PILGRIM-1

MULTIPLE CONTROLLED CELL REMOVAL

by

Petros T. Antonopoulos
Nuclear Fuel Division
November, 1979

Prepared by Petros Antonopoulos 11-30-79
Date

Reviewed by James W. Gosnell 12/2/79
Date

Approved by James A. Leny 12-2-79
Date

1542 117

Boston Edison Company
800 Boylston Street
Boston, Massachusetts 02199

TABLE OF CONTENTS

1542 118

LIST OF FIGURES

1542 119

LIST OF TABLES

1542 120

PILGRIM 1

MULTIPLE CONTROLLED CELL REMOVAL

1.0 Introduction

The Technical Specifications for Pilgrim Nuclear Power Station - Unit #1 prohibit withdrawal of more than one control rod when the mode switch is in the "refuel" position. The reason for this restriction is to preclude inadvertent criticality. Certain refueling maintenance activities such as replacement of control rods or control rod drive mechanisms can be done in less time and potentially with lower personnel radiation exposure, if more than one control rod can be withdrawn at a time. This study was undertaken by Boston Edison to demonstrate that multiple control rods can be removed from the core without violating the shutdown margin requirements as long as the adjacent fuel in the cell is removed prior to the control rod removal.

The purpose of this report is to present the method and results pertinent to multiple controlled cell removal for Pilgrim 1. From the reactor physics standpoint the removal of a controlled cell (four fuel assemblies plus control rod) affects the reactor state because of the following:

a. The removal of fuel

b. The removal of the control blade

c. The creation of a water filled gap which acts as a flux trap.

Although the final reactor state following the removal of a controlled cell will be determined by the reactivity contributions made by each of the effects listed above, the individual reactivity contributions will not be determined, only the total reactivity contribution will. The present analysis will show that at any cycle of Pilgrim 1 all reactivity contributions from multiple

controlled cell removal lead to a more subcritical state, and consequently increase the shutdown margin of the core.

This analysis consists of two sections, the benchmark section and the multiple controlled cell removal section. The benchmark section is intended to show that the method and the computer programs used reproduce accurately critical states of Pilgrim 1. This provides the necessary confidence in the method and computer programs so that the multiple controlled cell removal analysis can be performed. The multiple controlled cell removal analysis uses the same method and computer programs, in order to show that multiple controlled cell removal always results in a more subcritical state.

2.0 Method

The method used in this study has been based on Pilgrim 1 nuclear design parameters and cycle data such as assembly types, assembly layout, and assemblywise average exposure distribution. In addition, it utilizes the computer programs GAPCON-Thermal 2[1], CASMO[2], PDQ[3]. Among the computer programs, GAPCON-Thermal 2 is a fuel performance code and has been used to calculate the fuel temperature which is an input parameter to CASMO. CASMO is a lattice code capable of performing physics calculations for boiling and pressurized water reactors, in pin cell or assembly geometry. This code has the capability of performing controlled and uncontrolled fuel depletions at any void and can handle fuel rods with gadolinia. CASMO has been used to calculate macroscopic cross sections which are input to PDQ. PDQ is a fine mesh nuclear simulator capable of performing diffusion theory calculations.

Based on the Pilgrim 1 nuclear design parameters and cycle data the method proceeds as follows:

a. GAPCON-Thermal 2 is set up to calculate the fuel temperature at full power conditions. This fuel temperature is a necessary input to CASMO when full power calculations need to be performed.

b. For each assembly type a CASMO is set up in assembly geometry. For assemblies with zero exposure a beginning of cycle CASMO calculation is performed at the proper conditions. For assemblies with different than zero exposure, CASMO is set up and depleted uncontrolled at full power and average void conditions. The restart file is saved at the required exposure points and then a CASMO restart calculation is performed by attaching the required restart file and performing the necessary restart calculations at the proper conditions such as, zero power, cold (68^{o}F), controlled, no equilibrium xenon, etc. From each

CASMO calculation two group average macroscopic cross sections are calculated. The two group macroscopic cross sections are calculated in CASMO by flux and volume weighting the macroscopic cross sections of all fuel, fuel with gadolinia, water rod, channel, wide and narrow water gaps and the control blade (if present). For a given cycle the assemblies of the same type are gathered into groups of approximately equal exposure. For each group the average exposure is calculated and controlled or uncontrolled cross sections sets are calculated with CASMO at the average exposure. These sets of cross sections are input to PDQ and are assigned respectively to controlled or uncontrolled assemblies in the group.

c. For each cycle a quarter core or, if necessary, a full core PDQ is set up in two energy groups. Each assembly with its wide and narrow water gaps is homogenized in PDQ and is represented with an 8 x 8 plannar region. The quarter core geometry consists of 120 x 120 mesh grid and the full core geometry consists of 240 x 240 grid with 1.905 cm mesh size. A controlled cell in PDQ consists of four plannar regions which are assigned controlled cross sections. The removal of a controlled cell is simulated by assigning water cross sections to its four plannar regions. To determine whether the removal of a controlled cell leads to a more or less subcritical state two PDQ calculations are performed. The first calculation has all controlled cells in the core and the second has the cell or cells of interest removed. If the calculated Keff of the second case is less than the Keff calculated from the first case, it is concluded that the removal leads to a more subcritical state.

