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HIGH PERFORMANCE UO_2 PROGRAM
IRRADIATION OF 0.5 INCH DIAMETER,
SOLID PELLET UO_2 FUEL RODS AT
900,000 Btu/h-ft² PEAK HEAT FLUX
EPT-8 ASSEMBLY

M.F. LYONS
R.C. NELSON
T.J. PASHOS
C.R. WILSON
B. WEIDENBAUM

U.S. ATOMIC ENERGY COMMISSION
CONTRACT AT(04-3)-189
PROJECT AGREEMENT 17

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ATOMIC POWER EQUIPMENT DEPARTMENT
GENERAL ELECTRIC
SAN JOSE, CALIFORNIA

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Research and
Development Program
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M. F. Lyons
R. C. Nelson
T. J. Pashos
C. R. Wilson
B. Weidenbaum

Approved:

S. Naymark / 10/15/65

S. Naymark
Manager, Fuels and
Materials Development

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ATOMIC POWER EQUIPMENT DEPARTMENT

GENERAL ELECTRIC

SAN JOSE, CALIFORNIA

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PREFACE

This report is one of a series describing the individual fuel assemblies irradiated during the U. S. Atomic Energy Commission - Euratom sponsored High Performance UO_2 Program at the General Electric Company, Atomic Power Equipment Department. The report series is considered an Appendix to the final summary report on the program. All of the High Performance UO_2 Program final summary report will be issued under the single report number GEAP-5100. Major topics in the final report will be designated by the sequence GEAP-5100-1, 5100-2, 5100-3, etc. Sections of the Appendix will follow the sequence GEAP-5100-A, 5100-B, 5100-C, etc.

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ABSTRACT

The fabrication data, irradiation history, and the complete, correlated post-irradiation examination results are described for a four-rod fuel assembly--designated EPT-8*--that operated in the GETR-PWL** with significant central melting to a burnup of 1500 MWD/Te. The fuel rods were unsegmented, reactor-length rods containing 95 percent dense, solid, sintered UO_2 pellets in free-standing Zircaloy-2 cladding. This fuel assembly was the second of a series irradiated to investigate the feasibility and limitations in UO_2 fuel-rod operation with central melting. Post-irradiation examination of this assembly confirmed the clad swelling observations derived from the first assembly--EPT-6--and indicated that the swelling, expressed as a volume increase, is a function of the thermal performance level. This severe, localized clad swelling proved to be the basic obstacle to achieving satisfactory operation with central melting in high density fuel. Later work proved that the clad swelling resulted from the UO_2 phase change volume expansion and could be corrected by proper fuel rod design. This later work and the results and conclusions from the entire series of pellet fuel assembly irradiations, including EPT-8, have been described earlier in GEAP-4264.

*EPT-8 designates Euratom pellet assembly 800,000 Btu/h-ft² nominal peak heat flux.

**GETR-PWL - General Electric Test Reactor - Pressurized Water Loop

TABLE OF CONTENTS

	<u>Page No.</u>
PREFACE	iii
ABSTRACT	iv
SECTION I INTRODUCTION	1
SECTION II IRRADIATION HISTORY	2
SECTION III FABRICATION AND PERFORMANCE DATA OF EPT-8	3
SECTION IV PHOTOGRAPHIC ANALYSIS - ROD 8-A	17
A. External Post-Irradiation Appearance	18
B. Fracture Sections	23
C. Peak Heat Flux Zone	42
D. Maximum Burnup Zone	57
E. Other Sections	64
SECTION V ACKNOWLEDGMENTS	110

ILLUSTRATIONS

<u>No.</u>	<u>Title</u>	<u>Page</u>
1	EPT-8 Thermal Performance History	4
2	Dimensional Changes EPT-8	6
3	Fuel Rod Assembly Design	12
4	Assembly Pre-Irradiation Appearance	13
5	Fuel Rod Design	14
6	Gamma Scans EPT-8	16
7	Correlation of Swelling, Power, and Thermal Performance for EPT-8, Rod A	108
8	Photolocator Key for Rod 8-A	109

TABLES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1	Summary of Assembly EPT-8 Characteristics and Performance History	3
2	Coolant Conditions during Irradiation	3
3	Pre- and Post-Irradiation Dimensions	7
4	Chemical Analysis of 2.2% Enriched UO_2 Ceramic Grade Powder	8
5	Chemical Analysis of 2.2% Enriched UO_2 Sintered Pellets	9
6	Physical-Chemical Properties, Annealed Zircaloy Tubing	10
7	Fuel Rod Data EPT-8	11
8	Average Radial Estimates Made from Fracture Sections	38
9	Main Metallographic Sections EPT-8 Rod A	40

INTRODUCTION

In 1961 an experimental program was undertaken at the General Electric Atomic Power Equipment Department to systematically explore the feasibility and limitations in UO_2 fuel rod operation with central melting. The program was jointly sponsored by the U. S. Atomic Energy Commission and Euratom. The basic experimental plan was to irradiate a series of identical (except for enrichment) fuel assemblies at progressively increasing thermal performance conditions, and consequent central melting, until a fuel rod failure occurred. Two separate irradiation series were performed, the first with pellet containing fuel rods and then a second with compacted powder UO_2 . The irradiations were conducted in the GETR Pressurized Water Loop. Fuel assembly heat transfer during the irradiations was completely in the subcooled, forced convection cooled regime, without nucleate boiling.

The irradiation program was concluded in October, 1964, with the successful irradiation of a fuel assembly containing both powder and pellet fuel rods to high burnup, while operating continuously with gross central melting. The results from the initial pellet irradiation series have been summarized in a topical report (GEAP-4264) and summary reports are in preparation describing the powder fuel irradiation series and the final, high burnup assembly performance. However, these summary reports are necessarily incomplete regarding the individual assembly irradiation results and concerned primarily with the results and conclusions from the series as a whole. One of the most valuable assets of the program is the detailed post-irradiation examination data on the individual fuel rods. Since this program is the only known systematic investigation of central melting using reactor length fuel rods, these data are believed to be of outstanding technical interest and significance and should prove worthwhile for other investigators to analyze and interpret. To provide a permanent record and convenient reference to these results, a separate report is being prepared on each fuel assembly irradiated during the program. This report describes the correlated fabrication, irradiation and post-irradiation examination data from the second pellet fuel assembly irradiated - Assembly EPT-8. This second pellet assembly was designated to undergo appreciable central melting at the maximum axial power position.

IRRADIATION HISTORY

The fuel rods in Assembly EPT-8 contained 2.2% enriched UO_2 fuel pellet and were intended to operate at a nominal peak heat flux of 800,000 Btu/h-ft². The following actual conditions at initial, 30-MW (th) reactor power operation were:

Start-up Date - 6/1/62
General Electric Test Reactor (GETR) Cycle No. - 34
Control Rod Bank Position - 18.0 in.
Assembly Average, Peak Heat Flux - 890,000 Btu/h-ft²
Rod 8A Peak Heat Flux - 950,000 Btu/h-ft²

The coolant conditions during the EPT-8 assembly irradiation are listed in Table 2. Operation was uneventful for the entire 24-day reactor cycle with only 2 power cycles (one intermediate shut-down 15 June 1962, 1330-1500h) and no core refueling. The average thermal power of the assembly during operation was 260 kW. The chronological variation in the average heat flux of Rod 8A is shown in Figure 1. The following conditions prevailed at 30 MW- reactor power, 1-1/2 hours before shutdown:

Shut-Down Date - 6/24/62
Control Rod Bank Position - 27.5 in.
Assembly Average, Peak Heat Flux - 706,000 Btu/h-ft²
Rod 8-A Peak Heat Flux - 754,000 Btu/h-ft²
Assembly Average Burnup - 1532 MWD/T_e

