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**DATA REPORT FOR THE NONDESTRUCTIVE EXAMINATION
OF TURKEY POINT SPENT FUEL ASSEMBLIES
B02, B03, B17, B41 AND B43**

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Hanford Engineering Development Laboratory

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Hanford Engineering Development Laboratory

R.B. Davis

April 1980

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DATA REPORT FOR THE NONDESTRUCTIVE EXAMINATION OF
TURKEY POINT SPENT FUEL ASSEMBLIES
B02, B03, B17, B41 and B43

R. B. Davis

ABSTRACT

The fuel assembly sip test on all rods from assembly B17 were of sound integrity. Visual examination showed three general regions of rod surface appearance: a dark adherent "crud" layer at the bottom of the rod, black spalling crud layers in the middle and a spotty gray loose powdery coating with dark crud or oxide underneath towards the top. Rod lengths varied from 152.395 inches to 152.707 inches. Maximum rod bow measurements for rods G9, I9, and G7 were 0.038 inch to 040 inch and 0.022 inch for rods H6 and J8. Results from profilometry scans showed the maximum ovality for the five rods was 0.0066 inch with average diameters ranging from 0.4187 inch to 0.4198 inch. Extensive ridging from pellet-clad interaction over the entire length was evident on all rods. Gamma scan results showed no cesium peaking and no pellet gaps greater than 0.025 inch. No unusual areas, other than ridging and possible fuel-cladding bonding, were seen in the eddy current results.

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CONTENTS

	<u>Page</u>
Abstract	iii
Acknowledgements	iv
Figures	vi
Tables	viii
I. SUMMARY	1
II. INTRODUCTION	3
III. FUEL HISTORY AND CHARACTERISTICS	5
IV. FUEL CHARACTERIZATION	9
A. FUEL ASSEMBLY EXAMINATIONS AND RESULTS	11
1. Sip Testing	11
2. Fuel Assembly Visual Examination	16
3. Fuel Assembly Bow Measurements	17
4. Assembly Length Measurements	19
5. Flat-to-Flat Measurements	19
6. Weight Measurements	20
7. Gamma and Neutron Flux Measurements	23
B. FUEL ROD EXAMINATIONS AND RESULTS	28
1. Visual Examination	28
2. Rod Length Measurements	30
3. Weight Measurements	30
4. Rod Bow Measurements	32
5. Profilometry Scans	33
6. Eddy Current Examination	41
7. Gamma Scanning	49
8. Rod Sip Tests	63
Appendix A PROCEDURE FOR REMOVAL AND REPLACEMENT OF FUEL RODS	A-1
Appendix B REPLOTS OF PROFILOMETRY TRACES	B-1
Appendix C REPLOTS OF GAMMA SCAN TRACES	C-1

FIGURES

	<u>Page</u>
1 Core Map Illustrating the Locations of Characterization Assemblies During the Second Cycle of Reactor Operation of Turkey Point Unit 3	8
2 Process Flow Diagram for Nondestructive Examinations	10
3 Typical Turkey Point Fuel Assembly and Rod Length Reference Schemes	12
4 Turkey Point Fuel Assembly and Rod Positioning Scheme	13
5 Weighing Assembly B03	22
6 Locations of Gamma Dosimetry Measurements	25
7 Profilometry Results for Rod B02-H6	42
8 Profilometry Results for Rod B41-G7	43
9 Profilometry Results for Rod B41-J8	44
10 Profilometry Results for Rod B02-H6	45
11 Profilometry Results for Rod B41-H6	46
12 Profilometry Results for Rod B02-H6	47
13 Eddy Current Scanning System	48
14 Eddy Current Scan of Defect Standard	50
15 Eddy Current Scan of Rod B02-H6	51
16 Profilometry and Eddy Current Scans of Rod B02-H6	52
17 Profilometry and Eddy Current Scans of Rod B41-G7	53
18 Profilometry and Eddy Current Scans of Rod B17-G9	54
19 Profilometry and Eddy Current Scans of Rod B41-J8	55
20 Profilometry and Eddy Current Scans of Rod B41-J8	56
21 Eddy Current Scan of Rod B41-G7	57
22 Profilometry and Eddy Current Scans of Rod B17-G9	58

FIGURES (Cont'd)

	<u>Page</u>
23 Eddy Current Scan for Rod B41-J8	59
24 Profilometry and Eddy Current Scans of Rod B41-G7	60
25 Profilometry and Eddy Current Scans of Rod B43-H6	61

TABLES

<u>Table</u>		<u>Page</u>
1	Fabrication Statistics for Turkey Point Fuel Assemblies B02, B03, B17, B41 and B43	6
2	Turkey Point Unit 3 Operating Statistics During The First Two Cycles of Operation	7
3	Sip Test Results	15
4	Fuel Assembly Bow Measurements	18
5	Assembly Length Measurements	20
6	Assembly Flat-to-Flat Measurements	21
7	Assembly Weights	23
8	Axial Gamma Exposure Rates from Assembly B03 (R/h)	26
9	Gamma Dose Rates as a Function of Distance from the Assembly B03 Midplane	27
10	Neutron Fluxes at Surface of Assembly B43	27
11	Rod Length Measurements	31
12	Rod Temperature Measurements	31
13	Rod Weights (1b)	32
14	Rod Bow Measurements for Assembly B03	34
15	Rod Bow Measurements for Assembly B17	35
16	Rod Bow Measurements for Assembly B41	36
17	Rod Bow Measurements for Assembly B43	37
18	Profilometry Summary for Assembly B02	39
19	Profilometry Summary for Assembly B03	39
20	Profilometry Summary for Assembly B17	40
21	Profilometry Summary for Assembly B41	40
22	Profilometry Summary for Assembly B43	41

TABLES (Cont'd)

<u>Table</u>	<u>Page</u>
23 Gamma Scan Summary for Fuel Rods from Assembly B02	64
24 Gamma Scan Summary for Fuel Rods from Assembly B03	65
25 Gamma Scan Summary for Fuel Rods from Assembly B17	66
26 Gamma Scan Summary for Fuel Rods from Assembly B41	66
27 Gamma Scan Summary for Fuel Rods from Assembly B43	67

DATA REPORT FOR THE NONDESTRUCTIVE EXAMINATION OF
TURKEY POINT SPENT FUEL ASSEMBLIES, B02, B03, B17, B41 and B43 (WKXCAA)

I. SUMMARY

This document summarizes the results of the nondestructive characterization of five spent fuel assemblies from a pressurized water reactor (PWR). Non-destructive characterization was performed to establish the baseline condition of the fuel assemblies prior to dry surface storage demonstration testing at the Nevada Test Site. The fuel assemblies and rods will again be characterized at the completion of the demonstration test. Comparison of the post-test condition to the baseline condition will define degradation mechanisms and quantify the extent of the degradation.

Fuel assembly examinations included sip testing for breached rod(s), visual examination, neutron and gamma flux determinations and dimensional measurements. Assembly sip test results indicated assembly B41 contained one or more rods with a clad breach. The other fuel assemblies indicated sound integrity. Visual examination showed three general regions of surface appearance; a dark adherent crud layer at the bottom, black spalling crud layers in the middle and a gray loose powder coating at the top. Nearly all of the peripheral rods appeared in contact with the bottom tie plate and no damage or gross distortions were seen in the structural components. Neutron dosimetry exposures on one assembly measured fluxes at four energy intervals. A total flux of $7900 \text{ n}/(\text{cm}^2\text{-s})$ with an average energy of 1.3 MeV was determined. Gamma dosimetry exposures measured dose rates in and around one fuel assembly. The maximum surface dose rate was $5.88 \times 10^4 \text{ R/h}$. Fuel assembly bow measures the maximum assembly bow between 0.060 inch and 0.070 inch. Assembly lengths were found to be 153.359 ± 0.18 inches. Assembly mid-spacer grid flat-to-flat distances ranged from 8.253 inches to 8.322 inches. The fuel assemblies weighed 1450 ± 2 lb except for assembly B02 that weighed 15 pounds greater.

The fuel rod examinations included a visual examination, sip testing and dimensional, gamma flux and eddy current measurements. Rod visual examinations revealed a more detailed observation of the rod appearance showing axial scratches, crud deposits, cladding ridges and wear marks. Rod lengths ranged between 152.266 inches and 152.763 inches. Rod weights averaged 6.75 lb. The greatest rod bow measured 0.065 inch on two rods from Assembly B41. Results from profilometry scans showed evidence of clad ridging to varying degrees on all rods. The maximum ridge height based on local diameter increase was ~0.002 inch. Rod ovalities in general were between 0.001 inch and 0.002 inch with maximums ranging from 0.004 inch to 0.007 inch. The profilometry data did not show any gross anomalies such as bulges and blisters on any of the 25 rods examined. Data from gamma scans (gross and Cs^{137}) showed all rods to have activity depressions at pellet interfaces and at spacer grid locations. The Cs^{137} gamma scans were relatively noisier (electronic noise) than gross gamma scans but no cesium peaking was observed. Comparison of the two scans showed nearly 40 percent of the gross gamma activity was due to Cs^{137} . Eddy current scans on all the rods showed ridging signals of varying strengths. Wherever a strong ridge signal was observed, the data would correlate with variations in the profilometry data. Examination of the data indicated that several rods may contain internal defects; however, strong ridge signals and possible fuel-clad bonding confused the interpretation of the data. The five rods from assembly B41 were individually sip tested and none showed leakages.

II. INTRODUCTION

The Commercial Waste and Spent Fuel Packaging (CWSFP) Program is sponsored by the Department of Energy (DOE) and managed by Rockwell Hanford Operations (RHO) for the Office of Nuclear Waste Isolation (ONWI). The primary objective is to develop and demonstrate the technology for safe disposal of nuclear waste and spent commercial reactor fuel. A major objective of the Hanford Engineering Development Laboratory (HEDL) in this effort is to develop a performance prediction model for spent fuel disposal to support licensing of waste disposal repositories.

Performance modeling is based on data obtained from field disposal tests and laboratory fuel performance testing. The performance for spent fuel is established by comparison of pre-test and post-test conditions. These pre- and post-test conditions are qualified and quantified by a series of non-destructive and destructive tests conducted on the fuel assemblies and rods. Fuel assemblies designated for demonstration testing are nondestructively examined followed by post-test nondestructive and destructive examinations. A companion fuel assembly with near identical operating and fabrication characteristics is nondestructively and destructively examined as part of the pre- and post-test characterization. A comparison of the pre- and post-test nondestructive data and correlations between the companion and post-test destructive data will be used to establish and quantify, where possible, any changes that occur as a result of performance testing.

This document summarizes the data from the pre-test nondestructive examination of the first five fuel assemblies to be tested as part of the CWSFP Program. This document does not attempt to evaluate the condition of the fuel, but serves to provide a record that the examinations were conducted and indicates the type of data obtained. It was not practicable to include all of the data in its original form and only a summary is provided. The original data is being maintained by the Spent Fuel Research and Development (Spent Fuel R&D) group at HEDL to provide a basis for evaluating the effects of spent fuel disposal on the fuel rod/assembly condition. Four of these fuel assemblies

were sent to the Nevada Test Site (NTS) for disposal testing. The companion fuel assembly is currently being destructively examined. Results from the destructive examination will be reported after completion of that work.

