
         100                        1.          .90421
         777
          18 -.0305
          29 1490.
         777
       1280.      1280.     650.       580.      .000279   1.00
   .185        .215     .568        1.          1.         .08992
 2200.       0.         .925        .925        .925       .625
    1.       82.2
           1      -25.        1490.                      -556
           2      -25.        1400.
           3      -25.        1310.
           4      -25.        1220.
           5      -.01        1210.
           6      -100.       1210.                         2
           7      -150.       1200.
           8      -150.       1190.
           9      -.01        1180.
          10      -500.       1180.                         3
          11      -1000.      1170.
          12      -2000.      1060.
          13      -2000.      1050.
          14      -2000.       930.
          15      -2000.       710.
          16      -2000.       500.
          17      -2400.       325.
          18      -2000.       200.
          19      -2000.       100.
          20      -.01          50.
         777
```

TABLE 8-16

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

3.05 W/O 0.054 GMS/IN BORON ADD 557
  1  0  1  0  0  1  1  0  0  0  0  0  1  1  0  0                 4
          99         1.0
           3                    .891                   .1794
         100                                 1.0       .5520
           9                                           .1494
           4                                         .001374
           2                                          .01341
         777
          18 -.0305
          29 2591.
         777
       1280.       1280.      650.       580.      .000279   1.00
   .185        .215     .568        1.          1.          .08992
 2200.      0.          .925        .925        .925        .625
    1.      82.2
           1      -25.        1490.      1101.          -557
           2      -25.        1400.      1098.
           3      -25.        1310.      1096.
           4      -25.        1220.      1093.
           5      -.01        1210.      1089.
           6      -100.       1210.      1089.             2
           7      -150.       1200.      1080.
           8      -150.       1190.      1072.
           9      -.01        1180.      1058.
          10      -500.       1180.      1058.             3
          11      -1000.      1170.      1005.
          12      -2000.      1060.      900.
          13      -2000.      1050.      678.
          14      -2000.       930.      481.
          15      -2000.       710.      360.
          16      -2000.       500.      260.
          17      -2400.       325.      170.
          18      -2000.       200.      101.
          19      -2000.       100.      60.
          20      -.01          50.      50.
         777
```

TABLE 8-17

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

2.06 W/O PARTIAL CONTROL ROD ADD 561
  1  0  1  0  0  1  1  0  0  0  0  0  1  1  0  0                 4
         099 1.
         003            .891                    .07455
         100                        1.          .90421
         777
          18 -.0206
          29 2190.
         777
       1280.       1280.      650.       580.     .000279   1.00
   .185        .215     .568        1.           1.         .08992
 2200.     0.           .925        .925        .925        .625
    1.     82.2
           1      -25.        1490.       700.          -561
           2      -25.        1400.       700.
           3      -25.        1310.       700.
           4      -25.        1220.       700.
           5      -.01        1210.       700.
           6      -100.       1210.       700.             2
           7      -150.       1200.       700.
           8      -150.       1190.       700.
           9      -.01        1180.       700.
          10      -500.       1180.       700.             3
          11      -1000.      1170.       700.
          12      -2000.      1060.       700.
          13      -2000.      1050.       700.
          14      -2000.       930.       700.
          15      -2000.       710.       700.
          16      -2000.       500.       700.
          17      -2400.       325.       700.
          18      -2000.       200.       700.
          19      -2000.       100.       700.
          20      -.01          50.       700.
         777
```

TABLE 8-18

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

2.747 W/O FULL CONTROL ROD ADD 562
  1  0  1  0  0  1  1  0  0  0  0  0  1  1  0  0                 4
         099 1.
         003            .891                    .2936
         100                        1.          .5520            .
         304                                    .1048
         777
          18 -.02747
          29 4490.
         777
       1280.       1280.      650.       580.      .000279   1.00
   .185        .215     .568        1.          1,          .08392
 2200.      0.          .925        .925        .925        .625
     1.      82.2
           1      -25.        1490.      3000.          -562
           2      -25.        1400.      3000.
           3      -25.        1310.      3000.
           4      -25.        1220.      3000.
           5      -.01        1210.      3000.
           6      -100.       1210.      3000.             2
           7      -150.       1200.      3000.
           8      -150.       1190.      3000.
           9      -.01        1180.      3000.
          10      -500.       1180.      3000.             3
          11      -1000.      1170.      3000.
          12      -2000.      1060.      3000.
          13      -2000.      1050.      3000.
          14      -2000.       930.      3000.
          15      -2000.       710.      3000.
          16      -2000.       500.      3000.
          17      -2400.       325.      3000.
          18      -2000.       200.      3000.
          19      -2000.       100.      3000.
          20      -.01          50.      3000.
         777
```

