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INTERIM PROGRESS REPORT

on

POSTIRRADIATION EXAMINATION OF

 $\text{NpO}_2\text{-ZrO}_2$ TARGET RODS

to

SPACE NUCLEAR SYSTEMS

June 14, 1973

Contract No. AT(29-2)-2652 Modification No. 11

by

L. M. Lowry, Principal Investigator and
D. R. Farmelo, Staff Chemist

Approved by T. H. Smith

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INTERIM PROGRESS REPORT

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L. M. Lowry, Principal Investigator
D. R. Farmelo, Staff Chemist

INTRODUCTION

The primary objective of the fabrication, irradiation, and post-irradiation examination of two neptunium fueled target rods is to determine the ^{238}Pu yield in four compositions of $\text{NpO}_2\text{-ZrO}_2$ and to evaluate the effect of flux depression and spectral changes in the flux as a function of the NpO_2 concentration. The secondary objective of the postirradiation examination is to determine the irradiation stability of the target materials at the four compositions and the compatibility of the various fabrication materials.

Target Rod Fabrication

To experimentally demonstrate the feasibility of producing ^{238}Pu in commercial light water power reactors, Battelle's Columbus Laboratories Plutonium Fuels and Technology Division, under the supervision of Owen Kruger [and using the theoretical results from studies conducted by Southern Nuclear Engineering (SNE)], has fabricated two $^{237}\text{NpO}_2\text{-ZrO}_2$ fueled, stainless steel-clad target rods for irradiation in the Connecticut Yankee Reactor. Target pellets were right circular cylinders of 0.380 in. diameter and 0.350 to 0.650 in. long. The pellets were of four compositions of $^{237}\text{NpO}_2$ (CaO-ZrO_2). The four initial weight percent compositions were:

A section	71.69
B section	44.47
C section	25.53
D section	14.65

The pellets were encapsulated in 304L stainless steel tubing with a 16-mil-wall and heliarc welded with a helium cover gas. Each composition, A, B, C, and D was isolated in a gas tight compartment.

Target Rod Recovery

After fabrication, the two target rods were sent to the Connecticut Yankee Reactor, irradiated to an exposure of $\sim 3.2 \times 10^{20}$ fissions/cm³ and removed for storage in the reactor spent fuel pit. BCL personnel then cut the target rods under water in the spent fuel pit at the points indicated on the fabrication drawing (See Figure 1). On June 18, 1972, the four segments resulting from the cutting of the two target rods were removed from the spent fuel pit and shipped to BCL Remote Systems Technology at West Jefferson, Ohio for postirradiation examination. The postirradiation examination is being conducted by Mr. L. M. Lowry under the supervision of V. G. Scotti. A flow diagram for the destructive testing of the target rod is given in Figure 2.

Stereo Visual Examination

Upon receipt at BCL, the four sections of the target rods were transferred into the high level cell and each of the four sections was visually examined and photographed at 0, 90, 180, and 270 degrees. Photos of the as-received rods are given in Figure 3. The rods external condition was excellent with no detectable irregularities such as bow, corrosion, or crud deposits. Diameter measurements using a micrometer were made at five evenly spaced intervals along each of the four sections and at the same circumferential orientation at each point. These readings were repeated at 90 degree rotations of each section. The results of these measurements are tabulated in Table 1.

These micrometer measurements indicate no significant diametral changes. The postirradiation cladding measurements in the area of the fuel pellets averaged 0.421 in. as compared to the preirradiation average diameter of 0.422 in. The maximum postirradiation diameter measurements near the stabilizing fins were 0.430 in. as compared to the maximum preirradiation diameter of 0.427 in.

Gamma Scan

The four sections of the $\text{NpO}_2\text{-ZrO}_2$ target rods were gamma scanned using a 50 mil slit collimator. The signal from a single channel analyzer, with a gamma ray energy window from 0.770 to 0.776 Mev in conjunction with a 2 inch NaI (Tl) crystal, was used to drive a strip chart recorder. The gamma ray peak at about 0.775 Mev is the zirconium 95 and niobium 95 decay energy peak. The strip chart time markers represent 1/16 in. rod intervals. Gamma-scan strip charts are graphically represented in Figure 4. The fuel column stack heights before and after irradiation are given below. The gamma-scan showed gaps within some columns and the gap widths are also tabulated below.