III. FUEL HISTORY AND CHARACTERISTICS

The five fuel assemblies are from Turkey Point Unit 3, which is a Westinghouse design PWR owned and operated by Florida Power and Light. All five assemblies resided in the reactor core during the first two cycles of operation. Table 1 lists pertinent fabrication statistics for the fuel assemblies and Table 2 lists the reactor operating statistics for the first two cycles. Figure 1 shows the locations of the fuel assemblies within the reactor core during the second cycle of operation. The core map for the first cycle was unavailable and could not be included in this report.

TABLE 1

FABRICATION STATISTICS FOR TURKEY POINT
FUEL ASSEMBLIES B02, B03, B17, B41 and B43

Vendor	Westinghouse Electric Corp
Type (Rod Array)	15 x 15
Assembly Parameters	
Transverse Dimension	8.426 in.
Assembly Weight	1420 lb.
Assembly Length	161.3 in.
Guide Tubes	
Number	20
Upper OD	0.544 in.
Wall Thickness	0.017 in.
Material	Zr-4
Instrument Tubes	
Number	1
OD	0.544 in.
Wall Thickness	0.017 in.
Material	Zr-4
Spacer Grids	
Number	7
Material	Inconel 718
Spring Material	Inconel 718
Fuel Rods	
Number	204
Length	152.0 in.
OD	0.422 in.
Wall Thickness	0.0243 in.
Material	Zr-4
Fuel Length	144.0 in.
Orifice Plate Material	304 SS
Plenum Springs	
Working Length	6.80 in.
Material	Inconel 718
Fuel Pellet	
Material	UO ₂
Enrichment	2.559 Weight % U ²³⁵
Density	92% Theoretical
Weight/Assembly	0.448 Metric Ton/Uranium

TABLE 2

TURKEY POINT UNIT 3 OPERATING STATISTICS DURING
THE FIRST TWO CYCLES OF OPERATION

Date Charged	January 12, 1972
Date Discharged	November 25, 1975
Irradiation Time	827 Full Power Days
Reactor Average Thermal Power	13.96 MW/Assembly
Reactor Operating Power Density	82.6 kW/Liter
Core Average Linear Power	182 W/cm
Core Peak-to-Average Power Ratio	1.141
Core Average Burnup	25,665 MWd/MTU
Core Peak Burnup	28,564 MWd/MTU

HEDL 7901-234.2

FIGURE 1. Core Map Illustrating the Locations of Characterization Assemblies During the Second Cycle of Reactor Operation of Turkey Point Unit 3.

IV. FUEL CHARACTERIZATION

Characterization in this report refers to the processes of qualifying and quantifying the condition of the spent fuel. Characterization consisted of nondestructive and destructive tests that quantified certain chemical, physical and nuclear characteristics. The two efforts of the nondestructive tests are tests conducted on the fuel assemblies and tests conducted on the fuel rods. The fuel assembly tests included sip testing for breached rod(s) within a fuel assembly, visual examinations, dimensional measurements and, in one case, measurements of gamma and neutron fluxes. The fuel rod tests included a rod sip test, visual examination, and dimensional, gamma flux and eddy current measurements. The specific examinations and their sequences are shown in Figure 2. All examinations were conducted at the Battelle Columbus Laboratories Nuclear Materials Technology facility (BCL).

Fuel assembly sip testing was performed on arrival at the facility with the assemblies still in their shipping casks. Assemblies were then removed from the shipping casks and stored under water until all assemblies had arrived. The assembly visual examinations and bow measurements were conducted in the storage pool. The remainder of the assembly examinations and all of the rod examinations were conducted in the hot cell. Each fuel assembly was examined independently. While one assembly was being examined the other four remained in the storage pool.

A strongback was used to transfer each assembly between the storage pool and the hot cell. While in the hot cell, the assembly remained in the strongback. Access to fuel rods was obtained by cutting a three-inch diameter hole in the top tie plate of the fuel assembly. Five rods were subsequently removed for examination. Rods from the same relative positions were examined for each assembly. As the rods were removed, a zero degree radial orientation mark was put on the top end plug. Each rod was placed in a protective tube and stored in a basket until examined. Several rods were examined simultaneously at different work stations. When examinations were complete, rods were reinserted into the fuel assemblies at original positions and

FIGURE 2. Process Flow Diagram for Nondestructive Examinations.

orientations. The hole in the fuel assembly used for removing and replacing rods was covered with a plate and locked against the top orifice plate. Length, weight and flat-to-flat measurements were performed on the fuel assembly after the cover plate was secured. A more detailed description of the procedure used to cut the hole and attach the cover plate is provided in Appendix A.

Gamma and neutron dosimetry was conducted on B03 and B43 fuel assemblies, respectively, at the completion of the nondestructive examinations.

The position and length reference schemes used during the examinations are summarized in Figures 3 and 4. Fuel assembly and rod identification numbers were used to maintain traceability throughout the examinations. The four faces of the fuel assembly were designated A, B, C and D. A serial number stamped on the top tie plate was used to designate Face A. Faces B, C and D were oriented clockwise from Face A (looking down from the top). All fuel assembly axial measurements were made with respect to the top of the bottom tie plate. The spacer grids were numbered from "1" to "7", with "1" at the bottom and "7" at the top. The zero degree radial orientation on the fuel rods was specified as the radius perpendicular to Face A when the rods were removed from the assembly. Degrees were counted clockwise when viewed from the top (Figure 4). Fuel rod positions were designated by a two character code. Face A was sequentially lettered and Face B was sequentially numbered (Figure 4). Rod axial measurements were referenced with respect to the bottom of the bottom end plug except in the case of gamma scans where reference was made to the bottom of the fuel column.

A. FUEL ASSEMBLY EXAMINATIONS AND RESULTS

1. Sip Testing

Assembly sip testing was performed in the cask upon arrival and departure at BCL to determine the presence of any breached fuel rods within the fuel

FIGURE 3. Typical Turkey Point Fuel Assembly and Rod Length Reference Schemes.

HEDL 7901-234.1

FIGURE 4. Turkey Point Fuel Assembly and Rod Positioning Scheme.

assembly. The assemblies arrived and departed at BCL in separate shipments and the sip tests were conducted accordingly.

Apparatus and Procedure - A 12-inch length of 0.5-inch diameter pipe was attached to the top vent valve on the shipping cask. One end of a piece of Tygon tubing was clamped to the pipe and the other end was placed in a 50-gallon waste drum. A second pipe extension with a ball valve and hose connector was attached to the bottom drain valve. A hose was attached to the bottom pipe and the cask filled with dionized water at a flow rate of approximately one gallon per minute. A cask fill required approximately 80 minutes and a small amount of water was allowed to overflow through the top vent valve into the drum to flush any loose crud from the cask cavity. A pint of water was then drawn from the cavity through the bottom valve. After an appropriate soak period (Table 3), a second or third water sample was withdrawn. All samples were analyzed for Cs^{134} and Cs^{137} in a gamma ray spectrometer. Problems were encountered with gamma energy peak separation using a sodium-iodide detector on the low concentration background sip samples from the arrival sip tests. Therefore, a more sensitive germanium-lithium detector was used for the analysis of the departure sip samples. A significant increase in activity from the background to the soak samples was interpreted as an indication of the presence of a leaking rod(s).

Results - A water sip test analysis summary is presented in Table 3 for shipments arriving and leaving BCL. Due to the low cesium concentration in the as-received background sip samples, the table only lists the combined Cs^{134} and Cs^{137} activities. Total cesium gamma activity levels for arrival sip tests and departure sip tests showed an approximate order of magnitude increase between background samples and two-hour soak samples. The major difference was shown in the concentrations of assemblies B41 and B43. The table shows an additional 15-hour soak sip test for shipments leaving BCL reflecting the rate of activity increase. Comparisons of the sip test results for assemblies B02, B03 and B43 show the rate leveling off while the rate for assembly B41 appears to be steadily increasing. Because of the large concentration of cesium and the increasing rate, assembly B41 was designated as a potential

TABLE 3
SIP TEST RESULTS

<u>Order of Shipment</u>	<u>Assembly</u>	<u>Sample</u>	<u>Total Cesium</u>	<u>Cs137</u>	<u>Cs134</u>
Shipments As-Received at BCL			Activity ($\mu\text{Ci/ml}$)		
1	B02	Background 2 h soak	3.8×10^{-5} 3.5×10^{-4}	2.2×10^{-4}	1.3×10^{-4}
2	B03	Background 2 h soak	2.4×10^{-5} 1.1×10^{-4}	3.2×10^{-5}	8.2×10^{-5}
3	B17	Background 2 h soak	1.5×10^{-5} 9.9×10^{-5}	3.4×10^{-5}	6.5×10^{-5}
4	B41	Background 2 h soak 20 h soak	2.2×10^{-4} 3.4×10^{-3} 1.3×10^{-2}	2.3×10^{-3} 1.2×10^{-2}	1.1×10^{-3} 1.9×10^{-3}
5	B43	Background 2 h soak	1.2×10^{-4} 4.3×10^{-4}	4.0×10^{-4}	3.5×10^{-5}
Shipments Leaving BCL					
1	B02	Background 2 h soak 15 h soak	6.0×10^{-6} 1.3×10^{-5} 1.0×10^{-5}	6.0×10^{-6} 1.1×10^{-5} 8.1×10^{-6}	$<1.0 \times 10^{-6}$ $<2.0 \times 10^{-6}$ $<2.0 \times 10^{-6}$
2	B03	Background 2 h soak 15 h soak	7.3×10^{-6} 2.7×10^{-5} 4.0×10^{-5}	7.3×10^{-6} 2.5×10^{-5} 3.8×10^{-5}	$<1.0 \times 10^{-6}$ $<2.0 \times 10^{-6}$ $<2.0 \times 10^{-6}$
3	B41	Background 2 h soak 15 h soak	1.6×10^{-5} 1.3×10^{-4} 2.2×10^{-2}	1.3×10^{-5} 1.0×10^{-4} 1.6×10^{-2}	3.1×10^{-6} 3.5×10^{-5} 6.4×10^{-3}
4	B43	Background 2 h soak 15 h soak	1.9×10^{-4} 9.3×10^{-4} 1.8×10^{-3}	1.4×10^{-4} 6.9×10^{-4} 1.3×10^{-3}	5.3×10^{-5} 2.4×10^{-4} 5.2×10^{-4}

leaker. Residual contamination from the preceeding shipment of assembly B43 is believed to contribute to the relatively large concentrations in each sip sample.

2. Fuel Assembly Visual Examination

An underwater visual examination was conducted on each fuel assembly and recorded on video tape to document the external appearance.

Apparatus and Procedure - Visual examinations equipment consisted of an underwater television camera, pool side monitor, video tape recorder and microphone for recording comments. The camera was mounted on a stationary pole attached to the pool liner and submerged 18 feet below the surface of the water. The examination was conducted with the fuel assembly suspended in the vertical position next to the camera by a grappling tool.