TABLE 8-19

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

3.05 W/O FULL CONTROL ROD ADD 566
  1  0  1  0  0  1  1  0  0  0  0  0  1  1  0  0                 4
         099 1.
         003          .891        1.          .2936
         100                      1.          .5520
         304                                  .1048
         777
          18 -.0305
          29 4490.
         777
       1280.       1280.      650.       580.     .000279   1.00
   .185        .215     .568        1.          1.          .08992
 2200.       0.         .925        .925        .925        .625
    1.       82.2
           1      -25.        1490.      3000.          -566
           2      -25.        1400.      3000.
           3      -25.        1310.      3000.
           4      -25.        1220.      3000.
           5      -.01        1210.      3000.
           6      -100.       1210.      3000.             2
           7      -150.       1200.      3000.
           8      -150.       1190.      3000.
           9      -.01        1180.      3000.
          10      -500.       1180.      3000.             3
          11      -1000.      1170.      3000.
          12      -2000.      1060.      3000.
          13      -2000.      1050.      3000.
          14      -2000.       930.      3000.
          15      -2000.       710.      3000.
          16      -2000.       500.      3000.
          17      -2400.       325.      3000.
          18      -2000.       200.      3000.
          19      -2000.       100.      3000.
          20      -.01          50.      3000.
         777
```

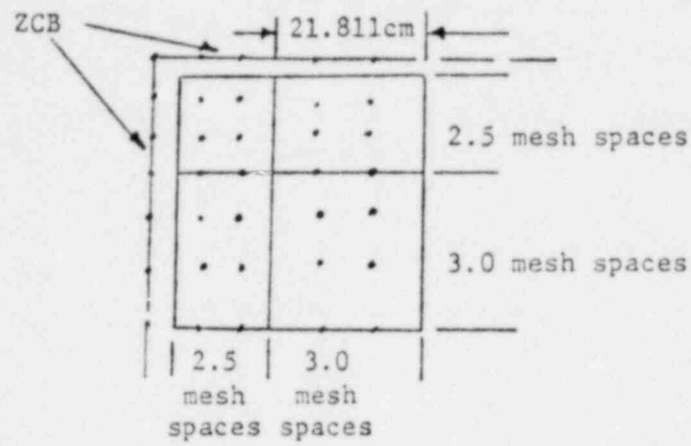
TABLE 8-20

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

THREE MILE ISLAND FIRST CYCLE STEP 1
AL 9 30 30 32 0 0
ST 100. 518. 618. 926. 1100. 1371. 1545. 1753. .01
BL 1490. 1215. 1190. 1185. 1156. 1127. 990. 854. 695.
PR 10*-1
MA 562 555 551 554 551 554 556 556 551 555 551 554 551 555 556 551 553
MA 561 554 566 556 551 553 551 556 551 557 556 556 550 550 550
CB  32 * 0.
BU     2 * 7.1E-5
DX 3*4.362196 26*7.2703267
DY 3*4.362196 26*7.2703267
OV 30 1 30 1 30   1 1 4 1 4   2 1 4 4 7   3 1 4 7 10   4 1 4 10 13
OV 5 1 4 13 16   6 1 4 16 19   7 1 4 19 22   8 1 4 22 25   2 4 7 1 4
OV 9 4 7 4 7   10 4 7 7 10   11 4 7 10 13   12 4 7 13 16   13 4 7 16 19
OV 14 4 7 19 22   15 4 7 22 25   3 7 10 1 4   10 7 10 4 7   16 7 10 7 10
OV 17 7 10 10 13   18 7 10 13 16   19 7 10 16 19   20 7 10 19 22
OV 21 7 10 22 25   4 10 13 1 4   11 10 13 4 7   17 10 13 7 10
OV 22 10 13 10 13   23 10 13 13 16   24 10 13 16 19   25 10 13 19 22
OV 5 13 16 1 4   12 13 16 4 7   18 13 16 7 10   23 13 16 10 13
OV 26 13 16 13 16   27 13 16 16 19   28 13 16 19 22   6 16 19 1 4
OV 13 16 19 4 7   19 16 19 7 10   24 16 19 10 13   27 16 19 13 16
OV 29 16 19 16 19   7 19 22 1 4   14 19 22 4 7   20 19 22 7 10
OV 25 19 22 10 13   28 19 22 13 16   8 22 25 1 4   15 22 25 4 7
OV 21 22 25 7 10   31 22 25 10 16   31 10 16 22 25
OV    32 16 19 19 22 32 19 22 16 19
AD

        ADD DECKS
```