TABLE 1
EPT-8 SUMMARY OF ASSEMBLY CHARACTERISTICS AND HISTORY

Fuel Enrichment	2.2%
Fuel Type	Solid Pellet
Average Fuel Column Length	$34 \pm 1/4$ inches
Assembly Thermal Power	260 kW
Irradiation Period	6/1/62 - 6/24/62
Number of Rods with Clad Swelling	4
Maximum Rod Diameter Increase	53 mils
Surface Heat Flux:	
Nominal Peak for EPT-8	800,000 Btu/h-ft ²
At Start-Up:	
Assembly Average	890,000 Btu/h-ft ²
8A Peak	950,500 Btu/h-ft ²
At Shut-Down:	
Assembly Average	706,000 Btu/h-ft ²
8A Peak	754,700 Btu/h-ft ²
Assembly Average Burn-Up	1,532 MWD/T _e

TABLE 2
COOLANT CONDITIONS DURING IRRADIATION EPT 8

Pressure	1000 psia
Saturation Temperature	545°F
Fuel Assembly Inlet Temperature	344°F
Fuel Assembly Outlet Temperature	~370°F
Flow Velocity at Fuel Rods	23 ft/sec
pH (LiOH Regenerated Demineralized)	9.5 to 10.0
Dissolved H ₂	25 to 65 cc/kg
Flow	87 gal/min
Mass Velocity	4.69×10^6 lb/h-ft ²
Film Heat Transfer Coefficient	9,700 Btu/h-ft ² - °F
Density at Inlet Temperature	56 lb/ft ³
Specific Heat	1.05 Btu/lb - °F

Figure 1. Thermal Performance History

POST-IRRADIATION EXAMINATION EPT-8

None of the fuel rods in Assembly EPT-8 could be removed without slitting their shroud tubes. The results of the dimensional examination showed that all four fuel rods had experienced significant clad swelling. Figure 2 shows the dimensional results for the EPT-8 fuel rods. The dimensional data on EPT-8 are summarized in Table 3.

It is again evident that the clad swelling is almost perfectly symmetrical and occurs at the peak heat flux location at start-up. The maximum diameter increase observed in the maximum power rod, rod 8A, is 53 mils. This diameter increase is only slightly larger than that observed in rod 6D which operated at a significantly lower peak heat flux. However, the fuel rod length over which swelling occurred is generally longer than that in the EPT-6 rods. This observation indicated that the fuel rod volume increase from clad swelling was a more significant parameter than the maximum diameter increase and the volume increase was used for subsequent correlation of results on fuel rod swelling. Rod 8A, the maximum power rod, was selected for destructive examination.

Figure 2. Dimensional Changes - Assembly EPT-8

TABLE 3
ASSEMBLY EPT-8 PRE- AND POST-IRRADIATION DIMENSIONS

Fuel Rod	Axial Distance from top (inches)	Outside Diameter in inches at 0-180 deg. Orientation			Outside Diameter in inches at 90-270 deg. Orientation		
		Irradiation		Change, (mils)	Irradiation		Change, (mils)
		Pre-	Post-		Pre-	Post-	
8-A	4	0.564	0.563	-1	0.564	0.563	-1
	16	0.563	0.562	-1	0.563	0.562	-1
	20	0.564	0.565	+1	0.563	0.562	-1
	24	0.563	-	-	0.563	-	-
	26	-	0.567	-	-	0.567	-
	27	-	0.572	-	-	0.572	-
	28	0.564	-	-	0.563	-	-
	29	-	0.581	-	-	0.581	-
	30	-	0.610	-	-	0.610	-
	31	-	0.592	-	-	0.594	-
	32	0.563	0.576	+13	0.563	0.575	+12
	34	-	0.571	-	-	0.571	-
	36	0.564	-	-	0.564	-	-
8-B	4	0.565	0.565	0	0.564	0.565	+1
	16	0.564	0.563	-1	0.564	0.564	0
	20	0.563	0.563	0	0.563	0.563	0
	24	0.564	0.566	+2	0.563	0.564	+1
	25	-	0.568	-	-	0.566	-
	26	-	0.571	-	-	0.567	-
	27	-	0.579	-	-	0.578	-
	28	0.564	0.588	+24	0.563	0.591	+28
	29	-	0.581	-	-	0.581	-
	30	-	0.583	-	-	0.585	-
	31	-	0.575	-	-	0.576	-
	32	0.564	0.572	+8	0.564	0.570	+6
	33	-	0.567	-	-	0.570	-
	34	-	0.566	-	-	0.565	-
8-C	35	-	0.566	-	-	0.565	-
	36	0.565	0.565	0	0.564	0.565	+1
	4	0.565	0.563	-2	0.566	0.563	-3
	16	0.564	0.563	-1	0.565	0.563	-2
	20	0.564	0.563	-1	0.564	0.564	0
	24	0.564	0.565	+1	0.564	0.563	-1
	28	0.564	0.571	+7	0.564	0.571	+7
	29	-	0.573	-	-	-	-
	30	-	0.577	-	-	0.573	-
	31	-	0.571	-	-	0.579	-
	32	0.565	0.571	+6	0.564	0.570	+6
	33	-	0.568	-	-	0.567	-
	34	-	0.564	-	-	0.565	-
	35	-	-	-	-	0.565	-
	36	0.565	0.564	-1	0.566	0.564	-2

TABLE 3. (Continued)

Fuel Rod	Axial Distance from top (inches)	Outside Diameter in inches at 0-180 deg. Orientation			Outside Diameter in inches at 90-270 deg. Orientation		
		Irradiation		Change, (mils)	Irradiation		Change, (mils)
		Pre-	Post-		Pre-	Post-	
8-D	4	0.563	0.567	+4	0.564	0.567	+3
	16	0.563	0.562	-1	0.563	0.563	0
	20	0.563	0.564	+1	0.563	0.567	+4
	24	0.563	0.564	+1	0.563	0.563	0
	28	0.563	0.583	+20	0.563	0.581	+18
	29	-	0.580	-	-	0.578	-
	30	-	0.583	-	-	0.580	-
	31	-	0.573	-	-	0.576	-
	32	0.563	0.571	+8	0.563	0.573	+10
	33	-	0.565	-	-	0.567	-
	34	-	0.567	-	-	0.564	-
	35	-	0.565	-	-	0.563	-
	36	0.563	0.564	+1	0.564	0.563	-1

Over-All Length (inches)*

8-A	39.014	39.071	+0.057
8-B	39.020	39.082	+0.062
8-C	39.031	39.087	+0.056
8-D	39.032	39.086	+0.054

* Accuracy of length ± 0.010 inch

TABLE 4
CHEMICAL ANALYSIS OF 2.2% ENRICHED
UO₂ CERAMIC GRADE POWDER

<u>Element</u>	<u>Impurity Content, PPM</u>
Al	< 2
B	< 0.20
Cd	< 0.10
Ca	33
C	55
F	50
Fe	12
Si	13
Cl	< 25
Cr	12
Cu	32
Mn	< 1
N	< 10
V	< 10*
Ti	< 100*
Co	< 5
Mo	< 1*
Ni	< 10
Ag	0.15
<hr/>	
O:U Ratio	2.07
Particle Size, μ (Fisher Sub-Sieve)	1.04
Bulk Density, gm/cc	1.19
U ²³⁵ , %	2.183