The examination started with verification of the serial number on Face A of the assembly. Each face of the assembly was examined sequentially from A to B, C and D. The assembly was raised and lowered in front of the camera as required. Each face and spacer grid was identified by the examiner on the audio portion of the video tape. In all cases where abnormalities were observed, movement of the assembly was stopped and the abnormality was observed at a greater magnification. Assemblies B02, B03, B17, and B43 were scanned at 3X magnification. Assembly B41, the designated leaker, was scanned at 6X magnification.

Results - Particular differences between the fuel assemblies were few. No distinct abnormalities were observed during the visual examination. All of the structural components of the fuel assemblies were black and appeared to be uniformly oxidized. No unusual physical damage or distortion was apparent. The visible fuel rods and structural components appeared of sound integrity. Nearly all rods were in contact with the bottom tie plate.

Only the rods on the face of the assembly could be observed in detail. The crud pattern on the rods was continuous and uniform from zero inches to 48 inches from the bottom. Between 48 inches and 100 inches, the crud looked patchy and darker in appearance. From 100 inches to 130 inches, the crud turned black and the patchy areas became larger. From 130 inches to the end of each rod, the crud became a light grey. Most changes in the crud appearance were gradual; however, there were sharp changes at some of the spacer grid locations. Between zero inches and 54 inches, shiny marks spiraling to the right were seen on some of the rods. The spiral pattern had an approximate 1.25 inch period. Circumferential rings were observed on some of the rods between 70 inches and 145 inches. The circumferential rings were spaced approximately 0.6 inch apart. Several faces on the assemblies showed the middle rods to be bowed. Some rods appeared to touch adjacent rods.

3. Fuel Assembly Bow Measurements

Fuel assemblies were examined for bow while vertically suspended in the storage pool from the top tie plate. This examination determined the degree of bow in each face of the assemblies.

Apparatus and Procedure - Apparatus for measuring assembly bow consisted of a wire stretched between the two tie plates and a periscope with a calibrated eye piece. The distance between the fixed wire and each of the seven spacer grids was measured. The assembly was moved past the periscope by a hoist.

Results - The distance between the spacer grids and the wire are presented in Table 4. Bow measurement was not conducted on Assembly B17, the companion assembly.

Each assembly showed a small amount of bow along two faces. The maximum bow was 0.070 inch on assembly B43 along Face A. Points of contact between the reference wire and the grid spacers were recorded as zero bow (Table 4). Measurement accuracy in all cases was ± 0.050 inch.

TABLE 4

FUEL ASSEMBLY BOW MEASUREMENTS

Distance Between Wire and Spacer Grid at Each
Spacer Grid Location on Each Face

<u>Assembly</u>		<u>Position of Measurement (in.)</u>						
		1	2	3	4	5	6	7
B02	FACE A	0.030	0.050	0.030	0.050	0.040	0.020	0.0
	FACE B	0.020	0.015	0.050	0.065	0.065	0.030	0.0
	FACE C	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FACE D	0.030	0.030	0.020	0.0	0.0	0.0	0.0
B03	FACE A	0.020	0.030	0.005	0.005	0.015	0.025	0.045
	FACE B	0.020	0.040	0.065	0.050	0.025	0.0	0.0
	FACE C	0.020	0.030	0.040	0.035	0.030	0.0	0.0
	FACE D	0.030	0.020	0.0	0.0	0.0	0.0	0.0
B41	FACE A	0.010	0.030	0.060	0.050	0.040	0.0	0.0
	FACE B	0.0	0.010	0.050	0.050	0.040	0.020	0.0
	FACE C	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FACE D	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B43	FACE A	0.015	0.030	0.050	0.070	0.040	0.040	0.040
	FACE B	0.010	0.010	0.020	0.040	0.020	0.010	0.040
	FACE C	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	FACE D	0.015	0.015	0.015	0.010	0.010	0.010	0.0

4. Assembly Length Measurements

The assembly length measurement determined the distance between two reference points on each fuel assembly.

Apparatus and Procedure - The length of each fuel assembly was measured between two reference points, the top of the bottom tie plate and the bottom of the top tie plate (Figure 3). Measurements were made along the two long edges of Face A with the assembly positioned horizontally. Two knife edges were mounted on a piece of angle iron spanning the assembly. One of the knife edges was mounted to the angle iron. The other knife edge was mounted on a micrometer spindle that mounted on the angle iron. The measurements were made by butting the fixed knife edge against the bottom tie plate and expanding the micrometer spindle against the top tie plate. The micrometer reading was recorded and compared to the number from a standard rod. The difference between the two numbers was added to the known length of the standard rod.

Results - Table 5 lists the results from these measurements. The lengths of the fuel assemblies are within 0.050 inch of each other. The accuracy of these measurements is ± 0.005 inch.

5. Flat-to-Flat Measurements

The flat-to-flat measurements determined the distances between two opposite faces on the fuel assemblies at positions between grid spacers.

Apparatus and Procedure - Flat-to-flat dimensions were measured with the assembly in a horizontal position while in the strongback. Measurements were made on the A-C and B-D faces at the midpoints between the seven grid spacers using a large set of calipers. Three measurements were made at each position and the results averaged.

TABLE 5
ASSEMBLY LENGTH MEASUREMENTS

<u>Assembly</u>	<u>A-B Corner (in.)</u>	<u>A-D Corner (in.)</u>
B02	153.338	153.339
B03	153.356	153.365
B17	153.353	153.338
B41	153.368	153.382
B43	153.374	153.385

Results - The average flat-to-flat measurements and 1σ standard deviations for each average are presented in Table 6. The expression used for the standard deviation was:

$$S = \sqrt{\frac{\sum X^2 - \frac{(\sum X)^2}{n}}{n - 1}}$$

The flat-to-flat distances range from 8.253 inches to 8.322 inches with no apparent pattern to the variations.

6. Weight Measurements

Weight measurements were made on each assembly after the rods were nondestructively examined, reinserted and the assembly cover plate installed.

Apparatus and Procedure - The assemblies were weighed using a load cell, sling and digital indicator. The load cell was rated for loads between zero and 2000 pounds and calibrated to an accuracy of ± 3.0 pounds. The strongback with the assembly was placed in a sling and attached to the load cell hooked to the in-cell overhead crane. The assembly was suspended horizontally and the weight read directly from the digital display. Figure 5 shows the weighing of assembly B03.

TABLE 6

ASSEMBLY FLAT-TO-FLAT MEASUREMENTS

<u>Assembly</u>	<u>Orientation</u>	<u>Position From Bottom of Fuel Assemblies (in.)</u>					
		15 in.	46 in.	72 in.	99 in.	125 in.	146 in.
B02	A-C	8.299 $\pm$ 0.001	8.297 $\pm$ 0.004	8.285 $\pm$ 0.005	8.290 $\pm$ 0.005	8.300 $\pm$ 0.005	8.293 $\pm$ 0.005
	B-D	8.299 $\pm$ 0.003	8.300 $\pm$ 0.002	8.299 $\pm$ 0.003	8.302 $\pm$ 0.002	8.297 $\pm$ 0.002	8.301 $\pm$ 0.001
B03	A-C	8.279 $\pm$ 0.006	8.308 $\pm$ 0.003	8.283 $\pm$ 0.004	8.313 $\pm$ 0.005	8.298 $\pm$ 0.001	8.285 $\pm$ 0.003
	B-D	8.301 $\pm$ 0.005	8.317 $\pm$ 0.007	8.298 $\pm$ 0.005	8.291 $\pm$ 0.004	8.305 $\pm$ 0.002	8.308 $\pm$ 0.002
B17	A-C	8.301 $\pm$ 0.002	8.297 $\pm$ 0.003	8.263 $\pm$ 0.002	8.281 $\pm$ 0.001	8.288 $\pm$ 0.003	8.296 $\pm$ 0.006
	B-D	8.296 $\pm$ 0.015	8.302 $\pm$ 0.006	8.303 $\pm$ 0.001	8.301 $\pm$ 0.004	8.291 $\pm$ 0.004	8.303 $\pm$ 0.002
B41	A-C	8.312 $\pm$ 0.001	8.296 $\pm$ 0.005	8.299 $\pm$ 0.001	8.277 $\pm$ 0.003	8.292 $\pm$ 0.003	8.289 $\pm$ 0.003
	B-D	8.307 $\pm$ 0.003	8.308 $\pm$ 0.005	8.322 $\pm$ 0.003	8.317 $\pm$ 0.005	8.301 $\pm$ 0.003	8.302 $\pm$ 0.002
B43	A-C	8.302 $\pm$ 0.002	8.279 $\pm$ 0.001	8.285 $\pm$ 0.005	8.303 $\pm$ 0.001	8.295 $\pm$ 0.006	8.272 $\pm$ 0.002
	B-D	8.292 $\pm$ 0.002	8.300 $\pm$ 0.002	8.295 $\pm$ 0.005	8.309 $\pm$ 0.001	8.301 $\pm$ 0.001	8.298 $\pm$ 0.005

FIGURE 5. Weighing Assembly B03. Neg 7814182-84.8-1

The tare weight consisting of sling and strongback was measured the same way and later subtracted from the combined weights to determine net fuel assembly weights.

Results - The weights of the assemblies are summarized in Table 7. The weights of B03, B41 and B43 were nearly identical. Assembly B02 weighed 15 pounds more than the other three. The reason for this difference is uncertain but is probably due to buildup of fabrication tolerances. Assembly B17 was not weighed because the rods were not replaced and a cover plate was not attached.

TABLE 7
ASSEMBLY WEIGHTS

<u>Assembly</u>	<u>Weight (lb)</u>
B02	1465
B03	1450
B41	1452
B43	1448

7. Gamma and Neutron Flux Measurements

Gamma and neutron flux measurements were conducted on fuel assemblies B02 and B43 to characterize the radiation field.

Apparatus and Procedure - Thermal luminescence detectors (TLDs) were used to record the gamma exposure rates. Three hundred fifteen TLDs were exposed in capsules each containing five TLDs. The five TLDs were stacked side by side, wrapped in tissue paper and placed inside a gelatin capsule. Each capsule was wrapped in aluminum foil to prevent contamination of the capsule during irradiation. The capsules were separated into four groups of 13 for axial irradiations, one group of seven capsules for irradiation perpendicular to the axis and four individual capsules (two for cell background counts and two for

control samples). Each group of capsules was placed in an aluminum tube for support and spacing. Each capsule was separated 12 inches from adjacent capsules in the tube. The four 13-foot tubes each containing 13 TLD packets and the one seven-foot tube containing seven TLD packets were placed in the cell and irradiated individually for 10 minutes. Two of the tubes were exposed within the fuel assembly (Figure 6), one in a guide thimble tube and one in the central instrument tube. The third tube was exposed resting on the surface of the assembly and the fourth was exposed one foot above the fuel assembly. The seven-foot tube was irradiated perpendicular to the axis at the axial midplane. All exposures were conducted while the assembly was resting horizontally on the cell table. The TLDs were prepared and analyzed by the Battelle Northwest Laboratory (BNL).

