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HIGH PERFORMANCE UO_2 PROGRAM
IRRADIATION OF 0.5 INCH DIAMETER,
SOLID PELLET UO_2 FUEL RODS AT
700,000 Btu/h-ft² PEAK HEAT FLUX

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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 reports 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.

ABSTRACT

The fabrication data, irradiation history, and the complete, correlated post-irradiation examination results are described for a four-rod fuel assembly - designated EPT-6* - that operated in the GETR-PWL** with slight central melting to a burnup of ~1200 MWD/Te. The fuel rods were unsegmented, reactor-length rods containing 95 percent dense, solid, sintered UO_2 pellets in freestanding Zircaloy-2 cladding. This fuel assembly was the first 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 provided the first indication of the basic obstacle to operation with central melting; namely, severe, localized clad swelling accompanying the onset of 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-6, have been described earlier in GEAP-4264.

*EPT-6 designates Euratom pellet assembly, 600,000 Btu/h-ft² nominal peak heat flux.

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

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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 UO_2 powder. The irradiations were conducted in the GETR Pressurized Water Loop. Fuel assembly heat transfer during the irradiations were 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 final 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 first pellet fuel assembly irradiated - Assembly EPT-6. This initial pellet assembly was designed to undergo slight central melting at the maximum axial power position.

IRRADIATION HISTORY

The fuel rods in Assembly EPT-6 contained 1.5% enriched UO_2 fuel pellets and were intended to operate at a nominal peak heat flux of $600,000 \text{ Btu/h-ft}^2$ (190 w/cm^2). The following actual conditions obtained at initial, 30 MW (th) reactor power operation were:

Start-up Date - 4/23/62

General Electric Test Reactor (GETR) Cycle No. - 33

Control Rod Bank Position - 19.3 in. (49 cm)

Assembly Average, Peak Heat Flux - $680,000 \text{ Btu/h-ft}^2$ (214 w/cm^2)

Rod 6A Peak Surface Heat Flux - $628,000 \text{ Btu/h-ft}^2$ (198 w/cm^2)

Rod 6D Peak Surface Heat Flux - $734,000 \text{ Btu/h-ft}^2$ (232 w/cm^2)

The coolant conditions during the EPT-6 assembly irradiation are listed in Table 1. The assembly operated satisfactorily for the entire 25 - day GETR Cycle 33 and experienced 6 full power cycles. The average thermal power of the assembly during operation was 200 kW. The GETR was refueled on May 10, 1962 which lowered the control rod bank position from 28.4 inches (72 cm) before refueling to 25.6 inches (65 cm) after refueling. The chronological variation in average heat flux of Rod 6D during the cycle is shown in Figure 1.

The dates and approximate times of the 5 interim shut-downs are as follows:

No. 1	24 April 1962	1000-2200 h
No. 2	26 April 1962	1420-1430 h
No. 3	28 April 1962	1510-1525 h
No. 4	10 May - 11 May 1962	2050-1130 h
No. 5	13 May 1962	1730-1015 h

The following conditions prevailed at 30 MW (th) reactor power immediately before the final shut-down:

Shut-Down Date - 5/19/62

Control Rod Bank Position - 31.5 in. (80 cm)

Assembly Average, Peak Heat Flux - $560,000 \text{ Btu/h-ft}^2$ (177 w/cm^2)

Rod 6-D Peak Heat Flux - $605,000 \text{ Btu/h-ft}^2$ (191 w/cm^2)

Assembly Average Burnup - 1250 MWD/T_e ($0.34 \times 10^{20} \text{ fissions/cm}^3$)

TABLE 1
COOLANT CONDITIONS DURING IRRADIATION

Pressure	1000 psia
Saturation Temperature	545° F
Fuel Assembly Temperatures:	
Inlet	344° F
Outlet	370° F
Flow Velocity at Fuel Rods	16 ft/sec
Mass Velocity	3.22×10^6 lb/h-ft ²
Flow Rate	57 gal/min
pH (LiOH Regenerated Demineralized)	9.5 to 10.0
Dissolved H ₂	25 to 65 cc/kg
Crud Deposition	None
Cooling Regime	Forced Convection (Without Nucleate Boiling)
Film Heat Transfer	
Coefficient	7,100 (Btu/h-ft ² - °F)
Density	56 lb/ft ³
Specific Heat	1.05 Btu/lb-°F

*For a More Detailed Description see GEAP-4264

Figure 1. Thermal Performance History

POST-IRRADIATION EXAMINATION EPT-6

When assembly EPT-6 was initially examined in the RML, only rod 6A was easily removed from its shroud tube. After considerable physical effort, rod 6B was withdrawn from its shroud tube but the rod surface was badly scarred by the lateral spacers in the process. Neither rod 6C nor 6D could be withdrawn and it was necessary to slit the shroud tubes full length to effect removal. Subsequent dimensional examination revealed severe clad swelling in rods 6C and 6D. Rod 6B was slightly swollen and 6A was just perceptibly swollen. The dimensional increase of 6A was less than the experimental measurement accuracy and may not be significant. Figure 2 illustrates the diameter changes in the EPT-6 assembly fuel rods as a function of axial position. The dark shaded areas on the plots shown in Figure 2, indicate the differences in the diameter measurements at 0 and 90 degree rotational orientations of the fuel rods. It is evident that the clad swelling is almost perfectly symmetrical and is confined to a very short, 4 inch axial section of the rods, centered at a position approximately 9 inches above the bottom end of the fuel rod. This axial position corresponds to the peak heat flux location at start-up which indicates clad swelling occurred at startup.

The maximum diameter increase occurred in rod 6D and was 47 mils or an approximately 8% circumferential elongation of the cladding. Based on its integrated gamma activity, determined during gamma scanning, rod 6D was also the maximum power rod in the assembly. This result coupled with the axial location of the swelling indicated strongly that the clad swelling was related to thermal performance level of the fuel rod (see Figure 8). In Table 2, the pre- and post-irradiation measurements of assembly EPT-6 are summarized.

The visual appearance of the rods 6C and 6D was generally identical to the pre-irradiation condition except at the location of the swelling. At this location, the rod surfaces were badly scored from the lateral spacers during the initial attempt to remove them from their shroud tubes. Rod 6D was selected for destructive examination because it was the maximum power rod and also the rod with the maximum diameter increase. Subsequently, rod 6A was also destructively examined for comparison.

