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GEAP-13760

AEC RESEARCH AND DEVELOPMENT REPORT
JANUARY 1972

MASTER

SEFOR FUEL ROD FABRICATION 1967-1968

M. L. JOHNSON
T. E. LANNIN
G. R. PFLASTERER
R. E. WALLACE

U. S. ATOMIC ENERGY COMMISSION
CONTRACT AT(04-3)-540

GENERAL ELECTRIC

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SEFOR FUEL ROD FABRICATION 1967-1968

M. L. Johnson
T. E. Lannin
G. R. Pflasterer
R. E. Wallace "

Approved:

G. R. Pflasterer
Project Engineer
SEFOR R&D

E. E. Olich, Manager
Mechanical Components and
Reactor Design Subsection

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Prepared for the
Southwest Atomic Energy Associates
for Transmittal to the
U. S. Atomic Energy Commission
Under Contract AT(04-3)-540

BREEDER REACTOR DEPARTMENT • GENERAL ELECTRIC COMPANY
SUNNYVALE, CALIFORNIA 94086

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ACKNOWLEDGEMENT

Invaluable contributions were made to the fuel procurement effort by Messrs. S. A. Wilson and K. M. Horst, both of the General Electric Co., Nuclear Energy Division.

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ABSTRACT

The report describes the fabrication of fuel rods which were procured for the initial core of the Southwest Experimental Fast Oxide Reactor (SEFOR). Fabrication of 756 standard $\text{PuO}_2\text{-UO}_2$ fuel rods, 18 guinea pig rods having increased fissile material enrichment and 245 loose fuel pellets was contracted. The product was delivered to the reactor site in the calendar year 1968.

Several significant problems were encountered during production or uncovered during subsequent quality control inspections. Among these were oxygen-to-metal ratio, high volatile content, low plutonium content in redissolved pellet scrap, porosity of end plug materials and control of welding parameters. These problems resulted in a high reject and rework rate. However, the accepted rods that were loaded into the full-power reactor core have operated with no known leaks, cladding deformation or other defects or damage during reactor operation to date, which includes operation at the design power level of 20 megawatts and transient tests.

SECTION 1

INTRODUCTION

This report describes the fabrication of fuel rods which were procured for the initial core of the Southwest Experimental Fast Oxide Reactor (SEFOR).

SEFOR is a 20 MWt fast spectrum reactor fueled with $\text{PuO}_2\text{-UO}_2$ and cooled with sodium. SEFOR has characteristics similar to the large, soft spectrum fast breeder reactors fueled with mixed $\text{PuO}_2\text{-UO}_2$. Economic studies of these large power reactors indicate the potential for producing low-cost power. SEFOR is being used to obtain physics and engineering data at fuel compositions, temperatures, and crystalline states characteristic of power reactor operating conditions. SEFOR is particularly designed for the systematic determination of the Doppler coefficient of reactivity at temperatures up to the vicinity of fuel melting.

There are two parts to the SEFOR Project: (1) the design and construction of the reactor and (2) a related research and development program. Funds for the design and construction of the facility were provided by the Southwest Atomic Energy Associates (a group of seventeen-investor-owned utility companies located in the South and Southwest parts of the United States), together with the Karlsruhe Laboratory of the Federal Republic of Germany, Euratom, and the General Electric Company.

The United States Atomic Energy Commission is supporting the Research and Development Program. There are two phases to the Research and Development Program:

Phase I - Preoperational research and development

Phase II - The reactor test program after the start of reactor operation.

This report describes work performed under Phase I, Task 9 of the program. Fabrication of 756 standard fuel rods, 18 guinea pig fuel rods

having a fissile material enrichment one-third higher than standard, and 245 loose fuel pellets of standard enrichment was contracted. The loose fuel pellets were procured for use in fabrication of instrumented fuel assemblies which were fabricated at Vallecitos Nuclear Center. The contract provided enough fuel for the initial core plus approximately 130 spare fuel rods. The contract also included fabrication of 40 boron carbide rods, 18 stainless steel rods, and five UO_2 rods, plus miscellaneous metal components. These rods were procured for reactivity adjustment, and the metal components were used by General Electric to fabricate foil holder rods and other miscellaneous rods for special experiments.

SECTION 2

SUMMARY

The fabrication and quality control exercised during the SEFOR Core I $\text{PuO}_2\text{-UO}_2$ fuel fabrication resulted in a product that has operated with no known leaks, cladding deformation, or other defects or damage during reactor operation to date, which includes operation at the design power level of 20 megawatts and the transient tests. The success is attributable largely to comprehensive quality control plans and efforts by both Nuclear Fuel Services Company (NFS), the contractor, and the General Electric Company (GE). However, there were many problems encountered both during production and after production that resulted in high reject rates and extensive rework. Most notable of these was the occurrence of low enrichment fuel pellets. All such reject pellets were made from redissolved hard scrap. The discrepancy was detected by fuel rod worth measurements that were a part of the planned reactor program.

Other significant problems were high moisture and volatile content of fuel pellets, high oxygen-to-metal ratio in fuel pellets, difficulty in controlling end plug welding parameters, and porous end plug material resulting in helium leaks. All these problems were resolved prior to delivery of the fuel rods to SEFOR.

SECTION 3

FUEL ROD DESCRIPTION

The SEFOR fuel rod is shown in Figure 3-1. The rod contains two stacks of $\text{PuO}_2\text{-UO}_2$ pellets inside type 316 stainless steel tubing. End plugs are type 304 stainless steel. The two pellet stacks are separated by a stainless steel bulkhead which is electron beam welded to the cladding. Upper and lower reflectors are made of nickel. Inconel-X springs hold the pellets in place during shipping and handling. Depleted uranium dioxide insulator pellets at both ends of the fuel pellet stacks protect the metal components from the high fuel temperatures.

Several design features of the SEFOR fuel rods were incorporated to satisfy requirements of the experimental program at the expense, in some cases, of increased difficulty of fabrication: (1) SEFOR fuel rods are loaded and unloaded as individual rods rather than in sub-assemblies. This feature permits periodic surveillance of any selected rod at any desired point in the experimental program. (2) The two pellet columns reduce the axial expansion of the core during transient tests, permitting a better measure of the Doppler coefficient, which is a prime objective of the experimental program. (3) The end plug weld design was chosen in order to minimize the thermal stresses in the cladding and end plugs during transient tests.

The standard fuel rod contains pellets having a $\text{Pu-239} + 241/\text{Pu+U}$ ratio of 0.187. Guinea pig fuel rods have a ratio of 0.25, and are used during the test program as surveillance rods. All other features of the two types of rods are identical.

The special non-fueled core rods are shown in Figures 3-2 through 3-5.

FIGURE 3-1

FIGURE 3-2

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING—			
APPLIED PRACTICES	SURFACES	TOLERANCES UNLESS OTHERWISE SPECIFIED	FINISHES
145A5481	✓	1/16	—

117C1364

GENERAL ELECTRIC
 TITLE
 UO₂ CORE ROD
 SEFOR R10
 TASK 9.0

PART NO.	NAME	DRAWING NO.	DESCRIPTION, MATERIAL, WEIGHT
1	TOP END PLUG	129 B 2357 P4	
2	TUBE	159 A 2747 P1	
3	BOTTOM END PLUG	129 B 2359 P1	
4	SPRING	159 A 2752 P1	
5	UO ₂ PELLET	175 A 8597 P1	
6	DEFLECTOR	159 A 2751 P1	
7	SPACER	175 A 8594 P1	
8	CORE ROD TITANIUM TUBING ASSY	135C4906 FIG. 5	
9	DRAWING LIST	194X786	

FCF 191A650

"C" APPLIES FOR THIS DISTANCE.

(GI) SEE NOTES 1 & 2

NOTES:

1. FABRICATION AND QUALITY CONTROL PRACTICES SHALL CONFORM WITH FUEL ROD SPEC. 22A1548 SECTIONS 3.1, 3.3, 4.1, 4.2, 4.4, 4.5 (EXCEPT OMIT INITIAL 1 MICRON EVACUATION), 4.6, 4.7, 5.0, 6.1 & 6.2.
2. ASSEMBLY TO BE STRAIGHT WITHIN .005/FT.
3. WELD SHALL BE FULL PENETRATION AND HAVE AN OUTSIDE DIA. OF .980 MAX.
4. ENGRAVE SERIAL No. .010 DP x 5/16 HIGH CENTERED ON ONE END OF SLOT. LINE WIDTH 3/64. SERIALIZE USING LETTERS BETWEEN DA AND DZ.

DESCRIPTION OF GROUPS	REVISIONS	APPROVED TO
	1. B. 11-11-11 ADDED NOTE 4 & 5	
	2. B. 11-11-11 ADDED PT. 11-11-11	
	3. B. 11-11-11 ADDED P. 9	
DATE OF REVISION	APPROVED	117C1364
11/11/11	A. P. O.	SUNNYVALE, CAL.

FIGURE 3-3

GEAP-13760

117C4366

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING.--				
APPLIED PRACTICES	SURFACES	TOLERANCES ON MACHINED DIMENSIONS		
		FRACTIONS	DECIMALS	ANGLES
145A5481	✓	± 1/16	± .005	± .005

117C1366		TITLE PRACTICE CORE ROD		
FIRST MADE FOR SEFOR R&D		TASK 90		
DATE OF WORK	BY WH	PART NO	NAME	DRAWING NO., DESCRIPTION, MATERIAL, WEIGHT
		1	TUBE	159A 2747 PI
		2	BOTTOM END PLUG	129B 2359 PI
		3	SPRING	159A 2752 PI
		4	ROD	175A 8598 PI
		5	TOP END PLUG	129B 2357 P4
		6	CORE ROD - EXTENSION AND MOUNTING, 2 IN	135C 4906 FIG 4
		7	DRAWING LIST	194 X 783

FCF 191 X 658

NOTES:

1. FABRICATION AND QUALITY CONTROL PRACTICES SHALL CONFORM WITH FUEL ROD SPEC. 22A154B SECTIONS 3.1, 3.3, 4.1, 4.2, 4.4, 4.5 (EXCEPT OMIT INITIAL 1 MICRON EVACUATION), 4.6, 4.7, 5.0, 6.1 & 6.2.
2. ASSEMBLY TO BE STRAIGHT WITHIN .005/FT.
3. WELD SHALL BE FULL PENETRATION AND HAVE AN OUTSIDE DIA. OF .980 MAX.
4. ENGRAVE SERIAL No. .010 DP $\times \frac{5}{16}$ HIGH CENTERED ON ONE END OF SLOT. LINE WIDTH TO BE $\frac{3}{16}$ IN. SERIALIZED USING LETTERS BETWEEN SA AND SZ. 1