Nine solid state track recorders (SSTR's) were used to determine neutron flux. Sets of three SSTR's were sandwiched between two 4-inch x 2-inch aluminum plates and wrapped in aluminum foil for the exposure. The three packages were placed at the axial midplane of the fueled region on the surface of the assembly. The exposures were conducted while the fuel assembly was resting horizontally on the hot cell table. The three packages were irradiated simultaneously for five days.

Results - Table 8 presents the results for the four tubes exposed axially to the fuel assembly. Table 9 presents the results for the tube exposed perpendicular to the fuel assembly. The tables list the average exposure rates of the five TLDs in each packet along with the 1 uncertainty in percent. The uncertainty is based on the statistical counting errors and does not account for experimental errors. The expression used for the standard deviation was:

$$S = \sqrt{\frac{\sum x^2 - \frac{(\sum x)^2}{n}}{n - 1}}$$

Table 10 presents the results of the neutron flux determinations along with estimated uncertainty percentages for each neutron energy interval.

1. 12 INCHES ABOVE ASSEMBLY FLAT
2. CONTACT IN MIDDLE OF FLAT
3. GUIDE THIMBLE TUBE
4. CENTRAL INSTRUMENT TUBE
5. PERPENDICULAR TO FUEL ASSEMBLY

HEDL 7902-074.1

FIGURE 6. Locations of Gamma Dosimetry Measurements.

TABLE 8

AXIAL GAMMA EXPOSURE RATES FROM ASSEMBLY B03 (R/h)

Distance From BOF Assembly (ft)	Position of Irradiation							
	<u>Instrument Tube</u>		<u>Guide Thimble</u>		<u>Assembly Surface</u>		<u>One Foot Away</u>	
	Exposure Rate	1 σ Uncertainty (%)	Exposure Rate	1 σ Uncertainty (%)	Exposure Rate	1 σ Uncertainty (%)	Exposure Rate	1 σ Uncertainty (%)
1	3.87×10^4	10	1.75×10^5	7	1.32×10^3	12	1.74×10^3	6
2	1.33×10^5	3	1.79×10^5	4	3.26×10^3	3	3.25×10^3	4
3	1.74×10^5	5	1.69×10^5	2	2.24×10^4	4	6.02×10^3	8
4	1.80×10^5	4	1.67×10^5	7	3.81×10^4	3	8.39×10^3	6
5	1.81×10^5	4	1.74×10^5	4	4.29×10^4	3	8.03×10^3	9
6	1.71×10^5	4	1.65×10^5	4	5.67×10^4	5	1.18×10^4	3
7	1.68×10^5	9	1.72×10^5	8	5.88×10^4	3	1.23×10^4	4
8	1.68×10^5	8	1.76×10^5	5	4.86×10^4	5	1.20×10^4	5
9	1.72×10^5	8	1.65×10^5	3	6.33×10^4	5	1.24×10^4	2
10	1.67×10^5	4	1.25×10^5	4	6.23×10^4	7	1.31×10^4	5
11	1.63×10^5	2	4.77×10^4	6	6.57×10^4	4	1.29×10^4	8
12	1.27×10^5	6	7.18×10^3	5	6.26×10^4	3	1.17×10^4	5
13	6.29×10^4	8	1.16×10^3	5	5.79×10^4	4	1.03×10^4	4

TABLE 9
GAMMA DOSE RATES AS A FUNCTION
OF DISTANCE FROM THE ASSEMBLY B03 MIDPLANE

<u>Distance (ft)</u>	<u>Exposure Rate (R/h)</u>	<u>1σ Uncertainty (%)</u>
0	5.88×10^4	3
1	1.55×10^4	7
2	7.99×10^3	3
3	4.62×10^3	4
4	3.37×10^3	5
5	2.55×10^3	5
6	1.90×10^3	6
7	1.56×10^3	4

TABLE 10
NEUTRON FLUXES AT SURFACE
OF ASSEMBLY B43

<u>Energy Interval</u>	<u>Flux n/(cm²·s)</u>	<u>Estimated 1σ Uncertainty (%)</u>
Thermal (<0.4 eV)	14	50
Epithermal (0.5 eV - 0.1 MeV)	140	50
Fast (0.1 MeV - 2 MeV)	6520	30
High Energy (>2 MeV)	1230	20
Average Total Flux = 1.3 MeV	7900	30

B. FUEL ROD EXAMINATIONS AND RESULTS

Five rods from each fuel assembly were selected for individual examinations. The same rods were removed from each assembly and are identified by their positions (Figure 4). The rods examined are G9, G7, J8, I9 and H6.

1. Visual Examination

Fuel rods were visually examined using video equipment to document the physical appearance.

Apparatus and Procedure - Rods were examined through a stereo optical viewing system. The objective lens was inside the hot cell and the eyepiece, video camera, recorder, monitor and operating controls outside. The rods were held in a flat horizontal tray that moved in a horizontal plane beneath the objective lens. Two light sources were used to decrease shadows. A steel measuring tape was fastened to the tray next to the rods to identify the position of any visible feature on the rod surface in terms of the distance from the end of the rod. Included in the field of view was a section of the rod and a corresponding portion of the tape measure.

The examination began after a fuel rod was loaded into the viewing tray and the radial orientation established. All visual scans began at the bottom of the rod by verifying that the bottom end cap was butted against a stop corresponding to zero inches on the measuring tape. Each rod was scanned at 13X magnification at four radial orientations: 0° , 90° , 180° and 270° .

Results - None of the rods exhibited gross distortions or bow while resting in the horizontal tray. The external appearance was generally the same for all rods. At the bottom of each rod, the oxide layer was uniform with a dull luster. At approximately 40 inches from the bottom, there was a patchy crud layer. The patchy crud layer became coarser as the distance from the bottom increased. At approximately 110 inches from the bottom, the crud became uniform and dark. The crud layer was thick and black covering the circumference

of the rod up to 130 inches. Some rods showed spalling or cracking of the thick crud layers in this region. Usually, an abrupt transition in this crud pattern occurred at approximately 130 inches from the bottom. Here, the black crud turned to a light gray. In places where the light gray areas had been contacted through handling, the oxide layer was removed and a dull metallic luster showed beneath the gray.

Generally, at 80 inches and 105 inches (locations of spacer grids 4 and 5) there were local changes in the crud appearance. At 80 inches, a five-inch to six-inch region of dark uniform crud was observed. A three-four to four-inch region of broken crud was observed at 105 inches. Wear marks were observed at some of the spacer grid locations; but, there was no particular grid location where the wear marks were prevalent. Oval-shaped blemishes were observed on a few of the rods but not enough to determine any particular pattern.

Circumferential rings were observed on nearly all the rods toward the tops. The rings repeated themselves at 0.6 inch intervals. During profilometry and gamma scan examinations, these rings were identified as ridges which corresponded with gamma flux depressions at pellet interfaces.

Practically all the rods showed some roughness at the end plugs. The roughness extended completely around the rods. Axial scratches were observed on nearly all the rods. These scratches extended from a few inches to the length of the entire rod. Scratches that occurred during rod pulling operations were identified by their shiny appearance. The scratches from previous handling were oxidized. In the lower regions of the rod, the old scratches were speckled with small crud deposits.

Most of the rods were visually examined prior to profilometry. Those rods visually examined after profilometry had shiny circumferential marks attributed to profilometer contact points.

2. Rod Length Measurements

The rod length measurements were made between the bottom of the bottom end plug and the top of the top end plug.

Apparatus and Procedure - The lengths of the rods measured to an accuracy of ± 0.010 inch by comparing the length of each rod to that of a calibrated standard.

To perform measurements, a series of axially aligned V-groove blocks were mounted at two-foot intervals along the top edge of an I-beam. The grooves were used to position the rod between a fixed stop at one end and a micrometer barrel mounted at the other end. The temperature of each rod was measured to correct for changes caused by thermal expansion using a contacting thermocouple. The same measurement procedure was followed for the standard rod.

Results - The length measurements and the temperature of each rod at contact are shown in Tables 11 and 12. The rod lengths varied between 152.266 inches and 152.764 inches.

3. Weight Measurements

The weight measurements determined the weights of the individual fuel rods.

Apparatus and Procedure - The fuel rod weights were measured with a sling, digital indicator, support tray and a calibrated load cell rated for weights between zero pound and 25 pounds.

Each fuel rod was placed in the support tray. The sling was attached to the load cell suspended by the hot cell hoist. The weight was read directly from the digital display. The tare weight of the sling and tray was measured the same way.

TABLE 11

ROD LENGTH MEASUREMENTS (in.)

<u>Rods</u>	<u>B02</u>	<u>B03</u>	<u>B17</u>	<u>B41</u>	<u>B43</u>
G7	152.686	152.455	152.700	152.426	152.576
G9	152.557	152.386	152.395	152.644	152.591
J8	152.466	152.266	152.631	152.616	152.452
I9	152.708	152.414	152.707	152.513	152.765
H6	152.523	152.430	152.518	152.452	152.592

TABLE 12

ROD TEMPERATURE MEASUREMENTS (°F)*

<u>Rods</u>	<u>B02</u>	<u>B03</u>	<u>B17</u>	<u>B41</u>	<u>B43</u>
G7	71	82	84	82	82
G9	72	82	82	82	83
J8	80	81	85	83	82
I9	70	81	85	82	83
H6	72	82	82	84	82

*The coefficient of thermal expansion used for the conversion of the standard rod was 1×10^{-6} in./in./°F.

Results The fuel rod weights are listed in Table 13 and are accurate to ± 0.05 lb. The rod weights vary between 6.70 pounds and 6.82 pounds with an average weight of 6.75 pounds.

TABLE 13

ROD WEIGHTS (lb)

<u>Rod</u>	<u>B02</u>	<u>B03</u>	<u>B41</u>	<u>B43</u>
G9	6.73	6.73	6.79	6.73
H6	6.74	6.79	6.71	6.81
G7	6.76	6.73	6.75	6.73
J8	6.70	6.70	6.72	6.82
I9	6.72	6.77	6.74	6.77

4. Rod Bow Measurements

Fuel rod bow measurements were made with the rod restrained at seven axial positions corresponding to the locations of the fuel assembly grid spacers.

Apparatus and Procedure - A series of seven axially aligned V-block grooved pedestals were mounted on the top edge of an I beam. The pedestals were mounted such that the rod was supported at the same spacer grid locations as the fuel assembly. Gage blocks were mounted at the mid-spacer grid locations. A wire was stretched parallel to the V-block grooved supports. Photographs of the rod edge, wire and gage block were taken at each mid-spacer grid location. The rod bow was determined at four radial orientations; 0° , 90° , 180° and 270° . The distance between the wire and rod edge were measured from the photograph using the gage block. The standard rod was placed in the same device. The distance between the wire and standard rod was measured the same way. The distances between the standard rod and the fuel rod were subtracted and the resultant number recorded as the rod bow.

Results - Tables 14, 15, 16 and 17 list the bow measurements for each of the five rods from assemblies B03, B17, B41 and B43. The accuracy of these measurements is ± 0.005 inch. The tables list the difference between the edges of the standard rod and the tested rod. A positive difference is bow in the outward direction and negative difference is inward bow. The measurements from B02 were found to be in error and are not included in this report.

5. Profilometry Scans

Profilometer scans were performed to obtain fuel rod diameter and ovality measurements as a function of axial position.

