2

DOE/ET/34010-1

CEND-382

June, 1980

MASTER

THE EVALUATION AND DEMONSTRATION OF METHODS FOR IMPROVED FUEL UTILIZATION

FIRST SEMI-ANNUAL
PROGRESS REPORT

October 1979 - March 1980

Prepared for
The United States
Department
of Energy

Omaha Public Power District

CE POWER
SYSTEMS

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared by Combustion Engineering, Inc., as an account of work sponsored by the United States Department of Energy. Neither DOE nor Combustion Engineering, Inc., nor any person acting on behalf of either:

- A. Makes any warranty or representation, expressed or implied including the warranties of fitness for a particular purpose of merchantability, with respect to the accuracy, completeness or usefulness of the information contained in this report, or that the use of any information, apparatus, method or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

Evaluation and Demonstration of Methods
for Improved Fuel Utilization

First Semi-Annual Progress Report:
September 1979 - March 1980

MASTER

By:
U. Decher

The material contained in this report represents the cooperative effort of the following individuals: M. A. Book, L. V. Corsetti, I. B. Fiero, J. C. Lavake, K. M. Madden, G. P. Smith, R. M. Versluis of the Nuclear Power Systems Division of Combustion Engineering, Inc. and J. K. Gasper, J. T. Lu and K. C. Holthaus of Omaha Public Power District.

June 25, 1980

Prepared for the United States Department of Energy
Under Contract Number: DE-AC02-79ET34010
by:

C-E Power Systems
Combustion Engineering, Inc.
1000 Prospect Hill Road
Windsor, CT 06095

Omaha Public Power District
1623 Harney Street
Omaha, NE 68102

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

fy

Evaluation and Demonstration of Methods for
Improved Fuel Utilization

ABSTRACT

*improved
of fuel management
and burnup*

~~The purpose of this program is to demonstrate two techniques for improving fuel utilization in current Pressurized Water Reactors (PWR): (1) more efficient fuel management, and (2) high burnup. These demonstrations are being performed in the Fort Calhoun reactor, located near Omaha, Nebraska, this reactor is a 1420 Mwt PWR owned and operated by Omaha Public Power District. More efficient fuel management will be achieved through the implementation of a low leakage concept called SAVFUEL (Shimmed And Very Flexible Uranium Element Loading), which is expected to reduce uranium requirements by two to four percent (2% to 4%). The burnup will be increased sufficiently to reduce uranium requirements by five to fifteen percent (5% to 15%) depending on the means chosen to exploit the additional burnup capabilities of the fuel.~~

The current Phase I program will be accomplished in two parts, one to demonstrate SAVFUEL and the other to demonstrate high burnup. Use of SAVFUEL fuel management causes some of the fuel rods to experience a different power history from cycle to cycle in comparison to more conventional fuel management. Therefore, Phase IA will include a demonstration that this duty cycle does not have a deleterious effect on fuel performance. Phase IB will include poolside and hot cell examinations of selected fuel rods of the current (14 x 14) design which will be irradiated for three, four and five cycles and are expected to achieve a peak rod average burnup of greater than 45 GWD/T.

This report outlines the program and covers the progress during the period from October 1979 to March 1980. Four fuel assemblies scheduled to demonstrate the SAVFUEL duty cycle and loaded into the core in

December 1978 were inspected visually prior to their second exposure cycle. In addition, seventeen fuel assemblies were inspected after their fourth exposure cycle having achieved assembly average burnup up to 36 GWD/T. One assembly has been reinserted into Cycle 6 for a fifth exposure cycle. The preliminary results of all visual fuel inspections which appear to show excellent fuel rod performance are presented in this report. Data reduction from the fuel inspection is currently in progress.

In addition, this report contains the results of a licensing activity which was performed to allow insertion of a highly burned assembly into the reactor for a fifth irradiation cycle. These results formed the basis of an incremental license submittal which has been approved by the NRC.

Summary

The general objective of the program is to demonstrate two techniques for improving uranium resource utilization in current Pressurized Water Reactors. These two techniques are: (1) to develop and demonstrate a low leakage fuel management scheme and (2) to extend discharge burnup for the current 14 x 14 fuel design. These demonstrations are being performed in the Fort Calhoun Reactor located near Omaha, Nebraska. Phase I, the current program, consists of lead bundle demonstrations of the uranium utilization improvements. These lead bundle demonstrations will be followed by a core-wide implementation in a future Phase II demonstration program.

Part A of Phase I will be a demonstration, in Cycles 5, 6 and 7, that the different power history of the SAVFUEL (Shimmed And Very Flexible Uranium Element Loading) fuel management scheme does not cause detrimental effects on fuel performance, including PCI (Pellet Clad Interaction) behavior. The four assemblies which will experience the modified power duty cycle are part of Batch G inserted in Fort Calhoun in December, 1978.

Part B of Phase I includes poolside and hot cell examinations of fuel rods which will have been irradiated for three, four and five cycles and will have achieved an anticipated peak rod average burnup of greater than 45 GWD/T. Included in the examinations will be measurements of internal void volumes and fuel rod gas pressure, dimensional changes, and clad corrosion; pellet and clad microstructure will also be examined for selected rods for correlation with corresponding fission gas release and corrosion behavior. Most of the rods to be examined are from Batch D, which was inserted in the core at the beginning of Cycle 2 in May, 1975. A visual examination has been completed after four cycles of irradiation in February 1980. This is to be followed by detailed poolside and hot cell exams after five cycles of irradiation in 1981.