⑥ SEE NOTES 1 & 2

[illegible]

REV NO 012
135C4801

FOIL HOLDER	ROD
-------------	-----

FIRST MADE FOR SEFOR RAD TASK 9.0

DATE OF REPORT		TO NO.		FROM MADE FOR		SEFOR R4D TASK 9.0	
	REPORT NO.	SERIAL NO.	PAGE NO.	NAME	DRAWING NO., DESCRIPTION, MATERIAL, WEIGHT		
			61	1	SNELL ASM	136B 81030 GI	
				2	PIN	155A2771 PI	
				3	PILOT	175A 9371 PI	
				4	TUBE	175A 9372 PI	
				5	PLUG	175A 9379 PI	
				6	SLEEVE	175A 9369 PI	
				7	BOT FROM EXID PLUG	136B 1025 PI	
				8	SPIROL PIN	125-0625-M-C-P SPIROL CEM. CO	
1	X			9	COB 200-Exhaustion and setting asm	135C 4906 FIG 6	
2	X	10		10	DRAWING LIST	194 X 718

✓ P8G-YP7

DO NOT WELD IN
SLOTS

OR ENGR. APPD. EQUIV.
F.C.F. 191 X 658

SECTION

A-A

SEE NOTE 2

P8G-YP30
SEE NOTE 1

2 SECURE BY SPREADING
TANGS WITH 90° PUNCH

NOTES:

L. LEAK CHECK WELD WITH HELIUM MASS SPECTROMETER LEAK DETECTOR. MAX. PERMISSIBLE LEAK RATE
IS 1×10^{-8} CC/SEC.

2. CONTENTS OF P4 TO BE PROVIDED BY EXPERIMENTOR.

DESCRIPTION OF GROUPS	REVISIONS	PRINTS
	<p>1 <i>10/25/57</i> <i>10/25</i></p> <p>ADDED PT. NO. 9 <i>kg</i></p> <p>2 <i>11/15/57</i> <i>11/15</i></p> <p>ADDED P. 10</p>	

MADE BY B. Nardone Apr. 21, 1967	APPROVED [Signature] May 10, 1967	APO SUNNYVALE, CALIF.	QRY NO 135C4801
-------------------------------------	--------------------------------------	--------------------------	--------------------

135C4801

FIGURE 3-5

The GE specifications applicable to the fuel rods are:

<u>Title</u>	<u>Specification Number</u>
PuO ₂ -UO ₂ Fuel pellets	22A1545 Rev. 4
Plutonium Nitrate	22A1546 Rev. 3
Uranyl Nitrate	22A1547 Rev. 3
Fuel Rod	22A1548 Rev. 4
UO ₂ Insulator Pellets	22A1583 Rev. 2
QC Plan for Fuel Pellets	FP-136 Rev. 6
QC Plan for Fuel Rods	FP-138 Rev. 3

SECTION 4

FUEL PELLET FABRICATION AND QUALITY CONTROL PLAN4.1 General

Fuel pellets for the SEFOR first core are fabricated by the process of co-precipitation of ammonium diuranate-plutonium-hydroxide, filtration, reduction of the filter cake to $\text{PuO}_2\text{-UO}_2$ powder, cold-pressing the powder into pellets, sintering, and grinding to finished size. The process is outlined in a flow chart shown in Figures 4-1 to 4-3. Quality control is described in Table 4-1.

The fuel pellets were fabricated by the procedures described in "NFS Fuel Pellet Fabrication Process Manual", 256A101, Rev. 6., and "Quality Control Procedure", NFS-m-10, Rev. 3.

4.2 Fuel Pellet Fabrication4.2.1 Lot Preparation

The plutonium for the fuel arrives at the production facility in ten-liter containers in the form of plutonium nitrate in nitric acid solution. Uranium, in the form of uranium nitrate in nitric acid solution, is prepared by the fuel fabricator and stored in 55 gallon plastic-lined drums. Master mix lots of plutonium-uranium nitrate are prepared by weighing the calculated amounts of plutonium nitrate solution and uranyl nitrate solution into a large tank which is poisoned with boronated raschig rings for criticality control. Master mix lots contain from 60 kg to 180 kg of plutonium. Most of the uranyl nitrate is added to the tank first. A metering pump then introduces the plutonium nitrate into a line which contains circulating uranyl nitrate. When the pre-determined number of containers of plutonium nitrate has been added to the tank, the exact amount of plutonium added is determined by weight of the solution added. The amount of

FIGURE 4-1. FUEL PELLET FABRICATION FLOW CHART

FIGURE 4-2. FUEL PELLET FABRICATION FLOW CHART
(continued)

FIGURE 4-3. FUEL PELLET FABRICATION FLOW CHART
(continued)

TABLE 4-1

SEFOR FUEL PRODUCTIONQUALITY CONTROL BY NFSUranyl Nitrate Solution

<u>QC Point</u>	<u>Characteristic</u>	<u>Specification Limit</u>	<u>Frequency</u>
1a	% U-235 in total U	0.22 ± .01%	1 sample per lot by NFS 1 sample per lot by independent laboratory (Lot size 450 kg U)
1b	Impurities		2 samples per lot
	Ag	500 ppm max.	
	Al	500 ppm max	
	B	5 ppm max	
	C	150 ppm max	
	Ca	25 ppm max	
	Cd	20 ppm max	
	Cl	25 ppm max	
	Cr	500 ppm max	
	Cu	500 ppm max	
	F	130 ppm max	
	Fe	500 ppm max	
	Mg	25 ppm max	
	Na	500 ppm max	
	Ni	500 ppm max	
	Pb	500 ppm max	
	Si	100 ppm max	
	Sn	500 ppm max	
	V	500 ppm max	
	Zn	500 ppm max	
1c	H ion concen- tration	0.75 to 1.25 M	1 analysis per lot
1d	gm U/gm solution	>100 gm U/liter	2 analyses per lot

TABLE 4-1
(continued)Plutonium Nitrate Solution

<u>QC Point</u>	<u>Characteristic</u>	<u>Specification Limit</u>	<u>Frequency</u>
2a	% Pu-239 + 241/ Pu (total)	None	First five lots then every fifth lot
2b	% 239, 240, 241, 242	8-9% 240	First five lots then every fifth lot
2c	Impurities		First five lots then every fifth lot
	Total	3000 ppm max	
	SO ₄	2000 ppm max	
	Al	1000 ppm max	
	B	20 ppm max	
	C	300 ppm max	
	Cr	100 ppm max	
	Ca	50 ppm max	
	Cd	500 ppm max	
	Fe	1000 ppm max	
	Mg	200 ppm max	
	Na	1000 ppm max	
	Ni	100 ppm max	
	U	2000 ppm max	
	Cl	25 ppm max	
	F	130 ppm max	
	V	200 ppm max	
	Cu+Zn+Si+Ti	800 ppm max	
	Ag+Mn+Mo+Pb+Sn	200 ppm max	
2d	H ion concen- tration	3-6M	1 sample per lot
2e	gm Pu/liter solution	180-270 gm/liter	1 sample per lot

Pu-U Nitrate Master Mix

3a	Uranyl Nitrate addition	Exact calculated amount $\pm 0.1\%$ rela- tive for weighing precision	Each drum
3b	Plutonium Nit- rate addition		Each bottle

TABLE 4-1
(continued)Pu-U Nitrate Master Mix

<u>QC Point</u>	<u>Characteristic</u>	<u>Specification Limit</u>	<u>Frequency</u>
3c	gm Pu/gm Pu+U	Calculated	Each master mix lot
3d	gm U/gm Pu+U	Calculated	Each master mix lot
3e	Pu/Pu+U ratio	Calculated composition $\pm 0.1\%$ absolute including all uncertainties	Each master mix lot
3f	Pu-239+241/Pu+U ratio	Calculated composition $\pm 0.1\%$ absolute including all uncertainties	Each master mix lot
3g	Verification of Pu/Pu+U ratio by chemical analysis	Calculated composition $\pm 0.3\%$ absolute	3 samples per master mix lot
3h	Pu-239+241/Pu+U grand average	Calculated composition $\pm 0.05\%$ absolute	Once for each project composition
3g	Impurities		
	B	10 ppm	One sample per lot
	Other Metals	2000 ppm	
<u>Filtrate Storage</u>			
4a	gm Pu/liter solution		1 sample per co-precipitation batch
4b	gm U/liter solution		1 sample per co-precipitation batch
<u>Condensate Storage</u>			
5a	gm Pu/liter solution	10^{-3} microcuries/cc	1 sample per container

TABLE 4-1
(continued)Concentrate Storage

<u>QC Point</u>	<u>Characteristic</u>	<u>Specification Limit</u>	<u>Frequency</u>
6a	gm U/liter solution		1 sample per container
6b	gm Pu/liter solution		1 sample per container

PuO₂-UO₂ Powder

7a	% Moisture	0.5%	1 sample per bottle
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Clean Hard Scrap Recycle

8a	Impurities		1 sample per batch
	C	300 ppm max	
	B	10 ppm max	
	Other metals	2000 ppm max	
8b	Grain size	-200 mesh	1 sample per batch

Pellet Diameter Inspection

<u>QC Point</u>	<u>Characteristic</u>	<u>Specification Limit</u>	<u>Frequency</u>
9a	Diameter	.875 ± .001 inches	First 5 per batch, then every 10th pellet

Pellet Batch Evaluation

10a	Squareness and flatness of ends		6.5% AQL
10b	Density-whole pellet	92.6 ± 2% of theoretical density	2.5% AQL
10c	Density-within pellet	Average ± 2%	Qualify process on six pellets at start and after any process change
10d	Single phase of mixed oxide	5% max second phase	3 pellets per batch

TABLE 4-1
(continued)Pellet Batch Evaluation

<u>QC Point</u>	<u>Characteristic</u>	<u>Specification Limit</u>	<u>Frequency</u>
10e	Qualification of single phase		3 pellets during pre-production
10f	O/Pu+U ratio	1.98 $\pm$ 0.01	Analyze material from center and surface of pellet from 1 sample per batch until 3 successive batches are acceptable, then 1 sample per batch thereafter.
10g	Verification of Pu/Pu+U ratio	0.3% absolute	3 samples per batch until 3 successive batches are acceptable then 1 sample every 5th batch thereafter
10h	Impurities		One sample per batch until 3 successive batches are acceptable. One sample every 5th batch thereafter.
	H	5 ppm max	
	B	10 ppm max	
	N	200 ppm max	
	C	250 ppm max	
	Cl	25 ppm max	
	F	25 ppm max	
	All others specified for starting materials	2500 ppm max	
10i	Volatiles	.05cc (STP) gas/gm (30 ppm H ₂)	One sample from each batch until five successive batches are acceptable
10j	Process control of homogeneity of plutonium	1% max deviation from average	Autoradiography 3 samples per batch Wet chemistry 1 pellet per batch until 3 successive batches are acceptable, then one pellet every third batch