*No Determination

TABLE 5
CHEMICAL ANALYSIS 2.2% ENRICHED UO₂
SINTERED PELLETS

Element	Impurity Content, PPM				
	200	200	100	100	100
Al	200	200	100	100	100
Bi	-	-	-	-	-
B	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Cd	< 1	< 1	< 1	< 1	< 1
Ca	10	10	10	10	10
Cr	20	20	20	20	20
Co	< 2	< 2	< 2	< 2	< 2
Cu	100	100	100	200	200
Fe	1000	1000	500	1000	1000
Pb	< 1	< 1	< 1	< 1	< 1
Mg	5	10	5	10	10
Mn	< 1	< 1	< 1	< 1	< 1
Mo	< 3	< 3	< 3	< 3	10
Si	200	300	60	60	100
Ag	1	3	5	0.1	5
Na	< 35	< 35	< 35	< 35	< 35
Sn	5	5	5	5	5
V	< 15	< 15	< 15	< 15	< 15
Zn	< 10	< 10	< 10	< 10	< 10
Ni	1000	200	100	100	50
Sb	< 2	< 2	< 2	< 2	< 2
N	-	-	-	-	-
C	30	< 10	< 10	20	< 10
F	28	18	19	15	22
O:U Ratio	2.01	2.00	2.00	2.00	2.00
Density, %	94.0 to 96.0 TDS*				
U ²³⁵ , %	2.26	2.20	2.27		

*Based on 25 Pellets

TABLE 6
PHYSICAL-CHEMICAL PROPERTIES, ANNEALED ZIRCALOY TUBING

Ingot No. 28601, Lot No. 494

Corrosion Weight Gain - 15.8 and 15.5 mg/dm² in 3 days at 750°F, 1500 psi steam (399°C, 605 × 10⁶ kg/m².)

Chemical Analysis:

<u>Alloy Elements</u>	<u>%</u>
Sn	1.53
Fe	0.132
Cr	0.103
Ni	0.054
Fe + Cr + Ni	0.289

<u>Impurity, ppm</u>		<u>Impurity, ppm</u>		<u>Impurity, ppm</u>	
Al	29	Hf	79	V	<20
B	<0.3	Mg	<20	W	<20
C	172	Mn	<20	U	<0.2
Ca	<20	Mo	<20		
Cd	<0.3	Na	<20	H	17
Cl	<20	Pb	<20	N	23
Co	<5	Si	35	O	910
Cu	<20	Ti	<20		

Longitudinal Mechanical Properties:

Ultimate Tensile Strength, ksi (kg/m ²)	84.1 (59.0 × 10 ⁶)	81.1 (57.0 × 10 ⁶)
Yield Strength (0.2% offset) ksi, (kg/m ²)	65.0 (45.6 × 10 ⁶)	63.9 (44.8 × 10 ⁶)
Elongation in 2 inches (5 cm), %	16.5	17.7
Hardness (Rockwell B)	92.0/93.0	91.5/93.0
Grain Size:	33.6% and 34.4% o. d. expansion at 60 degrees	
Flare Test:	10,500-psi yield pressure, (7.4 × 10 ⁶ kg/m ²)	
Burst Test:	11,000-psi burst pressure, (7.7 × 10 ⁶ kg/m ²)	

TABLE 7
FUEL ROD DATA

Rod - EPT -	8A	8B	8C	8D
Cladding Diameter, in				
Outside	0.5642-0.5652	0.5642-0.5668	0.5645-0.5663	0.5635-0.5648
Inside	0.5092-0.5106	0.5081-0.5091	0.5091-0.5100	0.5092-0.5100
Pellet Diameter, in				
Outside	0.503 +0.001 -0.000 (Centerless Ground)			
Inside	Solid	Solid	Solid	Solid
Average Pellet Height, in	0.519	0.518	0.518	0.518
Fuel Column Length, in	34-1/4	34-9/32	34-3/16	34-1/4
Fuel Weight, Grams	1139.6	1134.8	1136.2	1135.2
Plenum Length, in	2-3/4	2-3/4	2-13/16	2-3/4
Fission Gas Released Based on Atoms of Kr ⁸⁵				
Atomes Produced $\times 10^{-19}$, Based on:				
Calorimetry	1.253	1.241	1.045	1.225
Spectrometry	-	0.397	0.251	0.370
Gas-Chromatography	-	0.515	0.327	0.468
Release Percents:				
Spectrometry	-	32.0	24.0	30.2
Gas-Chromatography	-	41.5	31.3	38.2
UO ₂ Volume Expansion Analysis Results				
Calculated Volume, in ³ :				
Molten Zone	1.439	1.375	0.850	1.342
Zone between 1600° and 2800°C	1.349	1.349	1.329	1.347
Free Volume Densification, in ³ :				
From Molten Zone	0.072	0.069	0.043	0.067
From Zone 1600° to 2800°C	0.034	0.034	0.033	0.034
Pellet - Cladding Gap Volume, in ³	0.1478	0.1207	0.1289	0.1415
Total Available Free Volume, in ³	0.254	0.224	0.205	0.243
Calculated UO ₂ Thermal Expansion, in ³	0.333	0.323	0.251	0.318
Fuel Rod Volume Increase, in ³ :				
Calculated Net	0.079	0.099	0.046	0.075
Experimental	0.1660	0.0974	0.0479	0.0958
Fuel Rod Power Split - Power Output, %:				
Physics Analysis	26.6	25.5	22.7	25.2
Gamma Scan	26.52	25.96	21.85	25.66
Fuel Rod Burnup, MWD/T _e				
Chemical Average	1660	-	-	-
Physics	-	-	-	-
Calorimetry	1630	-	-	-

Figure 3. Fuel Rod Assembly Design

V17520
TOP OR INLET END
SHOWING LIFTING TEE

V17524
FUEL ELEMENT TOP END
PLUG AND LOCKING PIN

V17523

V17521
RESTRAINING BAND
AROUND FLOW TUBES

V17522
NOSE PIECE WITH SCREEN
AT THE BOTTOM OR EXIT END

Figure 4. Pre-Irradiation Appearance

1	END PLUG
2	DISK
3	PIN
4	SPRING
5	TUBE
6	PELLET
7	END PLUG
8	PIN

GAMMA SCAN RESULTS

Based on previous experience with gamma scans from fuel rods without central melting, a normal gamma activity profile is a smooth, regular curve with a shape approximating the average thermal neutron flux profile during irradiation. Rods containing UO_2 pellets usually exhibit slight depressions in the profile at the pellet interfaces. The gamma scan has therefore been used to locate the individual pellets and, thereby, show the general, post-irradiation condition of the fuel column.

The gamma scan of Rod 8A exhibits multiple activity spikes. Nearly one-half of the length of this rod exhibits perturbations from a normal gamma scan profile. The average activity level over this perturbed zone appears to be essentially constant, which is indicative of activity concentration and equilibration over the molten zone. It has been demonstrated, both analytically and experimentally, that the activity spikes are not the result of radial cracks in the pellets. The gamma energy observed is greater than 0.7 MeV so that self-shielding by the fuel should be slight. Gamma scans taken at different radial orientations of the fuel rod do not differ significantly.

FIGURE 6. GAMMA SCANS EPT-8

↑
ROD BOTTOM

EPT 8 ROD A
 AREA UNDER CURVE - 179.73 in.²
 AVERAGE ORDINATE - 4.150 in. (18.9 mv)
 PART OF ASSEMBLY TOTAL POWER - 26.52%

↑
ROD TOP

↑
ROD BOTTOM

EPT 8 ROD C
 AREA UNDER CURVE - 148.10 in.²
 AVERAGE ORDINATE - 3.4 in. (15.5 mv)
 PART OF ASSEMBLY TOTAL POWER - 21.85%

↑
ROD TOP

↑
ROD BOTTOM

EPT 8 ROD B
 AREA UNDER CURVE - 175.96 in.²
 AVERAGE ORDINATE - 4.00 in. (18.2 mv)
 PART OF ASSEMBLY TOTAL POWER - 25.96%

↑
ROD TOP

↑
ROD BOTTOM

EPT 8 ROD D
 AREA UNDER CURVE - 173.9
 AVERAGE ORDINATE - 3.4 in. (18.2 mv)
 PART OF ASSEMBLY TOTAL POWER 25.66%

↑
ROD TOP

EPT 8
RODS A, B, C, AND D

PHOTOS TAKEN AT LOCATION OF LATERAL SPACERS

FOLD OUT PAGES 108 AND 109 BEFORE VIEWING PHOTOGRAPHS.