Figure 2 Dimensional Changes - Assembly EPT-6

TABLE 2. Assembly EPT-6 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			Irradiation		
		Pre-	Post-	Change, (mils)	Pre-	Post-	Change, (mils)
6-A	4	0.565*	0.565	0	0.565	0.563	-2
	16	0.564	0.564	0	0.564	0.563	-1
	20	0.564	0.564	0	0.564	0.563	-1
	24	0.564	0.564	0	0.564	0.564	0
	28	0.564	0.566	+2	0.564	0.565	+1
	32	0.565	0.565	0	0.564	0.566	+2
	36	0.565	0.565	0	0.565	0.564	-1
6-B	4	0.564	0.563	-1	0.565	0.563	-2
	16	0.564	0.563	-1	0.563	0.562	-1
	20	0.563	0.564	+1	0.564	0.563	-1
	24	0.564	0.564	0	0.564	0.564	0
	28	0.564	0.567	+3	0.564	0.568	+4
	32	0.564	0.570	+6	0.564	0.569	+5
	36	0.564	0.564	0	0.565	0.563	-2
6-C	4	0.563	0.561	-2	0.563	0.561	-2
	16	0.561	0.560	-1	0.561	0.561	0
	20	0.560	0.560	0	0.560	0.559	-1
	24	0.560	0.562	+2	0.560	0.561	+1
	28	0.561	0.564	+3	0.560	0.564	+4
	30	-	0.605	-	-	0.605	-
	32	0.561	0.578	+17	0.561	0.575	+14
	34	-	0.563	-	-	0.564	-
	36	0.562	0.562	0	0.562	0.561	-1
6-D	4	0.564	0.563	-1	0.565	0.563	-2
	16	0.563	0.562	-1	0.563	0.562	-1
	20	0.563	0.563	0	0.564	0.563	-1
	24	0.563	0.564	+1	0.564	0.565	+1
	28	0.563	0.567	+4	0.564	0.568	+4
	30	-	0.579	-	-	0.581	-
	31	-	0.610	-	-	0.611	-
	32	0.564	0.572	+8	0.564	0.573	+9
	34	-	0.563	-	-	0.564	-
	36	0.564	0.564	0	0.564	0.563	-1
Over-All Length inches **							
6-A		39.018	39.126	+0.108			
6-B		39.008	39.145	+0.137			
6-C		39.006	39.086	+0.080			
6-D		39.004	39.062	+0.058			

* 0.565 inch = 1.435 cm

** Accuracy of length ± 0.010 inch

TABLE 3
CHEMICAL ANALYSIS OF 1.5% ENRICHED
UO₂ CERAMIC GRADE POWDER

<u>Element</u>	<u>Impurity Content, PPM</u>
Al	2
B	0.20
Cd	<0.10
Ca	26
C	43
F	49
Fe	10
Si	4
Cl	<25
Cr	3
Cu	21
Mn	3
N	<10
V	<10*
Ti	<100*
Co	<5
Mo	<1*
Ni	10
Ag	<0.10
<hr/>	
U:O Ratio	2.07
Particle Size, μ (Fisher Sub-Sieve)	0.93
Bulk Density, gm/cc	1.14
U ²³⁵ , %	1.497

*No Determination

TABLE 4
CHEMICAL ANALYSIS 1.5% ENRICHED UO_2
SINTERED PELLETS

<u>Element</u>	<u>Impurity Content, PPM</u>	
Al	100	20
Bi	<1	<1
B	<0.2	<0.2
Cd	<1	<1
Ca	10	10
Cr	25	25
Co	<2	<2
Cu	65	65
Fe	500	200
Pb	<1	<1
Mg	5	5
Mn	<1	<1
Mo	10	<3
Si	30	30
Ag	3	10
Na	<35	<35
Sn	5	10
V	<15	<15
Zn	<10	<10
Ni	100	50
Sb	<2	<2
N	160	390
C	<10	<10
F	16	18
U:O Ratio	2.03, 2.01, 2.00	
Density, %	94.1 to 97.3*	
U^{235}	1.46 $\pm$ 0.04	
	1.50 $\pm$ 0.04	

* Based on 15 Pellets

TABLE 5. 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	< 20	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:	ASTM 6-7	
Flare Test:	33.6% and 34.4% o.d. expansion at 60 degrees	
Burst Test:	10,500-psi yield pressure, (7.4 × 10 ⁶ kg/m ²)	
	11,000-psi burst pressure, (7.7 × 10 ⁶ kg/m ²)	

TABLE 6
EPT-6 ASSEMBLY CHARACTERISTICS AND HISTORY

Fuel Enrichment	1.5%
Fuel Type	Pellet, Solid
Average Fuel Col. Length	34± 1/4 in.
Assembly Thermal Power	200 kW
Irradiation Period	4/23/62 through 5/19/62
Number of Rods with C lad	
Swelling	3
Maximum Rod Diameter	
Increase	47 mils.
Surface Heat Flux:	
<u>Nominal for Ept 6</u>	600, 000 Btu/h-ft ²
<u>At Startup:</u>	
Assembly Average	680, 000 Btu/h-ft ²
6A Peak	628, 000 Btu/h-ft ²
6D Peak	734, 000 Btu/h-ft ²
<u>At Shutdown:</u>	
Assembly Average	560, 000 Btu/h-ft ²
6A Peak	515, 000 Btu/h-ft ²
6D Peak	600, 000 Btu/h-ft ²
Assembly Average Burn-up	1250 MWD/T _e