The last set of cards needed for this problem is the mesh width description cards DX and DY and the mesh point composition overlay cards (OV). For this problem a 4 x 4 mesh point configuration is used for the assemblies. The mesh diagram for quarter core is shown below



Partial Quarter Core

For the central assembly, the mesh widths are

$$\Delta x = \frac{21.811}{2 \times 2.5}$$

$$= 4.3622 \text{ cm.}$$

For all other assemblies the mesh widths are

$$\Delta x = \frac{21.811}{3}$$

$$= 7.2703 \text{ cm.}$$

Step 2, Cycle 1 (From 7931 MWd/MTU to 13,360 MWd/MTU)

New ADDs for assemblies in positions 20, 7 and 26 are needed because the control rods are interchanged in these positions. Since the burnup for these assemblies at the core average burnup of 7931 MWd/MTU is not known beforehand, the data obtained in scar of step 1 are consulted and exact burnup for these assemblies can now be found; they are for positons 20, 7, and 26, 5341 MWd/MTU, 9870 MWd/MTU, and 7393 MWd/MTU, respectively. The control rods can now be simulated for the assemblies at position 7 and 26 starting at their actual burnup corresponding to core average burnup of 7931 MWd/MTU.

Table 8-21 lists the new ADDs needed for step 2 and Table 8-22 through 8-24 list the input for PSU-LEOPARD.

Table 8-21. ADDs Needed for Step 2

ADD ID	Description at Core BU=7931 MWd/MTU
570*	3.05 w/o, Full control rod simulation from 9870 MWd/MTU
571*	2.06 w/o, Full control rod simulation from 7393 MWd/MTU
572*	3.05 w/o, Full control rod removed at 5341 MWd/MTU

With the new ADDs 570, 571, and 572, SCAR can now be run for step 2 of cycle 1. Table 8-25 lists the step 2 SCAR input.

Step 3, Cycle 1 (from 13,360 MWd/MTU to 14,400 MWd/MTU)

Following the procedure of step 2, new ADDs for assemblies in positions 1, 7, and 26 are needed because at core average burnup of 13,360 MWd/MTU, the control rods are removed from these positions.

Table 8-26 lists the ID for new ADDs used in step 3 and Table 8-27 through 8-29 lists their PSU-LEOPARD input.

Table 8-26. New ADDs Used in Step 3

ADD ID	Description at Core BU=13,363 MWD/MTU
573*	2.747 w/o Full control rod withdrawn at 12,655 MWd/MTU
574*	2.06 w/o Full control rod simulation from 7393 - 10,730
575*	3.05 w/o Full control rod simulation from 9870 - 14,400 MWd/MTU

Table 8-30 lists the SCAR input for step 3 of Cycle 1.

8.3 Sample Problem for the MIT FLARE

The Oyster Creek Nuclear Reactor, a 1600 MWt, BWR, is analyzed with the MIT FLARE. The Oyster Creek core is composed of 560 fuel assemblies each containing 49 fuel rods in a square array (Fig. 8-10). Each fuel rod consists of a zircaloy tubular cladding, in which sintered UO_2 pellets are stacked to a

*Note that the burnups can be obtained from the corresponding LEOPARD input by summing the individual burnup steps.