EPT-8 OVERALL EXTERNAL POST-IRRADIATION APPEARANCE

NEG. No. 19376/19380

1/2X

LOW POWER PERISCOPE PICTURE OF FUEL ASSEMBLY
EPT 8 AFTER IRRADIATION.

0° 90° 180° 270°

NEG. No. 19357, 19361, 19366, AND 19371
1-1/2X
ROD A. AT TOP LATERAL SPACER.

NEG. No. 19358, 19362, 19367, AND 19372
1-1/2X
ROD A, AT 28.7 INCH LATERAL SPACER.

POST-IRRADIATION APPEARANCE OF EPT 8 ROD ROTATED
THRU 360° AT THE LOCATION OF THE LATERAL SPACERS.

NEG. No. 19359, 19363, 19368, AND 19373
1-1/2X
ROD A, AT 19-1/4 INCH LATERAL SPACER.

NEG. No. 19360, 19364, 19369, AND 19374
1-1/2X
ROD A, AT 9-1/2 INCH LATERAL SPACER.

NEG. No. 19356, 19365, 19370, AND 19375
1-1/2X
ROD A, AT BOTTOM LATERAL SPACER.

ROD A

1

0° 90° 180° 270°

NEG. No. 19357, 19361, 19366, AND 19371

1-1/2X

ROD B AT TOP LATERAL SPACER.

NEG. No. 19358, 19362, 19367, AND 19372

1-1/2X

ROD B AT 28.7 INCH LATERAL SPACER.

NEG. No. 19359, 19363, 19368, AND 19373

1-1/2X

ROD B AT 19-1/4 INCH LATERAL SPACER.

NEG. No. 19360, 19364, 19369, AND 19374

1-1/2X

ROD B AT 9-1/2 INCH LATERAL SPACER.

NEG. No. 19356, 19365, 19370, AND 19375

ROD B AT THE BOTTOM LATERAL SPACER.

ROD B

POST IRRADIATION APPEARANCE OF EPT 8 ROD B ROTATED THRU 360° AT THE LOCATION OF THE LATERAL SPACERS.

0° 90° 180° 270°

NEG. No. 19357, 19361, 19366, AND 19371 1-1/2X
ROD C AT THE TOP LATERAL SPACER.

NEG. No. 19358, 19362, 19367, AND 19372 1-1/2X
ROD C AT THE 28.7 INCH LATERAL SPACER.

POST-IRRADIATION APPEARANCE OF EPT 8 ROD C ROTATED
THRU 360° AT THE LOCATION OF THE LATERAL SPACERS

NEG. No. 19359, 19363, 19368, AND 19373 1-1/2X
ROD C AT 19-1/4 INCH LATERAL SPACER.

NEG. No. 19360, 19364, 19369, AND 19374 1-1/2X
ROD C AT 9-1/2 INCH LATERAL SPACER.

NEG. No. 19356, 19365, 19370, AND 19375 1-1/2X
ROD C AT BOTTOM LATERAL SPACER.

ROD C

0° 90° 180° 270°

NEG. No. 19357, 19361, 19366, AND 19371
1-1/2X
ROD D AT TOP LATERAL SPACER.

NEG. No. 19358, 19362, 19367, AND 19372
1-1/2X
ROD D AT 28.7 INCH LATERAL SPACER.

POST-IRRADIATION APPEARANCE OF EPT 8 ROD D ROTATED
THRU 360°, AT THE LOCATION OF THE LATERAL SPACERS.

NEG. No. 19359, 19363, 19368, AND 19373
1-1/2X
ROD D AT 19-1/4 INCH LATERAL SPACER.

NEG. No. 19360, 19364, 19369, AND 19374
1-1/2X
ROD D AT 9-1/2 INCH LATERAL SPACER.

NEG. No. 19356, 19365, 19370, AND 19375
1-1/2X
ROD D AT THE BOTTOM LATERAL SPACER.

ROD D

EPT 8 ROD A

FRACTURE SECTIONS

FOLD OUT PAGES 108 AND 109 BEFORE VIEWING PHOTOGRAPHS.

ROD ELEVATION 1"

NEG. No. 19497/19499

4X

NEG. No. 19498

4X

NEG. No. 19499

4X

BOTTOM OF PELLET ONE, VARIOUS VIEWS.

ROD ELEVATION 5.2''

NEG. No. 19479

4X

BOTTOM OF PELLET 9

NEG. No. 19480

4X

TOP OF PELLET 8

ROD ELEVATION 8.4"

NEG. No. 19482

3X

NEG. No. 19509

3X

BOTTOM OF PELLET 15, 2 VIEWS.

NEG. No. 19481

5X

TOP OF PELLET 14

ROD ELEVATION 9.4''

NEG. No. 19484

4X

BOTTOM OF PELLET 17.

NEG. No. 19483

4X

TOP OF PELLET 16.

ROD ELEVATION 10.2''

NEG. No. 19502

4X

EST. BOTTOM OF PELLET 19.

NEG. No. 19501

4X

EST. TOP OF PELLET 18.

ROD ELEVATION 13.6''

NEG. No. 19486

BOTTOM OF PELLET 25

4X

NEG. No. 19485

TOP OF PELLET 24

4X

ROD ELEVATION 17.1''

NEG. No. 19506

3X

EST. BOTTOM OF PELLET 32

NEG. No. 19505

4X

EST. TOP OF PELLET 31

ROD ELEVATION 17.7''

NEG. No. 19503

EST. BOTTOM OF PELLET 33

4X

NEG. No. 19504

EST. TOP OF PELLET 32

4X

ROD ELEVATION 18.4''

NEG. No. 19488

BOTTOM OF PELLET 34

4X

NEG. No. 19487

TOP OF PELLET 33

4X

ROD ELEVATION 22.1"

NEG. No. 19490

BOTTOM OF PELLET 41

4X

NEG. No. 19489

TOP OF PELLET 42

4X

ROD ELEVATION 26.3"

NEG. No. 19492

BOTTOM OF PELLET 49

4X

NEG. No. 19491

TOP OF PELLET 48

4X

ROD ELEVATION 30.0''

NEG. No. 19508

BOTTOM OF PELLET 56

3X

NEG. No. 19507

TOP OF PELLET 55

4X

ROD ELEVATION 30.5''

NEG. No. 19494

4X

BOTTOM OF PELLET 57

NEG. No. 19493

4X

TOP OF PELLET 56

ROD ELEVATION 35.2''

NEG. No. 19495

BOTTOM OF END PLUG

4X

NEG. No. 19496

TOP OF PELLET 65

4X

TABLE 8
AVERAGE RADIAL ESTIMATES MADE FROM FRACTURE SECTIONS

Rod Elevation, in	Neg. Nos.	Outer Limit of Grain Growth, in	Molten Boundary, in	Central Void, in
5.2	19479 and 19480	0.200	0	0.006
8.4	19481 and 19482	0.205	0.137	0.008
9.4	19483 and 19484	0.216	0.165	0.037
10.2	19501 and 19502	0.210	0.151*	0.033
13.6	19485 and 19486	0.201	0.158	0.029
17.1	19505 and 19506	0.189	0.161	0.029
17.7	19503 and 19504	0.187	0.164**	0.036
18.4	19487 and 19488	0.192	0.164	0.033
22.1	19489 and 19490	0.189	0.154	0.078
26.3	19491 and 19492	0.162	0.120	0.074
30.0	19507 and 19508	0.111	0	0
30.5	19493 and 19494	0.099	0	0

*Based on only one section - Negative No. 19501

**Based on only one section - Negative No. 19504

EPT 8 ROD A

MAIN METALLOGRAPHIC SECTIONS

ALL SECTIONS ARE "AS POLISHED" UNLESS MARKED "ETCHED."
ALL LIGHTING USED IS "BRIGHT FIELD" UNLESS MARKED "POLARIZED LIGHT."