TABLE 7
FUEL ROD DATA

<u>Rod - EPT -</u>	<u>6A</u>	<u>6B</u>	<u>6C</u>	<u>6D</u>
Cladding Diameter, in				
Outside	0.5647-0.5653	0.5642-0.5659	0.5611-0.5638	0.5642-0.5654
Inside	0.5058-0.5064	0.5060-0.5067	0.5064-0.5068	0.5051-0.5056
Pellet Diameter, in				
Outside	<u>0.500-0.501 (Centerless Ground)</u>			
Inside	Solid	Solid	Solid	Solid
Average Pellet Height, in	0.519	0.519	0.519	0.519
Fuel Column Length, in	33 3/4	34 5/16	34 1/4	34 3/16
Fuel Weight, Grams	1141.2	1147.8	1157.0	1158.2
Plenum Length, in	3 3/8	2 11/16	2 13/16	2 7/8
Heat Flux, Btu/h-ft ² :				
Peak During				
Irradiation	630,000	665,000	675,000	732,000
Peak at Shut-Down	515,000	545,000	550,000	600,000
	<u>Fission Gas Released Based on Atoms of Kr⁸⁵</u>			
Atoms Produced, Based				
On Calorimetry x10 ⁻¹⁹	0.906	0.963	0.973	1.058
Atoms Released x 10 ¹⁹ Based on:				
Spectrometry	10.5	30.0	29.9	—
Gas-Chromatography	11.3	25.6	29.0	—
Release Percents:				
Spectrometry	11.5	31.2	30.7	—
Gas-Chromatography	12.5	26.5	29.8	—
	<u>UO₂ Volume Expansion Analysis Results</u>			
Calculated Volume, in ³ :				
Molten Zone	0.235	0.364	0.389	0.596
Zone Between 1600 and 2800°C	1.125	1.191	1.199	1.270
Free Volume Densification, in ³ :				
From Molten Zone	0.012	0.018	0.019	0.030
From 1600 to 2800°C	0.028	0.030	0.030	0.032
Pellet Clad Gap Volume, in ³	0.103	0.113	0.118	0.0097
Total Available Free Volume, in ³	0.143	0.161	0.167	0.162
Calculated UO ₂ Thermal				
Expansion, in ³	0.148	0.172	0.176	0.210
Fuel Rod Volume increase, in ³				
a) Calculated Net	0.007	0.011	0.009	0.048
b) Experimental	0.0099	0.0320	0.1320	0.0911

Figure 3. Fuel 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

Figure 5. Fuel Rod Design

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 and one of the main values of gamma scan has been to locate the individual pellets and, thereby, show the general, post-irradiation condition of the fuel column.

The gamma scan from rod 6D, is a normal profile in most respects. However, the scan indicates that definite pellet separation occurred in the region of maximum clad swelling, 9 inches above the rod bottom. This separation was confirmed by sectioning and metallography. Axial separation of the pellets has not been observed in any other rod examined during the program and the reason for its occurrence in rod 6D is unexplained. It cannot be attributed to clad swelling alone since subsequent rods exhibited greater clad swelling without axial separation.

The most unusual feature of the rod 6D gamma scan is the sharp activity spike near the axial midpoint of the rod. This type of spike had not been observed before and it is believed to be an indication of a concentration of fission products in the hottest zone of the rod; probably a concentration within the UO_2 that was molten just before shutdown. When coupled with the autoradiograph results there is little doubt that the axial relocation and concentration of fission product activity actually occurs.*

*See GEAP-4264 Section IX-E.

GENERAL INFORMATION

SCINTILLATION DETECTOR SWITCH 10
SLIT WIDTH 0.010 in.
ROD SPEED 0.19 in/min.
PAPER SPEED 0.25 in/min.
HIGH VOLTAGE 1800
DISCRIMINATOR 3.40
OUTPUT 1.52
TIME CONSTANT 2 sec.
RANGE KNOBS x 300 x 10
1.0 x 10⁶ cpm = 25 mv.

EPT 6-A ROD A
GAMMA SCANNED 5/28/62
SCAN No. 1 (DOWN SCAN)
AREA UNDER CURVE 159.05 in.²
AVERAGE ORDINATE 3.675 in. (16.8 mv.)

EPT 6-ROD C
GAMMA SCANNED 5/26/62
SCAN No. 1 (UP SCAN)
AREA UNDER CURVE 169.76 in.²
AVERAGE ORDINATE 3.86 in. (17.6 mv.)

EPT 6-ROD B
GAMMA SCANNED 5/28/62
SCAN No. 1 (UP SCAN)
AREA UNDER CURVE 164.30 in.²
AVERAGE ORDINATE 3.76 in. (17.1 mv.)

EPT 6-ROD D
GAMMA SCANNED 5/6/62
SCAN No. 1 (UP SCAN)
AREA UNDER CURVE 195.73 in.²
AVERAGE ORDINATE 4.45 in. (20.15 mv.)

EPT-6 ROD-A

FRACTURE SECTIONS

ROD ELEVATION 1 Inch

NEG. No. 22021

3X

BOTTOM OF PELLET 1.

ROD ELEVATION 5 1/8 Inches

NEG. No. 22023

3X

BOTTOM OF PELLET 9.

NEG. No. 22022

3X

TOP OF PELLET 8.

ROD ELEVATION 9 1/4 Inches

NEG. No. 22026

3X

BOTTOM OF PELLET 17

NEG. No. 22024

3X

TOP OF PELLET 16.

ROD ELEVATION 13 3/8 Inches

NEG. No. 22028 3X
BOTTOM OF PELLET 25.

NEG. No. 22025 3X
TOP OF PELLET 24.

ROD ELEVATION 17 1/8 Inches

NEG. No. 22029 3X
BOTTOM OF PELLET 32.

NEG. No. 22027 3X
TOP OF PELLET 31.

ROD ELEVATION 19½ Inches

NEG. No. 26927

3X

TOP OF PELLET 36.

NEG. No. 26928

3X

BOTTOM OF PELLET 36.

ROD ELEVATION 21 3/8 Inches

NEG. No. 22032 3X
BOTTOM OF PELLET 41.

NEG. No. 22030 3X
TOP OF PELLET 40.

ROD ELEVATION 25½ Inches

NEG. No. 22033 3X
BOTTOM OF PELLET 49.

NEG. No. 22031 3X
TOP OF PELLET 48.

ROD ELEVATION 29½ Inches

NEG. No. 22035 3X
BOTTOM OF PELLET 57.

NEG. No. 22034 3X
TOP OF PELLET 56.

ROD ELEVATION 33 3/8 Inches

NEG. No. 22037 3X
BOTTOM OF PELLET 63.

NEG. No. 22036 3X
TOP OF PELLET 62.

EPT-6 ROD-A

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
NUMBER OF DAYS AFTER END OF IRRADIATION.

EPT-6 ROD-A

PEAK HEAT FLUX ZONE

ROD ELEVATION $9\frac{1}{4}$ Inches FROM BOTTOM

ROD ELEVATION 9¼ Inches

NEG. No. 8716-01 (OFF 600 SiC)
PHOTOMACROGRAPH OF TRANSVERSE FUEL ROD
SECTION AT START-UP PEAK HEAT FLUX
ZONE BETWEEN PELLETS 16 & 17.

10X

ROD ELEVATION 9¼ Inches

NEG. No. 8716-03 (AS POLISHED) 10X
 β - γ AUTORADIOGRAPH OF SAME SECTION AS
IN NEG. 8716-01.