Apparatus and Procedure - The profilometer was built at the BCL. It consisted of two Linear Variable Differential Transformers (LVDT)s with output fed into a two channel differential transformer. The signal from the transformer was fed to a strip chart recorder providing an analog trace of the LVDT signal. Tick marks on the strip chart indicate the axial position of the signal with respect to a known starting position.

The in-cell components consisted of holding, rotating and support structures and two LVDTs mounted on a moveable crosshead through an air bearing. The amplifier and strip chart recorder were located outside the hot cell. The sensing heads were 0.125-inch diameter sapphire rods contacting the rods diametrically. The spiral profilometry scan was obtained by rotating the rod between the two LVDTs while the crosshead was raised. For each revolution of the rod, the transducer heads moved 0.125 inch axially along the rod.

A step standard, traceable to the National Bureau of Standards, was used to check calibration of the system before and after scanning each rod. After initial calibration, the rod was loaded into the profilometer and the crosshead moved to the lower end of the rod and the scan started. Each rod was scanned in 35-inch sections. The analog output was charted at a one-to-one relationship with the rod lengths. One spiral profilometry scan was conducted on each fuel rod.

TABLE 14

ROD BOW MEASUREMENTS FOR ASSEMBLY B03

<u>Rod</u>	<u>Position</u>	Orientation/Distance (in.)			
		<u>0⁰</u>	<u>90⁰</u>	<u>180⁰</u>	<u>270⁰</u>
I9	1	0.002	0.001	0.002	0.002
	2	0.004	0.003	0.002	0.003
	3	0.002	0.011	-0.003	-0.001
	4	0.008	0.011	0.005	0.000
	5	0.011	-0.003	0.003	0.008
	6	0.003	-0.008	0.000	0.032
J8	1	0.001	-0.002	0.006	0.008
	2	0.005	0.003	-0.006	-0.003
	3	0.001	0.014	0.008	-0.006
	4	-0.008	-0.009	0.012	0.011
	5	0.016	0.016	-0.017	-0.007
	6	0.007	-0.005	0.008	0.005
G7	1	-0.003	-0.002	0.008	0.008
	2	0.007	0.003	0.003	0.006
	3	0.009	0.015	0.019	-0.007
	4	0.001	0.004	0.004	0.000
	5	-0.002	0.013	0.008	0.011
	6	0.022	0.013	0.013	-0.004
H6	1	0.007	-0.001	0.008	0.011
	2	-0.005	0.021	0.003	-0.013
	3	0.004	0.002	0.003	0.008
	4	0.007	0.001	-0.005	0.000
	5	-0.014	0.005	0.019	0.003
	6	0.000	-0.002	-0.006	0.000
G9	1	0.006	0.003	-0.003	0.002
	2	0.005	-0.005	-0.010	0.016
	3	0.002	-0.001	-0.009	0.020
	4	0.005	-0.007	-0.003	0.017
	5	-0.003	0.009	0.013	0.003
	6	-0.004	-0.010	0.006	0.015

TABLE 15

ROD BOW MEASUREMENTS FOR ASSEMBLY B17

<u>Rod</u>	<u>Position</u>	Orientation/Distance (in.)			
		<u>0°</u>	<u>90°</u>	<u>180°</u>	<u>270°</u>
G9	1	-0.002	0.006	-0.005	-0.005
	2	0.008	-0.003	-0.001	0.010
	3	0.012	-0.003	-0.010	0.004
	4	-0.003	-0.015	-0.003	0.006
	5	0.010	0.016	-0.012	-0.018
	6	-0.040	-0.029	-0.003	0.042
I9	1	0.005	-0.002	0.003	0.003
	2	-0.002	-0.001	0.011	0.000
	3	0.027	-0.018	0.027	0.032
	4	0.035	-0.010	-0.007	0.015
	5	0.020	-0.005	-0.005	0.021
	6	0.007	-0.006	-0.014	0.022
J8	1	0.003	0.005	0.011	0.004
	2	-0.012	-0.006	0.018	0.009
	3	0.011	-0.022	0.004	0.022
	4	-0.006	0.022	-0.005	-0.015
	5	0.020	-0.009	-0.010	0.002
	6	0.001	-0.007	0.002	0.012
G7	1	0.005	0.014	0.005	0.001
	2	-0.009	0.004	0.019	-0.010
	3	0.011	0.010	-0.016	0.007
	4	-0.006	0.007	0.014	-0.020
	5	0.007	0.002	-0.010	0.006
	6	-0.018	0.014	0.012	-0.038
H6	1	0.005	0.010	0.010	-0.009
	2	-0.001	-0.016	0.000	0.019
	3	0.002	0.022	0.002	-0.015
	4	0.005	0.005	-0.005	-0.014
	5	-0.007	-0.017	-0.001	0.020
	6	-0.004	0.008	-0.008	-0.020

TABLE 16

ROD BOW MEASUREMENTS FOR ASSEMBLY B41

<u>Rod</u>	<u>Position</u>	Orientation/Distance (in.)			
		<u>0⁰</u>	<u>90⁰</u>	<u>180⁰</u>	<u>270⁰</u>
G7	1	-0.003	0.005	0.015	-0.004
	2	-0.020	0.021	0.026	-0.019
	3	0.005	0.018	0.003	-0.019
	4	0.000	0.011	-0.014	0.001
	5	0.018	0.005	0.003	0.009
	6	-0.007	0.000	-0.002	-0.001
I9	1	0.017	0.010	-0.005	-0.005
	2	0.001	-0.010	0.002	0.017
	3	0.000	0.001	-0.001	0.005
	4	0.012	-0.010	-0.010	0.010
	5	-0.010	-0.005	0.010	0.008
	6	0.027	-0.016	-0.033	0.011
H6	1	0.005	0.005	0.005	-0.003
	2	-0.002	0.001	0.008	0.000
	3	0.010	0.003	-0.002	-0.001
	4	0.012	0.011	-0.007	-0.007
	5	0.010	0.009	0.001	-0.005
	6	-0.003	0.002	0.000	-0.004
J8	1	0.017	0.020	-0.006	-0.012
	2	0.041	-0.032	-0.048	0.059
	3	-0.025	-0.029	0.045	0.016
	4	0.030	0.065	-0.025	-0.051
	5	0.045	-0.028	-0.040	0.0041
	6	-0.020	0.014	0.018	-0.017
G9	1	0.007	-0.001	0.001	0.013
	2	-0.001	-0.005	0.009	0.008
	3	0.010	-0.015	-0.010	0.016
	4	0.030	0.065	-0.025	-0.051
	5	0.045	0.028	-0.040	0.041
	6	-0.020	0.014	0.018	-0.017

TABLE 17

ROD BOW MEASUREMENTS FOR ASSEMBLY B43

<u>Rod</u>	<u>Position</u>	Orientation/Distance (in.)			
		<u>0⁰</u>	<u>90⁰</u>	<u>180⁰</u>	<u>270⁰</u>
I9	1	0.000	-0.012	-0.004	0.009
	2	0.017	-0.003	-0.015	0.000
	3	-0.014	-0.013	0.005	0.000
	4	0.008	0.009	0.000	-0.005
	5	-0.001	-0.010	-0.003	0.005
	6	0.004	-0.001	0.000	0.008
J8	1	-0.001	-0.002	-0.010	-0.002
	2	-0.011	-0.039	0.023	0.022
	3	-0.014	0.010	0.003	-0.024
	4	0.031	0.030	-0.037	-0.012
	5	0.014	-0.054	0.008	0.045
	6	0.010	0.008	0.018	-0.001
G7	1	-0.001	0.006	-0.005	-0.013
	2	-0.007	0.016	0.015	-0.010
	3	0.016	-0.011	-0.025	0.005
	4	-0.010	0.010	0.022	-0.005
	5	-0.002	0.010	-0.001	-0.009
	6	-0.002	0.009	0.010	-0.002
H6	1	0.017	-0.014	-0.028	-0.001
	2	-0.013	0.010	0.008	-0.005
	3	-0.014	-0.008	0.006	0.004
	4	-0.012	0.028	0.007	-0.027
	5	0.005	0.003	-0.012	-0.013
	6	0.017	-0.008	-0.013	0.013
G9	1	-0.004	-0.008	-0.007	-0.006
	2	0.015	0.009	-0.013	0.003
	3	0.003	-0.034	-0.003	0.028
	4	0.000	0.023	-0.009	-0.027
	5	0.020	0.011	-0.010	-0.014
	6	-0.001	-0.003	-0.005	0.019

Results - The original strip chart recordings of the profilometry scans are maintained by the Spent Fuel R&D group at HEDL. Tables 18, 19, 20, 21 and 22 summarize the profilometry scans by assembly number. The tables list the minimum, maximum and average diameters and the maximum and average ovalities of each rod. Averages were made by the summation of 20 random points along the rod. Figure 7 shows typical examples of the data obtained. Replots of the spiral profilometry analog outputs are provided in Appendix B. The replots illustrate the gross diameter change experienced by each rod. The bars shown on the replots represent the ovality of the rod at that point.

In most cases, the rods exhibited two mils to three mils of ovality from zero inches to 20 inches from the bottom (Figure 7). At 20 inches, the ovality decreased and the rod appeared quite smooth, with an occasional ridge or localized ovality. Localized reidging increased at 60 inches and became more concentrated around 80 inches to 90 inches. The crud layer became thicker in this region. Generally a buildup was noticed adjacent to the spacer grid location at 80 inches. Figure 8 shows an average diameter increase believed to be crud buildup next to the spacer grid. Figure 9 shows the typical ridging and ovality observed at the mid-spacer grid location at 90 inches. The frequency of ridges increased toward the tops of the rods; however, these changes were no greater in size at the top than at any other location along the rod. From 120 inches to the end of the rod, the average rod diameter and average ovality increased. Quite often, the greatest ovality on the rod existed between 120 inches and 140 inches. Figure 10 demonstrates the typical increase in ovality in this region of the rod.

On a few rods, multipoint contact was observed. Normally, the ovality has two large diameter points relative to two small diameter points on the circumference. Multipoint contact has four large diameter points relative to four small diameter points. Rods with multipoint contact would appear square in the crosssectional view. An example of multipoint contact is shown in Figure 11.