NUMBERS AFTER AUTORADIOGRAPH CAPTIONS INDICATE
NUMBERS OF DAYS AFTER END OF IRRADIATION

TABLE 9
MAIN METALLOGRAPHIC SECTIONS ROD 8-A

TYPE OF SECTION	TRANSVERSE		LONGITUDINAL		
Section Number	8596	8597	8598	8599	8600
Section Shows	PHF*	MBU**	MS†	RB††	TV‡
Photo Collection Page No.					
Axial Distance from Rod Bottom, in	9.6	17.9	8.4 - 9.4	1.0 - 2.3	26.8 - 28.0
Control Rod Bank Position, in	18.0	26.8	18.0	18.0	27.5
Post-Irradiation Diameter, in:					
Fuel	0.535	-	-	-	-
Clad	0.598	0.564	0.606	0.564	0.563
Fractional Diameter Increase at Section	1.061	-	1.074	-	-
Rod 8A Average Heat Flux, Btu/h-ft ²	583,000	590,000	583,000	583,000	571,000
Axial Peaking Factor at Section	1.62	1.33	1.62	0.92	0.84
Peak Heat Flux During Rod Life, Btu/h-ft ²	944,500	784,700	944,500	536,400	479,600
Estimated Heat Flux after Swelling, Btu/h-ft ²	1,001,000	-	1,014,000	-	-
End of Life Heat Flux, Btu/h-ft ²	696,600	753,700	679,500	365,400	479,600
Normalized Radius For Melting, αM	0.523	0.573	0.430	-	0.195
Flux Depression Factor Before Swelling:	0.179	0.165	0.198	-	2.33
T_s ($h_{gap} = 2000$), °F	1046	1102	1028	-	831
$\int_{T_s}^{T_m} k dt$, watts/cm	56.4	56.4	60.8	-	50.6
$\int_0^{T_m} k dt$, watts/cm	88.3	89.8	92.3	-	78.1

*Peak Heat Flux Zone

**Maximum Burnup Zone

†Maximum Swelling Zone

††Rod Bottom

‡Top of Void

TABLE 9 (Continued)

TYPE OF SECTION	TRANSVERSE		LONGITUDINAL		
Section Number	8596	8597	8598	8599	8600
Section Shows	PHF*	MBU**	MS†	RB††	TV‡
After Swelling:					
$\int_0^{T_m} kdt$, watts/cm	59.9	-	65.4	-	-
$\int_{T_0}^{T_m} kdt$, watts/cm	92.7	89.8	98.2	-	78.1
Based on Autoradiography					
Normalized Radius for					
Melting, αM	0.620	0.642	0.643	-	0.293
Flux Depression Factor	0.151	0.144	0.144	-	0.224
Before Swelling:					
T_s ($h_{gap} = 2000$), °F	1291	1133	1291	887	831
$\int_{T_s}^{T_m} kdt$, watts/cm	64.5	51.1	61.5	-	48.5
$\int_0^{T_m} kdt$, watts/cm	101.5	84.8	98.5	-	76.0
After Swelling:					
T_s ($h_{gap} = 2000$), °F	1348	-	1361	-	-
$\int_{T_s}^{T_m} kdt$, watts/cm	68.4	-	66.0	-	-
$\int_0^{T_m} kdt$, watts/cm	106.4	84.8	104.2	-	76.0

EPT 8 ROD A

PEAK HEAT FLUX
AND MAXIMUM SWELLING SECTION

ROD ELEVATION 9.6 INCHES

NEG. No. 8596-01 (OFF 600 SiC)

7X

PHOTOMACROGRAPH OF A TRANSVERSE FUEL ROD SECTION
AT LOCATION OF PEAK HFAT FLUX, AT PELLETT 17

ROD ELEVATION 9.6 INCHES

NEG. No. 8596-02

7X

$\beta - \gamma$ AUTORADIOGRAPH OF SAME SECTION AS IN NEG. No. 8596-01

(300)

ROD ELEVATION 9.6 INCHES

NEG. No. 8596-38

10X

β - γ AUTORADIOGRAPH MADE AFTER REPOLISHING OF
SAME SECTION AS IN NEG. No. 8596-37

(1040)

ROD ELEVATION 9.6 INCHES

NEG. No. 8596-37

10X

ANOTHER PHOTOMACROGRAPH OF THE SAME TRANSVERSE
SECTION AS IS SHOWN IN NEG. No. 8596-01 AFTER REPOLISHING

TRANSVERSE SECTION AT ROD ELEVATION 9.6 INCHES

NEG. No. 8596-03/8596-08 μ

100X

COMPOSITE OF THE RADIAL SECTION OUTLINES
ON NEG. No. 8596-01

NEG. No. 8596-09 μ

500X

OUTSIDE DIAMETER OF FUEL AT FUEL*CLAD INTERFACE

NEG. No. 8596-10 μ

500X

AREA IN OUTERMOST GRAIN SIZE TRANSITION ZONE

NEG. No. 8596-11 μ

500X

FUEL SHOWING METALLIC PHASE IN GRAIN SIZE
TRANSITION ZONE

NEG. No. 8596-12 μ

500X

AREA NEAR EDGE OF CENTRAL VOID

TRANSVERSE SECTION AT ROD ELEVATION 9.6 INCHES

NEG. No. 8596-13/8596-18

100X

COMPOSITE OF THE RADIAL SECTION OUTLINED ON
NEG. No. 8596-01 ETCHED TO SHOW GRAIN BOUNDRIES

NEG. No. 8596-20 μ

500X

AREA NEAR OUTSIDE DIAMETER OF THE FUEL

NEG. No. 8596-21 μ

500X

AREA AT OUTERMOST EDGE OF THE GRAIN TRANSITION ZONE

NEG. No. 8596-22 μ

500X

AREA IN THE METALLIC PARTICLE BAND OF THE GRAIN
SIZE TRANSITION ZONE

NEG. No. 8596-19 μ

500X

UNUSUAL AND UNIDENTIFIED PARALLEL STRIATIONS

NEG. No. 8596-23 μ

100X

AREA NEAR THE EDGE OF THE CENTRAL VOID

CLAD AT ROD ELEVATION 9.6 INCHES

NEG. No. 8596-24 μ

250X

REPRESENTATIVE AREA OF CLAD OUTSIDE
DIAMETER SHOWING HYDRIDE

NEG. No. 8596-25 μ

250X

SAME AREA AS IN NEG. No. 8596-24 μ USING
POLARIZED LIGHT TO SHOW GRAIN STRUCTURE

ROD ELEVATION 8.4 TO 9.4 INCHES

NEG. No. 8598-01 (OFF 600 SiC)