330

RADIAL MICROSCOPIC SECTION AT ROD ELEVATION 9 1/4 Inches
AS POLISHED

NEG. No. 8716-04/8716-11

COMPOSITE OF RADIUS OUTLINED ON NEG. No. 8716-01 SHOWING LENTICULAR VOIDS AT CENTER OF FUEL.

100X

NEG. No. 8716-14
CENTER VOID EDGE INCLUDING LENS-SHAPED VOID.

500X

NEG. No. 8716-13
FUEL STRUCTURE IN TRANSITION ZONE.

500X

NEG. No. 8716-12
CLADDING-FUEL INTERFACE.

500X

RADIAL MICROSCOPIC SECTION AT ROD ELEVATION 9 1/4 Inches

NEG. NOS. 8716-15/8716-21

SAME SECTION AREA AS SHOWN ON PREVIOUS PAGE BUT RADIAL SECTION HAS BEEN ETCHED TO SHOW THE GRAIN BOUNDARIES.

100X

NEG. No. 8716-22

500X

CENTRAL VOID EDGE INCLUDING LENS-SHAPED VOID SHOWING GRAIN BOUNDARIES AND PHASES.

NEG. No. 8716-23

500X

FUEL STRUCTURE IN TRANSITION ZONE SHOWING GRAIN BOUNDARIES AND PHASES.

NEG. No. 8716-24

500X

FUEL CLADDING INTERFACE SHOWING GRAIN BOUNDARIES AND PHASES

NEG. No. 8716-25 100X
REPRESENTATIVE CLADDING SECTION

NEG. No. 8716-31/8716-32 250X
COMPOSITE OF CLADDING SECTION

NEG. No. 8716-27 500X
CLADDING OUTSIDE DIAMETER

NEG. No. 8716-29 500X
CLADDING INSIDE DIAMETER

NEG. No. 8716-26 100X
REPRESENTATIVE CLADDING SECTION AS SEEN ON
PAGE 15, USING POLARIZED LIGHT TO SHOW
GRAIN STRIUCTURE.

NEG. No. 8716-33/8716-34 250X
COMPOSITE OF CLADDING THICKNESS

NEG. No. 8716-28 500X
CLAD OUTSIDE DIAMETER SHOWING HYDRIDE

NEG. No. 8716-36 500X
CLADDING INSIDE DIAMETER.

EPT-6 ROD-A

MAXIMUM BURNUP ZONE

ROD ELEVATION $19\frac{1}{2}$ Inches FROM BOTTOM

ROD ELEVATION $19\frac{1}{2}$ Inches

NEG. No. 9010-01 (OFF 600 SiC)

10X

PHOTOMACROGRAPH OF TRANSVERSE FUEL
ROD SECTION AT LOCATION OF MAXIMUM
BURN-UP BETWEEN PELLETS 36 AND 37.

ROD ELEVATION 19½ Inches

NEG. No. 9010-U2

10X

β - γ AUTORADIOGRAPH OF SAME SECTION AS IN
NEG. No. 9010-01.

740

ROD ELEVATION 19½ Inches

NEG. No. 9010-27

10X

ANOTHER β - γ AUTORADIOGRAPH OF THE
SECTION SHOWN IN 9010-01 AFTER POLISHING

1000

RADIAL MICROSCOPIC SECTION AT ROD ELEVATION 19½ Inches

NEG. Nos. 9010-03/9010-06 (OFF 600 SiC)

COMPOSITE OF RADIAL SECTION OUTLINED ON
NEGATIVE 9010-01

50X

NEG. Nos. 9010-13/9010-19 (OFF 600 SIC)

LARGE COMPOSITE OF RADIAL SECTION
OUTLINED ON NEG. No. 9010-01

100X

NEG. NO. 9010-07
AXIAL REGION SHOWING GRAIN BOUNDARIES,
PHASES, AND METALLICS.

500X

NEG. No. 9010-08/9010-11

COMPOSITE OF TRANSITION REGION OF RADIAL COMPOSITE.

500X

NEG. No. 9010-12
OUTSIDE DIAMETER OF FUEL SHOWING STARTING
GRAIN SIZE.

500X

NEG No. 9010-20

500X

"AS SINTERED" GRAIN STRUCTURE NEAR OUTSIDE DIAMETER.

NEG. No. 9010-21 (ETCHED)

500X

"AS SINTERED" GRAIN STRUCTURE NEAR OUTSIDE DIAMETER, ANOTHER VIEW.

NEG. No. 9010-22/9010-23 (ETCHED)

250X

COMPOSITE OF CLADDING WALL SHOWING GRAIN BOUNDARIES.

GEAP-5100A

NEG. No. 9010-24/9010-26 (ETCHED)

250X

COMPOSITE OF SAME PART OF CLADDING WALL AS SHOWN PREVIOUS PAGE USING POLARIZED
LIGHT TO BETTER SHOW GRAIN STRUCTURE.

GEAP-5100A

EPT 6-A

EPT-6 ROD-D

FRACTURE SECTIONS

ROD ELEVATION 4 5/8 Inches

NEG. No. 19211

4X

BOTTOM OF PELLET 8.

NEG. No. 19212

4X

TOP OF PELLET 7.

ROD ELEVATION 5-7½ Inches

NEG. No. 19148 ¼X
FUEL PELLETS 9-13 AS SEPARATED.

ROD ELEVATION $5\frac{1}{2}$ In.

NEG. No. 19152 3/2X
MIDDLE OF PELLET 9.

ROD ELEVATION $5\text{--}3\frac{3}{4}$ In.

NEG. No. 19151 3/2X
PELLETS Nos. 10 & 11, SHOWING THE BOTTOM OF PELLET 10.

ROD ELEVATION 6 3/8 Inches

NEG. No. 19150 3/2 X
BOTTOM OF PELLETT 12.

ROD ELEVATION 6 3/8 In. 7 In.

NEG. No. 19153 5/2X
LONGITUDINAL DIVISION OF PELLETT 12.

ROD ELEVATION 7 Inches

NEG. No. 19149

3/2X

BOTTOM OF PELLET 13.

ROD ELEVATION $7\frac{1}{2}$ Inches

NEG. No. 19126 4X
BOTTOM OF PELLET 14.

NEG. No. 19127 4X
TOP OF PELLET 13.

ROD ELEVATION 8 Inches

NEG. No. 19125 4X
BOTTOM OF PELLET 14.