TABLE 4-1
(continued)Pellet Batch Evaluation

<u>QC Point</u>	<u>Characteristic</u>	<u>Specification Limit</u>	<u>Frequency</u>
10k	Qualification of Pu homogeneity	1% max deviation from average	Two pellets from pre-production one pellet containing granules 1% high in Pu content, one pellet containing granules 1% low in Pu content.
10l	Continuity of material identification		Maintain Complete records
11a	Physical Integrity	Surface cracks .003 inches wide max. Surface pits .030 inches diameter 5% max cylindrical surface missing 10% max end surface missing	100%

PuO₂-UO₂ Fuel Stacks

12a	Pellet column length	± 1/16	100%
12b&c	Fuel stack weight (individual rod)	Nominal ± 2%	100%
12d	Fuel stack weight (average for project)	Nominal ± .05%	Once for project
12e	Weight Pu-239+241 in fuel rods	Nominal calculated amount. ± 2% tolerance due to all uncertainties (95% confidence level)	Each rod
12f	Weight of Pu and Pu-239+241 in project		Sum of all rods shipped

additional uranyl nitrate required for the exact composition is calculated and the final addition of uranyl nitrate is made by the same system used for introducing plutonium nitrate. The master mix is circulated continuously to assure complete mixing.

4.2.2 Co-Precipitation

Co-precipitation is accomplished in small batches containing approximately 800 grams of plutonium. Co-precipitation is accomplished by transferring a part of the master mix lot into a column and metering aqueous ammonia into the master mix solution under controlled conditions of temperature and metering rate.

4.2.3 Plutonium-Hydroxide-Ammonium-Diuranate Filtration

The slurry from the co-precipitation columns is filtered in tray-type filters. Filtrate is collected in a glass column and visually checked for the presence of plutonium or uranium. If present, the filtrate is re-cycled through the filters until the filtrate is relatively clear, then is transported to storage columns where the filtrate is passed through more filters. Clear filtrate is boiled to 50 percent reduction in volume and stored in 55 gallon drums until analyzed, then is shipped as waste.

4.2.4 Plutonium-Hydroxide-Ammonium-Diuranate Drying

The filter cake from a co-precipitation batch is loaded into approximately four stainless steel drying trays and is furnace dried in an air atmosphere under controlled time and temperature conditions. The dried cake is granulated.

4.2.5 $\text{PuO}_2\text{-UO}_2$ Powder Reduction

The granulated cake is loaded into Inconel trays (approximately four trays per co-precipitation batch), and the cake is reduced to $\text{PuO}_2\text{-UO}_2$ powder under controlled conditions of temperature, time and furnace atmosphere. Powder is transferred from the trays into storage bottles. One bottle contains the powder from four trays which constitute a co-precipitation batch.

4.2.6 PuO₂-UO₂ Powder Blending

Parent blends are prepared by removing five bottles of powder (five co-precipitation batches) from storage and blending them together in a twin-shell blender. Parent blends are separated into five equal parts which are again stored in plastic bottles. Cross blends are prepared by removing five bottles from storage (these five bottles each contain one-fifth of five separate parent blends) and blending the contents in a twin-shell blender. Five such cross blends are uniform in composition, and pellets from these cross blends constitute the material for a pellet batch.

4.2.7 Scrap Re-Cycle

Re-cycled scrap from previous pellet batches may be added to the cross blends after it has been determined that the scrap meets specifications on impurities. The primary source of scrap is sintered pellets that do not meet specifications on surface condition. The amount of re-cycle material in any cross blend is limited to 10 percent of the blend. The re-cycle material is prepared by milling and screening. Blended re-cycle material is added to each bottle of cross blend material by splitting the virgin and re-cycle material in four to six equal portions and manually blending the portions in a plastic bottle for approximately 10 minutes. The blended portions are then combined and blended for approximately 10 minutes.

4.2.8 Slugging

Powder is pressed in a hydraulic press to low density (4-7 grams/cc), then agglomerated and screened to produce coarse material more suitable for pellet pressing. Sterotex die lubricant (0.2 w/o) is added to the powder prior to pressing.

4.2.9 Pellet Pressing

Pellets are pressed to the desired density (± 0.1 gm/cc) in a hydraulic press. Green pellets are inspected for soundness, chips, laminations, etc. Acceptable pellets are loaded into molybdenum boats for sintering.

4.2.10 Pellet Sintering

Pellets are sintered at controlled conditions of time, temperature and atmosphere to produce pellet meeting the specification requirements. Sintered pellets are visually inspected for physical condition, diameter, and length. Density calculations are made prior to grinding.

4.2.11 Pellet Grinding

Pellets are ground on the cylindrical surface to produce pellets meeting the $\pm$ one mil diameter tolerance. A coolant is used during grinding, and pellets are washed in de-ionized water after grinding to remove the residual grinder coolant. The pellets are then dried under heat lamps to remove the moisture.

4.2.12 Final Inspection

Finished pellets are inspected for all specified characteristics after drying. Acceptable pellets are transported to the stacking station.

4.2.13 Pellet Stacking

Pellets are stacked in graduated V-troughs to make stacks of the correct length. Each stack is identified with the pellet batch number. Stacks are weighed on a precision balance and the weight is recorded.

4.2.14 Pellet Loading

Pellet stacks are loaded into the fuel rod tubes by sliding the stack from a V-trough into a horizontal fuel rod tube. Prior to loading, an insulator pellet is added to each end of the stack and the overall length is checked against drawing dimensions. All stacks are visually checked to see that pellets are properly seated on each other, with no chips or particles separating pellets. After loading, records are prepared to show the batch number and weight of both stacks loaded into each serialized fuel rod tube. A temporary rubber plug is inserted in the tube ends to prevent pellet motion during transport to the welding box. Loaded rods are sealed in a plastic sleeve for storage until ready for welding.

4.3 Fuel Pellet Quality Control

A quality control plan was prepared by Nuclear Fuel Services and approved by General Electric. The plan included inspections for all important attributes on a sampling frequency designed to assure a suitable product. The Nuclear Fuel Services quality control plan was based on a quality control specification prepared by General Electric Company. The General Electric quality control specification was prepared specifically for SEFOR and was submitted as a part of the specifications in the bid package. The plan followed for SEFOR production is summarized in Table 4-1. Quality control sampling points are shown on the pellet flow chart, Figures 4-1, 4-2, and 4-3.

SECTION 5

FUEL ROD FABRICATION AND QUALITY CONTROL PLAN5.1 General

The fuel rod is shown in Figure 3-1. Assembly begins with the electron beam welding of the bulkhead near the midpoint of the fuel rods.

The upper pellet stack is made to the proper length and inserted in the upper end of the tube. The spring is inserted in the lower end of the tube, followed by the lower pellet stack. Reflectors are inserted in both ends and the ends are cleaned and capped. Rods are bagged for transfer to the welding chamber. Machined end plugs and upper springs are placed in the welding chamber. The chamber is pumped down and back-filled with helium. The upper spring and the end plugs are installed and fusion welded. End plugs are aligned and positioned by collet-type fixtures. The weld parameters are automatically programmed to produce welds of uniform quality.

Figure 5-1 illustrates the fuel fabrication flow sheet. Table 5-1 summarizes the quality control.

The fuel rods were fabricated by the procedures described in "Fabrication and Quality Control Procedure for SEFOR Core I Fuel Rods", NFS-M-11, Rev. 5.

5.2 Fuel Rod FabricationFuel Rod Tubing

The fuel rod tubing is seamless type 316 stainless steel conforming to GE Specification B50YP79-S1. Tubing was manufactured by the Tube Methods Company and ultrasonically tested by independent test laboratories.

FIGURE 5-1
FUEL ROD FABRICATION FLOW CHART

TABLE 5-1

SEFOR FUEL ROD PRODUCTIONQUALITY CONTROL BY NFS

<u>QC Point</u>	<u>Item Inspected</u>	<u>Characteristics*</u>
14	Tubing (suppliers certification)	(1) Impurities and alloying elements (2) Tensile strength (3) Yield strength (4) Percent elongation (5) Hardness (6) Grain size (7) Flaring, flange reverse flattening (8) Physical integrity (9) Inside diameter (10) Wall thickness (11) Length (12) Bow (13) Visual appearance (14) Identification
15	Tubing Other metal components	Same as Point 14 (1) Dimensions (2) Cleanliness (3) Composition (4) Weight
16	EB Weld	(1) Cleaning (2) Weld location (3) Spacer location (4) Weld penetration (5) Visual
17	Tubing & Spacer Assembly	(1) Visual (2) Dimensions (3) Length (4) Wall thickness (5) Inside Diameter (6) Helium leak test (7) Weight

*For methods, limits, and frequency, see SEFOR Facility Design and Safety Analysis Report, Supplement 5.

TABLE 5-1
(continued)

<u>QC Point</u>	<u>Item Inspected</u>	<u>Characteristics*</u>
18	Miscellaneous Components	Cleanliness
19	End Plug Welding	(1) Current recording (2) Visual (3) Bead Height (4) Drop-through (5) Penetration (6) Vacuum recording (7) Porosity
20	Serial No.	(8) Height (9) Depth (10) Line Width
21	Fuel Rod	Helium leak check
22	Fuel Rod Dimensional Inspection	(1) Surface contamination (2) Weld contamination (3) Length (4) Bow (5) Plenum Length (6) End plug runout (7) External weld bead dimensions (8) Visual
23	Fuel Rod and QC Record Certification	(1) Weight (2) Pellet stack Ident. (3) Pellet stack weight (4) Pu-239+Pu-241 weight

*For methods, limits, and frequency, see SEFOR Facility Design and Safety Analysis Report, Supplement 5.

End Plugs and Spacers

End plugs and spacers are type 304 stainless steel having a nickel equivalent of 11.56 percent and a chromium equivalent of 19.23 percent, producing approximately 4 percent ferrite in the weld region. Material meets GE Specification B50YP17-S6.

Springs

Springs are Inconel X-750, satisfying GE Specification B50YP25A2.