8X

PHOTOMACROGRAPH OF A LONGITUDINAL SECTION OF
FUEL NEAR PEAK HEAT FLUX REGION SHOWING PELLETS
15 AND 16

ROD ELEVATION 8.4 TO 9.4 INCHES

NEG. No. 8598-02

8X

β - γ AUTORADIOGRAPH OF SAME SECTION
AS IN NEG. No. 8598-01

(300)

ROD ELEVATION 8.4 TO 9.4 INCHES

GEAP-5100B

NEG. No. 8598-28

ANOTHER β - γ AUTORADIOGRAPH MADE AFTER THE
REPOLISHING SHOWN IN NEG. No. 8598-27

(1040)

10X

52

NEG. No. 8598-27

10X

ANOTHER VIEW OF THE SAME SECTION AS SHOWN IN
NEG. No. 8598-01 AFTER REPOLISHING

53

LONGITUDINAL SECTION AT ROD ELEVATION 8.4 TO 9.4 INCHES

NEG. No. 8598-03/8598-09

COMPOSITE OF THE RADIUS OUTLINED ON NEG. No. 8598-01

100X

NEG. No. 8598-13

500X

OUTSIDE DIAMETER OF FUEL NEAR FUEL-CLAD INTERFACE

NEG. No. 8598-12

500X

AREA NEAR OUTERMOST EDGE OF GRAIN SIZE
TRANSITION ZONE SHOWING POROSITY DISTRIBUTION

NEG. No. 8598-11

500X

AREA IN GRAIN SIZE TRANSITION ZONE SHOWING
METALLIC PHASE AND POROSITY MORPHOLOGY

NEG. No. 8598-10

500X

AREA NEAR CENTRAL VOID SHOWING VOIDS AND
PHASES IN FUEL

LONGITUDINAL SECTION AT ROD ELEVATION 8.4 TO 9.4 INCHES

NEG. No. 8598-14/8598-20

COMPOSITE OF SAME AREA AS IN NEG. No. 8598-03/8598-09
ETCHED TO SHOW GRAIN BOUNDRIES

200X

NEG. No. 8598-21

500X

OUTSIDE DIA METER OF FUEL NEAR FUEL-CLAD INTERFACE

NEG. No. 8598-22

500X

AREA IN OUTERMOST REGION OF GRAIN SIZE TRANSITION ZONE

NEG. No. 8598-23

500X

METALLIC PHASE AT AUTORADIOGRAPH "BRIGHT BAND."

NEG. No. 8598-24

500X

AREA NEAR CENTRAL VOID SHOWING PHASE STRUCTURE

CLAD AT ROD ELEVATION 8.4 TO 9.4 INCHES

NEG. No. 8598-25

REPRESENTATIVE OUTSIDE DIAMETER OF
CLAD NEAR PELLET INTERFACE

250X

NEG. No. 8598-26

SAME AREA AS SHOWN IN NEG. No. 8598-25 USING
POLARIZED LIGHT TO SHOW GRAIN STRUCTURE.

250X

EPT 8 ROD A

MAXIMUM BURNUP SECTION

ROD ELEVATION 17.7 INCHES

NEG. No. 8597-01

7X

PHOTOMACROGRAPH OF TRANSVERSE FUEL ROD SECTION
AT THE LOCATION OF THE MAXIMUM BURN-UP IN PELLET 32.

ROD ELEVATION 17.7 INCHES

NEG. No. 8597-02

7X

β - γ AUTORADIOGRAPH OF SAME SECTION AS IN NEG. No. 8597-01.

(300)

TRANSVERSE SECTION AT ROD ELEVATION 17.7 INCHES

NEG. No. 8597-03/8597-06

COMPOSITE OF RADIAL SECTION OUTLINED
ON NEG. No. 8597-01.

100X

NEG. No. 8597-12

500X

OUTSIDE EDGE OF CENTRAL VOID SHOWING VARIOUS PHASES.

NEG. No. 8597-11

500X

TRANSITION FROM SMALL COLUMNAR GRAINS TO HIGH DENSITY FUEL.

NEG. No. 8597-10

500X

OUTERMOST GRAIN SIZE TRANSITION.

NEG. No. 8597-9

500X

OUTSIDE DIAMETER OF FUEL AT FUEL-CLAD INTERFACE.

TRANSVERSE SECTION AT ROD ELEVATION 17.7 INCHES

NEG. No. 8597-13/8597-18

100X

ETCHED COMPOSITE OF SAME AREA AS IN NEG. Nos.
8597-03/8597-08 SHOWING GRAIN STRUCTURE.

NEG. No. 8597-19

500X

OUTSIDE EDGE OF CENTRAL VOID SHOWING VARIOUS
PHASES AND GRAIN STRUCTURE.

NEG. No. 8597-20

500X

TRANSITION FROM SMALL COLUMNAR GRAINS TO HIGH
DENSITY FUEL, SHOWING GRAIN STRUCTURE.

NEG. No. 8597-21

500X

OUTERMOST GRAIN SIZE TRANSITION ZONE.

NEG. No. 8597-22

500X

OUTSIDE DIAMETER OF FUEL AT FUEL-CLAD INTERFACE.

TRANSVERSE SECTION AT ROD ELEVATION 17.7 INCHES

NEG. No. 8597-03/8597-08 μ

RADIAL COMPOSITE OF SAME AREA (APPROXIMATELY) AS SHOWN IN
NEG. No. 8597-03/8597-08, FURTHER POLISHED TO BETTER SHOW POROSITY.

100X

NEG. No. 8597-12 μ

EDGE OF CENTRAL VOID SHOWING PHASES.

500X

NEG. No. 8597-11 μ

TRANSITION ZONE FROM SMALL COLUMNAR GRAINS
TO HIGH DENSITY FUEL.

500X

NEG. No. 8597-10 μ

OUTERMOST GRAIN SIZE TRANSITION ZONE.

500X

NEG. No. 8597-09 μ

OUTSIDE DIAMETER OF FUEL AT FUEL-CLAD INTERFACE.

500X

CLAD AT ROD ELEVATION 17.7 INCHES

NEG. No. 8597-23

250X

REPRESENTATIVE OUTSIDE DIAMETER OF CLAD
SHOWING HYDRIDE.

NEG. No. 8597-24

250X

USING POLARIZED LIGHT TO SHOW GRAIN STRUCTURE AND
SIZE OF SAME AREA SHOWN IN NEG. No. 8597-23

EPT 8 ROD A

OTHER SECTIONS

LONGITUDINAL SECTION AT BOTTOM OF CENTRAL VOID
ROD ELEVATION 1 TO 2 INCHES

NEG. No. 19565

1-1/2X

LOW POWER PERISCOPE PICTURE OF LONGITUDINAL
FRACTURE SECTION SHOWING PELLETS 1-8.

NEG. No. 19573

2-1/2X

HIGH POWER PERISCOPE PICTURE OF LEFT END OF
LONGITUDINAL FRACTURE SECTION SHOWN IN
NEG. Nos. 19566/19572, INCLUDING PELLETS 1 AND 2. MET. 8599.

NEG. Nos. 19566/19572

HIGH POWER PERISCOPE PICTURE OF UPPER PIECE OF
FRACTURE SECTION SHOWN IN NEG. No. 19565.

4X

ROD ELEVATION 1 TO 2 INCHES

NEG. No. 8599-01 (OFF 600 SiC)

7X

PHOTOMACROGRAPH OF SAME LONGITUDINAL SECTION AS SHOWN IN
NEG. No. 19573 SHOWING THE BOTTOM OF THE CENTRAL VOID.

ROD ELEVATION 1 TO 2 INCHES

NEG. No. 8599-02

7X

β - γ AUTORADIOGRAPH OF LONGITUDINAL SECTION
SHOWN IN NEG. No. 8599-01.