3.0 Benchmark Calculations

The intent of this section is to provide confidence in the programs and the method used in the analysis. The first part of the benchmark calculations consist of pin cell CASMO criticality calculations and the second consists of CASMO-PDQ calculations at the beginning of Pilgrim 1 cycle 4.

3.1 CASMO Criticality Calculations

A number of CASMO criticality calculations for uniform moderated lattices have been performed on pin cell geometry using the 25 energy group library and the experimental criticality data of Reference 4. Table 1 lists the results of this analysis. Considering all the cases analyzed, the calculations result in a Keff mean value of 1.00076 with a standard deviation of a sample about the mean of ±.00617 which is in very good agreement with the criticality data.

3.2 Pilgrim 1 BOC-4 Critical Calculations

Five cold critical states from the beginning of cycle 4 of Pilgrim 1 were used to test the accuracy of the method. Quarter core PDQ calculations, using CASMO generated cross sections, were performed in order to calculate the effective multiplication factor. The calculations used the control rod positions and coolant temperatures of the BOC-4 critical states. The data from the cold critical states are shown on Tables 2 through 6. Figure 1 shows the cycle 4 assembly layout from Reference 5, and the beginning of cycle 4 assemblywise exposure distributions from the plant process computer. The fuel assembly design parameters were obtained from References 6,7, and 8.

For the first critical state two group average macroscopic cross sections were generated for the fuel types and conditions shown on Table 7. Similar cross section sets were generated for the remaining critical states using their respective coolant temperatures. The water cross sections were calculated in CASMO, by flux and volume weighting the wide and narrow water gap cross sections of 8DB219 assembly at the critical state coolant temperature.

1542 125

TABLE 1

CASMO Criticality Calculations for Uniform Water - Moderated Lattices

CASE	CASMO Keff
9	1.00290
10	1.00323
11	1.00096
12	1.00801
13	1.01141
14	1.00909
15	1.00071
16	.99561
17	1.00590
18	1.00401
19	1.00246
20	.99380
21	.99473
22	.99384
23	.99337
24	.99213

1542 126

TABLE 2

CRITICAL STATE 1

BOC-4 Pilgrim 1

Date 11-14-77

Coolant Temperature 157°F

Control Rod Notch Position Withdrawn

51				48	0	48	0	48	0	48			
47			4	0	0	0	4	0	0	0	4		
43		48	0	48	0	48	0	48	0	48	0	48	
39	4	0	0	0	8	0	0	0	4	0	0	0	4
35	0	48	0	48	0	48	0	48	0	48	0	48	0
31	0	0	4	0	0	0	8	0	0	0	8	0	0
27	0	48	0	48	0	48	0	48	0	48	0	48	0
23	0	0	8	0	0	0	4	0	0	0	4	0	0
19	0	48	0	48	0	48	0	48	0	48	0	48	0
15	4	0	0	0	4	0	0	0	8	0	0	0	4
11		48	0	48	0	48	0	48	0	48	0	48	
07			4	0	0	0	4	0	0	0	4		
03				48	0	48	0	48	0	48			
	02	05	10	14	18	22	26	30	34	38	42	46	50

1542 127

TABLE 3

CRITICAL STATE 2

BOC-4 Pilgrim 1

Date 11-15-77

Coolant Temperature 289°F

Control Rod Notch Position Withdrawn

51				48	0	48	0	48	0	48			
47			12	0	0	0	12	0	0	0	12		
43		48	0	48	0	48	0	48	0	48	0	48	
39	12	0	0	0	12	0	0	0	12	0	0	0	12
35	0	48	0	48	0	48	0	48	0	48	0	48	0
31	0	0	12	0	0	0	20	0	0	0	12	0	0
27	0	48	0	48	0	48	0	48	0	48	0	48	0
23	0	0	12	0	0	0	12	0	0	0	12	0	0
19	0	48	0	48	0	48	0	48	0	48	0	48	0
15	12	0	0	0	12	0	0	0	12	0	0	0	12
11		48	0	48	0	48	0	48	0	48	0	48	
07			12	0	0	0	12	0	0	0	12		
03				48	0	48	0	48	0	48			
	02	06	10	14	18	22	26	30	34	38	42	46	50