Reflectors

Reflectors are made from nickel bar stock certified to ASTM B160.

Internal Spacer Welding

The internal spacer (bulkhead) was positioned and welded by the Buehler Corporation. Two adjacent electron beam welds (See insert, Figure 3-1) fused the tip of the spacer to the tube wall.

Cleaning

Metal components are cleaned in accordance with GE Specification P4CYP3-S1, Alkali Cleaning of Iron Base and Nickel Base Alloys. Tubes and internal spacers are cleaned prior to electron beam welding.

Helium Testing the Electron Beam Weld

The electron beam welds are helium leak tested by the "sniff" method prior to fuel loading.

Fuel Rod Assembly

The loaded fuel rod tubes and the metal components are placed in the weld chamber. The chamber is then pumped to one micron mercury, held for one hour, and back-filled with helium. The chamber is then pumped to 200 microns and back-filled to one atmosphere with helium.

End plugs are positioned in collets and the fuel rod tube in a powered rotatable chuck. End plugs are properly positioned with respect to the tube and the welding electrode manually positioned. The rod is rotated during welding. Weld current, speed and volts are pro-

grammed to produce welds of uniform quality. Dummy rods are welded before and after each batch of production rods for quality control purposes, such as metallography.

Serialization

Welded rods are serialized by engraving a serial number on the conical surface of the bottom end plug.

Helium Leak Test

Rods to be leak tested are placed in a pressurization chamber where they are exposed to 300 psig external helium pressure for 15 minutes minimum. They are then placed in an evacuation chamber and subjected to a conventional helium mass spectrometer leak test. Any rod leaking in excess of 1×10^{-8} cc/sec is rejected. The leak check is repeated after two weeks.

Bottom End Plug Slot Machining

A fixture orients the rod properly for milling the bottom end plug slot. The slot is machined with a conventional milling machine cutter.

Passivation

The rod is degreased with acetone, then passivated in a 20 volume percent nitric acid, 80 percent tap water bath for 20 minutes, followed by a tap water rinse and a hot rinse with water having a PH of 7 ± 1 and a resistivity of 50,000 ohms minimum. The rinsed rod is dried with nitrogen, weighed, and packed for shipment.

5.3 Fuel Rod Quality Control

Table 5-1 describes the quality control applied to fuel rod fabrication. QC points in the table refer to the flow sheet QC points in Figure 5-1.

SECTION 6

GE QUALITY CONTROL MANAGEMENT6.1 General

General Electric Company engineers were involved in all facets of the fuel procurement. The mechanical design engineer, the materials engineer, and the project engineer responsible for the SEFOR fuel design retained primary responsibility for quality control management throughout the fabrication efforts. In addition to reviewing all written contracts, plans, and procedures prepared by the fuel fabricator, the materials engineer was in residence at the factory during a major part of the production period, and visited suppliers' plants during procurement of metal components. Receiving inspection of the completed fuel rods was performed at the SEFOR site by the fuel mechanical design engineer. Production samples were periodically selected and sent to the Nuclear Energy Division laboratories for verification of NFS quality control and results.

6.2 Review and Approval of Process Description and QC Plans

The specifications which were included in the fuel bid package required that the fuel fabricator submit for approval a detailed description of the fabrication process to be followed and the quality control measures to be exercised during production. The required manuals were reviewed well ahead of pre-production efforts and were revised as necessary to describe changes that were made. All changes required the same approvals as the initial documents. All product and quality control specifications are included in the SEFOR Facility Design Safety Analysis Report, Supplement 5.

6.3 Resident Engineer at the NFS Plant

A General Electric Company materials engineer was assigned to the NFS plant approximately six months before pellet productions began. He was in residence through the first two months of production and visited the plant frequently during the balance of production.

Assigned duties were:

- (1) Observe production operation
- (2) Review daily production records
- (3) Observe preparation of nitrate solution and Pu-U master mixes
- (4) Observe quality control measures periodically
- (5) Review vendor's certification
- (6) Visit vendor's plants during critical periods of production
- (7) Select quality control samples for transmittal to Nuclear Energy Division laboratories
- (8) Implement decisions on reject material
- (9) Insure that inspection and test devices are adequate for the intended purpose and calibrated at approximate intervals
- (10) Submit audit forms and reports routinely.

6.4 Pre-Production Pellet Examination

Dummy fuel rods, UO_2 insulator pellets and $\text{PuO}_2\text{-UO}_2$ fuel pellets were submitted to GE for evaluation prior to production release. UO_2 pellets and dummy fuel rods were examined by the San Jose Fuels Laboratory. Mixed oxide pellets were examined by the Plutonium Development Laboratory at the Vallecitos Nuclear Center. Quantities examined and characteristics inspected as shown in Tables 6-1 through 6-4. Results of all pre-production tests are discussed in Section 8.

6.5 Examination of Production Pellets and Dummy Fuel Rods

Tables 6-5 through 6-7 describe the quantities and characteristics for GE inspections performed on dummy fuel rods, UO_2 pellets, and mixed oxide pellets during the course of production. Results of these examinations are discussed in Section 8.

TABLE 6-1

GE INSPECTION

PRE-PRODUCTION FUEL RODS (Filled with Depleted UO₂ Pellets)

<u>Characteristic</u>	<u>Rods Inspected</u>
Leak Check	3
Identification	3
Weld Visual Inspection	3
Rod Diameter	3
Weld Diameter	3
Weight	3
Top End Plug Hole Location	3
Bottom End Plug Slot Orientation	3
Tube straightness	3
End Plug Runout	3
Gas Plenum Length	3
Electron Beam Weld Location	3
Pellet Stack Weight	3
Pellet Stack Length	3
Tubing I.D.	3
Tubing Wall	3
Tubing Composition	1
Tubing Hardness	1
Tubing Grain Size	1
Tubing Tensile Strength	2
Tubing Yield Strength	2
Percent Elongation	2
Weld Metallography	2
Tonsile Test of Welds	1
Spring Length	3
Spring Stiffness	1
End Plug Composition	1
End Plug Hardness	1

TABLE 6-2

GE INSPECTION

PRE-PRODUCTION FUEL RODS (Filled with Stainless Steel Slugs)

These rods are to be used for drop tests; these tests are not part of the fuel rod specifications.

1. Prior to the drop tests, the following tests will be made similar to those for the UO_2 filled rods:

Dimensional Inspections

Visual Weld Inspection

Helium Leak Check

2. The following drop tests are intended to simulate the types of drop considered to be most probable during receiving inspection and in-cell handling:
 - a. Drop the rod four feet nose first using a vertical pipe as a guide. This will subject the rod to compression impact without bending loads.
 - b. Stand the rod on end and allow to fall over onto a flat surface.
 - c. Drop the rod four feet nose first and allow to fall after initial impact.
 - d. Hold the rod horizontal at an elevation of three feet and drop onto a flat surface.
 - e. Stand the rod on end and allow it to fall across a steel bar fulcrum at approximately the midpoint.

All drops will be onto a 1/4 inch steel plate laid on a concrete slab. Rods and/or pieces will be photographed after each drop, and notes will be made describing the test and results. Because only 3 rods are available, rods will be re-used for the next test if not bent or broken. If bent or broken, the tests will be repeated with a new rod. In addition to drop tests, some welds on pre-production rods

TABLE 6-2 (Continued)

will be pulled apart in the tensile tests to provide more quantitative data and others will be sectioned and examined by metallography.

3. After the drop test, the rods will be helium leak checked.

TABLE 6-3

GE INSPECTION

PRE-PRODUCTION FUEL PELLETS

<u>Characteristic</u>	<u>Pellets Inspected</u>
Diameter	4
Length	4
Dish Depth	4
Density	4
Percent Second Phase	1
Oxygen/Metal Ratio	2
Pu/Pu + U	1
Pu _f /Pu + U	1
Impurities	1
Volatiles	1
Homogeneity	1
Physical Appearance	4
U-235/U	1

TABLE 6-4

GE INSPECTION

PRE-PRODUCTION UO_2 PELLETS

<u>Characteristic</u>	<u>Pellets Inspected</u>
Diameter	10
Length	10
Dish Depth & Diameter	10
Weight	10
Density	10
Appearance	10
O/U Ratio	1
U-235/U	1
Impurities	1
Identification	10

TABLE 6-5

GE INSPECTION

PRODUCTION FUEL RODS

Ten dummy rods made at the beginning of production (prior to welding plutonium contaminated rods) will be inspected by GE as follows:

Helium Leak Check

Identification

Weld Visual Inspection

Rod Diameter

Weld Diameter

Top End Plug Hole Location

Bottom End Plug Slot Orientation

Tube Straightness

End Plug Runout

Electron Beam Weld Location

Additionally, one top end plug weld joint and one bottom end plug weld joint for each 100 rods produced will be sectioned and examined by GE. These welds will be made at the time a lot of production rods are being welded and will be equally spaced throughout production. Dimensional inspection will be made using the fixture provided for SEFOR site receiving inspection.

TABLE 6-6

GE INSPECTION
PRODUCTION UO_2 PELLETS

<u>Characteristic</u>	<u>Pellets Inspected</u>
Diameter	10
Length	10
Dish Depth and Diameter	10
Weight	10
Density	10
Physical Appearance	10
O/U Ratio	1
U-235/U	1
Impurities	1
Identification	10

TABLE 6-7
GE INSPECTION

PRODUCTION FUEL PELLETS

MASTER MIX	LOT 1		LOT 2		LOT 3		LOT 4		LOT 5		TOTAL
SHIPMENT	1	2	1	2	1	2	1	2	1	2	
Diameter	2	1	2	7	2	7	2	4	2	1	30
Length	2	1	2	7	2	7	2	7	2	1	30
Density	2	1	2	7	2	7	2	7	2	1	30
Physical Appearance	2	1	2	7	2	7	2	4	2	1	30
O/M Ratio ⁽¹⁾	2	1	2	1	2	1	2	1	2	1	15
Pu/Pu + U ⁽²⁾	1	1	1	1	1	1	1	1	1	1	10
Second Phase	1	0	1	0	1	0	1	0	1	0	5
Dish Depth	1	0	1	0	1	0	1	0	1	0	5
Pu _f /Pu + U	1	0	1	0	1	0	1	0	1	0	5
Impurities ⁽³⁾	1	0	1	0	1	0	1	0	1	0	5
Volatiles ⁽⁴⁾	1	0	1	0	1	0	1	0	1	0	5
Homogeneity ⁽⁵⁾	1	0	1	0	1	0	1	0	1	0	5

NOTE: The numbers in the blocks represent the number of pellets to be examined. The number of duplicate analyses on a pellet for a given characteristic will be determined by GE.