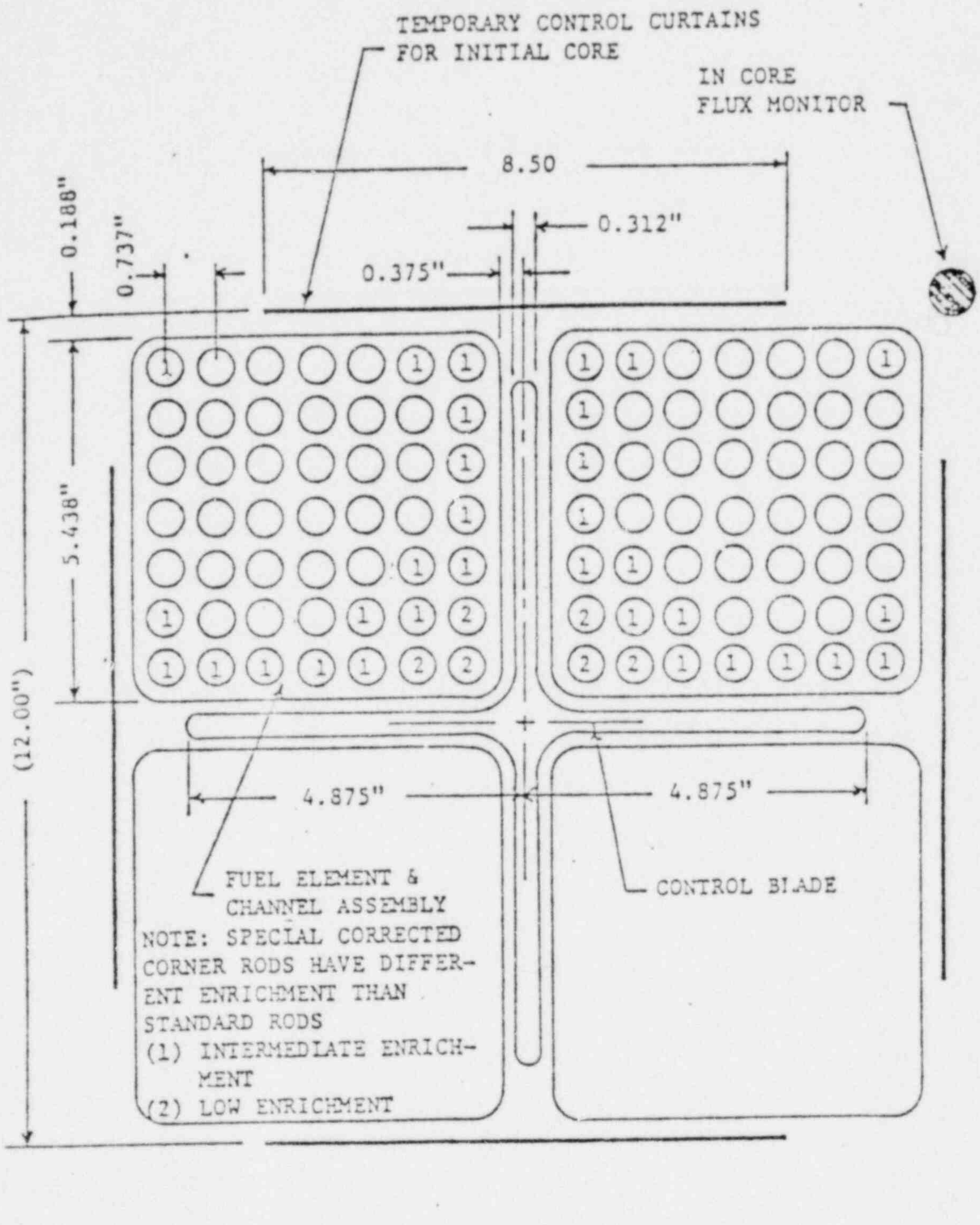


Figure 8-10 Core Lattice Unite

TABLE 8-22

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

3.05 W/O FULL ROD FROM 7931 MWD/MTU AVE ADD 570
  1  0  1  0  0  1  1  0  0  0  0  0  1  1  0  0                 4
         099 1.
         003            .891                    .2936
         100                        1.          .5520
         304                                    .1048
         777
          18 -.0305
          29 1490.
         777
       1280.       1280.      650.       580.     .000279   1.00
   .185        .215     .568        1.          1.          .08992
 2200.      0.          .925        .925        .925        .625
    1.      82.2
           1     -25.         1490.                    -556
           2     -25.         1400.
           3     -25.         1310.
           4     -25.         1220.
           5     -.01         1210.
           6     -100.        1210.
           7     -150.        1200.
           8     -150.        1190.
           9     -.01         1180.
          10     -500.        1180.
          11     -1000.       1170.
          12     -2000.       1060.
          13     -2000.       1050.
          14     -2000.        930.
          15     -1870.       710.
          16     -.01         520.
          17     -130.        520.       3000.         -570.
          18     -2000.       500.       3000.
          19     -2400.       325.       3000.
          20     -2000.       200.       3000.
          21     -2000.       100.       3000.
          22     -.01         50.        3000.
         777
```

TABLE 8-23

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

2.06 W/O FULL ROD FROM 7931 MWD/MTU AVE ADD 571
  1  0  1  0  0  1  1  0  0  0  0  0  1  1  0  0                 4
         099 1.
         003          .891                  .2936
         100                      1.        .5520
         304                                .1048
         777
          18 -.0206
          29 1490.
         777
       1280.      1280.      650.       580.     .000279   1.00
   .185        .215   .568        1.            1.         .08992
 2200.      0.        .925        .925          .925       .625
    1.      82.2
           1     -25.       1490.                      -551
           2     -25.       1400.
           3     -25.       1310.
           4     -25.       1220.
           5     -.01       1210.
           6     -100.      1210.