NEG. No. 19124 4X
TOP OF PELLET 16.

ROD ELEVATION 10 Inches

NEG. No. 19123 3X
BOTTOM OF PELLET 20.

NEG. No. 19122 3X
TOP OF PELLET 19.

ROD ELEVATION 14 Inches

NEG. No. 19213 4X
BOTTOM OF PELLET 27

NEG. No. 19214 4X
TOP OF PELLET 26.

ROD ELEVATION 18 Inches

NEG. No. 19131 3X
BOTTOM OF PELLET 34.

NEG. No. 19130 3X
TOP OF PELLET 33.

ROD ELEVATION 18½ Inches

NEG. No. 19129 3X
BOTTOM OF PELLET 35.

NEG. No. 19128 3X
TOP OF PELLET 34.

ROD ELEVATION 19¼ Inches

NEG. No. 19133 3X
BOTTOM OF PELLET 36.

NEG. No. 19132 3X
TOP OF PELLET 35.

ROD ELEVATION 23 $\frac{3}{4}$ Inches

NEG. No. 19143 4X
BOTTOM OF PELLET 46.

NEG. No. 19144 4X
TOP OF PELLET 45.

ROD ELEVATION 27 7/8 Inches

NEG. No. 19139 3X
EST. BOTTOM OF PELLETT 53.

NEG. No. 19140 3X
EST. TOP OF PELLETT 52.

NEG. No. 19147 4X
LOOSE FUEL REMOVED FROM TOP
OF PELLETT 52.

ROD ELEVATION 28 3/8 Inches

NEG. No. 19142 4X
BOTTOM OF PELLET 54.

NEG. No. 19141 4X
TOP OF PELLET 53.

ROD ELEVATION 31¼ Inches

NEG. No. 19145 3X
EST. BOTTOM OF PELLET 59.

NEG. No. 19146 3X
EST. TOP OF PELLET 58.

ROD ELEVATION 31 7/8 Inches

NEG. No. 19134 3X
BOTTOM OF PELLET 60.

NEG. No. 19135
TOP OF PELLET 59.

ROD ELEVATION 35½ Inches

NEG. No. 19138 3X
TOP OF FUEL COLUMN BELOW Zr-2
DISC, PELLETT 65.

ROD ELEVATION 35 7/8 Inches

NEG. No. 19137 3X
COMPRESSION SPRING IN PLENUM

NEG. No. 19136 3X
Zr-2 DISC ABOVE FUEL.

EPT-6 ROD-D

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
NUMBER OF DAYS AFTER END OF IRRADIATION.

TABLE 8
MAIN METALLOGRAPHIC SECTIONS ROD 6-D

When Section was of Interest	<u>Start-Up (4/24/62)</u>			<u>Shut-Down (5/14/62)</u>
Section was Made to Show	PHF*	MS**	MS**	PHF, MBU***
Section Number	8561	8577	8576	8560
Pages in Photo Collection				
Axial Distance from Bottom of Rod, in.	8	8 1/4 - 9 1/4	9 1/4-10 1/4	18 1/4
Control Rod Bank Position, in.	19.3	19.3	19.3	28.1
Post Irradiation Diameter, in.:				
Fuel	0.544	---	---	---
Clad	0.606	0.589	0.574	0.564
Fractional Diameter Increase at Section:	1.072	1.043	1.019	---
Rod Average Heat Flux at Time of Interest, Btu/h-ft ²	453,000	453,000	453,000	483,000
Axial Peaking Factor at Section	1.57	1.59	1.62	1.32
Peak Heat Flux at Section Life, Btu/h-ft ²	711,000	720,000	734,000	638,000
Estimated Heat Flux after Swelling, Btu/h-ft ²	746,000	1,001,000	751,000	763,000
End of Life Heat Flux, Btu/h-ft ²	406,000	425,000	448,000	596,000
Normalized Radius for Melting (αM)	---	---	---	0.133
Flux Depression Factor	---	---	---	0.24
Before Swelling:				
T_s ($h_{gap} = 2000$), °F	---	---	---	964
$\int_{T_s}^{T_m} kdt$, watts/cm	---	---	---	65.0
$\int_0^{T_m} kdt$, watts/cm	---	---	---	95.4

* Peak Heat Flux Zone
** Maximum Swelling Zone
***Maximum Burnup Zone

TABLE 8. (Continued)

	<u>Start-Up (4/24/62)</u>			<u>Shut-Down (5/14/62)</u>
After Swelling:				
$\int_0^{T_m} kdt$, watts/cm	---	---	---	95.4
	<u>Based on Autoradiography</u>			
Normalized Radius for Melting, (αM)	---	0.496	---	0.410
Flux Depression Factor	0.185	---	---	0.205
Before Swelling: T_s , °F	1056	1070	1075	1007
$\int_{T_s}^{T_m} kdt$, watts/cm	59.5	---	---	59.4
$\int_0^{T_m} kdt$, watts/cm	91.7	---	---	90.7
After Swelling:				
T_s , °F	1108	---	---	---
$\int_{T_s}^{T_m} kdt$, watts/cm	64.0			
$\int_0^{T_m} kdt$, watts/cm	97.3	---	---	91.1

EPT-6 ROD-D

PEAK HEAT FLUX ZONE

ROD ELEVATION 8 Inches FROM BOTTOM

ROD ELEVATION 8 Inches

NEG. No. 8561-01 (OFF 600 SiC) 10X
PHOTOMACROGRAPH OF TRANSVERSE FUEL
ROD SECTION AT PEAK HEAT FLUX ZONE
BETWEEN PELLETS 15 & 16.

ROD ELEVATION 8 Inches

NEG. No. 8561-00

10X

β^- γ AUTORADIOGRAPH OF SAME SECTION
AS IN NEG. No. 8561-01

330

NEG. Nos. 8561-2/8561-8

COMPOSITE OF RADIAL SECTION OUTLINED ON NEG. No. 8561-01

100X

NEG. Nos. 8561-9/8561-15

COMPOSITE OF SAME RADIAL SECTION ETCHED TO SHOW GRAIN BOUNDARIES.

100X

NEG. No. 8561-24 (ETCHED) 100X

TERMINUS OF A RADIAL CRACK IN THE OUTER BAND OF FUEL.

NEG. No. 8561-25 (ETCHED) 100X

ENLARGEMENT OF CRACK TERMINUS.