1542 128

TABLE 4

CRITICAL STATE 3

BOC-4 Pilgrim 1

Date 11-16-77

Coolant Temperature 180^{o}F

Control Rod Notch Positions Withdrawn

51				48	0	48	0	48	0	48			
47			8	0	0	0	8	0	0	0	8		
43		48	0	48	0	48	0	48	0	48	0	48	
39	8	0	0	0	8	0	0	0	8	0	0	0	8
35	0	48	0	48	0	48	0	48	0	48	0	48	0
31	0	0	8	0	0	0	10	0	0	0	8	0	0
27	0	48	0	48	0	48	0	48	0	48	0	48	0
23	0	0	8	0	0	0	8	0	0	0	8	0	0
19	0	48	0	48	0	48	0	48	0	48	0	48	0
15	8	0	0	0	8	0	0	0	8	0	0	0	8
11		48	0	48	0	48	0	48	0	48	0	48	
07			8	0	0	0	8	0	0	0	8		
03				48	0	48	0	48	0	48			
	02	06	10	14	18	22	26	30	34	38	42	46	50

1542 129

TABLE 5

CRITICAL STATE 4

BOC-4 Pilgrim 1

Date 11-19-77

Coolant Temperature 111°F

Control Rod Notch Positions Withdrawn

51				48	0	48	0	48	0	48			
47			0	0	0	0	0	0	0	0	0		
43		48	0	48	0	48	0	48	0	48	0	48	
39	0	0	0	0	4	0	0	0	4	0	0	0	0
35	0	48	0	48	0	48	0	48	0	48	0	48	0
31	0	0	4	0	0	0	4	0	0	0	4	0	0
27	0	48	0	48	0	48	0	48	0	48	0	48	0
23	0	0	4	0	0	0	4	0	0	0	0	0	0
19	0	48	0	48	0	48	0	48	0	48	0	48	0
15	0	0	0	0	0	0	0	0	4	0	0	0	0
11		48	0	48	0	48	0	48	0	48	0	48	
07			0	0	0	0	0	0	0	0	0		
03				48	0	48	0	48	0	48			
	02	06	10	14	18	22	26	30	34	38	42	46	50