In late 1979, an incremental licensing effort was performed for the Cycle 6 submittal to the NRC; this effort was needed to gain NRC approval for reinserting a Batch D fuel assembly for a fifth exposure cycle. The projected burnup of the Batch D fuel assembly extended beyond the limits of the base license submittal, and hence a supplementary analysis was required to assure acceptable performance under normal operation and under accident conditions. This analysis indicated acceptable performance during the fifth exposure cycle, and the results of the analysis were incorporated into the license submittal.

A visual examination was performed in February 1980, at EOC5, after one exposure cycle on the Batch G fuel assemblies and four exposure cycles on the Batch D fuel assemblies. This examination showed excellent fuel rod and assembly performance to maximum assembly-average burnups exceeding 36 GWD/T. Fuel rod shoulder gap observations indicated more than adequate clearance to accommodate additional irradiation-induced fuel rod growth during subsequent exposure cycles, and peripheral fuel rod channel width observations indicated no channel closures greater than 25%. Measurements of the coolant activity indicate no fuel failures.

Four Batch G assemblies have been retained on the periphery of the core and rotated 180° in order to simulate the second exposure cycle of the SAVFUEL power cycle. In addition, one Batch D fuel assembly has been reinserted into the core for a fifth exposure cycle. Detailed fuel inspections of the SAVFUEL demonstration fuel assemblies are being planned for end of Cycles 6 and 7 and for the high burnup demonstration assemblies at end of Cycle 6.

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
Abstract	2
Summary	4
1. Introduction	9
2. Phase IA Program Description	10
2.1 Introduction	10
2.2 Phase IA Workscope	12
3. Phase IB Program Description	18
3.1 Introduction	18
3.2 Phase IB Workscope	18
4. Simulation of SAVFUEL Duty Cycle - Progress to Date	23
4.1 Introduction	23
4.2 Characterization of Rods	23
4.3 PCI Evaluation Prior to Cycle 7	26
4.4 Poolside Inspection After Cycle 5	26
5. High Burnup Demonstration - Progress to Date	26
5.1 Introduction	26
5.2 Incremental Licensing Cycle 6, the Fifth Exposure Cycle for One Batch D Assembly	27
5.3 Poolside Inspection After Cycle 5	30
6. References	38

List of Tables

<u>Table</u>		<u>Page</u>
2.1	Simulation of SAVFUEL Duty Cycle Pre-irradiation Characterization Program Scope	13
2.2	Phase IA Simulation of SAVFUEL Duty Cycle Poolside Inspection Program scope on Four Batch B Assemblies	15
2.3	Simulation of SAVFUEL Duty Cycle, Hot Cell Program Scope	17
3.1	Phase IB Lead Bundle High Burnup Demonstration Poolside Inspection Program	19
3.2	Ft. Calhoun Maximum Rod Burnups (GWD/T)	20
3.3	Phase IB High Burnup Demonstration Hot Cell Program Scope	22
5.1	Accumulated Burnups for the Batch D Demonstration Assemblies at End of Cycle 5	32

List of Figures

<u>Figure</u>		<u>Page</u>
2.1	Typical Ft. Calhoun Equilibrium SAVFUEL Cycles versus OUT-IN Comparison	11
4.1	OPPD/DOE Fuel Utilization Program	24
4.2	Location of Characterized Rods in Each Test Assembly	25
5.1	Fuel Pin Pressure History of the Batch D Assembly versus Burnup	28
5.2	Ft. Calhoun Cycle 6 Batch D Double-Ended Guillotine Break at Pump Discharge Legs Peak Clad Temperature	29

5.3	Assembly D005, Upper End Fitting	33
5.4	Assembly D005, Between Grids 4 and 5	33
5.5	Assembly D005, Grid 4	34
5.6	Assembly D005, Lower End Fitting	34
5.7	Assembly G038, Upper End Fitting	35
5.8	Assembly G038, Between Grids 4 and 5	35
5.9	Assembly G038, Grid 4	36
5.10	Assembly G038, Lower End Fitting	36
5.11	Assembly D005, Upper End Fitting, High Magnification to Show Differential Fuel Rod Growth	37

1. Introduction

In 1977, a major change in United States nuclear energy policy was announced which was to defer the plutonium fuel breeder as well as commercial reprocessing and recycling of plutonium in conventional light water reactors. At the same time, United States energy policy called for a reduction in the nation's reliance on oil and natural gas through an increased and more efficient use of current generation light water reactors. The success of these two national policies depends, in part, on the development of methods to enhance the fueling efficiency of these reactors. In recognition of this requirement, the United States Department of Energy has initiated a uranium utilization improvement program for light water reactors. This program seeks to develop and demonstrate a number of fuel design and operating procedure modifications which result in improved uranium utilization.

The current program being performed by Combustion Engineering and Omaha Public Power District has the objective of demonstrating two improvements. The first is a low leakage fuel management concept called SAVFUEL (Shimmed and Very Flexible Uranium Element Loading) which is expected to reduce uranium requirements by two to four percent (2% to 4%). The second improvement is to be achieved by demonstrating increased burnup capability of the current (14 x 14) fuel design to a peak rod average burnup of 45 GWD/T (batch average burnup 37 GWD/T) which will further reduce uranium requirements by five to fifteen percent (5% to 15%) depending on the means chosen to exploit the additional burnup capability of the fuel.