1). Representative sample from crushed pellet

2). Samples taken from center and surface of pellet

3). Tests performed at Battelle-Northwest using a representative sample from a crushed pellet: Ag, Al, As, B, Ba, Bi, Ca, Cd, Cr, Cu, Fe, In, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Si, Sn, Ti, Tl, V, Zn, Cl, and F.

4). Tests performed at Batelle-Columbus using representative sample from a crushed pellet.

a. Total Gas

b. Carbon (as CO or CO₂), N₂, H₂, O₂ (only if total gas release is greater than 50 µl/gm.

c. Moisture

5). Alpha Autoradiograph

6.6 Receiving Inspection at the SEFOR Site

Non-destructive tests were performed on the fuel rods following receipt at the SEFOR site. Tests performed are described in Table 6-8. Emission gamma scanning was not originally included in the receiving inspection, but because of variations of rod worth made early in the experimental program, many of the rods were emission gamma scanned. Also, a helium mass spectrometer leak check after heating the end plugs to 700-800°F was added because of a high incidence of leakers discovered during the room temperature leak check. Results of the receiving inspection are discussed in Section 8.

TABLE 6-8

FUEL RECEIVING INSPECTION BY GE

	<u>Frequency</u>
Weight	100%
External Dimensions	100%
Visual Appearance	100%
End Plug Runout	100%
End Plug Hole and Slot Alignment	100%
Bow	100%
Cold Leak Check	100%
Hot Leak Check	100%
Transmission Gamma Scan	10%
Emission Gamma Scan	As necessary to define production dates of rods low in plutonium content.

SECTION 7

PRODUCTION DEVELOPMENT7.1 General

The SEFOR Core I fuel is one of the first large orders of $\text{PuO}_2\text{-UO}_2$ fuel rods. The dearth of production experience with mixed oxide pellet fabrication plus the unique design requirements of the fuel rod caused pre-production development for both fuel pellets and fuel rod fabrication.

7.2 End Plug Weld Development

A requirement of SEFOR design was to produce a uniform wall transition between tubing and end plugs in order to minimize thermal stresses introduced during transient reactor tests. The lip weld was specified by GE for this reason. The lip weld, in addition to minimum stresses, provides precise alignment between components. It also provides enough base metal for the weld, eliminating the need for filler rods.

The design proposed by GE is shown in Figure 7.1. The design joined a 55-mil end plug to a 40-mil wall tube. NFS began to develop the weld, and modified the design as shown in Figure 7.2. The NFS design had the added advantage of a uniform 40-mil wall on both components. The plug was also shorter, thus providing a more rigid structure to support in the weld fixture. The weld also required less heat input. Figure 7.3 is a photomicrograph of the NFS modified lip weld.

7.2.1 Weld Blowouts

The two groups engaged in the weld development work (GE and NFS) found relative ease in establishing rotating speeds, weld current, and overlap time, but on the other hand, each also experienced the same

FIGURE 7-1

LIP WELD

FIGURE 7-2

MODIFIED LIP WELD

FIGURE 7-3

N.F.S. MODIFIED LIP (6th Submittal - Vent Gap)

unexpected problem with weld blowouts. It was originally assumed that plenum and void volumes in the various rod configurations would be sufficient to maintain the heated back-filled helium at a low enough pressure to avoid blowing out the molten weld puddle. This was a false assumption.

During initial weld test programs at NFS, specimens consisted of a short piece of open tubing welded to a bottom end plug. Weld current, rotation speed, overlap time, and electrode gap, for example, were quickly established. With this confidence steel-filled practice core rods were made first, but to considerable surprise, the welds either blew out or bulged to an excessive degree. The effect of heating the helium in the enclosed volume of a rod quickly became evident. Figure 7-4 graphically describes the effect of the weld heating and expanding the back-fill gas.

The first approach at NFS was to reduce the heat input as much as possible (and still get proper penetration) by increasing the rotation speed and reducing the current. This provided some improvement in that no actual blowouts occurred, but swelling and consequent wall thinning frequently and unpredictably occurred. Experiments with chills proved to have little effect. (One attempt was even made to over-pressure the weld chamber near the time of weld closures but the weld blew inward instead).

The problem was solved in a different way by each group. Each group simply provided some means of relieving the pressure produced when the helium was heated in the region adjacent to the molten metal on the inside of the tube. Figures 7-5 and 7-6 show the various modifications to the plugs required to achieve this end.

An obvious method is drilling a vent hole in the end plug and then plug welding the hole after the lip weld completion. This, however, presented complications to NFS of repeating the weld design and welder qualifications, so other approaches were sought which would produce the least changes.

FIGURE 7-4

N.F.S. MODIFIED LIP

(Severe Swelling from Internal Gas) (From early steel-filled rod prior to venting)

FIGURE 7-5

MODIFIED LIP WELD & VENT GAP
(FUEL ROD)

FIGURE 7-6

MODIFIED LIP WELD & VENT HOLE

The first modification was to cut venting nicks in the lip of the end plug to provide a leak passage for the expanded gas. This proved inadequate because the nicks often did not coincide with the point of closure where the gas pressure reaches a maximum. The second development was to simply machine 5 mils off the lip radius and nick vents in the end of the tube on the face of the lip. This was also inadequate for the same reason. The final solution was to back off the end plug about 5 mils, thereby presenting a continuous vent path as shown in Figure 7-5. The plug in the floating tailstock no longer rotated with this design; therefore, several nicks were formed in the lip to provide frictional contact for rotation between the plug and the driver tube.

This method was very satisfactory but has one critical point: As one complete turn is made, the rod again becomes a sealed chamber so that a blowout or swelling may occur during heating in the overlap period. Therefore, a maximum time was determined for weld overlap in order to avoid swelling, as well as a minimum time in order to insure adequate closure.

The same weld was made by GE Fuels Development Shop on extension rods and tightener rods. Fixturing did not allow supporting the end plugs rigidly as was the case with NFS, but FDS tack welded the end plug to the tubing in order to prevent warping during welding. Blowout was subsequently eliminated by drilling a 1/16 diameter vent hole in the end plugs, as shown in Figure 7-6, and then plug welding the vent hole as a final step. (Early vent-hole test-welding also resulted in blowouts as a result of excessive heat input until proper design was achieved).

7.2.2 Incomplete Fusion

A second problem with the weld design is shown in Figure 7-7. Improper positioning of the electrode occasionally resulted in incomplete fusion of the lip. The problem was controlled by more careful positioning of the electrode prior to welding.

FIGURE 7-7

NFS MODIFIED LIP

EFFECT OF IMPROPER ELECTRODE POSITION

(Triangular Hole is Inside Corner of Plug Lip)

40X

7.2.3 Cracking

A problem recognized by GE prior to NFS development efforts was hot-short cracking. Material selected for the fuel rods and components were initially based on high temperature strength characteristics. Of the stainless alloys, 316 SS appeared to be the best compromise in terms of present-day knowledge of its properties. This alloy, unfortunately, has a reputation for cracking in the weld zone during cooling under restrained conditions (hot-short cracking). The generally accepted reason for this characteristic is that a small amount of ferrite is necessary to provide a minimum of ductility in the cast structure. The lack of ferrite may be overcome by introducing a filler metal of high ferrite composition such that after dilution in the molten zone the resulting mixture will contain sufficient ferrite to prevent cracking through the critical brittle cooling range. Inasmuch as a fusion weld (no filler metal) was required by the design an alternate approach was made to introduce ferrite by making the end plugs (which are less critical in strength requirements than the tubing) out of the more ferritic 304 stainless steel grade.

Calculations, based on a new constitution diagram for stainless steel weld metal originally devised by A. L. Schaeffler,⁽⁴⁾ were used to determine the ferrite in the weld zone of the particular steels selected for this contract. Figure 7-8 shows the relative ferrite compositions of the various heats of tubing and end plug materials, and Table 7-1 shows the chromium and nickel equivalents. Without considering the nitrogen content, Figure 7-8 shows 4 percent ferrite content at the center of the weld after dilution. Welding experience shows this to be acceptable.

It should be pointed out that hot-shortness (as this condition is frequently called) requires tensile stresses on the weld area for this to occur. This circumstance is often encountered, for example, in welding thick-walled, heavily restrained piping. In the case of SEFOR designs the tubing is relatively light and efforts are also made to allow shrinkage to occur without permitting undue

FIGURE 7-8. SCHAEFFLER DIAGRAM

TABLE 7-1

	<u>Material</u>	<u>Heat Number</u>	<u>Cr. Equiv. %</u>	<u>*</u> <u>Ni Equiv.%</u>
1.	316 Tubing	W00949	20.376	16.44
2.	316 Tubing	W91668	20.33	16.43
3.	316 Tubing	W01782	20.64	15.59
4.	316 Tubing	W03078	20.24	15.91
5.	304 Bar stock	51323	19.23	11.56
6.	304 Bar Stock	57185	19.54	11.24
7.	304 Bar stock	57186	18.86	10.58

*Increase 3% if 0.1% nitrogen assumed. (Nitrogen was not included in chemistry).

end restraints on the weldment. Therefore, these welds may not have failed due to this cause even if these precautions were not taken, but since these stresses are very difficult to measure, the advantage of the ferrite in the 304 SS plugs was considered cheap insurance.

7.2.4 Weld Fixtures

The NFS weld chamber and fixtures are shown in Figure 7-9, A through D. Picture C shows the horizontal driven tube collet in the center, the floating top end plug collet to the left, and the bottom end collet to the right. The floating end plug collets are caused to rotate by making friction nicks on the plug lip. Picture D illustrates the use of a magnifier for accurate positioning of the electrode angle and gap. The electrode angle is permanently fixed on the holder which swings from the top end plug position on the left to the bottom end plug position on the right. The bottom plug collet on the right is shown raised out of the line of rotation. In this case, the top end weld would be completed, the collet backed off and raised, the rod slid through the driven collet to the bottom end position, and the bottom plug fixed and welded in the identical manner. Picture B shows the chamber closed and the two viewing ports located opposite the two weld positions in order to avoid parallax.

Vaporization of oils and greases from the drive mechanisms resulted in loose black deposits adjacent to the welds, but subsequent dust decontamination of the chamber after each weld batch (required when fuel rods were fabricated), resulted in removing these oils and greases from the atmosphere. The welding arc, however, was very stable and presented no trouble, even with these contaminants. Fuel particles inside the loaded rods were picked up by the weld to varying degrees but caused no problems because the particles floated to the surface as a spot of slag and was easily removed with abrasive cloth.