<u>Rod</u>	<u>Section</u>	<u>Height Before Irradiation (in.)</u>	<u>Height After Irradiation (in.)</u>	<u>Pellet Gaps After Irradiation (in.)</u>
1	A	9.468	9.563	0.188
1	B	9.937	10.188	0.313
1	C	9.906	10.125	0.250
1	D	43.030	42.875	0
2	A	9.406	9.626	0.313
2	B	9.937	10.188	0.313
2	C	9.906	9.875	0
2	D	43.046	43.313	0.375

Target rod number two was chosen by SNE and BCL personnel for destructive testing. Using the gamma scan chart as a guide, six rod positions were chosen from which specimens would be sectioned for metallographic examination, for chemical analysis, for X-ray spectrometry and electron probe microanalysis. The rod positions from which eight cladding neutron dosimetry samples were to be removed was also chosen.

The fuel rod power distribution and therefore the gamma scan intensity is a function of the product of the target material and incident flux as is the ^{238}Pu production. It is concluded then, that the ^{238}Pu produced is related to the gamma scan intensity.

A comparison of the initial neptunium concentration and the gamma scan intensity for rod number two was made and the results are given below.

<u>Rod</u>	<u>Section</u>	<u>Concentration (%)</u> <u>NpO₂</u>	<u>Average Gamma Scan</u> <u>Intensity (c/min)</u>
2	D	14.65	30K
2	C	25.53	40K
2	B	44.47	55K
2	A	71.69	75K

Since the neutron flux was the same over virtually the entire length of the target rod, the gamma scan intensities indicate that the ^{238}Pu yield will increase with increased Np concentration although the function may not be linear. (See Figure 5.) The equation for the curve of ^{237}Np concentration versus gamma scan intensity is $Y = (1.4 X^{0.88} + 15)(10^3)$, where Y is the relative gamma intensity and X is the initial weight ^{237}Np concentration (%). The results of the chemical analysis will yield the exact relationship between the fission product yield (gamma scan intensity) and the ^{238}Pu yield.

Cover Gas Analysis

The neptunium rod number two sections A, B, C, and D were punctured and the cover gas collected using mercury diffusion pumps and a Teopler pump. A minimum of 95 percent of the gas was collected from each section and the gases from sections A and D were mass analyzed. The volume percents of the molecular and atomic constituents are tabulated in Table 2. The xenon and krypton isotopic analysis results are given in Table 3. The gases from sections B and C were stored. The quantity of gas in section A was 1.82 cc at STP and in section D was 3.36 cc at STP. Also, in both sections A and D the mass spectrometer detected about 0.03 volume percent of an undetermined hydrocarbon, probably a C_3 compound, and in section D about 0.08 volume percent benzene (C_6H_6). The total hydrogen content of the cover gas including the amount contributed by water is less than 2.5 ppm of fuel and the water content in the gas is less than 1 ppm of fuel.

There appears to have been some air contamination or gases released from the pellets since the mass spectrometer analysis indicates some concentration of water, oxygen, and nitrogen. The volume and isotopic percents of xenon and krypton are about the values expected. However, the abundant and nonconsistent volume percents of argon are assumed to have been introduced during fabrication of the target pellets.

Target Rod Disassembly

A slitting device was used to open the rod number two sections A, B, C, D top, and D bottom and expose the fuel pellets for visual examination. Composite pictures of these sections are included. (See Figures 6 and 7.) The cladding inner surface was bright and shiny and there was no evidence of fuel-cladding incompatibility. The cladding was relatively ductile.

The fuel pellets were cracked to varying degrees, from virtually whole pellets to numerous cracks, however, there was no evidence of pulverization. The cracking was probably due to thermal stresses. The pellets were light to dark grey. The A and B sections showed color variations within a pellet with the ends being very light grey and the centers (longitudinally) being darker grey as shown in the composite pictures. The reason for this discoloration is not known at this time.

The pellet cracking and discoloration does not appear to have been deleterious to the irradiation performance.

The irradiated target rods were in excellent mechanical and chemical condition.

Metallographic Examination

Using the preliminary area choices indicated on the gamma scan chart and viewing the photos taken after the slitting operation, six pellet specimens from rod number two were removed. The specimens were mounted in epoxy. The specimen numbers, the types of mounts, the specimen positions with respect to the top of each section, and the preirradiation weight percents of neptunium dioxide are given below.