NEG. No. 8561-23 100X
REPRESENTATIVE SECTION OF THE CLADDING NEAR THE BULGE
SHOWING HARDNESS INDENTS

NEG. No. 8561-22 250X
A REPRESENTATIVE SECTION OF THE CENTRAL REGION OF THE CLADDING
SHOWING TWINNING

NEG. No. 8561-21 250X
SAME AREA AS SHOWN IN NEG. No. 8561-22 USING POLARIZED
LIGHT TO SHOW GRAIN STRUCTURE.

NEG. No. 8561-20 500X
ENLARGEMENT OF SAME AREA (AS NEG. No. 8561-21).

TABLE 9.

MICROHARDNESS DATA SHEET

EPT 6-D

Bulge In Clad at Peak Heat Flux

0.1 kg Load

Met 8561

40 x Objective

 $0.3283 \times 10^{-3} \mu\mu$

(Conversion Factor)

<u>Test No.</u>	<u>Aver. Dia. Length, Filar Units</u>	<u>Dia. Length, mm.</u>	<u>DPH</u>
1	85.5	0.0281	235
2	91.0	0.0299	207
3	89.0	0.0292	218
4	85.0	0.0279	238
5	89.0	0.0292	218
6	87.5	0.0287	225
7	88.5	0.0291	219
8	82.5	0.0271	253
9	83.5	0.0274	247
10	87.5	0.0287	225
11	89.0	0.0292	218
			227.6 Aver.

CLAD SURFACES SHOWING OXIDE FILM

NEG. No. 8561-17 660X
OUTER SURFACE OF CLADDING

NEG. No. 8561-18 660X
INNER SURFACE OF CLADDING

CLAD SURFACES USING POLARIZED LIGHT TO SHOW GRAIN STRUCTURE

NEG. No. 8561-16 660X
OUTER SURFACE OF CLADDING (AS ON
NEG. No. 8561-17).

NEG. No. 8561-19 660X
INNER SURFACE OF CLADDING (AS ON NEG.
No. 8561-18).

LONGITUDINAL SECTION IN REGION OF MAXIMUM SWELLING AT ROD ELEVATION 7½-9 Inches

NEG. Nos. 8559-01/8559-04 6¼X
COMPOSITE OF COMPLETE SECTION POLISHED
BELOW THE MID-PLANE, HENCE THE CENTRAL
VOID IS NOT VISIBLE.

NEG. Nos. 8576-01/8576-02, 8577-01/8577-02 5½X
COMPOSITE SECTION OF OTHER HALF OF ROD
NOT POLISHED AS MUCH AS SECTION SHOWN
IN NEG. Nos. 8559-01/8559-04, HENCE CENTRAL
VOID IS VISIBLE.

ROD ELEVATION $7\frac{1}{2}$ –8 Inches

NEG. No. 8577-33 (OFF 600 SiC) 7X

PHOTOMACROGRAPH OF THE PART OF THE ROD
SHOWN IN 8577-01/8577-02 FURTHER POLISHED

ROD ELEVATION 7½-8 Inches

NEG. No. 8577-34

7X

β - γ AUTORADIOGRAPH OF THE SECTION
SHOWN IN NEG. No. 8577-33

1000

ROD ELEVATION 8-9 Inches

NEG. No. 8576-04

7X

PHOTOMACROGRAPH OF THE PART OF THE ROD
SHOWN IN NEG. No. 8576-01/8576-02

ROD ELEVATION 8-9 Inches

NEG. No. 8576-05

7X

β - γ AUTORADIOGRAPH OF THE SECTION SHOWN
IN NEG. No. 8576-04.

1000

NEG. No. 8576-03

750X

REFERENCE PHOTOMICROGRAPH OF THE SURFACE
FILM.

RADIAL MICROSCOPIC SECTION AT ROD ELEVATION 7½-8 Inches

NEG. No. 8577-14/8577-20 (OFF 600 SIC)

COMPOSITE PHOTOMICROGRAPH OF THE RADIAL SECTION OUTLINED ON NEG. No. 8577-02.

100X

NEG. No. 8577-21/8577-27

COMPOSITE PHOTOMICROGRAPH OF THE RADIAL SECTION OUTLINED ON NEG. No. 8577-02, ETCHED

100X

NEG. No. 8577-31

750X

METALLIC PARTICLE IN COLUMNAR GRAIN ZONE.

NEG. No. 8577-28

750X

AREA IN GRAIN-SIZE TRANSITION ZONE.

NEG. No. 8577-30

750X

LARGEST FREE UO₂ PARTICLE FOUND.

NEG. No. 8577-29

750X

EXTREME OUTSIDE DIAMETER OF FUEL.

NEG. No. 8577-11 (ETCHED) 250X
REPRESENTATIVE AREA SHOWING HYDRIDE

MICROSCOPIC SECTION IN AREA OF MAXIMUM HYDRIDE IN CLAD

NEG. No. 8577-09 750X
ENLARGEMENT OF AREA SHOWN IN NEG. No.
8577-10.

NEG. No. 8577-10 250X
SAME AREA AS IN NEG. No. 8577-11 USING
POLARIZED LIGHT TO SHOW GRAIN STRUCTURE.

CLAD SECTION AT END OF ZONE OF MAXIMUM SWELLING

NEG. No. 8577-12 (ETCHED)
BRIGHT FIELD

250X

NEG. No. 8577-13 (ETCHED)
POLARIZED LIGHT USED TO SHOW GRAIN
STRUCTURE IN SAME AREA.

250X

OUTSIDE DIAMETER OF CLAD NEAR MAXIMUM SWELLING

NEG. No. 8577-07 (ETCHED)
BRIGHT FIELD.

750X

NEG. No. 8577-08

750X

POLARIZED LIGHT USED TO SHOW GRAIN STRUCTURE

CLAD CORROSION AT ZONE OF MAXIMUM SWELLING

PACKING COMPOUND

CLAD O.D.

NEG. No. 8577-03 (OFF 1 μ)

750X

CORROSION FILM ON ONE SIDE OF ZONE.

PACKING COMPOUND

CLAD O.D.

NEG. No. 8577-04 (OFF 1 μ)

750X

CORROSION FILM ON OTHER SIDE OF ZONE.

NEG. No. 8577-06 (OFF $\frac{1}{4} \mu$) 750X
FINER POLISHING OF CLADDING EDGE TO SHOW
CORROSION FILM

NEG. No. 8577-05 (OFF 1μ) 750X
MAXIMUM CORROSION IN UNIQUE AREA.