1542 130

TABLE 6

CRITICAL STATE 5

BOC-4 Pilgrim 1

Date 11-25-77

Coolant Temperature 137^{o}F

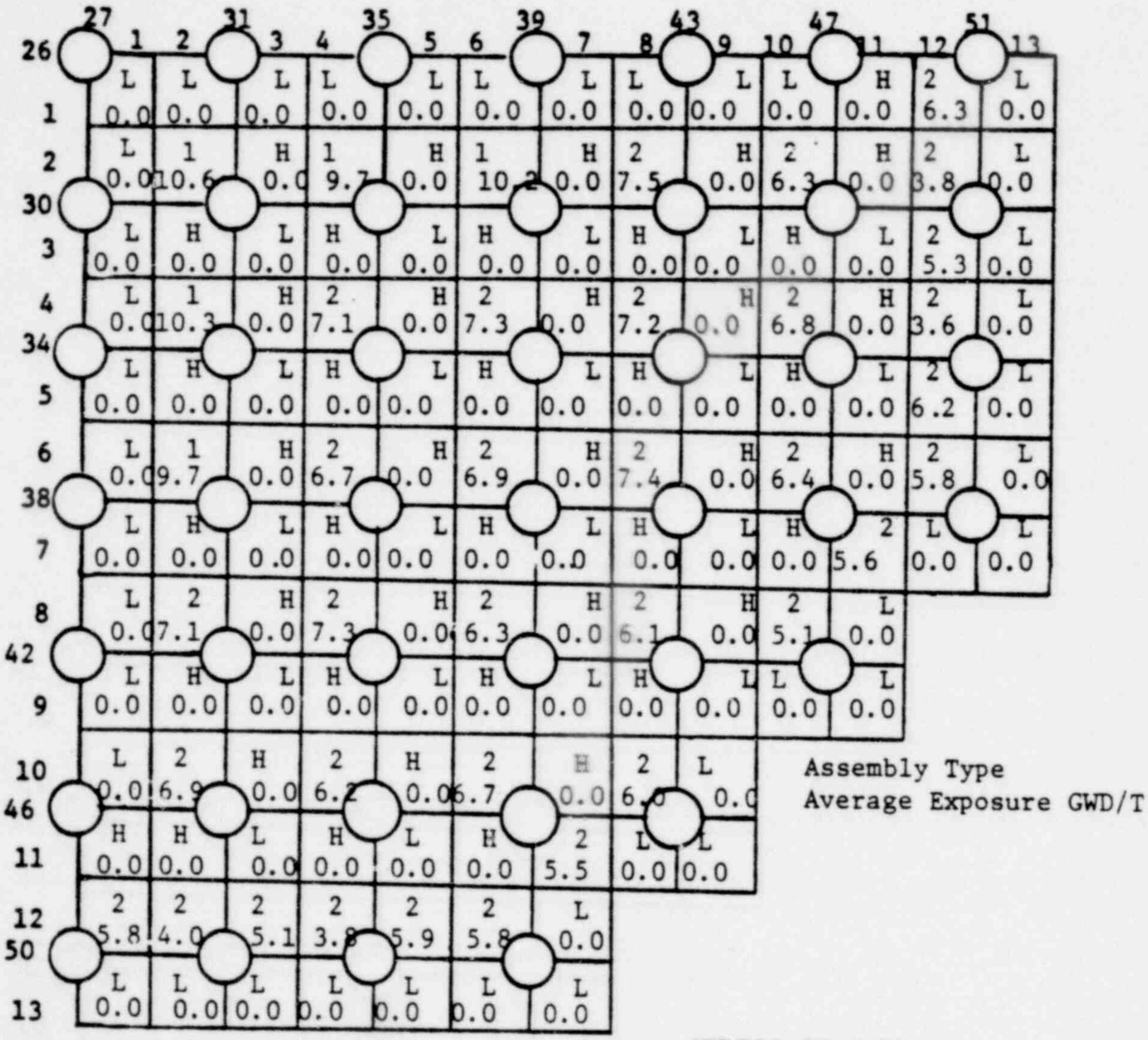
Control Rod Notch Positions Withdrawn

51				48	0	48	0	48	0	48			
47			4	0	0	0	4	0	0	0	4		
43		48	0	48	0	48	0	48	0	48	0	48	
39	4	0	0	0	4	0	0	0	4	0	0	0	4
35	0	48	0	48	0	48	0	48	0	48	0	48	0
31	0	0	4	0	0	0	8	0	0	0	4	0	0
27	0	48	0	48	0	48	0	48	0	48	0	48	0
23	0	0	4	0	0	0	4	0	0	0	4	0	0
19	0	48	0	48	0	48	0	48	0	48	0	48	0
15	4	0	0	0	4	0	0	0	4	0	0	0	4
11		48	0	48	0	48	0	48	0	48	0	48	
07			4	0	0	0	4	0	0	0	4		
03				48	0	48	0	48	0	48			
	02	06	10	14	18	22	26	30	34	38	42	46	50

1542 131

FIGURE 1

PILGRIM BOC-4



		NUMBER IN CORE
1 -	8DB262	20
2 -	8DB262	132
L -	8DB219L	244
H -	8DB219H	184
	TOTAL	580

1542 132

TABLE 7

Cross Section Sets Generated by CASMO for Critical State 1

Fuel Type	Exposure (GWD/MT)	Void	Mod T. (°F)	Fuel T (°F)	EQ.Xe	Control
8DB219L	0	0	157	157	No	No
8DB219L	0	0	157	157	No	Yes
8DB219H	0	0	157	157	No	No
8DB219H	0	0	157	157	No	Yes
8DB262	4	0	157	157	No	No
8DB262	4	0	157	157	No	Yes
8DB262	7	0	157	157	No	No
8DB262	7	0	157	157	No	Yes
8DB262	11	0	157	157	No	No
8DB262	11	0	157	157	No	Yes

The calculation of the effective multiplication factor for each critical state should be estimated by performing three dimensional calculations so that the partially withdrawn control rods will be accurately represented. Since three dimensional calculations are prohibitively expensive the effective multiplication factor was estimated by performing two dimensional PDQ calculations. First, a quarter core PDQ calculation was performed having fully inserted all the fully inserted and all the partially withdrawn control rods for the critical state. Second, another quarter core PDQ calculation for the same critical state was performed having fully inserted all the fully inserted control rods, while all the partially withdrawn rods were fully withdrawn. The above PDQ calculations provide effective multiplication factors $Keff^1$ and $Keff^2$ which satisfy the following relation:

$$Keff^1 < Keff \text{ (critical state)} < Keff^2$$

Since two dimensional PDQ calculations can not account for the reactivity contributions of the withdrawn notches an estimate of Keff (critical state) is obtained by adjusting $Keff^1$. The adjustment to $Keff^1$ is estimated assuming that the reactivity worth of the partially inserted control rods is proportional to the number of notches they are inserted. For example, consider critical state 1

$$Keff^1 = .998248$$

$$Keff^2 = 1.019404$$

from Table 2 it can be seen that there are 20 partially withdrawn control rods. The worth of these control rods when fully inserted is $-2.07897\% \Delta\rho$. In critical state 1 these control rods are withdrawn a total of 100 notches out of the 960, therefore, the reactivity adjustment to $Keff^1$ is:

$$2.07897 \times \frac{100}{960} = .216559\% \Delta\rho$$

1542 134

Consequently, the estimated Keff (critical state 1) = 1.000411. Table 8 shows the results of all the benchmark calculations. The value of the estimated Keff depends on the coolant temperature. To understand the sensitivity to the coolant temperature, the calculation of critical state 1 was repeated at 137°F. The estimated Keff's for the two critical state 1 calculations are:

Keff (157) = 1.000411

Keff (137) = 1.003871

From these Keff's it is seen that for a -20°F change in the coolant temperature the estimated Keff changes only by +.35%. In addition, this brief calculation shows that the moderator temperature coefficient at BOC-4 conditions is negative. The negative moderator temperature coefficient suggests that the multiple controlled cell removal analysis be performed at 68°F coolant temperature. From Table 8 and the results of the above calculation it is concluded that the method used in the benchmark calculation is acceptably accurate.