TABLE 18
PROFILOMETRY SUMMARY FOR ASSEMBLY B02

<u>Rod</u>	<u>Ovality (in.)</u>		<u>Diameter (in.)</u>		
	<u>Maximum</u>	<u>Average</u>	<u>Minimum</u>	<u>Average</u>	<u>Maximum</u>
G7	0.0038	0.0010	0.4176	0.4193	0.4225
G9	0.0046	0.0015	0.4169	0.4196	0.4232
H6	0.0050	0.0020	0.4168	0.4184	0.4232
J8	0.0068	0.002	0.4153	0.4187	0.4222
I9	0.0046	0.0010	0.4171	0.4188	0.4223

TABLE 19
PROFILOMETRY SUMMARY FOR ASSEMBLY B03

<u>Rod</u>	<u>Ovality (in.)</u>		<u>Diameter (in.)</u>		
	<u>Maximum</u>	<u>Average</u>	<u>Minimum</u>	<u>Average</u>	<u>Maximum</u>
G7	0.0064	0.0020	0.4153	0.4174	0.4219
G9	0.0048	0.0020	0.4159	0.4181	0.4218
H6	0.0067	0.0020	0.4163	0.4197	0.4234
J8	0.0044	0.0015	0.4173	0.4194	0.4230
I9	0.0044	0.0012	0.4183	0.4202	0.4233

TABLE 20
PROFILOMETRY SUMMARY FOR ASSEMBLY B17

<u>Rod</u>	<u>Ovality (in.)</u>			<u>Diameter (in.)</u>	
	<u>Maximum</u>	<u>Average</u>	<u>Minimum</u>	<u>Average</u>	<u>Maximum</u>
G7	0.0054	0.0008	0.4179	0.4197	0.4235
G9	0.0054	0.0015	0.4172	0.4193	0.4234
H6	0.0049	0.0015	0.4170	0.4187	0.4224
J8	0.0066	0.0015	0.4174	0.4191	0.4241
I9	0.0054	0.0025	0.4173	0.4198	0.4231

TABLE 21
PROFILOMETRY SUMMARY FOR ASSEMBLY B41

<u>Rod</u>	<u>Ovality (in.)</u>			<u>Diameter (in.)</u>	
	<u>Maximum</u>	<u>Average</u>	<u>Minimum</u>	<u>Average</u>	<u>Maximum</u>
G7	0.0047	0.0020	0.4175	0.4197	0.4236
G9	0.0064	0.0014	0.4177	0.4198	0.4232
H6	0.0043	0.0015	0.4176	0.4192	0.4230
J8	0.0043	0.0015	0.4170	0.4200	0.4209
I9	0.0057	0.0020	0.4178	0.4191	0.4220

TABLE 22
PROFILOMETRY SUMMARY FOR ASSEMBLY B43

<u>Rod</u>	<u>Ovality (in.)</u>		<u>Diameter (in.)</u>		
	<u>Maximum</u>	<u>Average</u>	<u>Minimum</u>	<u>Average</u>	<u>Maximum</u>
G7	0.0056	0.0025	0.4161	0.4194	0.4227
G9	0.0047	0.0010	0.4168	0.4195	0.4231
H6	0.0043	0.0020	0.4180	0.4203	0.4234
J8	0.0053	0.0015	0.4176	0.4193	0.4231
I9	0.0070	0.0015	0.4174	0.4192	0.4258

Uniform ridging was observed on some of the rods. The ridges were spaced 0.6 inch apart. Uniform ridging is shown in Figure 12.

6. Eddy Current Examination

One encircling coil eddy current scan was made on each rod to obtain a detailed "road map" of cladding discontinuities i.e., throughwall holes, fuel-cladding bond areas, changes in thickness, inclusions and cracks in the cladding.

Apparatus and Procedure - The in-cell eddy current apparatus consisted of a rod holding fixture, a motor driven leadscrew, a copper excitation coil and a coil holder mounted to the lead screw (Figure 13). During scanning, the fuel rod was held stationary and the coil moved along the length of the rod.

The output from the coil was fed to an analyzer that drove the strip chart recorder pens. Horizontal, vertical and differential output signals were recorded. The horizontal channel showed cladding outer diameter discontinuities and the vertical channel showed inner diameter discontinuities. The differential channel conditioned the vertical channel output to intensify the signals of localized discontinuities.

FIGURE 7. Profilometry Results for Rod B02-H6 Between 8 inches and 14 Inches from the Bottom of the Rod Showing Ridges and Uniform Ovality.

FIGURE 8. Profilometry Results for Rod B41-G7 Showing the Increase in Rod Diameter and Ridges Above a Spacer Grid Location.

FIGURE 9. Profilometry Results for Rod B41-J8 Showing Typical Ridging and Ovality Between Spacer Grids 4 and 5.

FIGURE 10. Profilometry Results for Rod B02-H6 Showing Typical Increase in Ovality Toward the Top of the Rod.

FIGURE 11. Profilometry Results for Rod B41-H6 Showing a Typical Increase in Diameter Toward the Top of the Rod (A Typical Region of Multipoint Contact).

FIGURE 12. Profilometry Results for Rod B02-H6 Showing Uniform Ridging Between 44 inches and 48 inches from the Bottom of the Rod. Ridges appear at equally spaced intervals 0.6 inch apart.

FIGURE 13. Eddy Current Scanning System. Neg 7814182-84.4.2-3

Calibration of the eddy current instrument was conducted at the beginning of each series of eddy current inspections. The system was calibrated for each frequency employed in the operation using a standard having the same diameter and wall thickness as the fuel rod. The standard contained various types of artificial defects which included longitudinal and circumferential notches on the inner and outer surfaces, a hole through the wall and a ridge on the outer surface. Figure 14 shows the eddy current signals for the standard. The artificial defects used for calibration and comparison are identified in the figure.

Each fuel rod was scanned with the encircling coil in 35-inch sections starting from the bottom of the rod. An additional scan of the calibration rod provided a calibration chart recording for each rod. The rods were scanned at a linear speed of 1.2 inches per minute.

Results - Figures 15 through 25 show typical eddy current signals on several rods. These figures are provided to show the range of indications found in the eddy current scans. Some of the figures include the profilometry scan of the same region. Correlations between the eddy current scan and profilometer scan can be made in some cases.

Changes in the slope of the eddy current signal indicate the areas where discontinuities exist in the cladding. Interpretation of the signal is difficult since the combination of any two singular discontinuities do not yield an additive signal.

7. Gamma Scanning

Gamma scanning was performed to determine the relative gamma activity and infer the distribution of decay heat generation along the length of the rod.

Apparatus and Procedure - The gamma scanning system used two 18-foot precision ball screws, a crosshead, rod holder, support structure, collimator and a gamma ray spectrometer. The fuel rods were loaded

Figure 14. Eddy Current Scan of Defect Standard Showing Longitudinal and Circumferential Notches on Outer Surface, Longitudinal Notches on Inner Surface, Hole Through the Wall and Ridge on Outer Surface.

Figure 15. Eddy Current Scan of Rod B02-H6 Showing Potential Defect Signals at 9.0, 9.7, 11.3, and 11.9 inches from the Bottom of the Rod.

Figure 16. Profilometry and Eddy Current Scans of Rod B02-H6 Showing Uniform Ovality at Pellet Midsection with Ridges at Pellet Interfaces.

FIGURE 17. Profilometry and Eddy Current Scans of Rod B41-G7 Showing Decrease in Diameter and Possible Fuel Cladding Contact Between 47 inches and 50 inches from the Fuel Rod Bottom.

FIGURE 18. Profilometry and Eddy Current Scans of Rod B17-G9 Showing a 0.0014-inch Ridge 46.2 inches from the Fuel Rod Bottom.

Figure 19. Profilometry and Eddy Current Scans of Rod B41-J8 Showing Two Large Ridges at Pellet Interfaces with a Possible Defect Signal at 66.75 inches from the Bottom of the Fuel Rod.

FIGURE 20. Profilometry and Eddy Current Scans of Rod B41-J8 Showing Possible Defect Signals at 83.0 inches and 83.4 inches from the Bottom of the Rod.

FIGURE 21. Eddy Current Scan of Rod B41-G7 Showing Diameter Change and Pronounced Ridging at Spacer Grid Locations.

Figure 22. Profilometry and Eddy Current Scans of Rod B17-G9 Showing a 0.0014-inch Diameter Change with a 0.0033-inch Ovality at 89 inches from the Fuel Rod Bottom.

Figure 23. Eddy Current Scan for Rod B41-J8 Showing a Rod Section Where the Diameter Has Decreased and Possible Fuel Cladding Contact.

Figure 24. Profilometry and Eddy Current Scans of Rod B41-G7 Showing a Possible Defect Signal Accompanying a 0.0022-inch Ridge at 95.7 inches from the Bottom of the Rod.

FIGURE 25. Profilometry and Eddy Current Scans of Rod B43-H6 Showing Possible Defect Signals at 119.4, 120.0, 120.4, and 122.2 inches from the Bottom of the Rod.

horizontally into the rod holder and clamped to the crosshead. After loading, a winch positioned the rod holder vertically. The crosshead, spanning the ball screws, moved the rod vertically in front of the slit collimator. The ball screws were driven by a variable speed motor allowing the rods to be scanned continuously.

Lead collimating rings were positioned between the slit collimator and a sodium-iodide (NaI) counting crystal. The signal from the NaI crystal was fed to amplifiers and an analyzer. The analyzer recorded counts of a specific energy level (Cs^{137}) or recorded all counts above a specified energy level (gross gamma scan). The count rate signal was fed to a variable speed strip chart recorder to give a continuous analog output of the rod. A chart tick marker indicated the axial position of the signal with respect to the bottom of the fuel column. All rods were scanned from the top to the bottom. They were traversed past the slit collimator at a rate of two inches per minute. The slit collimator was set at 0.025 inch.

Prior to gamma scanning a set of fuel rods, the gamma spectrometer was adjusted to maximize the analog output to the rod with the highest activity. This allowed for a relative comparison of the gamma activities with other rods from the same assembly. Comparisons between rods of different fuel assemblies could not be made because of adjustments made to equipment between assembly examinations. Attention was focused on the locations of relative depressions in the gamma activity which were believed to be in the fuel column. The gap widths were determined using an area method where the length of the activity depression (L) was divided by the length of the average activity (A) adjacent to the gap. This was multiplied by the half height width ($W_{0.5}$) of the activity depression, $\frac{L}{A} W_{0.5} = W$.

Results - Each fuel rod was scanned twice, once for gross gamma distribution and the second time for Cs^{137} distribution. The analog output from these scans was digitized and replotted. The replots are included as Appendix C .

Both gross and Cs^{137} gamma scans exhibited typical flat chopped cosine curve profiles. The curves leveled off at 20 inches from either end of the fuel column. Gamma flux depressions were observed at nearly all the pellet interfaces. No unusual spikes or "hot spots" were observed. An approximate 10-% depression in the gamma activity was observed at each of the spacer grid locations. Most gap widths were less than 0.05 inch; however, several rods exhibited larger gaps. The maximum gap width was 0.395 in. on Rod B43-G7 at 139.81 inches from the bottom. Summary results from the gamma scan examinations are listed on Tables 23, 24, 25, 26 and 27.

8. Rod Sip Tests

Sip testing was performed on rods from assembly B41 to determine if one of the selected rods was breached as indicated by assembly sip test results. No other rods were sip tested.

Apparatus and Procedure - The rod sip test used a stainless steel tube, vacuum pump and helium gas analyzer. Suspect rods were individually loaded into a stainless steel pressure chamber and the chamber evacuated to 10^{-4} torr. The off-gas was collected and analyzed for gaseous fission products. If no fission gas was detected, the rod was pressurized with helium to 200 psi for two hours. Once the rods were removed, a helium sniffer probe was passed over the rod axially at four radial orientations. A breach would have been identified by the detection of helium.

Results - The five rods, removed from assembly B41 for nondestructive examination, were sip tested. No rods showed gaseous fission products or helium leakage. This indicated that the breached rod in assembly B41 was not among the five rods selected for detailed examination.