<u>Rod</u>	<u>Rod Section and Specimen No.</u>	<u>Specimen Mounted</u>	<u>Inches from Top of Section</u>	<u>Preirradiation w/o NpO₂</u>
2	D, Met 1	longitudinally	4.0 - 4.5	14.65
2	D, Met 3	transversely	19.25 - 19.75	14.65
2	D, Met 4	longitudinally	39.0 - 39.5	14.65
2	C, Met 6	longitudinally	3.75 - 4.25	25.53
2	B, Met 8	transversely	4.5 - 5.0	44.47
2	A, Met 11	transversely	5.5 - 6.0	71.69

A schematic drawing of target rod number two and the sampling positions are shown in Figure 8.

The six metallographic specimens were wet ground with 120, 240, 400, and 600 grit SiC papers and polished with Linde A plus 2 percent CrO₃ on Texmet cloth. In the as-polished condition, a macroscopic photo (3.5X) was taken, traverse photos from center to edge at 100X were taken and 500X photos of center and edge were taken for each specimen. The macro and the 500X center and edge photos and one 100X typical photo are included in this report in Figures 9 through 14.

The specimen photos for sections C and D show very little variation in density, however, the specimen from section B has fewer voids than either section C or D. The A section specimen has almost no voids. The preirradiation and postirradiation densities for each section of target rod number two are compared below.

<u>Rod</u>	<u>Section</u>	<u>Average Preirradiation density, % theoretical</u>	<u>Approximate Postirradiation density, % theoretical</u>
2	D	93	90
2	C	91	90
2	B	90	90
2	A	99	99

Several of the metallographic samples are being analyzed on the X-ray spectrometer and electron microprobe. After these tests are completed the specimens will be reground, repolished, etched, and photographed for further metallographic examination.

Under metallographic examination in the as-etched condition, there appears to be no incompatibility between the cladding and fuel, and other than cracking there are no detectable anomalies. The conclusion is again that the target rods were in excellent mechanical and chemical condition.

Postirradiation Chemical Analyses

Six chemistry samples were selected from target rod number two for analysis of total Np and Pu, ppm 236-Pu in 238-Pu, and the Pu isotopic composition as shown in Table 4. To obtain a representative sample, an entire pellet was pulverized to -60 mesh with a Diamond-Plattner type crusher for each of the six samples. The samples were then ground to -200 mesh with a remote motorized mortar and pestle. Extreme care was taken in both the crushing and grinding operations to avoid cell contamination and sample cross-contamination.

One gram samples, weighed to ± 0.0001 gram, were then transferred to the chemistry cell for dissolution in preparation for the above mentioned analyses. They were initially reacted in a 6N HCl-1N HF solution containing a small amount of H_2O_2 . Final dissolution was achieved by fuming in H_2SO_4 . The samples were subsequently diluted to 100 ml for total Pu and Np analyses by controlled-potential coulometry. Results, including Np conversion to Pu and relative gamma scan intensity, are also shown in Table 4.

The solutions were then diluted 200 fold in 8N HNO_3 for the ppm 236-Pu/238-Pu and Pu isotopic analyses. Two to three milliliter aliquots were taken from each solution under identical conditions for shipment to Savannah River Laboratory (SRL) and Mound Laboratory. All results are shown in Table 5. At present, mass spectrometric analyses for Pu isotopic composition are being performed at SRL. Preliminary values shown in Table 6 are questionable due to lack of reproducibility. Reruns are scheduled as soon as possible.

Percent conversion values of Np to Pu (9 to 22 percent) for the four compositions were in reasonable agreement with predicted values (13 to 24 percent). The ppm 236-Pu in 238-Pu values (9 to 20) were approximately twice that of the calculated values (4 to 9). However, the experimental analyses are considered accurate due to the excellent agreement between the two laboratories. The calculated values may be low due to a lack of recently published information, which was not available at the time the calculations were performed. For example, it appears that the amount of 236-Np, from 237-Np (n, 2n), decaying to 236-Pu should be 49 percent⁽¹⁾, rather than 33 percent believed to be used in the calculations.

The Pu isotopic compositions listed in Table 5 are not in good agreement with calculated values, which predicted 238-Pu percentages of greater than 90 percent. Samples D-2, D-4, and C-7 are particularly low at 66 percent, 55 percent, and 72 percent, respectively. In correspondence with SRL it was recently learned that some difficulty has been encountered in reproducibility. Consequently, the reported values should be considered only as preliminary until reruns are performed. Negotiations are presently being made with Mound Laboratory to perform isotopic analyses for confirmatory purposes.