(300)

ROD ELEVATION 1 TO 2 INCHES

NEG. No. 8599-49

7X

ANOTHER β - γ AUTORADIOGRAPH TAKEN AFTER THE
REPOLISHING SHOWN IN NEG. No. 8599-50.

(1040)

ROD ELEVATION 1 TO 2 INCHES

NEG. No. 8599-50

7X

ANOTHER VIEW OF THE LONGITUDINAL SECTION
SHOWN IN NEG. No. 8599-01 AFTER REPOLISHING.

LONGITUDINAL SECTION AT BOTTOM OF CENTRAL VOID
ROD ELEVATION 1 TO 2 INCHES

NEG. No. 8599-03/8599-10

A RADIAL COMPOSITE OF THE AREA OUTLINED
ON NEG. No. 8599-01, SHOWING THE EXTRUDED ZONE. (No. 1)

100X

NEG. No. 8599-21

AREA NEAR EDGE OF CENTRAL VOID.

500X

NEG. No. 8599-22

AREA IN THE GRAIN SIZE TRANSITION ZONE.

500X

LONGITUDINAL SECTION AT BOTTOM OF CENTRAL VOID
ROD ELEVATION 1 TO 2 INCHES

NEG. No. 8599-33/8599-45

COMPOSITE OF SAME AREA AS SHOWN IN NEG. No. 8599-03/8599-13
AND 8599-31/8599-32, ETCHED TO SHOW GRAIN BOUNDARIES.

100X

NEG. No. 8599-46

AREA NEAR EDGE OF CENTRAL VOID.

500X

NEG. No. 8599-47

AREA IN THE GRAIN SIZE TRANSITION ZONE.

500X

NEG. No. 8599-48

AREA OF FUEL NEAR THE FUEL-CLAD INTERFACE.

500X

LONGITUDINAL SECTION AT BOTTOM OF CENTRAL VOID
ROD ELEVATION 1 TO 2 INCHES

NEG. No. 8599-14/8599-20 μ

RADIAL COMPOSITE No. 2 OUTLINED ON NEG. No. 8599-01,
SHOWING A REPRESENTATIVE AREA OF FUEL AWAY FROM
THE EXTRUDED ZONE.

100X

NEG. No. 8599-21 μ

AREA NEAR CENTRAL VOID.

500X

NEG. No. 8599-22 μ

AREA IN GRAIN SIZE TRANSITION ZONE.

500X

NEG. No. 8599-23 μ

AREA AT OUTSIDE DIAMETER OF FUEL
NEAR FUEL-CLAD INTERFACE.

500X

LONGITUDINAL SECTION AT BOTTOM OF CENTRAL VOID
 ROD ELEVATION 1 TO 2 INCHES

NEG. No. 8599-24/8599-29

COMPOSITE OF SAME AREA AS SHOWN IN NEG. No.
 8599-14/8599-20, ETCHED TO SHOW GRAIN BOUNDRIES.

100X

LONGITUDINAL SECTION AT BOTTOM OF CENTRAL VOID
ROD ELEVATION 1 TO 2 INCHES

NEG. Nos. 8599-03/8599-04, 8599-11/8599-13, 8599 31/8599-32

AXIAL COMPOSITE THROUGH BOTTOM (No. 1) FUEL PELLET
AT AN AREA ADJOINING RADIAL COMPOSITE NEG. Nos.
8599-03/8599-10.

100X

LONGITUDINAL SECTION AT BOTTOM OF CENTRAL VOID
ROD ELEVATION 1 TO 2 INCHES

NEG. Nos. 8599-39/8599-45

SAME AREA AS SHOWN IN NEG. Nos. 8599-03/8599-04,
8599-11/8599-13, 8599-31/8599-32, ETCHED TO SHOW
GRAIN BOUNDRIES.

100X

ROD ELEVATION 6.2 INCHES

NEG. No. 9119-01 (OFF 600 SiC)

10X

PHOTOMACROGRAPH OF A TRANSVERSE SECTION.

ROD ELEVATION 6.2 INCHES

NEG. No. 9119-02

10X

β - γ AUTORADIOGRAPH OF SAME AREA AS IN
NEG. No. 9119-01; 49 R/MIN. 26 MIN. EXPOSURE.

(1040)

ROD ELEVATION 6.2 INCHES

NEG. No. 9119-03

10X

α AUTORADIOGRAPH OF SAME AREA AS IN
NEG. No. 9119-01, 1 MIN. EXPOSURE.

(860)

ROD ELEVATION 6.2 INCHES

NEG. No. 9119-19

10X

α AUTORADIOGRAPH AS IN NEG. No. 9119-03
WITH 5 MIN. EXPOSURE.

(1040)

ROD ELEVATION 6.2 INCHES

NEG. No. 9119-16

10X

SAME SECTION AS IN NEG. No. 9119-01 AFTER
FURTHER POLISHING AND REMOVAL OF
FISSION PRODUCT MIGRATION SAMPLES.

TRANSVERSE SECTION AT ROD ELEVATION 6.0 INCHES

NEG. No. 9119-04/9119-11

COMPOSITE OF DIAMETRAL SECTION OUTLINED
ON NEG. No. 9119-01.

50X

NEG. No. 9119-14

EDGE OF MOLTEN ZONE FROM LAST REACTOR
CYCLE AS OUTLINED.

250X

NEG. No. 9119-12

INNER EDGE OF MOLTEN ZONE AS OUTLINED.

250X

NEG. No. 9119-13

OUTER EDGE OF MOLTEN ZONE AS OUTLINED.

250X

ROD ELEVATION 14.0 INCHES

NEG. No. 9121-01

10X

PHOTOMACROGRAPH OF A TRANSVERSE SECTION.

ROD ELEVATION 14.0 INCHES

NEG. No. 9121-02

10X

β - γ AUTORADIOGRAPH OF SAME AREA AS IN NEG. No.
9121-01; 58 R/MIN. FOR 21 MIN. EXPOSURE.

(1040)

ROD ELEVATION 14.0 INCHES

NEG. No. 9121-03

10X

α AUTORADIOGRAPH OF SAME AREA AS IN
NEG. No. 9121-01; 1 MIN. EXPOSURE.

(860)

ROD ELEVATION 14.0 INCHES

NEG. No. 9121-19

10X

α AUTORADIOGRAPH AS IN NEG. No. 9121-03
WITH 5 MIN. EXPOSURE.

(1040)

ROD ELEVATION 14.0 INCHES

NEG. No. 9121-16

10X

SAME SECTION AS IN NEG. No. 9121-01 AFTER FURTHER
POLISHING AND REMOVAL OF FISSION PRODUCT
MIGRATION SAMPLES.

TRANSVERSE SECTION AT ROD ELEVATION 6.0 INCHES

NEG. No. 9121-04/9121-11

COMPOSITE OF DIAMETRAL SECTION OUTLINED
ON NEG. No. 9121-01.

50X

NEG. No. 9121-12/9121-14

COMPOSITE OF EDGE OF MOLTEN ZONE AS OUTLINED.

250X

ROD ELEVATION 21.5 INCHES

NEG. No. 9122-01

10X

PHOTOMACROGRAPH OF A TRANSVERSE SECTION.

ROD ELEVATION 21.5 INCHES

NEG. No. 9122-02

10X

β - γ AUTORADIOGRAPH OF SAME AREA AS IN
NEG. No. 9122-01; 54 R/MIN. FOR 23 MIN. EXPOSURE.

(1040)

ROD ELEVATION 21.5 INCHES

NEG. No. 9122-03

10X

α AUTORADIOGRAPH OF SAME AREA AS IN
NEG. No. 9122-01; 1 MIN. EXPOSURE.