           7     -150.      1200.
           8     -150.      1190.
           9     -.01       1180.
          10     -500.      1180.
          11     -1000.     1170.
          12     -2000.     1060.
          13     -2000.     1050.
          14     -1393.     930.
          15     -.01       780.
          16     -7.        780.       3000.         -571
          17     -600.      715.       3000.
          18     -2000.     710.       3000.
          19     -.01       710.       3000.
          20     -2000.     500.       3000.            2
          21     -2400.     325.       3000.
          22     -2000.     200.       3000.
          23     -2000.     100.       3000.
          24     -.01       50.        3000.
         777
```

TABLE 8-24

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

3.05 W/O FULL ROD REMOVED AT 7931 MWD/MTU AVE ADD 572
  1  0  1  0  0  1  1  0  0  0  0  0  1  1  0  0                 4
         099 1.
         003          .891                  .07455
         100 .                    1.        .90421
         777
          18 -.0305
          29 4490.
         777
       1280.       1280.      650.       580.      .000279   1.00
   .185        .215      .568        1.          1.          .08992
  2200.      0.          .925        .925        .925        .625
     1.      82.2
           1      -25.        1490.      3000.             -566
           2      -25.        1400.      3000.
           3      -25.        1310.      3000.
           4      -25.        1220.      3000.
           5      -.01        1210.      3000.
           6      -100.       1210.      3000.
           7      -150.       1200.      3000.
           8      -150.       1190.      3000.
           9      -.01        1180.      3000.
          10      -500.       1180.      3000.
          11      -1000.      1170.      3000.
          12      -2000.      1060.      3000.
          13      -1341.      1050.      3000.
          14      -.01        1000.      3000.
          15      -9.0        1000.                        -572
          16      -650.       997.
          17      -2000.      930.
          18      -.01        710.
          19      -2000.      710.                            2
          20      -2000.      500.
          21      -2400.      325.
          22      -2000.      200.
          23      -2000.      100.
          24      -.01        50.
         777
```

TABLE 8-25