Electron Microprobe Analysis

Samples and standards have been prepared for initiation of microprobe analysis of the four irradiated $\text{ZrO}_2\text{-NpO}_2$ compositions. The first phase will consist of determining optimum conditions for the relative X-ray intensities of Pu, Np, and Zr on pure standards. This will subsequently be followed by diametral scans on the irradiated specimens. The first phase is in progress and preliminary results should be available in the near future.

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(1) Table of Isotopes, Lederer, C. M., et al, 6th ed., 1967.

Neutron Dosimetry

Six cladding samples (304L stainless steel) were sectioned from rod number two for neutron dosimetry. The thermal integrated flux (nvt) will be based on the reaction $^{59}\text{Co} (n, \gamma) ^{60}\text{Co}$ using radiochemical determinations for the ^{60}Co content. From the same sample, the fast flux (greater than 1 Mev) will be determined using radiochemical resolution of the ^{54}Mn content which is produced from the reaction $^{54}\text{Fe} (n, p) ^{54}\text{Mn}$. However, no results are available at this time.

Summary

The Plutonium Fuels and Technology Section of BCL fabricated two $\text{NpO}_2\text{-ZrO}_2$ fueled, stainless steel clad target rods. BCL not only developed the manufacturing processes, welding, radiography, and leak check procedures, but also developed the product and component engineering tests and analyses. The tests included chemical analyses of pellet and clad materials, gas release data for various batches of NpO_2 pellets, mass spectrometric analysis of gas and moisture contents released from the NpO_2 pellets at elevated temperatures, and the development of quality control procedures and check tests.

The two target rods were irradiated in the Connecticut Yankee Reactor to an exposure of $\sim 3.2 \times 10^{20}$ fissions/cm³. Each rod was cut into two sections for a shipment to BCL for postirradiation examination.

Upon receipt at BCL the four sections were visually examined, photographed and outside diameter measurements taken. No crud deposits or physical irregularities were detected during these examinations and measurements.

The four sections were then gamma scanned. From these scans, the fuel stack heights including gaps were measured and rod number two was chosen for destructive testing. The gamma intensities increased with increased neptunium concentration as expected.

The sections A, B, C, and D of rod number two were punched and the gases collected. The gas from sections A and D were mass analyzed. The volumes of krypton and xenon were as expected, however, there appears to have been some slight air contamination or gas release from the fuel during irradiation. The preirradiation data indicates some hydrogen, nitrogen, carbon monoxide, and water were present in the initial neptunium pellets⁽²⁾ and may have been released during irradiation. This would account for the gas in the mass spectrometer analysis.

The two parts of rod number two were then cut to separate sections A, B, C, and D. Each section was then slit open exposing the fuel pellets for visual examination and photographing. Using these photos in conjunction with the gamma scan, specimen locations were specified for metallographic examination, electron probe microanalysis, X-ray spectrometry, chemical analysis, and neutron dosimetry.

The metallographic examination of the as-polished specimens indicated no chemical or physical deterioration of either the fuel or clad. In fact, from the initial visual and the metallographic examination, the target rod fuel and cladding was considered to be in excellent mechanical and chemical condition.

The preliminary chemical analyses show fair agreement in the Np to Pu percent conversion values. However, the ppm of ^{236}Pu in ^{238}Pu were a factor of two higher than the predicted values. The experimental values are considered accurate since they were confirmed by two analytical laboratories. Some discrepancies occur between the experimental and predicted Pu isotopic values. These analyses are being repeated. The preliminary results do indicate, however, that a production of at least 84 atom percent ^{238}Pu is possible in an initial $^{237}\text{NpO}_2$ fuel of 71.67 weight percent.

Neutron dosimetry, electron probe microanalysis and X-ray spectrometry are in progress or scheduled to be completed in August 1973, however, no data is available at this time.

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(2) K. E. Roach, et al, "Plutonium-238 Production in Commercial Water Reactors Experimental and Analytical Program", Southern Nuclear Engineering, Inc., AT(29-2)-2741 (February, 1972).