1542 135

TABLE 8

Results of The Benchmark Calculations

	Mod Temp °F	Keff [1]	Keff [2]	Partially Withdrawn Rods: Reactivity Worth (Δρ %) Fully In	Notches When Fully In	Notches With-drawn	Reactivity Adjustment to Keff [1] (Δρ %)	Estimated Critical State Keff
Critical State 1	157	.998248	1.019404	-2.078970	960	100	.216559	1.000411
Critical State 2	289	.986049	1.008876	-2.294662	960	254	.607519	.991992
Critical State 3	180	.996345	1.017753	-2.111127	960	162	.356253	.999894
Critical State 4	111	1.000665	1.017068	-1.744523	384	32	.145377	1.002122
Critical State 5	137	1.001661	1.023293	-2.110436	960	84	.184663	1.003517

4.0 Multiple Controlled Cell Removal Analysis

The results of the benchmark calculations have shown that the method used is acceptably accurate and for this reason it can be applied to the multiple controlled cell removal analysis.

The objective of this analysis is to show that at any cycle of Pilgrim 1 removal of one or more controlled cells at a time always leads to a more subcritical state. This objective will be achieved in three steps. First, the effect of multiple control cell removal is evaluated at cold (68°F), Xenon-free conditions at the beginning-of-cycle 5 core loading configuration, which is a typical and representative reload configuration for Pilgrim 1. A sufficient number of cases are evaluated to verify that all representative conditions of removal of one or more controlled cells have been examined. It will be concluded that all representative combinations of controlled cell removals at BOC-5 lead to a more subcritical state. Since beginning-of-cycle is not the most reactive state in cycle 5, because of the gadolinia depletion effect, the second step of the analysis is to demonstrate that the conclusion reached in the first step is valid throughout cycle 5. Finally, the third step of the analysis is to demonstrate that the conclusion reached for cycle 5 is a general conclusion which applies to all cycles.

Figure 2 shows the BOC-5 core loading configuration for Pilgrim 1. This loading pattern is typical of reload cores which are loaded in a quarter-core symmetric,scatter pattern of high and low reactivity bundles. As such, the reactivity worth of individual four bundle cells varies from cell to cell. Removal of a controlled cell affects the reactivity of not only the cell which is removed, but also the adjacent cells as well. Before reaching any general conclusion on the effects of controlled cell removal, a sufficient number of cases must be examined to span the range of combinations representative of the core configuration, e.g. high reactivity cell adjacent

1542 137

FIGURE 2

PILGRIM 1 BOC-5

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	3 14.0	2H 9.4	FH 0.0	3 13.4	3 15.6	2H 9.6	FH 0.0	3 14.1	3 15.2	2H 10.9	FL 0.0	2H 11.2	2L 11.1
2	2H 9.7	FH 0.0	2L 6.0	FH 0.0	2L 6.3	FH 0.0	2L 4.9	FL 0.0	2L 5.9	FL 0.0	2L 5.6	FL 0.0	2L 11.5
3	FH 0.0	2H 9.3	FH 0.0	2L 10.1	FH 0.0	2H 10.7	FH 0.0	2H 9.9	FL 0.0	2L 11.6	FL 0.0	FL 0.0	2H 11.0
4	3 13.6	FH 0.0	2L 10.3	3 13.4	2L 11.6	FH 0.0	2L 5.9	3 13.6	2L 11.0	FL 0.0	2L 6.0	2L 6.2	2L 11.5
5	3 15.6	2L 6.2	FH 0.0	2H 11.0	3 15.4	2H 10.2	FL 0.0	2L 10.2	3 14.2	2H 10.6	FL 0.0	2L 10.6	2H 11.0
6	2H 9.5	FH 0.0	2H 10.7	FH 0.0	2H 10.1	FL 0.0	2L 4.0	FL 0.0	2L 6.0	FL 0.0	2L 5.6	2H 11.2	2L 11.3
7	FH 0.0	2L 4.1	FH 0.0	2L 6.2	FL 0.0	2L 8.3	FL 0.0	2H 10.6	FL 0.0	FL 0.0	2H 10.6	2L 11.1	2L 11.1
8	3 14.0	FL 0.0	2H 10.2	3 13.5	2L 10.2	FL 0.0	2H 10.3	2H 11.0	2H 11.3	2L 3.6	2L 11.4		
9	3 15.2	2L 6.1	FL 0.0	2L 10.9	3 14.7	2L 5.7	FL 0.0	2H 11.2	2L 10.1	2L 11.5	2L 11.4		
10	2H 10.8	FL 0.0	2L 11.6	FL 0.0	2H 10.3	FL 0.0	FL 0.0	2L 3.6	2L 11.5				
11	FL 0.0	2L 6.2	FL 0.0	2L 4.9	FL 0.0	2L 6.0	2H 10.3	2L 11.5	2L 11.5				
12	2H 11.2	FL 0.0	FL 0.0	2L 5.8	2L 11.0	2H 11.2	2L 11.0						
13	2L 11.1	2L 11.5	2H 11.1	2L 11.5	2H 11.0	2L 11.3	2L 11.3						