```
          1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

THREE MILE ISLAND FIRST CYCLE STEP 2
AL 4 30 30 32 0 0
ST 1328. 1851. 2253. .01
BL 700. 565. 380. 165.
PR 10*-1
CB 8033. 10182. 9890. 11198. 9487. 10053. 9870. 6590. 9588. 11186. 9694.
CB 10244. 8244. 7542. 5617. 9795. 10617. 7962. 7924. 5341. 3635. 8908.
CB 9173. 6808. 5568. 7393. 6934. 4134. 4737. 0. 0. 0.
MA 562 555 551 554 551 554 570 556 551 555 551 554 551 555 556 551 553
MA 561 554 572 556 551 553 551 556 571 557 556 556 550 550 550
BU     2 * 7.1E-5
DX 3*4.362196 26*7.2703267
DY 3*4.362196 26*7.2703267
OV 30 1 30 1 30   1 1 4 1 4   2 1 4 4 7   3 1 4 7 10   4 1 4 10 13
OV 5 1 4 13 16   6 1 4 16 19   7 1 4 19 22   8 1 4 22 25   2 4 7 1 4
OV 9 4 7 4 7   10 4 7 7 10   11 4 7 10 13   12 4 7 13 16   13 4 7 16 19
OV 14 4 7 19 22   15 4 7 22 25   3 7 10 1 4   10 7 10 4 7   16 7 10 7 10
OV 17 7 10 10 13   18 7 10 13 16   19 7 10 16 19   20 7 10 19 22
OV 21 7 10 22 25   4 10 13 1 4   11 10 13 4 7   17 10 13 7 10
OV 22 10 13 10 13   23 10 13 13 16   24 10 13 16 19   25 10 13 19 22
OV 5 13 16 1 4   12 13 16 4 7   18 13 16 7 10   23 13 16 10 13
OV 26 13 16 13 16   27 13 16 16 19   28 13 16 19 22   6 16 19 1 4
OV 13 16 19 4 7   19 16 19 7 10   24 16 19 10 13   27 16 19 13 16
OV 29 16 19 16 19   7 19 22 1 4   14 19 22 4 7   20 19 22 7 10
OV 25 19 22 10 13   28 19 22 13 16   8 22 25 1 4   15 22 25 4 7
OV 21 22 25 7 10   31 22 25 10 16   31 10 16 22 25
OV    32 16 19 19 22 32 19 22 16 19
AD
AD
```

ADD DECKS

TABLE 8-27

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

2.747 W/O FULL ROD REMOVED AT 1336 MWD/MTU AVE ADD 573
  1  0  1  0  0  1  1  0  0  0  0  0  1  1  0  0                 4
         003            .891                    .07455
         099 1.
         100                        1.          .90421
         777
          18 -.02747
          29 4490.
         777
       1280.       1280.      650.       580.       .000279  1.00
   .185       .215    .568        1.          1.          .08992
 2200.      0.            .925        .925        .925        .625
    1.      82.2
           1     -25.         1490.     3000.          -562
           2     -25.         1400.     3000.
           3     -25.         1310.     3000.
           4     -25.         1220.     3000.
           5     -.01         1210.     3000.
           6     -100.        1210.     3000.
           7     -150.        1200.     3000.
           8     -150.        1190.     3000.
           9     -.01         1180.     3000.
          10     -500.        1180.     3000.
          11     -1000.       1170.     3000.
          12     -2000.       1060.     3000.
          13     -2000.       1050.     3000.
          14     -2000.        930.     3000.
          15     -2000.       710.      3000.
          16     -2000.       500.      3000.
          17     -655.        325.      3000.
          18     -.01         280.      3000.
          19     -45.         280.                      -573
          20     -300.        275.
          21     -1400.       250.
          22     -2000.       200.
          23     -2000.       100.
          24     -.01         50.
         777
```

TABLE 8-28

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

2.06 W/O FULL ROD SIMULATION FROM 7931-13363 MWD/MTU AVE ADD 574
  1  0  1  0  0  1  1  0  0  0  0  1  1  0  0                   4
         099 1.
         003          .891                  .07455
         100                    1.          .90421
         777
          18 -.0206
          29 1490.
         777
       1280.      1280.     650.      580.   .000279  1.00
   .185      .215     .568      1.          1.        .08992
  2200.      0.       .925      .925        .925      .625
     1.      82.2
           1     -25.       1490.                       -551
           2     -25.       1400.
           3     -25.       1310.
           4     -25.       1220.
           5     -.01       1210.
           6     -100.      1210.
           7     -150.      1200.
           8     -150.      1190.
           9     -.01       1180.
          10     -500.      1180.
          11     -1000.     1170.
          12     -2000.     1060.
          13     -2000.     1050.
          14     -1393.     930.
          15     -.01       780.
          16     -7.        780.      3000.           -571
          17     -600.      715.      3000.
          18     -2000.     710.      3000.
          19     -730.      500.      3000.
          20     -.01       425.      3000.
          21     -70.       425.                      -574
          22     -200.      410.
          23     -1000.     400.
          24     -2400.     325.
          25     -2000.     200.
          26     -2000.     100.
          27     -.01       50.
         777
```

TABLE 8-29