In a second program, Combustion Engineering and Arkansas Power and Light will further extend the capability to implement the above improvements. The SAVFUEL capability will be extended by detailed design and safety analyses which will be required for implementing this fuel management scheme. High burnup will be demonstrated by irradiating the current 16 x 16 design fuel and by irradiating a number of fuel rods containing advanced fuel design concepts. These advanced fuel concepts are designed to extend the achievable peak rod average burnups to 64 GWD/T (or a batch average burnup of 50 GWD/T).

This report is the first semi-annual report of the C-E/OPPD program. It covers the progress during the period from October 1, 1979 to March 30, 1980.

2. Phase IA Program Description

2.1 Introduction

SAVFUEL is an alternate fuel management scheme to the conventional OUT-IN scheme which allows a reduction in the radial leakage while maintaining current peaking targets. For a reload core, this is achieved by placing once-burned assemblies in most of the peripheral locations; most of the fresh assemblies are mixed with the remaining once-burned and twice-burned assemblies in the core interior. Power peaks in the fresh assemblies which have been moved to the core interior are controlled with burnable poison shim rods which replace about two percent of the fuel rods in the feed batch.

SAVFUEL and OUT-IN fuel assembly placements are compared in Figure 2.1. The upper left-hand quadrant shows a typical SAVFUEL arrangement for the Ft. Calhoun reactor, while the lower right-hand quadrant shows the OUT-IN arrangement.

The SAVFUEL concept will be demonstrated by irradiating four Batch G fuel assemblies in such a way that a portion of their fuel pins will simulate the SAVFUEL power duty cycle. In addition, analysis will be performed to assure that the SAVFUEL concept can be implemented in the Fort Calhoun reactor.

Figure 2.1

TYPICAL FT. CALHOUN EQUILIBRIUM SAVFUEL CYCLE
VERSUS OUT-IN COMPARISON

NOTE:

THE ASSEMBLIES CONTAINING
CIRCLES BELONG TO THE LOW
ENRICHMENT SUB-BATCH;
THESE ASSEMBLIES ARE
SHIMMED

2.2 Phase IA Workscope

The following steps will be followed in Phase IA:

1. Characterize Selected Rods Prior to Fuel Bundle Assembly

Forty-eight (48) fuel rods in four Batch G assemblies will be characterized prior to core loading in Cycle 5. The scope of the pre-irradiation characterization program is given in Table 2.1. Rods will be characterized which will experience a normal OUT-IN duty cycle as well as rods which will experience the IN-OUT-IN duty cycle associated with SAVFUEL.

2. Incremental Fuel Management, Safety Analysis, and Licensing for Cycle 6

A modification to standard OUT-IN fuel management will be required to allow the four Batch G assemblies to remain on the core periphery during Cycle 6. Based on the fuel management analysis, a supplementary safety evaluation may be needed for the Cycle 6 licensing submittal.

3. Evaluate PCI Stresses and Other Safety Issues Prior to the Beginning of Cycle 7

When the four Batch G assemblies are moved to the core interior for Cycle 7, the rods which had been on the core periphery during Cycle 6 will experience a large increase in power. Detailed PCI calculations will be performed to gain confidence that PCI stresses will not be excessive when Cycle 7 begins. Other fuel management-dependent parameters which impact the safety analyses will also be evaluated.

TABLE 2.1

PHASE IA: SIMULATION OF SAVFUEL DUTY CYCLE
PRE-IRRADIATION CHARACTERIZATION PROGRAM SCOPE

A. PROGRAM PLANNING

B. CHARACTERIZATION - 4 Batch G Assemblies, Single Fuel Lot

1. Fuel Rods

a. 12 per Assembly

- (1) Length
- (2) Profilometry
- (3) Radiographs (Stack Length)
- (4) Fuel Lot Certification Data
- (5) Located in Pre-Determined Assembly Positions

2. Fuel Assembly

a. Dimensional Characterization of:

- (1) Guide Tube Length
- (2) Assembly Envelope (Spacer Grid Width)
- (3) Fuel Rod Channel Spacing
- (4) Shoulder Gap of Peripheral Fuel Rods (Distance from Top of Rod to Bottom of Upper End Fitting)

3. Data Reduction and Report

4. Devise an Alternate Strategy for Cycle 7, If Necessary

In the unlikely event that excessive clad stress is predicted at the beginning of Cycle 7, an alternate strategy will be devised which will reduce clad stresses to acceptable levels. A possible alternative would be to modify the fuel management so that the low power rods in the four test assemblies would see only a modest increase in power.

5. Perform Poolside Fuel Inspections After Cycles 5, 6 and 7

The effect of the SAVFUEL duty cycle on fuel rod performance will be determined through a poolside inspection campaign following each irradiation cycle. For comparison, selected rods which have experienced a standard OUT-IN duty cycle will also be inspected. The inspection following Cycle 5 will be a brief visual examination, while the inspections following Cycles 6 and 7 will be more detailed, as indicated in Table 2.2.

6. Hot Cell Examination Following Cycle 7

The scope of the planned hot cell program is summarized in Table 2.3. The purpose of this examination is to verify fuel rod performance generally and, in particular, to compare fission gas release behavior for rods of similar burnup which have experienced SAVFUEL and conventional OUT-IN power histories and to correlate the fission gas release to the corresponding fuel pellet microstructure. Fuel rod profilometry will be performed to confirm the poolside measurements.