TABLE 1. NEPTUNIUM ROD DIAMETERS

Rod No.	Section	Measurement No.	(1) Diameter 0°	Measurements 90°
1	A	1	0.4219	0.4217
1	A	2	0.4219	0.4215
1	A	3	0.4214	0.4217
1	A	4	0.4215	0.4213
1	A	5	0.4218	0.4218
1	B	1	0.4215	0.4214
1	B	2	0.4210	0.4215
1	B	3	0.4208	0.4208
1	B	4	0.4209	0.4212
1	B	5	0.4227	0.4227
1	C	1	0.4218	0.4210
1	C	2	0.4218	0.4213
1	C	3	0.4214	0.4205
1	C	4	0.4216	0.4219
1	C	5	0.4228	0.4230
1	D	1	0.4210	0.4225
1	D	2	0.4216	0.4215
1	D	3	0.4214	0.4215
1	D	4	0.4211	0.4213
1	D	5	0.4212	0.4218
2	A	1	0.4224	0.4216
2	A	2	0.4218	0.4210
2	A	3	0.4214	0.4212
2	A	4	0.4212	0.4216
2	A	5	0.4227	0.4227
2	B	1	0.4214	0.4220
2	B	2	0.4216	0.4219
2	B	3	0.4210	0.4215
2	B	4	0.4216	0.4219
2	B	5	0.4230	0.4230
2	C	1	0.4211	0.4212
2	C	2	0.4209	0.4213
2	C	3	0.4208	0.4216
2	C	4	0.4211	0.4210
2	C	5	0.4220	0.4221
2	D	1	0.4217	0.4230
2	D	2	0.4221	0.4220
2	D	3	0.4214	0.4219
2	D	4	0.4213	0.4205
2	D	5	0.4210	0.4203

(1) Measurements were evenly spaced along each section and were made at the same circumferential orientation at each point.

TABLE 2. GAS ANALYSIS

Rod	Section	Total Collection System Volume, cc	Gas ⁽¹⁾ Volume, cc	Volume Percent										
				H ₂	He	CH ₄	H ₂ O	O ₂	N	A	CO ₂	Kr	Xe	Xe/Kr
2	A	148.7	1.82	17.0	31.4	<0.01	2.6	1.60	4.42	42.3	0.12	0.06	0.48	8.00
2	D	502.8	3.36	43.1	40.7	0.04	1.9	1.59	4.43	5.68	0.93	0.12	1.35	11.25

(1) The quantity of gas is at STP.

TABLE 3. XENON AND KRYPTON ISOTOPIC ANALYSIS

Rod	Section	Isotopic Percent Krypton				Isotopic Percent Xenon			
		83	84	85	86	131	132	134	136
2	A	20.2	30.0	9.3	40.5	12.6	21.5	27.6	38.3
2	D	19.2	29.4	7.7	43.7	11.9	20.3	26.7	41.1

TABLE 4. NEPTUNIUM TO PLUTONIUM CONVERSION DATA

Sample Number	Section	w/o NpO ₂ initial ²	Inches from top of Section	Weight Np ⁽¹⁾ initial, grams	Weight Np ⁽¹⁾ final, grams	Weight Total Pu ⁽¹⁾ final, grams	Percent Conversion of Np to Pu	Relative Gamma Scan Intensity
1	2D	14.65	3.5-4	0.1290	0.1056	0.0213	16.5	18.8
2	2D	14.65	14.5-15	0.1290	0.0944	0.0242	18.8	27.5
4	2D	14.65	39.5-40	0.1290	0.0940	0.0289	22.4	32.1
7	2C	25.53	6.1-6.7	0.2248	0.1560	0.0365	16.3	40.9
9	2B	44.47	5.5-6	0.3917	0.3206	0.0523	13.3	55.0
11	2A	71.69	5-5.5	0.6316	0.5096	0.0575	9.1	73.3

(1) Based on a 1 gram sample

TABLE 5. PLUTONIUM ISOTOPIC COMPOSITIONS

Sample Number	Section	ppm Pu-236 ⁽¹⁾		SRL Pu Isotopic Composition, atomic percent				
		Pu-238		Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
		SRL	Mound					
1	2D	8.9	9.5	84.6	14.5	0.91	N	N
2	2D	8.9	8.5	65.9	31.6	2.5	N	N
4	2D	8.8	8.7	54.9	41.5	3.6	N	N
7	2C	10.6	11.0	71.8	26.6	2.1	N	N
9	2B	13.9	12.6	81.0	17.8	1.11	<0.2	<0.2
11	2A	20.2	20.7	84.0	15.2	0.73	<0.1	<0.05