Irregular rotation of the drive gave problems until a voltage regulator was installed in the supply line. Rotation speed was still checked prior to every weld. Rotation problems were also

A

B

C

D

FIGURE 7-9 N.F.S. WELD BOX AND WELD FIXTURES FOR SEFOR $\text{PuO}_2\text{-JO}_2$ FUEL RODS

encountered with early chuck arrangements when arcing (weld current passes through the chuck) occurred across the balls in the bearings, producing very high rotation friction. This problem was eliminated in the final design by using heavy carbon brushes conducting current directly to the copper collet in the rotating chuck.

End plug runout was generally acceptable as a result of the use of the rugged chucks; however, some rods that were found out of specification when inspected at SEFOR were easily cold straightened by a sharp rap on the end plug with a soft hammer.

7.2.5 Welding Machine

NFS used the Miller Model ESR-150 programmed automatic welding D. C. power supply. Helium was used for both back-fill and cover gas. Welding machine settings were carefully recorded during development and welder qualification tests, and the final settings strictly adhered to during production welding. Electrode gap settings were carefully established even though this is not critical with the constant-current Miller machine.

7.2.6 Repair Welds

The fuel rod vendor was early concerned with the possibility of repairing welds by making a shallow cover pass to correct undercutting or poor electrode positioning. It was found, however, that cracking could occur at the interface of the shallow repair weld and the original weld metal. This occurrence was not unexpected considering the hot short characteristics of 316 SS used for the tubing. As a result, such repairs were prohibited.

As a consequence of the high incidence of leaks, however, the vendor undertook several tests to recover the rods by machining off the leaking end plug and rewelding a new end plug in its place. This method proved metallurgically acceptable and numerous subsequent samples demonstrated these welds to be equal to the original with only inconsequential shortening of the rods as a result. Any prior-weld metal remaining on the tube was completely remelted, and a wholly new weld structure produced. Metallography performed on these repair welds are indistinguishable from original welds.

7.3 Electron Beam Welding (EBW)

Electron Beam Welding was proposed as a method for welding a center spacer in the fuel rods without requiring two sections of tubing and thus making two separate welds. The EBW also eliminated the problem of tubing bow at the weld if overlap was minimized and weld decay minimized without cratering. The weld design finally evolved to the form shown in Figures 7-10 and 7-11, showing two closely spaced electron beam weld passes.

Initially, only one wide weld pass was recommended by the vendor (Buehler Corporation, Indianapolis) but subsequent metallography showed cracking at the interface between the tube and the plug which was especially severe on the open side of the plug. An excessive amount of undercutting also appeared with this type of weld pass, and it was proposed that a second "cosmetic" pass would smooth out the undercut, and also remelt the cracked area at the interface. In addition, another narrow weld pass (which showed less undercutting) was made near the open end of the plug to act as a reinforcement of the original weld. The results are illustrated by Photomicrographs (Figures 7-11 and 7-12). (When the end of the plug was completely fused, no cracks occurred, but this required a beam positioning precision not possible with the existing weld fixtures). Although not all cracking was eliminated, a double pass was considered to be structurally adequate. Since the weld fixtures and spacer plugs were on hand, it was not thought economic and timely to redesign the plug in order to eliminate the minor cracking.

7.4 Fuel Pellet Pre-Production Work and Results

A trial run was made prior to beginning fuel production to demonstrate that the equipment and process would produce acceptable fuel pellets. The pre-production run duplicated the actual production process except that the co-precipitation batch size was 250 grams of contained plutonium (because of licensing restrictions) and the powder did not contain re-cycled scrap. Two pellet batches were made, one using the direct strike method of co-precipitation (adding ammonia

FIGURE 7-10

FUEL ROD SPACER WELD

Spec. #35

Number 2 weld was completed first with wide fusion zone producing undercutting. Cracking/or lack of fusion occurred at tube/plug interface. Number 1 weld was then made as reinforcement. Cracking at plug end at interface tends to occur if end not completely fused.

#2 Weld

#1 Weld

Spec. #1

Number 2 weld was given a "cosmetic" pass to improve undercutting and possibly remove interface cracks, but this was not successful. Number 1 weld was also made as reinforcement but cracks may be observed if end not completely fused.

The final procedure required a narrow number 1 weld as close to the end as possible and a narrow number 2 weld in the same position, and welded in that order.

FIGURE 7-11
ELECTRON BEAM WELDS

FIGURE 7-12

ELECTRON BEAM WELD

(Narrow Weld Pass Near Open End Spacer Plug)

Example of cracking which may occur when fission does not absorb end of plug. An unfused ring results which shrinks on cooling thus stressing the fused region at the tube/plug interface.

to the nitrate solution) and one by the reverse strike method (adding nitrate solution to ammonia). Each pellet batch contained several blended co-precipitation batches. Both methods produced pellets of similar quality. The direct strike was selected by NFS for production because of shorter filtering time.

Pre-production work resulted in three modifications to the production line: larger filters were installed to reduce the filtering time following co-precipitation, the grinder was replaced by a different type to improve pellet appearance, and sterotex was added to the powder to improve the die lubrication.

Pre-production pellets were evaluated by General Electric Company. Results of the evaluation are included in Table 7-2. Four characteristics were initially cause for further investigation: oxygen-to-metal ratio, methods for determining homogeneity, percent second phase, and volatile content.

General Electric results showed the oxygen-to-metal ratio to be stoichiometric or slightly hyperstoichiometric in conflict with NFS results, which showed the pellets to meet the specified oxygen-to-metal ratio of 1.97 to 1.99. After considerable effort, including exchanges of samples between laboratories, it was revealed that a moist gas being used by NFS in their analysis was distorting their results. Adjustments of furnace conditions and correction of NFS analytical methods produced pellets which meet the specification requirements.

During pre-production, an attempt was made to develop a method for evaluating homogeneity of the $\text{PuO}_2\text{-UO}_2$. Granules of $\text{PuO}_2\text{-UO}_2$ which were one-percent high in plutonium content were prepared and blended with powder of specified composition and pellets were prepared from the blend. Pellets were made in a similar manner using granules 1 percent low in plutonium content. Alpha autoradiographs of the pellets failed to detect the enriched or depleted particles, although in

TABLE 7-2

INITIAL RESULTS OF PRE-PRODUCTION PELLET EVALUATION

<u>Characteristic</u>	<u>Specification</u>	<u>NFS Results</u>	<u>GE Results</u>
A. Diameter	.875±.001	not reported	.8752 .8753 .8749 .8749
B. Length	5/8±3/32	not reported	.6123 .6320 .6388 .6419
C. Dish Depth	.015±.003	meets specification	.0184-.0235 .0160-.0209 .0125-.0192 .0163-.0166
D. Density (measured by immersion)	10.06-10.29g/cc	10.14 10.15 10.16 10.04	10.20 10.13 10.02 9.95
E. Percent second phase	5% max.	meets specification	meets specification
F. Oxygen/metal Ratio	1.98±.01	1.980	2.001
G. Pu239+241/Pu+U	18.7±0.3%	18.8	18.6% 19.0%
H. Impurities			
Hydrogen	5 ppm max	not measured	not measured
Boron	10 ppm max	<0.5 ppm	N.D.
Nitrogen	200 ppm max	6 ppm	not measured
Carbon	250 ppm max	27 ppm (average of approximately 25 analyses.)	30 ppm 100 ppm 170 ppm 330 ppm
Chloride	25 ppm max	24 ppm	<10 ppm
Fluoride	25 ppm max	10 ppm	<5 ppm
All others including Al, Ag, Ca, Cd, Cr, Cu, Fe, Ng, Mn, Mu, Na, Ni, Pb, Si, Sn, Ti, V	2500 ppm max	~800 ppm	~120 ppm

TABLE 7-2 (Continued)

<u>Characteristic</u>	<u>Specification</u>	<u>NFS Results</u>	<u>GE Results</u>
I. Volatiles	.05 cc/gm	not reported	.125 cc/gm .029 cc/gm
J. Homogeneity	1% deviation from nominal	meets specification	meets specification
K. Physical Appearance	comparison photos	meets specification	meets specification

the case of the enriched particles, they were apparently on the threshold of detection. It was agreed to continue use of alpha autoradiography during production, but to supplement this method with wet chemistry on one gram samples taken from different regions of the pellet. Because inhomogeneity in co-precipitation powder is very unlikely, the measurement of homogeneity is not considered to be a critical requirement.

Photomicrographs and alpha autoradiographs of pellet sections revealed a uniform distribution of small particles amounting to one percent or less of the prepared surface. Both General Electric and NFS made extensive tests to determine the composition of the inclusions. Etchants for carbides, nitrides, and stainless steel were tried with no conclusive results. NFS attempted to isolate a particle from hardness tests, and reported a hardness similar to the oxide matrix. An inclusion area was isolated at Vallecitos Nuclear Center and examined by x-ray diffraction. The sample isolated had some oxide remaining on it and the test showed strong oxide lines. Weak secondary lines could be interpreted as nitride or alpha iron if additional substantiating evidence were available. Work was also done at Vallecitos Nuclear Center using etchants. Results were fairly conclusive that the inclusion was not carbide or nitrides, and probably not molybdenum.

In an effort to determine if sterotex was contributing to the inclusions, NFS made pellets with and without sterotex, with no detectable difference in the amount of inclusions.

The inclusion present was less than the allowable limit of 5 percent second phase, and all specified impurities were found to be inside allowable limits, therefore the primary concern over their presence was the possibility of their contributing to the high volatile release (discussed in Section 8). Later work using the micro-probe positively identified the inclusions as chromium, nickel and iron

(the ingredients of stainless steel). The source of the contamination was concluded to be particles worn from screens during screening operations. The presence of stainless steel in the pellets is considered to be of little consequence to the SEFOR program.

NFS did not measure volatiles in pre-production material, and Vallecitos Nuclear Center did not have the required apparatus. Therefore, samples were sent to an outside laboratory for analysis. Initial results from the laboratory showed .0296 cc/gm and .1255 cc/gm on two tests using small samples. A third test produced 0.123 cc/gm. A fourth test was run at three increments of temperature (125-800C, 800-1350C and 1350-1650C) to determine at what temperature the gas was being released. All gas came off below 800C and the total release was 0.0069 cc/gm. At the same time a sample analyzed by a second laboratory was 54 percent hydrogen and 43 percent CO. These results led to assumption that the surface of the pellets was contaminated, probably by grinder coolant, and that the first results showing high release probably was due to the small sample being taken from the surface of the pellet. The laboratory then tested a large sample representing one-fourth of a pellet with a result of 0.0046 cc/gm. With these results, it appeared that the gas release was in specification limits, but particular attention should be given to washing and volatile measurements during early production. It was also concluded that the volatiles were not caused by the inclusions, and it was decided to release production. Early production pellets were scheduled for micro-probe measurements. Micro-probe measurements were not made on pre-production pellets because the machine was not available at the time.