TABLE 2.2

PHASE IA: SIMULATION OF SAVFUEL DUTY CYCLE
POOLSIDE INSPECTION PROGRAM SCOPE ON FOUR
BATCH G ASSEMBLIES

- A. PROGRAM PLANNING AND SCHEDULING
 - B. INSPECTION CAMPAIGN OUTLINE
 - 1. After Reactor Cycle 5 (Batch G first cycle)
 - a. Examination of Four Test Bundles With Mini-Stand
 - (1) Visual Exam, Growth, Channel Width Measurements
 - 2. After Reactor Cycle 6 and Cycle 7 (Batch G Second and Third Cycles)
 - a. Comprehensive Fuel Inspection Stand (CFIS) Shipment to Site, Setup and Checkout
 - b. Examination of Up to Four Test Bundles
 - (1) Visual Exam, Growth, Channel Width Measurements
 - c. Disassembly of One Bundle
 - (1) Single Rod Inspection
 - Up to 12 Rods With Visual, Eddy Current, Profilometry, and Length Measurements
 - (2) Removal of Up to 6 Rods Following Cycle 7 for Subsequent Hot Cell Work
 - d. Bundle Reassembly
 - e. CFIS Dismantling, Shipment to Windsor, and Refurbishing as Required
- C. DATA REDUCTION, EVALUATION AND REPORT
 - 1. Interim Reports Following Cycle 5 and 6 Exams
 - 2. Summary Report Following Cycle 7

7. SAVFUEL Analytical Evaluation

In parallel with the experimental SAVFUEL demonstration program, analytical evaluations of SAVFUEL will be made for the Fort Calhoun reactor. The purpose of this task is to demonstrate that SAVFUEL can indeed be applied to the Fort Calhoun Reactor and to confirm that the Phase IA duty cycle demonstration is prototypic of the fuel duty cycles which will be experienced when SAVFUEL is used core-wide. Having selected a reference cycle schedule and target discharge burnup, SAVFUEL fuel management calculations will be carried for several cycles. Results of the fuel management calculations will be used as input to fuel performance analyses which will be performed to calculate PCI stresses and fission gas pressures. The fuel management results will also be used to assess the impact on the safety analysis.

8. Assess the Acceptability of the SAVFUEL Duty Cycle

Based on the test and analytic results, the acceptability of the SAVFUEL duty cycle will be assessed. If the conclusion is favorable, as anticipated, then SAVFUEL fuel management will be used in the large scale Phase II demonstration.

9. Write Phase IA Summary Report

A comprehensive report will be prepared which summarizes all test results, analyses and conclusions.

TABLE 2.3

PHASE IA: SIMULATION OF SAVFUEL DUTY CYCLE
HOT CELL PROGRAM SCOPE

- A. SELECTION AND REMOVAL OF RODS FROM PHASE IA BUNDLES
- B. TRANSFER TO HOT CELL
- C. HOT CELL EXAMINATION
 - 1. Non-Destructive Examinations
 - a. Visual Exam
 - b. Gamma Scanning
 - c. Eddy Current Testing
 - d. Profilometry
 - 2. Destructive Examinations
 - a. Puncturing of Rods, Gas Collection, and Analysis
 - b. Pycnometry (Fuel Density Measurement)
 - c. Burnup Analysis
 - d. Metallography
 - e. Dispose of Rod Sections
- D. DATA ANALYSIS AND REPORTING
- E. SHIPMENT OF INTACT RODS BACK TO SITE FOR PERMANENT STORAGE
 - a. Seal Puncture Holes in Rods After Collecting Fission Gases (Only for rods which are not sectioned)
 - b. Ship Rods Back to Site
 - c. Reinsert in Assemblies (If required)

3.0 Phase IB Program Description

3.1 Introduction

The purpose of this task is to demonstrate that fuel of current design can achieve a peak rod average burnup of 45 GWD/T. As outlined in Tables 3.4 and 3.6, poolside and hot cell examinations will be performed on rods which will have been irradiated for three, four and five cycles in order to obtain fuel performance data over a range of burnups and residence times. The majority of rods to be examined are from Batch D and contain modern high density pellets having a stable microstructure; in addition, some rods from Batch C which contain lower density pellets will also be examined to determine the effect of pellet density and microstructure on high burnup performance.

3.2 Phase IB Workscope

The following steps will be followed in Phase IB.

1. Poolside Examination of Selected D Assembly Rods After Their Fourth Irradiation Cycle

Seventeen D assemblies which were inserted in Cycle 2 will be carried into Cycle 5 for their fourth irradiation cycle. As shown in Table 3.2, the fourth irradiation cycle will extend the maximum rod average burnup from 31 to 40 GWD/T. After Cycle 5, 16 D bundles will be examined visually as indicated in Table 3.1.

2. Safety and Performance Analysis of the D Assembly Which Will be Carried Into Reactor Cycle 6 for Its Fifth Irradiation Cycle

A single D assembly will be exposed for a fifth irradiation cycle so as to increase the maximum rod average burnup from 40 to 45 GWD/T, as shown in Table 3.2. Analyses will be performed to insure that this burnup extension will not raise any safety or performance concerns.