Assembly Type
Average Exposure GWD/T

	Number in Core
FH - P8DRB282	64
FL - P8DRB265L	120
2H - 8DB219H	124
2L - 8DB219L	212
3 - 8DB262	60
TOTAL	580

1542 138

to high reactivity cell, high reactivity cell adjacent to low reactivity cell, edge cell, interior cell, multiple cells,etc.

The cases which were evaluated and the resultant core K-effectives are shown in Table 10. The effect of removing one, two or three cells was examined by performing full core PDQ calculations. The remaining multiple cell removal cases, where 4 or 8 or 16 symmetric cells were removed at a time, were evaluated by performing quarter core PDQ calculations. The assembly design parameters were obtained from References 7, 8 and 9. Table 9 shows the fuel types and conditions for which average macroscopic cross sections were generated for the analysis. The water cross sections were generated in CASMO by flux and volume weighting the wide and narrow water gap cross sections of an 8DB219L assembly. To verify that the water cross sections have been properly determined a parametric study was performed and it is shown in Appendix A. The first case shown in Table 10 is the all-rods-in case with no cell(s) removed. The remaining cases are for various combinations of controlled cells removed. All cases in Table 10 were analyzed in quarter core geometry, except cases 14, 15 and 16 which were analyzed in full core geometry. From Table 10 it can be seen that for all cases considered the reactor reaches a more subcritical state after controlled cell removal as compared to the all-rods-in case with no cell(s) removed. The reactivity loss per cell removed for the various cases in Table 10 is plotted as a function of distance from the core center in Figure 3. From Figure 3 it can be seen that the reactivity loss is always positive and it is higher for cells removed closer to the core center. There are no anomalous points to suggest a need to consider additional cases. Since the removal covers uniformly the distance from the center to the core periphery, there is reasonable assurance that any other cells that have not been analyzed will follow the trend seen in Figure 3. It is therefore concluded that all representative combinations of controlled cell removals at BOC-5 lead to a more subcritical state.

1542 139

TABLE 9

Cross Section Sets for Multiple Controlled Cell Removal Analysis

Assembly Type	Cross Section
First Step	
8DB262	2G, Controlled, 68°F, 13.5 and 15 GWD/MT
8DB219L	2G, Controlled, 68°F, 4,6 and 11 GWD/MT
8DB219H	2G, Controlled, 68°F, 9.9 and 10.9 GWD/MT
P8DRB265L	2G, Controlled, 68°F, 0 GWD/MT
P8DRB282	2G, Controlled, 68°F, 0 GWD/MT
Second Step	
P8DRB265L	2G, Controlled, 68°F, 0 GWD/MT, No Gd
P8DRB282	2G, Controlled, 68°F, 0 GWD/MT, No Gd
Third Step	
P8DRB282	2G, Controlled, 68°F, 0 GWD/MT, No Gd
8DB219L	2G, Controlled, 68°F, 30 GWD/MT