7.5 Insulator Pellet Pre-Production Work and Results

UO₂ insulator pellets for the SEFOR fuel rods were fabricated under the same types of control used for PuO₂-UO₂ fuel pellets. A specification was written by General Electric which required GE approval of process descriptions and quality control plans prepared by the

fabricator. Evaluation of pre-production and production pellets by General Electric was also required. Characteristics examined by General Electric included impurities, oxygen-to-uranium ratio, surface condition, density dimensions and proper identification marks. The pre-production UO_2 pellets meet specification requirements in all respects. The pellets were uniformly excellent in appearance, almost free of chips, cracks, pits, etc. Production pellets were outside specification limits in density and possibly in U-235 content. The effect of these on the experimental program were evaluated and found to be insignificant and the production pellets were accepted for use. Analysis results for these characteristics are compared with the specification requirements in Table 7-3.

TABLE 7-3

PRODUCTION UO₂ INSULATOR PELLET EVALUATION

<u>Characteristic</u>	<u>Specification</u>	<u>Analysis Results</u>
a. U-235 Content	0.22 ± .01%	0.263 ± .038%
b. Density		
Sample Pellet:		
1	93 ± 2%	96.1
2		95.6
3		95.3
4		94.6
5		96.0
6		94.3
7		95.2
8		95.6
9		95.4
10		93.9

SECTION 8

PRODUCTION PROBLEMS8.1 General

Sections 4 and 5 described the originally approved process description and quality control plan. Problems encountered caused some revisions and additions described in this section. Major pellet production problems included volatiles, moisture, surface condition, metal inclusions, and low plutonium content. A high number of fuel rod helium leaks was a major problem in fuel rod production. Many rods were rejected after shipment to the SEFOR site because of pellets containing excessive volatiles and/or helium leaks.

8.2 Fuel Pellet Production Problems

Major problems which arose during pellet production were surface appearance, volatile content, inclusions, and low plutonium content; these problems are discussed in this section.

8.2.1 Surface Appearance

The surface appearance of pre-production pellets was fairly good on both batches; however, the batch prepared by the reverse strike method was somewhat better. Whether the direction of strike affected the surface condition cannot be definitely established. Possibly other slight differences in process conditions caused the difference in the two batches. Photographs of the two batches are shown in Figure 8.2-1 and Figure 8.2-2. The most prominent surface imperfection was a pitting which was attributed to a poor grinding operation which seemed to "tear" particles loose rather than shear them to form a smooth surface. A different type of grinder and grinding wheel was installed in the production line early in production to remedy this condition.

Figure 8.2-1
PRE-PRODUCTION PELLET
DIRECT STRIKE

Figure 8.2-2
PRE-PRODUCTION PELLET
REVERSE STRIKE

The first three batches of production pellets exhibited a very poor surface condition. Pellets were very badly cracked. Several test runs were made in an attempt to improve the appearance. Conditions which were varied included pre-slugging pressure, pressing pressure, furnace temperatures, furnace gas flow rate, sintering boat pellet and grog arrangements, and addition of recycle material to the virgin powder. Although the addition of recycle material was originally intended only as a means of economically disposing of scrap, recycling became a standard part of the process. Almost all of the pellets in the first batch were recycled to improve the integrity of later batches.

The test runs described above resulted in a process that was used for all except the first three batches. Although the pellets loaded into the fuel rods met the specification requirements, the appearance was not good. The reject rate due to sorting prior to loading was high enough to provide an adequate supply of recycle material for succeeding batches; however, in early batches, many marginally acceptable pellets were intentionally rejected simply to provide enough material for recycle. In later batches, the amount of recycle material was reduced, with good pellets resulting.

At the time pellets were removed from the furnace, the pellet appearance was generally good. Removal of the surface by grinding exposes the many shallow hairline cracks. (Figures 8.2-3A, 8.2-3B, and 8.2-3C). Drop tests have shown that the small cracks do not affect the pellet integrity. Breakage by repeated dropping of pellets 2-1/2 feet onto steel only results in corner chipping and cleavage along very large cracks that definitely exceed the specification limits, (Figure 8.2-3D). Of course, the influence of the smaller cracks on pellet cracking during irradiation cannot be determined.

Although all pellet batches were processed under essentially the same processing conditions, trial runs were made at the beginning of each powder batch to avoid any unexpected differences that might result in rejection of a large quantity of material. None of these trial runs resulted in major process changes.

A
ACCEPTABLE

B
ACCEPTABLE

C
ACCEPTABLE (See Text)

D
UNACCEPTABLE (See Text)

SEFOR FUEL PELLETT CRACK STANDARD

MAG. 6.8X

30 mils
3 mils
10 mils
5 mils

FIGURE 8.2-3

8.2.2 Volatile Release

The NFS apparatus for measuring volatile content was out of service during pre-production, and an outside laboratory (Laboratory A) was contracted to do the work. Results appear in Table 8.2-1. NFS equipment was repaired prior to beginning fuel production. Special attention was given to washing and drying after grinding. NFS routinely made tests of volatile content on each pellet batch, and all results were falling well inside the specification limit (Table 8.2-2). The first routine analysis of production pellets that was made for General Electric by the same laboratory (Laboratory A) used during pre-production produced repeatable alarmingly high gas release results. Release of 0.980 cc/gm and 0.760 cc/gm were reported, compared with the specification limit of 0.05 cc/gm (Table 8.2-2).

These results prompted a round-robin of four laboratories to determine the cause for the large difference between the NFS and GE results, plus a series of experiments to determine whether the high volatile release (if indeed high) was due to the presence of residual grinder coolant on the pellets. NFS was asked to stop fuel production until this work could be completed. The round-robin results (Table 8.2-3) and visits at the participating laboratories by GE personnel resulted in disqualification of Laboratories A, C, and D. The results of 0.980 cc/gm and 0.760 cc/gm were also disqualified when it was learned that the sample was not properly prepared due to a misunderstanding. Laboratory B and NFS were judged to be the most reliable. Laboratory B results were approximately 1-1/2 times the allowable limit.

Comparison gas release measurements were performed at Laboratory B and NFS, with a GE analytical chemist acting as observer. In these tests, the total gas evolution was measured at 1200°C. Table 8.2-4 shows the results of these measurements, which were performed on pellet samples carefully prepared by NFS.

TABLE 8.2-1

PRE-PRODUCTION RESULTS OF ANALYSIS FOR CONTAINED VOLATILES

NFS - No results - equipment out of service

Laboratory A

<u>Sample No.</u>	<u>Sample Size</u>	<u>Mesh Size</u>	<u>Results</u>
1	1 gm	chips	0.029 cc/gm
2	1 gm	chips	0.125 cc/gm
3	1 gm	chips	0.123 cc/gm
4	1 gm	chips	0.0069 cc/gm
5	14 gm	chips	0.0046 cc/gm

Laboratory B - Analysis of unknown gas sample size for constituents
resulted in 54% hydrogen and 43% CO.

TABLE 8.2-2

PRODUCTION RESULT OF ANALYSIS FOR CONTAINED VOLATILESNFS

<u>Batch No.</u>	<u>Result</u>
600	0.022 cc/gm
601	0.014 cc/gm
602	0.010 cc/gm
603	0.011 cc/gm
604	0.010 cc/gm
607	0.018 cc/gm
608	0.020 cc/gm
612	0.010 cc/gm

Laboratory A

<u>Batch No.</u>	<u>Sample No.</u>	<u>Sample Size</u>	<u>Mesh Size</u>	<u>Result</u>
603	1	10g	-100	0.980 cc/gm
603	2	10g	-100	0.760 cc/gm

(Note: These results were disqualified because of the fine mesh size and the resulting increase in adsorbed gases. Samples were screened to this size due to a misunderstanding.)

TABLE 8.2-3

ROUND-ROBIN RESULTS OF ANALYSIS FOR CONTAINED VOLATILES

<u>Laboratory</u>	<u>Sample 1</u>	<u>Sample 2</u>	<u>Sample 3</u>	<u>Sample 4</u>
	(unwashed)	(Washed)	(Unwashed)	(Washed)
A	0.120	0.070	0.132	0.054
B	0.110	0.071	0.094	0.074
C	0.270	0.270	0.230	0.280
D	0.048/.044	0.015/.010	0.036/.037/ 0.044	0.026/.010

(Results are in cc/gm)

TABLE 8.2-4

NFS - LAB B PELLET GAS CONTENT RESULTS

<u>Pellet Sample</u>	<u>NFS</u> (microliters per gram)	<u>Lab. B</u>
1	46	33 51
2	31 24	40 41
3*	7 21	7 5

*Sample 3 was vacuum outgassed at 900°C prior to the measurements.

These results indicated that previous Laboratory B measurements (which indicated 70 microliters per gram) were reliable, and that previous NFS results (which indicated 10 to 20 microliters per gram), were probably not representative of a significant number of production pellets.

NFS also performed an additional measurement which indicated 50 microliters per gram gas evolved from room temperature to 800°C, and 26.8 microliters per gram evolved from 800° to 1400°C.

Concurrent with this Laboratory B and NFS work, studies with UO_2 pellets at GE indicated that the pellet grinder coolant used at NFS was a potential source of volatile material contamination, which could be removed by vacuum outgassing the pellets at 800°F for 1 hour.

Two vacuum furnaces for the pellet production line were constructed at NFS, each capable of holding 15 kilograms of fuel pellets. Initial tests on UO_2 pellets at NFS indicated a gas content reduction from 90 microliters per gram to 20 microliters per gram after 1 hour at 1000°F under 1 micron Hg pressure. Results of gas content and oxygen-to-metal ratio analysis on pellets processed in these furnaces for 1 hour at 1000°F under 1 micron Hg pressure are shown in Table 8.2-5.

Prior to processing in the vacuum furnace, the pellet oxygen-to-metal values ranged from 1.986 to 1.988, thus, no significant change in the oxygen-to-metal occurred as a result of vacuum furnace processing.

NFS unloaded one rod from each of the pellet batches that had been previously loaded and welded into rods. Two pellets were taken from each rod (one pellet from each fuel segment) for gas analysis. Table 8.2-6 shows the results of these analyses, together with several results obtained at Laboratory B; it is clear that a large portion of the fabricated pellets would not meet the gas content specification.