TABLE 23

GAMMA SCAN SUMMARY FOR FUEL RODS FROM ASSEMBLY B02

<u>Rod</u>	<u>Location</u>	<u>Gap Width (in.)</u>	<u>Fuel Stack Length (in.)</u>
G7	16.43	0.036	144.56
	24.25	0.045	
	26.12	0.050	
	32.68	0.016	
	38.12	0.020	
	88.25	0.026	
	91.81	0.033	
	94.81	0.030	
G9	66.06	0.021	144.626
	113.68	0.023	
H6	None		144.25
I9	101.93	0.036	144.43
	120.00	0.033	
	120.62	0.041	
	129.75	0.033	
J8	25.62	0.039	144.43
	29.62	0.051	
	29.87	0.071	
	40.93	0.032	
	53.06	0.046	
	66.50	0.021	
	111.87	0.028	
	115.50	0.037	
	116.75	0.040	

TABLE 24

GAMMA SCAN SUMMARY FOR FUEL RODS FROM ASSEMBLY B03

<u>Rod</u>	<u>Location</u>	<u>Gap Width (in.)</u>	<u>Fuel Stack Length (in.)</u>
G7	19.38	0.058	144.50
	27.63	0.058	
	57.00	0.154	
	65.31	0.030	
	87.94	0.050	
	101.50	0.057	
	132.31	0.068	
G9	33.36	0.141	144.50
	49.31	0.045	
	60.56	0.154	
H6	None		144.56
I9	None		144.44
J8	22.13	0.030	144.56
	52.44	0.041	
	57.88	0.101	
	75.31	0.037	
	76.56	0.072	
	77.19	0.074	
	96.94	0.032	
	99.31	0.071	

TABLE 25

GAMMA SCAN SUMMARY FOR FUEL RODS FROM ASSEMBLY B17

<u>Rod</u>	<u>Location</u>	<u>Gap Width (in.)</u>	<u>Fuel Stack Length (in.)</u>
G7	54.00	0.047	144.44
	87.00	0.050	
	113.50	0.049	
	118.25	0.034	
G9	None		144.50
H6	None		144.31
I9	22.69	0.045	144.75
	34.63	0.054	
	44.81	0.110	
	56.19	0.061	
	112.19	0.050	
J8	112.50	0.044	144.50

TABLE 26

GAMMA SCAN SUMMARY FOR FUEL RODS FROM ASSEMBLY B41

<u>Rod</u>	<u>Location</u>	<u>Gap Width (in.)</u>	<u>Fuel Stack Length (in.)</u>
G7	12.19	0.037	144.31
	23.63	0.016	
	33.25	0.019	
	42.19	0.019	
G9	41.31	0.036	144.81
	79.63	0.051	
	119.19	0.083	
H6	11.38	0.056	144.31
	33.56	0.027	
	45.50	0.022	
	95.06	0.023	
I9	None		144.50
J8	None		144.81

TABLE 27

GAMMA SCAN SUMMARY FOR FUEL RODS FROM ASSEMBLY B43

<u>Rod</u>	<u>Location</u>	<u>Gap Width (in.)</u>	<u>Fuel Stack Length (in.)</u>
G7	66.44	0.042	144.56
	91.94	0.037	
	139.81	0.395	
G9	13.06	0.032	144.63
	16.63	0.066	
	52.31	0.038	
	73.06	0.060	
	105.56	0.043	
H6	None		144.44
I9	23.06	0.045	144.56
	29.06	0.031	
	116.56	0.076	
J8	None		144.38

APPENDIX A

PROCEDURE FOR THE REMOVAL AND REPLACEMENT OF FUEL RODS

FIGURES

<u>Figure</u>		<u>Page</u>
A-1	Cutting the Hole in Top Tie Plate for Rod Removal	A-4
A-2	Expansion Collar	A-5
A-3	As-Built Cover Plate	A-7

PROCEDURE FOR THE
REMOVAL AND REPLACEMENT OF FUEL RODS

Access to individual fuel rods was obtained through a three-inch diameter hole cut in the top tie plate of each fuel assembly. A horizontally mounted drill press was used for the cutting operation. A strongback constructed to hold the fuel assembly was secured in a guide bracket mounted on the base of the drill press. The bottom of the strongback rested on wooden 2-inch x 4-inch blocks. When the bracket was tightened, the strongback and assembly were held stationary with respect to the drill press (Figure A-1).

The cutting operation progressed in three steps: 1) the hole saw was used to cut into the top tie plate to a depth of 0.125 inch, 2) the weld bonding the instrument tube to the tie plate was removed by drilling with a conventional 0.5938-inch carbide bit and 3) the remainder of the plate was cut with a hole saw and removed. A new three-inch hole saw with a 0.25-inch arbor was used for each cutting operation. A one-half horsepower motor turned the hole saw and bit at 30 revolutions per minute. A safety stop on the drill press traveler prevented the hole saw from cutting the fuel rods. Periodically, the saw and bit were removed from the tie plate and lubricated. A water based lubricant was used and only small amounts were applied at a time. None of the rods were contaminated by the lubricant. A vacuum cleaner was used to maintain a clean cutting area.

The three-inch hole in the upper tie plate exposed approximately 30 rods. The procedure used to remove the five test rods (G9, G7, G6, I9 and J8) was the same for each fuel assembly. An expansion collar was placed over the end cap of the selected rod. The collar was tightened and the rod pulled out about six inches (Figure A-2). A zero degree orientation mark was scratched on the top end plug with a grinding tool. The zero degree orientation mark was determined by its relative orientation to Face A of the fuel assembly. The only exception to this process was rod G7 from assembly B02. During removal, the pulling device rotated and the zero degree orientation mark was lost. An arbitrary zero degree orientation mark was scratched onto this rod.

FIGURE A-1. Cutting the Hole in Top Tie Plate for Rod Removal. Neg 7807920-11cn

Figure A-2. Expansion Collar in Place for Rod Pulling.

After marking was completed, each rod was placed into a protective aluminum tube and then into a storage basket. Identification of each rod was maintained by an administrative inventory of the storage basket.

After the nondestructive tests were completed, the rods were reinserted into their respective fuel assemblies in their original positions and orientations. The hole in the top tie plate was sealed with a cover plate (Figure A-3). The cover plate was placed in the hole with three movable tabs rotated inward. After positioning the plate, the tabs were rotated outward with a screw driver. The locking screws were tightened with a torque wrench to 4 inch-pounds. Tightening the screws caused the tabs to raise and seat on the bottom of the tie plate.

A-7

FIGURE A-3. As-Built Cover Plate. Neg 7814182-85

APPENDIX B

REPLOTS OF PROFILOMETRY TRACES

FIGURES

<u>Figure</u>		<u>Page</u>
B-1	Replot of Profilometry Trace for B02-G9	B-4
B-2	Replot of Profilometry Trace for B02-G7	B-4
B-3	Replot of Profilometry Trace for B02-H6	B-5
B-4	Replot of Profilometry Trace for B02-J8	B-5
B-5	Replot of Profilometry Trace for B02-I9	B-6
B-6	Replot of Profilometry Trace for B03-G9	B-6
B-7	Replot of Profilometry Trace for B03-G7	B-7
B-8	Replot of Profilometry Trace for B03-H6	B-7
B-9	Replot of Profilometry Trace for B03-J8	B-8
B-10	Replot of Profilometry Trace for B03-I9	B-8
B-11	Replot of Profilometry Trace for B17-G9	B-9
B-12	Replot of Profilometry Trace for B17-G7	B-9
B-13	Replot of Profilometry Trace for B17-H6	B-10
B-14	Replot of Profilometry Trace for B17-J8	B-10
B-15	Replot of Profilometry Trace for B17-I9	B-11
B-16	Replot of Profilometry Trace for B41-G9	B-11
B-17	Replot of Profilometry Trace for B41-G7	B-12
B-18	Replot of Profilometry Trace for B41-H6	B-12
B-19	Replot of Profilometry Trace for B41-J8	B-13
B-20	Replot of Profilometry Trace for B41-I9	B-13
B-21	Replot of Profilometry Trace for B43-G9	B-14
B-22	Replot of Profilometry Trace for B43-G7	B-14
B-23	Replot of Profilometry Trace for B43-H6	B-15
B-24	Replot of Profilometry Trace for B43-J8	B-15
B-25	Replot of Profilometry Trace for B43-I9	B-16

REPLOTS OF PROFILOMETRY TRACES

This appendix contains replots of the profilometry traces for rods G9, G7, H6, J8 and I9 from assemblies B02, B03, B17, B41 and B43. These replots were drawn from the original strip charts maintained by the Spent Fuel R&D group at HEDL. The original plots were digitized every five inches for the purpose of making these replots. The bars indicate the ovality of each rod at these points.

HEDL /811-117.36

FIGURE B-1. Replot of Profilometry Trace for B02-G9.

HEDL /811-117.35

FIGURE B-2. Replot of Profilometry Trace for B02-G7.

HEDL 7811-117.29

FIGURE B-3. Replot of Profilometry Trace for B02-H6.

HEDL 7811-117.37

FIGURE B-4. Replot of Profilometry Trace for B02-J8.

HEDL 7811-117.27

FIGURE B-5. Replot of Profilometry Trace for B02-I9.

HEDL 7811-117.48

FIGURE B-6. Replot of Profilometry Trace for B03-G9.

HEDL 7811-117. 49

FIGURE B-7. Replot of Profilometry Trace for B03-G7.

HEDL 7811-117. 40

FIGURE B-8. Replot of Profilometry Trace for B03-H6.

HEDL 7811-117. 42

FIGURE B-9. Replot of Profilometry Trace for B03-J8.

HEDL 7811-117. 47

FIGURE B-10. Replot of Profilometry Trace for B03-I9.

HEDL 7811-117.38

FIGURE B-11. Replot of Profilometry Trace for B17-G9.

HEDL 7811-117.34

FIGURE B-12. Replot of Profilometry Trace for B17-G7.

HEDL 7811-117.55

FIGURE B-13. Replot of Profilometry Trace for B17-H6.

HEDL 7811-117.46

FIGURE B-14. Replot of Profilometry Trace for B17-J8.

HEDL 7811-117.41

FIGURE B-15. Replot of Profilometry Trace for B17-I9.

HEDL 7811-117.31

FIGURE B-16. Replot of Profilometry Trace for B41-G9.

HFDL 7811-117.33

FIGURE B-17. Replot of Profilometry Trace for B41-G7.

HEDL 7311-117.53A

FIGURE B-18. Replot of Profilometry Trace for B41-H6.

HEDL 7811-117.30

FIGURE B-19. Replot of Profilometry Trace for B41-J8.

HEDL 7811-117.39

FIGURE B-20. Replot of Profilometry Trace for B41-I9.

HEDL 7811-117.45

FIGURE B-21. Replot of Profilometry Trace for B43-G9.

HEDL 7811-117.43

FIGURE B-22. Replot of Profilometry Trace for B43-G7.

HEDL /811-117.44

FIGURE B-23. Replot of Profilometry Trace for B43-H6.