TABLE 3.1

PHASE IB: LEAD BUNDLE HIGH BURNUP DEMONSTRATION
POOLSIDE INSPECTION PROGRAM SCOPE

A. PROGRAM PLANNING AND SCHEDULING

B. INSPECTION PROGRAM OUTLINE

1. After Reactor Cycle 4
 - a. Examination of Five D Bundles (Three-cycle Exposure)
 - (1) Visual Exam, Limited Rod Growth and Channel Width Measurements
2. After Reactor Cycle 5
 - a. Examination of Up to Sixteen D Bundles (Four-cycle Exposure) With Mini-Stand
 - (1) Visual Exam
3. After Reactor Cycle 6
 - a. CFIS Shipment to Site, Setup and Checkout
 - b. Examination of
 - One D Bundle (Five-cycle Exposure)
 - One D Bundle (Four-cycle Exposure)
 - One D Bundle (Three-cycle Exposure)
 - One C Bundle (Four-cycle Exposure)
 - One C Bundle (Three-cycle Exposure)
 - (1) Visual Exam, Growth and Channel Width Measurements
 - (2) Disassembly of Up to Five Bundles
 - (3) Single Rod Inspection of Up to 20 Rods, Visual, Eddy Current, Profilometry and Length Measurements
 - (4) Selection of Rods for Subsequent Hot Cell Work
 - (5) Bundle Reassembly for In-Pool Storage
 - c. CFIS Dismantling, Shipment to Windsor and Refurbishment as Required
4. Inspection Data Reduction, Evaluation and Report
 - a. Interim Reports Following Cycle 4 and 5 Exams
 - b. Summary Report Following Cycle 6 Exam

TABLE 3.2

Achieved and Projected Burnups for Fort Calhoun (GWD/T)

C Batch Rods (Completed)

<u>Reactor Cycle</u>	<u>Number of Assemblies in Batch</u>	<u>Number of Exposure Cycles</u>	<u>Batch Average Burnup (GWD/T)</u>	<u>Max. Assy Average Burnup (GWD/T)</u>	<u>Max. Rod Avg Burnup (GWD/T)</u>
3	32	3	28	30	34
4	4	4	35	35	39

D Batch Rods (Completed)

<u>Reactor Cycle</u>	<u>Number of Assemblies in Batch</u>	<u>Number of Exposure Cycles</u>	<u>Batch Average Burnup (GWD/T)</u>	<u>Max. Assy Average Burnup (GWD/T)</u>	<u>Max Rod Average Burnup GWD/T</u>
4	40	3	26	28	31
5	17	4	34	36	40

D Batch Rods (Projected)

6	1	5	41	41	45
---	---	---	----	----	----

3. Poolside Examination of the D Assembly Following Its Fifth Irradiation Cycle

A detailed poolside inspection will be performed following reactor Cycle 6, as outlined in Table 3.1.

4. Hot Cell Examination of Selected C and D Assembly Rods After Cycles 5 and 6

Selected rods from C and D assemblies having burnups up to 40 GWD/T, and from the D assembly which has been in the reactor for five cycles and has achieved a peak rod average burnup of 45 GWD/T, will be sent to the hot cell after the end of Cycle 6. The scope of this hot cell program is outlined in Table 3.3 and will extend the fuel performance data base to higher burnup. Following this final phase of the hot cell program, all intact rods at the hot cell facility will be returned to Fort Calhoun for storage to minimize disposal costs.

5. Verify Fuel Performance Models Using Results of Fuel Examinations

Results obtained from the various fuel examinations will be compared to behavior predicted with current fuel performance models. Of particular interest will be the comparison between the measured and predicted fission gas release.

6. Assess the Desirability of a Fuel Design Change

Results of the various fuel inspections will be used to assess the desirability of fuel design changes which would improve fuel performance at high burnup.

7. Write Phase IB Summary Report

A report will be prepared summarizing the test results, the associated analytical predictions, and the conclusions reached.

TABLE 3.3

PHASE IB: HIGH BURNUP DEMONSTRATION
HOT CELL PROGRAM SCOPE

- A. SELECTION AND REMOVAL OF RODS FROM PHASE IB BUNDLES
- B. TRANSFER TO HOT CELL
- C. HOT CELL EXAMINATION
 - 1. Nondestructive Examinations
 - a. Visual Exam
 - b. Gamma Scanning
 - c. Eddy Current Testing
 - d. Profilometry
 - 2. Destructive Examinations
 - a. Puncturing of Rods, Gas Collection and Analysis
 - b. Pycnometry (Fuel Density Measurement.)
 - c. Burnup Analysis
 - d. Fuel Metallography
 - e. Cladding Examinations
 - f. Dispose of Rod Sections
- D. DATA ANALYSIS AND REPORTING
- E. SHIPMENT OF INTACT RODS BACK TO SITE FOR PERMANENT STORAGE
 - 1. Seal Puncture Holes in Rods After Collecting Fission Gases
(Only for rods which are not sectioned)
 - 2. Ship Rods Back to Site
 - 3. Reinsert in Assemblies (If required)

4. Simulation of SAVFUEL Duty Cycle - Progress to Date

4.1 Introduction

The progress to date in the SAVFUEL duty cycle simulation is shown in Figure 4.1. The four Batch G assemblies which were inserted for their first exposure in Cycle 5 have been irradiated in 1979 and were inspected in February 1980 during the scheduled EOC5 outage. Data reduction from this inspection extended beyond the time span of the reporting period for this progress report. Detailed results from this inspection will be made available in a separate topical report.