(1) Determined by alpha pulse height analysis

N = not available

FIGURE 1. NEPTUNIUM FUEL ASSEMBLY J-14 WITH TARGET ROD ASSEMBLY

Target Rod									
A		B		C		D			
Section		Section'		Section		Section			
	<u>P.V.</u>		<u>P.V.</u>		<u>P.V.</u>				<u>P.V.</u>
<u>nvt (1-2)</u>		<u>nvt (1-2)</u>		<u>nvt (1-2)</u>		<u>nvt</u>	<u>nvt</u>	<u>nvt (3-6)</u>	<u>X.S.</u>
	<u>M.S.</u>								
<u>Met (1)</u>		<u>Met (1)</u>		<u>Met (1)</u>		<u>Met</u>	<u>Met</u>	<u>Met (3)</u>	
<u>EMP</u>		<u>EMP</u>		<u>EMP</u>			<u>EMP</u>		
<u>X-Ray</u>		<u>X-Ray</u>		<u>X-Ray</u>			<u>X-Ray</u>		
<u>Chem (1-2)</u>		<u>Chem (1-2)</u>		<u>Chem (1-2)</u>		<u>Chem</u>	<u>Chem</u>	<u>Chem. (3-6)</u>	

Pu Total

Pu isotopic

nvt = Neutron dosimetry.

P.V. = Measure of quantity of gas in
the target rod section.

M.S. = Mass Spectrometer gas analysis.

Met = Metallographic examination.

E.M.P. = Electron Microprobe analysis.

X-ray = X-ray spectroscopic analysis.

Chem = Chemical analysis.

a. Rod 1 - Sections A, B, and C

b. Rod 1 - Section D

c. Rod 2 - Sections A, B, and C

d. Rod 2 - Section D

FIGURE 3. AS-RECEIVED NEPTUNIUM TARGET RODS 1 AND 2

FIGURE 4. NEPTUNIUM TARGET ROD GAMMA SCAN

FIGURE 5. PLOT OF INITIAL NpO_2 PERCENT CONCENTRATION VERSUS RELATIVE GAMMA SCAN INTENSITY

A

B

C

FIGURE 6. NEPTUNIUM TARGET ROD 2 - SECTIONS A, B, AND C
(SLIT OPEN FOR VISUAL EXAMINATION)

FIGURE 7. NEPTUNIUM TARGET ROD 2 - SECTIONS D TOP AND D BOTTOM
(SLIT OPEN FOR VISUAL EXAMINATION)

FIGURE 8. NEPTUNIUM ROD 2 SECTIONING SCHEMATIC

500X

HC32414

a. Edge

500X

HC32413

b. Center

100X

HC32409

c. Typical

3.5X

HC32364

d. Macro

FIGURE 9. NEPTUNIUM TARGET ROD 2 AS-POLISHED METALLOGRAPHIC SAMPLE 1 FROM SECTION D

500X

HC32405

a. Edge

500X

HC32404

b. Center

100X

HC32401

c. Typical

3.5X

HC32363

d. Macro

FIGURE 10. NEPTUNIUM TARGET ROD 2 AS-POLISHED METALLOGRAPHIC SAMPLE 3
FROM SECTION D

500X

HC32397

a. Edge

500X

HC32396

b. Center

100X

HC32392

c. Typical

3.5X

HC32362

d. Macro

FIGURE 11. NEPTUNIUM TARGET ROD 2 AS-POLISHED METALLOGRAPHIC SAMPLE 4
FROM SECTION D

500X

a. Edge

HC32389

500X

b. Center

HC32388

100X

c. Typical

HC32387

3.5X

d. Macro

HC32361

FIGURE 12. NEPTUNIUM TARGET ROD 2 AS-POLISHED METALLOGRAPHIC SAMPLE 6
FROM SECTION C

500X

a. Edge

HC32380

500X

b. Center

HC32381

100X

c. Typical

HC32376

3.5X

d. Macro

HC32360

FIGURE 13. NEPTUNIUM TARGET ROD 2 AS-POLISHED METALLOGRAPHIC SAMPLE 8 FROM SECTION B

500X

HC32371

a. Edge

500X

HC32372

b. Center

100X

HC32367

c. Typical

3.5X

HC32359

d. Macro

FIGURE 14. NEPTUNIUM TARGET ROD 2 AS-POLISHED METALLOGRAPHIC SAMPLE 11
FROM SECTION A