(860)

ROD ELEVATION 21.5 INCHES

NEG. No. 9122-15

10X

α AUTORADIOGRAPH AS IN NEG. No. 9122-03
WITH 5 MIN. EXPOSURE.

(1040)

ROD ELEVATION 21.5 INCHES

NEG. No. 9122-16

10X

SAME SECTION AS IN NEG. No. 9122-01 AFTER FURTHER
POLISHING AND REMOVAL OF FISSION PRODUCT
MIGRATION SAMPLES.

TRANSVERSE SECTION AT ROD ELEVATION 25.1 INCHES

NEG. No. 9122-04/9122-11

COMPOSITE OF DIAMETRAL SECTION OUTLINED ON
NEG. No. 9122-01.

50X

NEG. No. 9122-12/9122-14

COMPOSITE OF EDGE OF MOLTEN ZONE AS OUTLINED.

250X

ROD ELEVATION 24.7 INCHES

NEG. No. 9123-01

10X

PHOTOMACROGRAPH OF A TRANSVERSE SECTION.

ROD ELEVATION 24.7 INCHES

NEG. No. 9123-02

10X

β - γ AUTORADIOGRAPH OF SAME AREA AS IN NEG. No.
9123-01; 35 R/MIN. FOR 36.5 MIN. EXPOSURE.

(1040)

ROD ELEVATION 24.7 INCHES

NEG. No. 9123-03

10X

α AUTORADIOGRAPH OF SAME AREA AS IN
NEG. No. 9123-01; 1 MIN. EXPOSURE.

(860)

ROD ELEVATION 24.7 INCHES

NEG. No. 9123-14

10X

α AUTORADIOGRAPH AS IN NEG. No. 9123-03
WITH 5 MIN. EXPOSURE.

(1040)

ROD ELEVATION 24.7 INCHES

NEG. No. 9123-15

10X

SAME SECTION AS IN NEG. No. 9123-01 AFTER
FURTHER POLISHING AND REMOVAL OF
FISSION PRODUCT MIGRATION SAMPLES.

TRANSVERSE SECTION AT ROD ELEVATION 24.7 INCHES

NEG. No. 9123-04/9123-11

COMPOSITE OF DIAMETRAL SECTION OUTLINED ON
NEG. No. 9123-01.

50X

NEG. No. 9123-12/9123-13

COMPOSITE OF EDGE OF MOLTEN ZONE AS OUTLINED.

250X

ROD ELEVATION 26.3 TO 30.0 INCHES

NEG. No. 19564 1/2X
LOW POWER PERISCOPE PICTURE OF LONGITUDINAL
FRACTURE SHOWING PELLETS 48-55.

NEG. No. 19574 2-1/2X
HIGH POWER PERISCOPE PICTURE OF THE LONGITUDINAL
FRACTURE SECTION OUTLINED ON NEG. Nos. 19560/19563.

NEG. No. 19560/19563 2-1/2X
COMPOSITE OF HIGH POWER PERISCOPE PICTURES
SHOWING SAME LONGITUDINAL FRACTURE AS IN
NEG. No. 19564.

LONGITUDINAL SECTION AT TOP CENTRAL VOID
ROD ELEVATION 26.3 TO 30.0 INCHES

NEG. No. 8600-01 (OFF 600 SiC)

7X

PHOTOMACROGRAPH OF THE LONGITUDINAL SECTION
SHOWN IN NEG. No. 19574, INCLUDING PELLETS 50-52.

NEG. No. 8600-02

7X

β - γ AUTORADIOGRAPH OF SAME LONGITUDINAL SECTION
AS SHOWN IN NEG. No. 8600-01. TOP OF CENTRAL VOID.

(240)

LONGITUDINAL SECTION AT ROD ELEVATION 26.3 TO 30.0 INCHES

NEG. No. 8600-32/8600-39

DIAMETRAL SECTION

50X

AS POLISHED SECTION OF AREA OUTLINED ON
NEG. No. 8600-01.

LONGITUDINAL SECTION AT ROD ELEVATION 26.3 TO 30.0 INCHES

NEG. No. 8600-40/8600-47

SAME DIAMETRAL SECTION AS SHOWN IN NEG. No.
8600-32/8600-39 ETCHED TO SHOW GRAIN STRUCTURE.

50X

LONGITUDINAL SECTION AT ROD ELEVATION 26.3 TO 30.0 INCHES

NEG. NO. 8600-03/8600-10
AS POLISHED RADIAL SECTIONS

RADIAL COMPOSITE OF AREA OUTLINED ON
NEG. No. 8600-01, AS POLISHED.

100X

NEG. No. 8600-11

AREA NEAR ROD CENTRAL AXIS.

500X

NEG. No. 8600-12

AREA AT OUTER LIMIT OF GRAIN GROWTH.

500X

NEG. No. 8600-13

AREA AT FUEL-CLADDING INTERFACE.

500X

LONGITUDINAL SECTION AT ROD ELEVATION
26.3 TO 30.0 INCHES

NEG. No. 8600-21/8600-28

100X

ETCHED RADIAL COMPOSITE OF AREA OUTLINED
ON NEG. No. 8600-01.

NEG. NO. 8600-29

500X

AREA NEAR ROD CENTRAL AXIS.

NEG. No. 8600-30

500X

AREA AT OUTER LIMIT OF GRAIN GROWTH.

NEG. No. 8600-31

500X

AREA AT FUEL-CLADDING INTERFACE.

ROD ELEVATION 26.8 - 28.0

NEG. No. 8600-14/8600-20 μ

ANOTHER RADIAL SECTION OUTLINED ON NEG. No. 8600-01
REMOVED FROM MOLTEN ZONE SHOWING GRAIN STRUCTURE
AND POROSITY, AFTER THE SECTION WAS REPOLISHED.

100X

NOTES: ESTIMATES
MADE FROM
FRACTURE SECTIONS.

EXTERNAL POST-IRRADIATION APPEARANCE OF RODS A,B,C,D. ANGULAR ORIENTATION OF ROD				DISTANCE OF SPACER FROM BOTTOM	TOP	DISTANCE FROM ROD BOTTOM	TRANSVERSE SECTIONS					LONGITUDINAL SECTIONS	
							FRACTURE			METALLO- GRAPHIC		METALLO- GRAPHIC	
							LOOK- ING UP ↑	LOOK- ING DOWN ↓	PAGE NO.	SEC. NO.	PAGE NO.	SEC. NO.	PAGE NO.
19357	19361	19366	19371	38.0"									
						35.2"	19495	19496	37				
						65							
						64							
						63							
						62							
						61							
						60							
						59							
						58							
						57							
						56	19494	19493	36				
						55	19508	19507	35				
						54							
						53							
						52							
						51							
						50							
						49							
						48							
						47							
						46							
						45				9123	94-99		
						44							
						43							
						42							
						41							
						40	19490	19489	33				
						39				9122	88-93		
						38							
						37							
						36							
						35							
						34	19488	19487	32				
						33	19503	19504	31	8597	58-63		
						32	19506	19505	30				
						31							
						30							
						29							
						28							
						27							
						26							
						25				9121	82-87		
						24	19486	19485	29				
						23							
						22							
						21							
						20							
						19							
						18	19502	19501	28				
						17	19484	19483	27	8596	43-45		
						16							
						15	19482	19481	26				
						14	19509						
						13							
						12							
						11				9119	76-81		
						10							
						9							
						8	19480	19479	25				
						7							
						6							
						5							
						4							
						3	19497	19498					
						2	19499						
						1	19500		24				

RODS A, B, C, AND D

BOTTOM

EPT-8

ROD A

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