SAVFUEL demonstration assemblies were left on the periphery of the core for Cycle 6 and rotated so that several fuel pins in the assemblies would simulate the SAVFUEL power cycle. Licensing of this perturbation for Cycle 6 was accomplished as part of the normal submittal to the NRC.

4.2 Characterization of Fuel Rods

The characterization of the four Batch G Omaha fuel assemblies and associated fuel rods was completed. All four of the assemblies were visually examined and photographs taken to document their condition prior to irradiation.

Forty-eight (48) fuel rods were characterized and twelve (12) were placed in each of the four assemblies. The position of the characterized pins within each fuel assembly is shown in Figure 4.2. In addition to standard quality assurance measurements, the characterization also included:

- rod length measurements
- radiographs
- spiral profilometry
- two rods for archival material.

Figure 4.1
OPPD/DOE FUEL UTILIZATION PROGRAM

Figure 4.2

LOCATION OF CHARACTERIZED RODS IN EACH TEST ASSEMBLY

The following special measurements were made on two of the assemblies:

- peripheral rod shoulder gaps
- guide tube lengths
- fuel rod channel widths
- spacer grid widths (one assembly).

4.3 PCI Evaluation Prior to Cycle 7

This effort is currently in the early stages, consisting mainly of planning and of preparing core simulator models.

4.4 Poolside Inspection After Cycle 5 (SAVFUEL)

The poolside inspection campaign at Ft. Calhoun was performed during February 1980. All four of the characterized G fuel assemblies were visually inspected after one cycle of exposure by the use of an underwater television system. All assemblies were in good condition with no anomalies noted. The inspections were video recorded for subsequent determination of the dimensional behavior. Evaluations are now in progress to characterize channel widths on two assemblies and shoulder gaps on all four assemblies. The end of Cycle 5 assembly average burnup accumulated by the four demonstration assemblies is 7000 MWD/T (11,500 MWD/T lead pin average burnup).

5. High Burnup Demonstration - Progress to Date

5.1 Introduction

The progress of the high burnup demonstration is illustrated in Figure 4.1 At the end of Cycle 5, sixteen Batch D assemblies were discharged after four cycles of exposure. One Batch D assembly has been reinserted

for a fifth exposure in Cycle 6. Batch D assemblies along with the four Batch C assemblies discharged after four cycles at the end of Cycle 4 will be examined in detail after Cycle 6. A visual examination of the Batch D assemblies has been completed in February; however, data reduction is still in progress and results will be presented in a separate report.

5.2 Incremental Licensing Cycle 6, the Fifth Exposure for One Batch D Assembly

The objective of this activity is to support the use of the high burnup Batch D assembly in Cycle 6. This consisted of a performance evaluation of the high burnup demonstration assembly and the associated licensing activity. The high burnup assembly licensing analysis was performed with standard Combustion Engineering methodology. No special test assembly waiver was requested from the NRC.

Incremental Cycle 6 licensing activity consisted of a maximum pin pressure evaluation, an ECCS performance evaluation, clad collapse analysis, DNB margin analyses to accommodate fuel rod bow, and corrosion and hydriding analyses.

A pin pressure history for the hot rod in the Batch D assembly was calculated with current licensing models and the measured power history through Cycle 5. This pressure history was projected to the end of Cycle 6 and resulted in a hot rod pressure well below system pressure (2100 psia). Figure 5.1 shows the pressure history for both the hot rod and for the average rod in the Batch D assembly.

An ECCS analysis demonstrated that the LOCA response of the hottest fuel rod in the D assembly is much less limiting than the response of other higher power assemblies in the core during Cycle 6 and demonstrated conformance to acceptance criteria as presented in Reference 1. A peak clad temperature of 1300°F (Figure 5.2)^d was calculated for the hottest

Figure 5.1
FUEL PIN PRESSURE HISTORY
FOR THE BATCH D ASSEMBLY vs BURNUP

Figure 5.2
FT. CALHOUN CYCLE 6 BATCH D
1.0 x DOUBLE ENDED GUILLOTINE BREAK AT PUMP DISCHARGE LEG
PEAK CLAD TEMPERATURE

pin in the Batch D assembly during Cycle 6. The peak temperature is obtained 10 seconds after a double ended guillotine break at the pump discharge leg which is the worst break location. This temperature is well below the acceptance criteria of 2200 F.

The clad collapse analysis for Batch D was performed to verify that the fuel assembly is capable of operating for an additional burnup cycle without clad collapse. Results showed that the time to cladding creep collapse for the demonstration assembly is greater than 45,000 EFPH (effective full power hours) while the maximum cumulative exposure time expected at the end of Cycle 6 is less than 40,000 EFPH.

Effects on departure from nucleate boiling (DNB) resulting from fuel rod bow show that the DNB penalty is less than 7% at the burnup which the Batch D assembly will achieve in Cycle 6 (Reference 2). However, no penalty on core DNB margin is required since the Batch D assembly never achieves power peaks within 30% of the maximum radial pin peak in the core throughout Cycle 6.

Reports (Reference 3) were prepared by UPPU for the NRC which support operation of Cycle 6. The NRC has completed its evaluation and given its approval (Reference 4).

5.3 Poolside Examination After Cycle 5 (High Burnup Demonstration)

All seventeen (17) D fuel assemblies irradiated for four cycles were visually inspected using the TV camera during the February 1980 poolside inspection campaign. All assemblies were in good condition showing no anomalous visual indications.