1542 140

TABLE 10

Multiple Controlled Cell Removal

BOC-5 Results

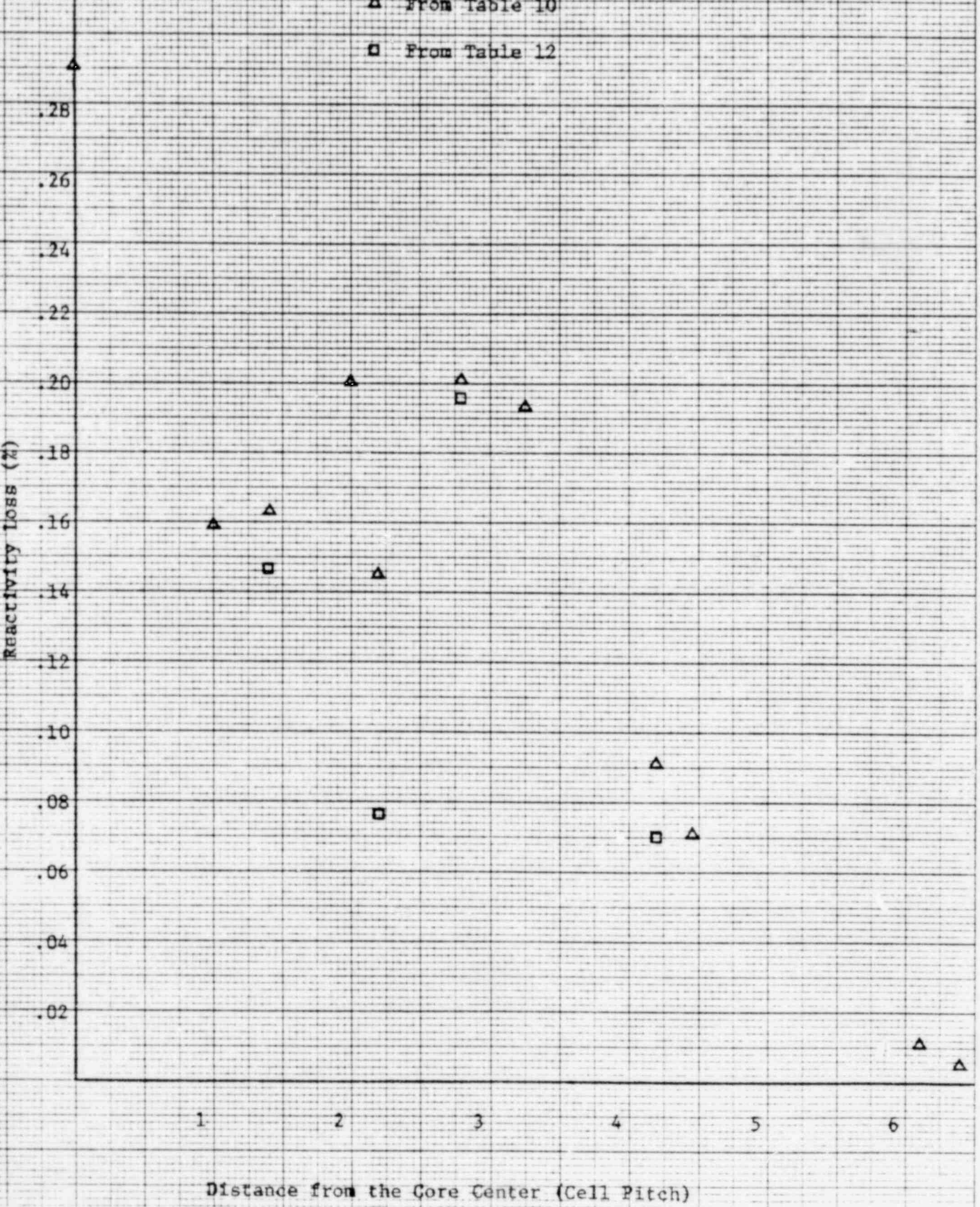
Cells Removed	Keff
1. None	.945166
2. 35-26, 27-34	.937744
3. 31-30	.939369
4. 47-42, 43-46	.944748
5. 39-30, 31-38	.931509
6. 51-30, 31-50	.944373
7. 35-30, 31-34	.934888
8. 35-34	.937729
9. 31-26, 27-30	.940316
10. 43-34, 35-42	.940103
11. 43&47-30, 31-42&46	.938685
12. 43-30, 31-42	.938803
13. 27-26	.942571
14. 31-30 UL*Full Core	.943292
15. 31-30 UL & UR*Full Core	.942032
16. 31-30 UL & UR & LL* Full Core	.940502

* UL - upper left, UR - upper right, LL - lower left

1542 141

FIGURE 3

Reactivity Loss Per Cell Removed
Versus
Distance from the Core Center



The beginning-of-cycle is not the most reactive state of the core in cycle 5. The most reactive state is reached when the reload bundles reach their peak reactivity as the gadolinia burn out. To examine whether the conclusion just reached is valid throughout cycle 5, it would require rerunning all cases, previously examined, but with new cross section sets updated for various cycle 5 exposure increments. An alternate approach and the one which is used herein is to make a conservative bounding calculation. The matter at issue is quite simply-is there a reactivity loss or is there a reactivity gain for controlled cell removal at the time the core is at its most reactive state in the cycle? If there is a reactivity gain, then one is concerned with the absolute value of Keff, since there is danger of inability to maintain shutdown margin. However, if there is a reactivity loss, then the absolute value of Keff is inconsequential since the results are in the conservative direction. The method used in this analysis to maximize the reacitivity state of the core for cycle 5 is to examine the case in which previously exposed bundles are assumed to remain at the BOC-5 exposure and the new reload bundles are assumed to have no gadolinia at zero exposure. This results in a reactivity of the reload bundles which is much greater than would ever be achieved in a normal cycle, and consequently a core reactivity state which is more reactive than any time in cycle 5.