HEDL 7811-117.32

FIGURE B-24. Replot of Profilometry Trace for B43-J8.

HEDL 7811-117.26

FIGURE B-25. Replot of Profilometry Trace for B43-I9.

APPENDIX C

REPLOTS OF GAMMA SCAN TRACES

FIGURES

<u>Figure</u>		<u>Page</u>
C-1	Replot of Gross Gamma Scan Trace for B02-G9	C-6
C-2	Replot of Gross Gamma Scan Trace for B02-G7	C-6
C-3	Replot of Gross Gamma Scan Trace for B02-H6	C-7
C-4	Replot of Gross Gamma Scan Trace for B02-J8	C-7
C-5	Replot of Gross Gamma Scan Trace for B02-I9	C-8
C-6	Replot of Gross Gamma Scan Trace for B03-G9	C-8
C-7	Replot of Gross Gamma Scan Trace for B03-G7	C-9
C-8	Replot of Gross Gamma Scan Trace for B03-H6	C-9
C-9	Replot of Gross Gamma Scan Trace for B03-J8	C-10
C-10	Replot of Gross Gamma Scan Trace for B03-I9	C-10
C-11	Replot of Gross Gamma Scan Trace for B17-G9	C-11
C-12	Replot of Gross Gamma Scan Trace for B17-G7	C-11
C-13	Replot of Gross Gamma Scan Trace for B17-H6	C-12
C-14	Replot of Gross Gamma Scan Trace for B17-J8	C-12
C-15	Replot of Gross Gamma Scan Trace for B17-I9	C-13
C-16	Replot of Gross Gamma Scan Trace for B41-G9	C-13
C-17	Replot of Gross Gamma Scan Trace for B41-G7	C-14
C-18	Replot of Gross Gamma Scan Trace for B41-H6	C-14
C-19	Replot of Gross Gamma Scan Trace for B41-J8	C-15
C-20	Replot of Gross Gamma Scan Trace for B41-I9	C-15
C-21	Replot of Gross Gamma Scan Trace for B43-G9	C-16
C-22	Replot of Gross Gamma Scan Trace for B43-G7	C-16
C-23	Replot of Gross Gamma Scan Trace for B43-H6	C-17
C-24	Replot of Gross Gamma Scan Trace for B43-J8	C-17
C-25	Replot of Gross Gamma Scan Trace for B43-I9	C-18
C-26	Replot of Cs ¹³⁷ Gamma Scan Trace for B02-G9	C-18
C-27	Replot of Cs ¹³⁷ Gamma Scan Trace for B02-G7	C-19
C-28	Replot of Cs ¹³⁷ Gamma Scan Trace for B02-H6	C-19
C-29	Replot of Cs ¹³⁷ Gamma Scan Trace for B02-J8	C-20
C-30	Replot of Cs ¹³⁷ Gamma Scan Trace for B02-I9	C-20

FIGURES (Cont'd)

<u>Figure</u>		<u>Page</u>
C-31	Replot of Cs ¹³⁷ Gamma Scan Trace for B03-G9	C-20
C-32	Replot of Cs ¹³⁷ Gamma Scan Trace for B03-G7	C-21
C-33	Replot of Cs ¹³⁷ Gamma Scan Trace for B03-H6	C-22
C-34	Replot of Cs ¹³⁷ Gamma Scan Trace for B03-J8	C-22
C-35	Replot of Cs ¹³⁷ Gamma Scan Trace for B03-I9	C-23
C-36	Replot of Cs ¹³⁷ Gamma Scan Trace for B17-G9	C-23
C-37	Replot of Cs ¹³⁷ Gamma Scan Trace for B17-G7	C-24
C-38	Replot of Cs ¹³⁷ Gamma Scan Trace for B17-H6	C-24
C-39	Replot of Cs ¹³⁷ Gamma Scan Trace for B17-J8	C-25
C-40	Replot of Cs ¹³⁷ Gamma Scan Trace for B17-I9	C-25
C-41	Replot of Cs ¹³⁷ Gamma Scan Trace for B41-G9	C-26
C-42	Replot of Cs ¹³⁷ Gamma Scan Trace for B41-G7	C-26
C-43	Replot of Cs ¹³⁷ Gamma Scan Trace for B41-H6	C-27
C-44	Replot of Cs ¹³⁷ Gamma Scan Trace for B41-J8	C-27
C-45	Replot of Cs ¹³⁷ Gamma Scan Trace for B41-I9	C-28
C-46	Replot of Cs ¹³⁷ Gamma Scan Trace for B43-G9	C-28
C-47	Replot of Cs ¹³⁷ Gamma Scan Trace for B43-G7	C-29
C-48	Replot of Cs ¹³⁷ Gamma Scan Trace for B43-H6	C-29
C-49	Replot of Cs ¹³⁷ Gamma Scan Trace for B43-J8	C-30
C-50	Replot of Cs ¹³⁷ Gamma Scan Trace for B43-I9	C-30

REPLOTS OF GAMMA SCAN TRACES

This appendix contains replots of the gamma scan traces for the gross gamma spectrum and Ce^{137} isotopic gamma energy for rods G9, G7, H6, J8 and I9 from assemblies B02, B03, B17, B41 and B43. These replots were drawn from the original strip charts maintained by the Spent Fuel R&D group at HEDL. The original charts were digitized every five inches for the purpose of making these replots.

HEDL 7811-117.6

FIGURE C-1. Replot of Gross Gamma Scan Trace for B02-G9.

HFDL 7811-117.7

FIGURE C-2. Replot of Gross Gamma Scan Trace for B02-G7.

HEDL 7811-117.12

FIGURE C-3. Replot of Gross Gamma Scan Trace for B02-H6.

HEDL 7811-117.1

FIGURE C-4. Replot of Gross Gamma Scan Trace for B02-J8.

HEDL 7811-117.5

FIGURE C-5. Replot of Gross Gamma Scan Trace for B02-I9

HEDL 7811-117.16

FIGURE C-6. Replot of Gross Gamma Scan Trace for B03-G9.

HEDL 7811-117.17

FIGURE C-7. Replot of Gross gamma Scan Trace for B03-G7.

HEDL 7811-117.20

FIGURE C-8. Replot of Gross Gamma Scan Trace for B03-H6.

HEDL 7811-117.15

FIGURE C-9. Replot of Gross Gamma Scan Trace for B03-J8.

HEDL 7811-117.19

FIGURE C-10. Replot of Gross Gamma Scan Trace for B03-I9.

HEDL 7811-117.8

FIGURE C-11. Replot of Gross Gamma Scan Trace for B17-G9.

HEDL 7811-117.14

FIGURE C-12. Replot of Gross Gamma Scan Trace for B17-G7.

HEDL 7811-117.21

FIGURE C-13. Replot of Gross Gamma Scan Trace for B17-H6.

HEDL 7811-117.13

FIGURE C-14. Replot of Gross Gamma Scan Trace for B17-J8.

FIGURE C-15. Replot of Gross Gamma Scan Trace for B17-I9.

FIGURE C-16. Replot of Gross Gamma Scan Trace for B41-G9.

HEDL 7811-117.3

FIGURE C-17. Replot of Gross Gamma Scan Trace for B41-G7.

HEDL 7811-117.2

FIGURE C-18. Replot of Gross Gamma Scan Trace for B41-H6.

HEDL 7811-117.11

FIGURE C-19. Replot of Gross Gamma Scan Trace for B41-J8.

HEDL 7811-117.9

FIGURE C-20. Replot of Gross Gamma Scan Trace for B41-I9.

HEDL 7811-117.25

FIGURE C-21. Replot of Gross Gamma Scan Trace for B43-G9.

HEDL 7811-117.24

FIGURE C-22. Replot of Gross Gamma Scan Trace for B43-G7.

HEDL 7811-117.23

FIGURE C-23. Replot of Gross Gamma Scan Trace for B43-H6.

HEDL 7811-117.10

FIGURE C-24. Replot of Gross Gamma Scan Trace for B43-J8.

HEDL 7811-117.22

FIGURE C-25. Replot of Gross Gamma Scan Trace for B43-I9.

HEDL 7811-117.54

FIGURE C-26. Replot of Cs^{137} Gamma Scan Trace for B02-G9.

HEDL 7811-117.57

FIGURE C-27. Replot of Cs^{137} Gamma Scan Trace for B02-G7

HEDL 7811-117.61

FIGURE C-28. Replot of Cs^{137} Gamma Scan Trace for B02-H6.

HEDL 7811-117.56

FIGURE C-29. Replot of Cs¹³⁷ Gamma Scan Trace for B02-J8.

HEDL 7811-117.53

FIGURE C-30. Replot of Cs¹³⁷ Gamma Scan Trace for B02-I9.

HEDL 7811-117.62

FIGURE C-31. Replot of Cs^{127} Gamma Scan Trace for B03-G9.

HEDL 7811-117.67

FIGURE C-32. Replot of Cs^{137} Gamma Scan Trace for B03-G7.

HEDL 7811-117.70

FIGURE C-33. Replot Cs^{137} Gamma Scan Trace for B03-H6.

HEDL 7811-117.66

FIGURE C-34. Replot of Cs^{137} Gamma Scan Trace for B03-J8.

HEDL 7811-117.69

FIGURE C-35. Replot of Cs^{137} Gamma Scan Trace for B03-I9.

HEDL 7811-117.63

FIGURE C-36. Replot of Cs^{137} Gamma Scan Trace for B17-G9.

HEDL 7811-117.65

FIGURE C-37. Replot of Cs^{137} Gamma Scan Trace for B17-G7.

HEDL 7811-117.71

FIGURE C-38. Replot of Cs^{137} Gamma Scan Trace for B17-H6.

HEDL 7811-117.64

FIGURE C-39. Replot of Cs^{137} Gamma Scan Trace for B17-J8.

HEDL 7811-117.68

FIGURE C-40. Replot of Cs^{137} Gamma Scan Trace for B17-I9.

HEDL 7811-117.50

FIGURE C-41. Replot of Cs¹³⁷ Gamma Scan Trace for B41-G9.

HEDL 7811-117.52

FIGURE C-42. Replot of Cs¹³⁷ Gamma Scan Trace for B41-G7.

HEDL 7811-117.51

FIGURE C-43. Replot of Cs^{137} Gamma Scan Trace for B41-H6.

HEDL 7811-117.60

FIGURE C-44. Replot of Cs^{137} Gamma Scan Trace for B41-J8.

HEDL 7811-117.58

FIGURE C-45. Replot of Cs^{137} Gamma Scan Trace for B41-I9.

HEDL 7811-117.74

FIGURE C-46. Replot of Cs^{137} Gamma Scan Trace for B43-G9.

HEDL 7811-117.73

FIGURE C-47. Replot of Cs^{137} Gamma Scan Trace for B43-G7.

HEDL 7811-117.75

FIGURE C-48. Replot of Cs^{137} Gamma Scan Trace for B43-H6.

HEDL 7811-117.59

FIGURE C-49. Replot of Cs^{137} Gamma Scan Trace for B43-J8.

HEDL 7811-117.72

FIGURE C-50. Replot of Cs^{137} Gamma Scan Trace for B43-I9.

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