EPT-6 ROD-D

MAXIMUM BURNUP ZONE

ROD ELEVATION 18 Inches FROM BOT TOM

ROD ELEVATION 18 Inches

NEG. No. 8560-01 8X
PHOTOMACROGRAPH OF TRANSVERSE FUEL
ROD SECTION AT ZONE OF MAXIMUM BURNUP
BETWEEN PELLETS 34 AND 35.

ROD ELEVATION 18 Inches

NEG. No. 8560-00 8X
 β - γ AUTORADIOGRAPH OF SECTION SHOWN
IN NEG. No. 8560-01
330

ROD ELEVATION 18 Inches

NEG. No. 8560-23 (OFF 600 SiC)

10X

PHOTOMACROGRAPH OF TRANSVERSE FUEL ROD
SECTION AT MAXIMUM BURN-UP ZONE
BETWEEN ESTIMATED PELLETS 34 & 35.

ROD ELEVATION 18 Inches

NEG. No. 8560-24

10X

β - γ AUTORADIOGRAPH OF SAME SECTION AS
IN NEG. No. 8560-23.

1000

NEG. Nos. 8560-02/8560-7

COMPOSITE OF RADIAL SECTION OUTLINED ON NEG. No. 8560-01

100X

NEG. Nos. 8560-08/8560-13

COMPOSITE OF SAME RADIAL SECTION ETCHED TO SHOW GRAIN BOUNDARIES.

100X

NEG. No. 8560-14

500X

TRANSITION REGION BETWEEN COLUMNAR AND
EQUIAXED GRAINS IN RADIAL SECTION ON
NEG. Nos. 8560-08/8560-13 (PAGE 66), SHOWS
POROSITY (OR 2nd PHASE) IN BOUNDARIES
OF SMALL EQUIAXED GRAIN.

NEG. No. 8560-21 100X
CLADDING SECTION SHOWING HARDNESS-TEST INDENTS

NEG. No. 8560-15 660X
OXIDE FILM ON OUTSIDE DIAMETER.

NEG. No. 8560-16 660X
SAME SECTION AS IN NEG. No. 8560-15 USING
POLARIZED LIGHT.

NEG. No. 8560-19 250X
AREA IN MID-SECTION

NEG. No. 8560-17 660X
OXIDE FILM ON INSIDE DIAMETER.

NEG. No. 8560-18 660X
SAME AREA AS IN NEG. No. 8560-17 USING
POLARIZED LIGHT.

NEG. No. 8560-20 250X
SAME AREA AS NEG. No. 8560-19 USING
POLARIZED LIGHT.

TABLE 10.
MICROHARDNESS DATA SHEET

EPT 6-D
Maximum Burnup Region
0.1 kg Load

Met 8560
40 x Objective
 $0.3283 \times 10^{-3} \mu\mu$
(Conversion Factor)

Test No.	Aver. Dia. Length, Filar Units	Dia. Length, mm.	DPH
1	93.5	0.0307	197
2	112.5	0.0369	136
3	103.0	0.0338	162
4	118.0	0.0387	124
5	86.5	0.0284	230
6	88.0	0.0289	222
7	91.0	0.0298	209
8	97.5	0.0320	181
9	88.0	0.0287	222
10	111.0	0.0364	140
11	86.5	0.0284	230
12	107.0	0.0351	151
13	71.5	0.0235	236*

14	66.5	0.0218	390*
15	113.5	0.0373	133
16	101.0	0.0332	168
17	86.0	0.0282	233
			182.5 Average

* Not Included in Average

EPT-6 ROD-D

OTHER ROD SECTIONS

ROD ELEVATION 3 Inches

NEG. No. 9124-01 (OFF 600 SiC) 10X
PHOTOMACROGRAPH OF A TRANSVERSE SECTION.

ROD ELEVATION 3 Inches

NEG. No. 9124-02 10X
 β - γ AUTORADIOGRAPH OF SAME AREA AS
IN NEG. No. 9124-01; 19 R/min. 70 Min.
EXPOSURE.

950

ROD ELEVATION 3 Inches

NEG. No. 9124-03

10X

α AUTORADIOGRAPH OF SAME AREA AS
IN NEG. No. 9124-01, 1 min. EXPOSURE.

950

ROD ELEVATION 3 Inches

NEG. No. 9124-12

10X

α AUTORADIOGRAPH AS IN NEG. No.
9124-03 WITH 5 MINUTE EXPOSURE.

950

ROD ELEVATION 3 Inches

NEG. No. 9124-13 (OFF 600 SiC) 10X
SAME SECTION AS IN NEG No. 9124-01 AFTER
FURTHER POLISHING AND REMOVAL OF
FISSION PRODUCTS MIGRATION SAMPLES.

DIAMETRAL MICROSCOPIC SECTION

GEAP-5100A

ROD ELEVATION 3 Inches

NEG. No. 9124-04/9124-11 (AS POLISHED)

COMPOSITE OF DIAMETRAL SECTION OUTLINED ON NEG. No. 9124-01.

50X

ROD ELEVATION 12-7/8 Inches

NEG. No. 9126-04/9126-11 (AS POLISHED)

COMPOSITE OF DIAMETRAL SECTION OUTLINED ON NEG. No. 9126-01.

50X

ROD ELEVATION 12-7/8 Inches

NEG. No. 9126-01 (OFF 600 SiC) 10X
PHOTOMACROGRAPH OF A TRANSVERSE SECTION.

ROD ELEVATION 12-7/8 Inches

NEG. No. 9126-02

10X

β - γ AUTORADIOGRAPH OF SAME AREA AS IN
NEG. No. 9126-01; 34 R/min. FOR 38 MINUTE
EXPOSURE.

950

ROD ELEVATION 12-7/8 Inches

NEG. No. 9126-03

10X

α AUTORADIOGRAPH OF SAME AREA AS IN
NEG. No. 9126-01; 1 MINUTE EXPOSURE

950

ROD ELEVATION 12-7/8 Inches

NEG. No. 9126-12

10X

α AUTORADIOGRAPH LIKE NEG. No. 9126-03
BUT WITH 5 MINUTE EXPOSURE

950

ROD ELEVATION 12-7/8 Inches

NEG. No. 9126-13

10X

SAME SECTION AS IN NEG. No. 9126-01 AFTER
FURTHER POLISHING AND REMOVAL OF
FISSION PRODUCTS MIGRATION SAMPLES.