Using the method just described, the first three cases from Table 10 were reanalyzed and the results are shown on Table 11. The cells which are assumed to be removed were selected because they are near the center of the core which is a high reactivity worth area. As can be seen, the core loses reactivity as control cells are removed. This demonstrates that the conclusion previously reached for beginning of cycle 5 is valid throughout the cycle.

The last issue to be addressed is whether this conclusion is valid for all cycles. This is verified by bounding the range of bundle enrichments which might be loaded in subsequent reloads and by evaluating the controlled cell removal

TABLE 11

Multiple Controlled Cell Removal

BOC-5 Fresh Assemblies Without Gd

	Cells Removed	Keff
1.	None	1.022974
2.	31-30	1.012614
3.	35-26, 27-34	1.011246

1542 144

effect. The maximum enrichment available for Pilgrim is that of the P8DRB282 bundle. In this analysis the maximum enrichment is bounded by assuming that the bundle contains no gadolinia. The first bounding case evaluates the removal effect assuming a full core of fresh P8DRB282 bundles without gadolinia. The results of this analysis are shown on Table 12 and the reactivity loss as a function of distance from the core center has been plotted on Figure 3. From Figure 3 it can be seen that the results of this fictitious cycle follow the trend established by the BOC-5 results. The second bounding case (the most conservative one) evaluates the effect of removing a single highly burned cell (consisting of four 8DB219L bundles at 30 GWD/MT in position 35-34) from a quarter-core of fresh P8DRB282 bundles without gadolinia. The results of this analysis are shown on Table 13. From Tables 12 and 13, it can be seen that the core reaches a less reactive state after the removal. Since the results of Tables 12 and 13 conservatively bound all future Pilgrim 1 cycles it is concluded that the removal of one or more controlled cells from any cycle of Pilgrim 1 will not violate shutdown margin requirements because it leads to a more sub-critical state.

1542 145

TABLE 12

Multiple Controlled Cell Removal

Fictitious Cycle With Fresh P8DRB282 Fuel No Gd

Cell Removed	Keff
1. None	1.140383
2. 43&47-30, 31-42&46	1.133016
3. 31-30	1.132806
4. 35-30, 31-34	1.126882
5. 31-26&30, 27-30	1.132351
6. 43-30, 31-42	1.133149
7. 35-34	1.130278

1542 146

TABLE 13

Multiple Controlled Cell Removal

Fresh Core of P8DRB282 With One Highly Burned 8DB219L

Cell Removed	Keff
1. None	1.131706
2. 35-34	1.130278

1542 147

5.0 Conclusion

The analysis presented in this report shows that the method used is acceptably accurate and that removal of more than one controlled cell at a time, from any cycle of Pilgrim 1 at shutdown conditions, does not violate the shutdown margin requirements because it leaves the reactor in a more subcritical state.

1542 148

APPENDIX A

After the removal of a controlled cell the volume is filled with water. The water cross section for PDQ are calculated in CASMO by flux and volume weighting the wide and narrow water gap cross sections. Keeping in mind that these gaps are small compared to the controlled cell volume, one might question whether these cross sections are appropriate. To answer this question two sets of water cross sections were generated for BOC conditions at 68°F one using the standard narrow and wide gap dimensions and the other using 10 cm and 12 cm thickness for the narrow and wide water gaps respectively. The results of this study is shown on Table 14. From Table 14 it can be concluded that for this analysis the water cross sections are not very sensitive to the water gap dimensions.

1542 149

TABLE 14

Water Cross Section Parametric Study

Cells Removed	Keff Standard Size Gaps	Keff 12 cm Wide Gap 10 cm Narrow Gap
1. None	.945091	.945026
2. 31-30	.939373	.939002

1542 150

References

1. C.E. Beyer, C.R. Hann, D.D. Lanning, F.E. Panisko and L.J. Parchen, "User's Guide for GAPCON-Thermal 2: A computer Program for Calculating the Thermal Behavior of an Oxide Fuel Rod", BNWL-11897, November, 1975.

2. A. Ahlin, M. Edenius, H. Haggblom, "CASMO A Fuel Assembly Burnup Program", Studvic Report AE-RF-76-4158 (Rev. Ed), June, 1978.

3. W.R. Cadwell, "PDQ-7 Reference Manual", WAPD-TM-678 (1967).

4. L.E. Strawbridge and R.F. Barry; "Criticality Calculations for Uniform Water - Moderated Lattices", NSE, 23,58-73 (1965)

5. Reload No. 3 Licensing Submittal for Pilgrim Nuclear Power Station Unit #1, May 1977, NEDO-21462-01.

6. Pilgrim Reload No. 3 Revision 1, Nuclear Design Report, August 1977, NEDE-21512.

7. Pilgrim Reload No. 1, Nuclear Design Report, March 1974, NEDE-20354.

8. BWR/4 and BWR/5 Fuel Design, October 1976, NEDE-20944-P.

9. Generic Reload Fuel Application, Licensing Topical Report NEDE-24011-P.