```
         1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

3.05 W/O FULL ROD SIMULATION FROM 7931-13363 MWD/MTU AVE ADD 575
  1 0 1 0 0 1 1 0 0 0 0 0 1 1 0 0                 4
         099 1.
         003          .891                   .07455
         100                      1.         .90421
         777
          18 -.0305
          29 1490.
         777
       1280.      1280.     650.      580.      .000279   1.00
  .185       .215     .568        1.          1.          .08992
 2200.       0.       .925        .925        .925        .625
    1.       82.2
           1      -25.       1490.                    -556
           2      -25.       1400.
           3      -25.       1310.
           4      -25.       1220.
           5      -.01       1210.
           6      -100.      1210.
           7      -150.      1200.
           8      -150.      1190.
           9      -.01       1180.
          10      -500.      1180.
          11      -1000.     1170.
          12      -2000.     1060.
          13      -2000.     1050.
          14      -2000.      930.
          15      -1870.     710.
          16      -.01       520.
          17      -130.      520.       3000.         -570.
          18      -2000.     500.       3000.
          19      -2400.     325.       3000.
          20      -.01       200.       3000.
          21      -100.      200.                     -575
          22      -900.      190.
          23      -1000.     150.
          24      -2000.     100.
          25      -.01       50.
         777
```

TABLE 8-30

```
          1         2         3         4         5         6         7
123456789012345678901234567890123456789012345678901234567890123456789012

THREE MILE ISLAND FIRST CYCLE STEP 3
AL 2 30 30 32 0 0
ST 1052. .01
BL 310. 200.
PR 10*-1
CB 12656. 15921. 15314. 17585. 15143. 16088. 14439. 10724. 14861. 17454.
CB 15231. 16703. 13986. 13479. 10237. 15266. 16869. 13264. 14717. 12523.
CB 7990. 14094. 14737. 12102. 11264. 10734. 11620. 7744. 8136. 0. 0. 0.
MA 573 555 551 554 551 554 575 556 551 555 551 554 551 555 556 551 553
MA 561 554 572 556 551 553 551 556 574 557 556 556 550 550 550
BU     2 * 7.1E-5
DX 3*4.362196 26*7.2703267
DY 3*4.362196 26*7.2703267
OV 30 1 30 1 30   1 1 4 1 4   2 1 4 4 7   3 1 4 7 10   4 1 4 10 13
OV 5 1 4 13 16   6 1 4 16 19   7 1 4 19 22   8 1 4 22 25   2 4 7 1 4
OV 9 4 7 4 7   10 4 7 7 10   11 4 7 10 13   12 4 7 13 16   13 4 7 16 19
OV 14 4 7 19 22   15 4 7 22 25   3 7 10 1 4   10 7 10 4 7   16 7 10 7 10
OV 17 7 10 10 13   18 7 10 13 16   19 7 10 16 19   20 7 10 19 22
OV 21 7 10 22 25   4 10 13 1 4   11 10 13 4 7   17 10 13 7 10
OV 22 10 13 10 13   23 10 13 13 16   24 10 13 16 19   25 10 13 19 22
OV 5 13 16 1 4   12 13 16 4 7   18 13 16 7 10   23 13 16 10 13
OV 26 13 16 13 16   27 13 16 16 19   28 13 16 19 22   6 16 19 1 4
OV 13 16 19 4 7   19 16 19 7 10   24 16 19 10 13   27 16 19 13 16
OV 29 16 19 16 19   7 19 22 1 4   14 19 22 4 7   20 19 22 7 10
OV 25 19 22 10 13   28 19 22 13 16   8 22 25 1 4   15 22 25 4 7
OV 21 22 25 7 10   31 22 25 10 16   31 10 16 22 25
OV    32 16 19 19 22 32 19 22 16 19
AD
```

ADD DECKS