ROD ELEVATION $17\frac{1}{4}$ Inches

NEG. No. 912/-01

10X

PHOTOMACROGRAPH OF A TRANSVERSE
SECTION.

4

ROD ELEVATION 17¼ Inches

NEG. No. 9127-02 10X
 β - γ AUTORADIOGRAPH OF SAME SECTION AS
IN NEG. No. 9127-01, 38 R/Min. FOR
33.5 IN EXPOSURE.

950

ROD ELEVATION 17 $\frac{1}{4}$ Inches

NEG. No. 9127-03 10X
α AUTORADIOGRAPH OF SAME AREA AS
IN NEG. No. 9127-01, 1 MINUTE EXPOSURE.

950

ROD ELEVATION 17¼ Inches

NEG. No. 9127-13

10X

α AUTORADIOGRAPH AS IN NEG. No.
9127-03 WITH 5 MINUTE EXPOSURE

950

ROD ELEVATION $17\frac{1}{4}$ Inches

NEG. No. 9127-14

10X

PHOTOMACROGRAPH OF SAME SECTION
AS IN NEG. No. 9127-01 AFTER FURTHER
POLISHING AND REMOVAL OF FISSION
PRODUCTS MIGRATION SAMPLES.

NEG. Nos. 9127-04/9127-11 (AS POLISHED)

COMPOSITE OF DIAMETRAL SECTION OUTLINED ON NEG. No. 9217-01.

50X

NEG. Nos. 9127-12
AREA ON EDGE OF MOLTEN ZONE.

250X

ROD ELEVATION 22 $\frac{1}{4}$ Inches

NEG. No. 9125-01 (OFF 600 SiC)

10X

PHOTOMACROGRAPH OF A TRANSVERSE SECTION

ROD ELEVATION 22 $\frac{1}{4}$ Inches

NEG. No. 9125-02

10X

β - γ AUTORADIOGRAPH OF SAME AREA AS
IN NEG. No. 9125-01; 33 R/Min. FOR 39
MINUTE EXPOSURE.

950

ROD ELEVATION 22 $\frac{1}{4}$ Inches

NEG. No. 9125-03 10X
α AUTORADIOGRAPH OF SAME AREA AS
IN NEG. No. 9125-01, 1 MINUTE EXPOSURE
950

ROD ELEVATION $22\frac{1}{4}$ Inches

NEG. No. 9125-14 10X
α AUTORADIOGRAPH AS IN NEG. No. 9125-13
WITH 5 MINUTE EXPOSURE.

950

ROD ELEVATION $22\frac{1}{4}$ Inches

NEG. No. 9125-14

10X

SAME SECTION AS IN NEG. No. 9125-01 AFTER
FURTHER POLISHING AND REMOVAL OF
FISSION PRODUCTS MIGRATION SAMPLES.

DIAMETRAL MICROSCOPIC SECTION AT ROD ELEVATION 22 $\frac{1}{4}$ Inches

NEG. No. 9125-04/9125-11

COMPOSITE OF DIAMETRAL SECTION OUTLINED ON NEG. No. 9125-01.

50X

NEG. No. 9125-12

250X

AREA ON EDGE OF MOLTEN REGION.

ROD ELEVATION 31-7/8 Inches

NEG. No. 9128-01 (OFF 600 SiC) 10X
PHOTOMACROGRAPH OF A TRANSVERSE SECTION

ROD ELEVATION 31-7/8 Inches

NEG. No. 9128-02

10X

β - γ AUTORADIOGRAPH OF SAME AREA AS IN
NEG. No. 9128-01; 9 R/Min. FOR 150 MINUTE
EXPOSURE.

950

ROD ELEVATION 31-7/8 Inches

NEG. No. 9128-03

10X

α AUTORADIOGRAPH OF SAME AREA AS IN
NEG. No. 9128-01, 1 MINUTE EXPOSURE.

950

ROD ELEVATION 31-7/8 Inches

NEG. No. 9128-04 10X
α AUTORADIOGRAPH AS IN NEG. No. 9128-03
WITH 5 MINUTE EXPOSURE
950

NEG. No. 9128-05 10X
SAME SECTION AS IN NEG. No. 9128-01
AFTER FURTHER POLISHING AND
REMOVAL OF FISSION PRODUCTS
MIGRATION SAMPLES.

EPT 6-D

TRANSVERSE SECTIONS					
PAGE LOCATION	METALLOGRAPHIC	FRACTURE SECTION			DISTANCE FROM BOTTOM (INCHES)
		PAGE LOCATION	LOOKING DOWN ↓	LOOKING UP ↑	
38/45	9010	28	22036	22037	33-3/8
		27	22034	22035	29-1/2
		26	22031	22033	25-1/2
		25	22030	22032	21-3/8
		24	26927	26928	19-1/2
		23	22027	22029	17-1/8
		22	22025	22028	13-3/8
		21	22024	22026	9-1/4
		20	22022	22023	5-1/8
		19		22021	1
					0

EPT 6-A

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65
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PHOTO LOCATOR KEY

TRANSVERSE SECTIONS						LONGITUDINAL SECTIONS		PAGE LOCATION
DISTANCE FROM BOTTOM (INCHES)	FRACTURE SECTION			METALLOGRAPHIC	PAGE LOCATION			
	LOOKING UP ↑	LOOKING DOWN ↓	PAGE LOCATION					
35-7/8	19137	19136	66					
35-1/2		19138	65					
31-7/8	19134	19135	54	9128	126 / 130			
31-1/4	19145	19146	53					
28-3/8	19142	19141	62					
27-7/8	19139	19140 19147	61					
23-3/4	19143	19144	60					
22-1/4				9125	119 / 125			
19-1/4	19133	19132	59					
18-1/2	19129	19128	58	8560	93 / 99			
18	19130	19131	57					
17-1/4				9127	113 / 118			
14	19213	19214	56					
12-7/8				9126	107 / 112			
10	19123	19122	55					
8	19125	19124	54	8561	71 / 78	8576	8559	79, 82 / 84
7-1/2	19126	19127	53			8577		79 / 81 ,
	19149		52			19153		85 / 91
	19150	19148	51			19154		
	19153		49					
	19151		50					
	19152							
4-5/8	19211	19212	48					
3				9124	102 / 107			
1								
0								

EPT 6-D

NOTE: DISTANCE MEASUREMENTS ARE ACCURATE; PELLET LOCATION IS APPROXIMATE. SCALE 1:3.114

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