Preliminary results indicate

- excellent fuel rod and assembly performance to maximum assembly burnups exceeding 36 GWD/T
- more than adequate fuel rod and shoulder gap clearance is available to accommodate additional irradiation induced fuel rod growth during subsequent exposure cycles
- no channel closures greater than 25%.

In addition, coolant activity measurements during Cycle 5 indicate no fuel failures. Selected TV pictures taken during the Cycle 5 exam are shown in Figures 5.3 to 5.11.

Figures 5.3 through 5.6 show selected axial positions of assembly D005 which is the assembly scheduled to be reinserted for a fifth exposure in Cycle 6. For comparison, the same axial positions of a Batch G assembly are shown in Figures 5.7 to 5.10. Some of the differences to be noted are that the Batch D assembly accumulated more crud than Batch G as evidenced on the grid surface, and that Batch D fuel rods have accumulated more differential rod growth. These differences are to be expected since the Batch D assembly has been exposed for four cycles whereas the Batch G assembly has been exposed for only one cycle. A high magnification picture of the differential rod growth in the D assembly is shown in Figure 5.11.

Data reduction of the end of Cycle 5 examination is currently in progress, and results will be available in a separate report.

Exposures achieved by the demonstration assemblies at the end of Cycle 5 are shown in Table 5.1.

Figure 5.3 ASSEMBLY D005 UPPER END FITTING

Figure 5.4 ASSEMBLY D005, BETWEEN GRIDS 4 AND 5

Figure 5.5 ASSEMBLY D005, GRID 4

Figure 5.6 ASSEMBLY D005, LOWER END FITTING

Figure 5.7 ASSEMBLY G038, UPPER END FITTING

Figure 5.8 ASSEMBLY G038, BETWEEN GRIDS 4 AND 5

Figure 5.9 ASSEMBLY G038, GRID 4

Figure 5.10 ASSEMBLY G038, LOWER END FITTING

Figure 5.11 ASSEMBLY D005, UPPER END FITTING
HIGH MAGNIFICATION TO SHOW
DIFFERENTIAL FUEL ROD GROWTH

TABLE 5.1

Accumulated Burnups for the Batch D Demonstration
Assemblies at End of Cycle 5

<u>Number of Assemblies</u>	<u>Assembly Average Burnup (GWD/T)</u>	<u>Maximum Pin Average Burnup (GWD/T)</u>
8	33.75	38.36
8	33.11	38.29
1*	36.52	40.17

*This assembly is being reinserted in Cycle 6 for a fifth exposure cycle.

6.0 References

1. Acceptance Criteria for Emergency Core Cooling Systems for Light Water Cooled Nuclear Power Reactors, Federal Register, Vol. 39, No. 3, Friday, January 4, 1974.
2. "Interim Safety Evaluation Report on Effects of Fuel Rod Bowing on Thermal Margin Calculations for Light Water Reactors", NRC Report.
3. Letters from W. C. Jones OPPD to R. Reid USNRC, December 4, 1979, February 12, 1980, February 25, 1980 and March 12, 1980.
4. "NRC Safety Evaluation of Cycle 6 submittal (1420 MWt) by the Office of Nuclear Reactor Regulation, Supporting Amendment No. 47 to Facility Operating License No. DPR-40, Omaha Public Power District, Fort Calhoun Station Unit No. 1", Docket 50-285.

Distribution

Mr. Thomas Abernathy, Chief (200)
Document Management Branch
U. S. Department of Energy
Technical Information Center
Oak Ridge, TN 22161

COMBUSTION ENGINEERING

M. G. Andrews
W. H. Bachman
M. A. Book
G. H. Chalder
W. P. Chernock
L. V. Corsetti
R. S. Darling
U. Decher(30)
R. N. Duncan
I. B. Fiero
N. Fuhrman
P. H. Gavin
W. A. Goodwin
S. C. Hatfield
K. J. Jurgen
R. A. Matzie
R. R. Mills
J. R. Parrette
P. E. Rohan
N. L. Shapiro
G. P. Smith(5)
S. M. Temple
W. B. Terney
O. J. Thomsen
R. M Versluis
L. W. Ward

Mr. John R. Jensen
Mechanical Engineering Division
American Electric Power Service
2 Broadway
New York, NY 10004

Mr Benjamin L. Dow Jr.
Arkansas Power & Light Co.
P. O. Box 551
Little Rock, AR 72203

Mr J. Tulenko
Babcock & Wilcox Company
Nuclear Power Generation Div.
P. O. Box 1260
Lynchburg, VA 24505

Mr. Thomas A. Coleman
Babcock & Wilcox Company
Nuclear Power Generation Div.
P. O. Box 1260
Lynchburg, VA 24505

Mr. M. S. Freshley
Battelle-Pacific Northwest Lab.
Battelle Boulevard
P. O. Box 999
Richland, WA 99352

Mr. C. L. Mohr, Manager
Nuclear Fuels
Battelle-Pacific Northwest Lab.
P. O. Box 999
Richland, WA 99352

Mr. W. M. Kiefer
Commonwealth Edison Company
P. O. Box 767
Chicago, IL 60690

Dr. Min L. Lee
Chief Nuclear Engineer
Consolidated Edison Co./N.Y., Inc.
4 Irving Place
New York, NY 10003

Mr. D. B. Wehmeyer
Detroit Edison Co.
2000 Second Avenue
Detroit, MI 48226

Mr. T. Snead
Duke Power Company
P. O. Box 33189
Charlotte, NC 28242

Mr. Floyd E. Gelhaus
Electric Power Research Inst.
P. O. Box 10412
Palo Alto, CA 94303

Mr. C. E. Crouthamel
Exxon Nuclear Company, Inc.
2595 George Washington Way
Richland, WA 99352

Dr. G. A. Sofer
Nuclear Fuels Engineering
Exxon Nuclear Company, Inc.
2101 Horn Rapids Road
Richland, WA 99352

Dr. K. N. Woods
2595 George Washington Way
Exxon Nuclear Company, Inc.
Richland, WA 99352

Mr. J. R. Tomonto
Florida Power & Light Company
P. O. Box 3100
Miami, FL 33101

Dr. W. A. Weinreich
Bettis Atomic Power Laboratory(W)
Box 79
West Mifflin PA 15122

Mr. D. O'Boyle
Commonwealth Edison Company
P. O. Box 767
Chicago, IL 60690

Mr. F. W. Buckman
Consumers Power Company
212 W. Michigan Avenue
Jackson, MI 49201

Mr. J. D. Korteheuer
Duke Power Company
P. O. Box 33189
Charlotte, NC 28242

Mr. R. G. Snipes
Duke Power Company
P. O. Box 33189
Charlotte, NC 28242

Dr. J. T. A. Roberts
Electric Power Research Inst.
P. O. Box 10412
Palo Alto, CA 94303

Mr. William J. Tunney
Long Island Lighting Company
175 E. Old Country Road
Hicksville, NY 11801

Mr. S. W. Wilczek, Jr.
Niagara Mohawk Power Corp.
300 Erie Boulevard West
Syracuse, NY 13202

Mr. John Hallam
Manager, Computer Engineering
Quadrex Corporation
1700 Dell Avenue
Campbell, CA 95008

Mr. I. Spiewak
Oak Ridge National Laboratory
P. O. Box X, Building 9201-3
Oak Ridge, TN 37830

Dr. S. Armijo
General Electric Company
Nuclear Energy Division
175 Curtner Avenue
San Jose, CA 95125

Dr. H. W. Schadler, Manager
Metallurgy Laboratory
General Electric Company
Research and Development Center
P. O. Box 8
Schenectady, NY 12301

Mr. Gordon Bond
GPU Service Corp.
260 Cherry Hill Road
Parsippany, NJ 07054

Mr. D. J. Groetch
Manager, Advanced Development Activity
Knolls Atomic Power Laboratory
Box 1072, F3, 12
Schenectady, NY 12301

Dr. William V. Johnston
Chief, Fuel Behavior Research Branch
Division of Reactor Safety Research
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Mr. D. L. Larkin
Washington Public Power Supply
System
P. O. Box 968
Richland, WA 99352

Mr. R. S. Miller
Westinghouse Electric Corp.
Nuclear Fuel Division
Box 355
Pittsburgh, PA

Dr. Joseph K. Gasper
Manager, Reactor and Computer
Technical Services
Omaha Public Power District
1625 Harney
Omaha, NE 68102

Mr. Martin L. Bowling
Virginia Electric & Power Company
Seventh and Franklin Streets
P. O. Box 1194
Richmond VA 23209

Mr. G. F. Daebeler
Philadelphia Electric Company
2301 Market Street
P. O. Box 8699
Philadelphia, PA 19101

Mr. B. H. Koske
Energy Conversion Engineer
Public Service Company of
New Mexico
P. O. Box 2267
Albuquerque, NM 87103

Mr. Kashmiri L. Mahna
Public Service Electric & Gas Co.
P. O. Box 570, Room 3347
Neward, NJ 07101

Mr. Richard R. O'Laughlin
Nuclear Fuel Manager
Public Service Company of Indiana
1000 East Main Street
Plainfield, IN 46168

Professor A. Sesonske
School of Engineering
Purdue University
West Lafayette, IN 47907

Mr. Philip D. Brown
Nuclear Engineer, Fuel
Cycle Services
409 Krystal Building
Chattanooga, TN 37401

Mr. Daniel D. Whitney
Sacramento Municipal Utility Dist
6201 S. Street
Box 15830
Sacramento, CA 95813

Mr. Michael Driscoll
Massachusetts Institute of Tech.
138 Albany Street
Cambridge, MA 02139

Dr. J. C. Turnage
Yankee Atomic Electric Company
20 Turnpike Road
Westborough, MA 01581

Mr. Peter A. Aucoin
Nuclear Assurance Corporation
24 Executive Park West
Atlanta, GA 30329

Mr. Howard L. Sobel
Section Head, Nuclear Materials
and Fuel Management Section
American Electric Power Service
Corporation
2 Broadway
New York, NY 10004

Mr. T. D. Chikalla, Manager
Ceramics and Graphite
Battelle-Pacific Northwest Laboratory
P. O. Box 999
Richland, WA 99352

Mr. R. L. Horowitz
General Electric - Research and
Development Corporate
P. O. Box 8
Schenectady, NY 12345

Dr. Elwyn Roberts
Manager, Irradiation Testing
Westinghouse Electric Corporation
P. O. Box 355
Pittsburgh, PA 15230