TABLE 8.2-5

GAS CONTENT AND OXYGEN/METAL RESULTS
FOR PELLETS AFTER
VACUUM FURNACE PROCESSING

<u>Position in Furnace and Furnace Number</u>		<u>Pellet Gas Content ($\mu\text{l/gm}$)</u>	<u>Oxygen- to-Metal Ratio</u>
Top	1	12	1.986
Top	1	14	
Top	2	22	1.987
Top	2	24	
Bottom	1	14	1.990
Bottom	2	44	1.987
Center	1	21	1.985
Center	2	12	1.986

TABLE 8.2-6

GAS CONTENT OF PELLETS TAKEN
FROM WELDED RODS

<u>Pellet Batch</u>	<u>Gas Release</u> <u>($\mu\text{l/gm}$)</u>
600	226, 391
	57
601	156
	47
602	54
	45
603	70
	25
604	99
	39
605	57
	116
606	119,68 (Lab B-110,120)
	102
607	72
	51 (Lab B-70)
608	62
	54
610	83
	54

Laboratory B performed mass spectrometer analysis of several gas samples and found the composition to be 50 to 68% H_2 and 48 to 31% CO (the variation is that observed between two samples tested), with trace amounts of other gases.

To determine the source of the high gas content shown in Table 8.2-6 NFS analyzed the gas evolution from four 10-gram samples taken from an unground pellet, and four samples taken from a ground pellet. Table 8.2-7 shows the results of these measurements.

While Table 8.2-7 shows that the variation among samples taken from the same pellet is rather large, it is clear that the ground pellet has an average gas content approximately twice that of the unground pellet.

On the basis of the information discussed above, GE and NFS concluded that the vacuum furnace process (800° to $1000^\circ F$ at 1 micron pressure for one hour) should reduce the pellet gas content to an acceptable value, and NFS resumed fuel rod production using this process.

At this point NFS had 269 completed and 58 partially completed fuel rods which could not be shown to meet the pellet gas content specification.

After a series of exploratory tests at GE (using UO_2 pellets in tests to demonstrate that a satisfactory vacuum could be obtained over the pellet column with a single vacuum line connection at the end of the tube) and NFS (using UO_2 and PuO_2-UO_2 pellets), NFS and GE concluded that outgassing the pellets while still in the fuel tubes was a practicable procedure. During this quarter NFS outgassed and re-welded approximately 50 rods using procedures agreed upon by NFS and GE. It has been concluded that, as evidenced by the data (see Tables 8.2-8 and 8.2-9), the procedure effectively outgasses the pellets and the probability that any fuel column has an average gas content in excess of 50 microliters per gram is negligibly small.

TABLE 8.2-7

COMPARISON OF GAS RELEASE FROM
GROUND AND UNGROUND PELLETS

<u>Unground Pellet</u> <u>($\mu\text{l/gm}$)</u>	<u>Ground Pellet</u> <u>($\mu\text{l/gm}$)</u>
22.1	38.0
27.9	31.8
8.3	27.3
3.9	19.4

TABLE 8.2-8

NFS OUTGAS FURNACE O/M AND GAS ANALYSIS RESULTS

Furnace Load No.	Pellet Gas Content (microliters/gm)	O/M	Sample Rod Number and Pellet Batch Number		Position of Rod in Furnace	Position of Pellet in Rod (1)
			Rod	Batch		
1	33		332	608	4	A
	37		↓	↓	↓	B
	30		↓	↓	↓	C
	34	1.990	↓	↓	↓	D
	33	1.988	326	608	5	A
2	40		↓	↓	↓	B
	(2) 55	1.980	113	600	1	A
	(2) 47		↓	↓	↓	B
	18		422	611	2	A
	(3) 19	1.988	↓	↓	↓	B
	(2) 28		397	611	7	A
	(2) 45		347	608	8	A
	(2) 56	1.986	↓	↓	↓	B
			↓	↓	↓	

Strip heaters installed in positions No. 1 and 8 between Furnace Loads 2 and 3.

3	22		427	611	1	A
	11	1.989	↓	↓	↓	B
	48		362	610	5	A
	20		↓	↓	↓	B
4	19		424	611	4	B
	20		361	610	8	A
5	17		400	611	1	A
	47		389	610	5	B

(1) Key for rod and pellet locations:

Rod Position in Furnace	1	2	3	4	5	6	7	8
	Outer			Center				Outer

Pellet Positions in Rod

A - Upper Pellet of Upper Stack C - Upper Pellet of Lower Stack
B - Lower Pellet of Upper Stack D - Lower Pellet of Lower Stack

(2) Temperature in Position No. 1 and 8 not high enough to effect satisfactory outgassing.

(3) One sample result lost because of malfunction of gas analysis system, therefore only one result was obtained from rod number 397.

TABLE 8.2-9

NFS RESULTS OF GAS RELEASE TESTS ON PELLETSTAKEN FROM RODS LOADED WITH PELLETS BEFORE OUTGASSING

<u>Batch Number</u>	<u>Prior to Outgassing (microliters/gm)</u>	<u>After Outgassing in Rod (From Table 8.2-8)</u>
600	225, 56	(55, 47) ⁽²⁾
601	160, 47	46, 48, 28, 36 ⁽¹⁾
602	54, 46	32 ⁽¹⁾
603	70, 26	
604	30, 100	
605	55, 108	
606	118, 112, 55 (Lab.B-110,120) ⁽³⁾	
607	51, 73 (Lab.B-70) ⁽³⁾	
608	54, 64, 50	33, 40, 33, 47, 30, 34, (45, 56) ⁽²⁾
610	87, 54	48, 20, 20, 47
611	51, 49, 50	20, 17

-
- (1) Outgassed in test rig, prior to construction of production rod outgassing furnace.
- (2) Outgassed in rod at too low temperature.
- (3) Samples sent to Laboratory B by NFS.

The pellet sampling plan for the outgassed rods provides for a total of 39 pellet samples (28 analyses at NFS and 11 at GE); the samples being taken throughout preproduction and production runs to check the consistency of the process. All gas release results for the outgassed rods must be less than 50 microliters per gram.

The pellet gas release quality control plan (results to date shown in Table 8.2-8) results in the following numbers of pellet analyses:

Qualification Tests (2 furnace runs)

13 gas analyses at NFS

5 O/M analyses at NFS

Pre-Production Tests (3 furnace runs)

8 gas analyses at NFS

1 O/M analyses at NFS

Production Tests (about 40 furnace runs)

7 gas analyses at NFS

11 gas analyses at GE-VNC.

The results of gas analyses after outgassing, shown in Table 8.2-8, show that the center fuel rod positions are at a sufficiently high temperature to effectively outgas the pellets. However, initial results (second run) on rods in the outer positions (no. 1 and 8) showed that the pellets were not being properly outgassed in these locations due to too low temperatures. As shown in Table 8.2-8, addition of strip heaters in the outer furnace positions (No. 1 and 8) resulted in sufficiently high temperature to accomplish effective outgassing in these positions.

In Table 8.2-9, the results of gas analyses after outgassing are compared with results from pellets prior to outgassing. The data in Table 8.2-9 do not indicate a difference in gas content among pellet batches.

The furnace consisted of a flat hinged box approximately 40-inches long, 24-inches wide and 14-inches deep. The furnace had a capability for 10 rods which were outgassed by cutting off the end plugs, and fitting an O-ring sealed cap, containing a 1-micron filter plug, to a vacuum manifold.

Approximately 4-1/2 hours were required to heat the furnace from room temperature to operation temperature (800°F) under a 100-micron Hg vacuum. This temperature was held for a period of 4 hours, under vacuum conditions. Four and one-half hours were required for cool-down, with the vacuum maintained over the pellets during this time.

Since the rods are heated in air, an oxide layer is formed on the outer surface of the fuel rod tubing (the end plug and weld areas remain cool and hence un-oxidized). The removal of this oxide layer was investigated by GE and NFS, and a satisfactory removal procedure was determined.

The following is an outline of the rod outgassing procedure used at NFS:

1. Remove existing end plugs from the rods using the approved procedures. Remove nickel reflectors from rods.
2. Insert special vacuum end fittings on the end of the tubes.
3. Place 8 rods in the vacuum outgas furnace.
4. Connect vacuum fittings to vacuum manifold and pump down rods below 100 microns. Monitor vacuum with thermocouple vacuum gauge located on vacuum manifold.
5. Heat furnace to 800°F, monitor temperature with thermocouples, hold at 800°F for 4 hours.
6. Cool furnace under vacuum, then back-fill with helium. Fuel not to be exposed to air above 300°F. Disconnect vacuum manifold lines.
7. Remove rods from furnace, place in decontamination facility and remove vacuum end fittings. Examine exposed inner surface of rods for evidence of condensate.

8. Decontaminate and weld end plugs by approved procedure.
9. Make first helium leak check. (Specification limit = 1×10^{-8} cc/sec.)
10. Remove oxide layer on fuel tube as follows:
 - a. Loosen oxide by rubbing tube with "Scotch-Brite".
 - b. Use damp cloth to remove oxide loosened by "Scotch-Brite" rub until no smear is observed on cloth.
11. Passivate rod.
12. Rub rod with damp cloth until no smear is observed on cloth.
13. Make second helium leak check not less than 2 days after first leak check.

Because of wide variation (factor of two on some pellet samples) in the fuel-gas release results obtained using small (3 grams) pellet samples, work was initiated to obtain gas release measurements on an entire column of fuel pellets (10 to 25 pellets). While the small sample gas release results indicate (on a statistical basis) that fuel rod cladding stresses are acceptable, several gas release values from Batch 617 samples (32 rods in the batch) in excess of the fuel specification limit were obtained by GE (NFS results on 10-gram samples were all below the specification limit). It is believed that the source of wide variation in gas release results lies in pellet surface contamination from the pellet grinding coolant. Past measurements have shown an association between high gas release and grinder coolant contamination, but have not been entirely conclusive. Since the value of interest for cladding stress analysis is the average gas release for an entire fuel column, it was decided to perform a measurement of this quantity at 1000°F (earlier results show most of the gas is evolved at 800°F).

Two different approaches to the gas-pressure measurement were pursued. One method uses a diaphragm-type pressure transducer (strain gauge) connected to the fuel tube by a capillary tube. This arrangement reduces the unheated volume (transducer and part of the capillary

tube are at room temperature) to approximately 10% of the total free volume in the heated tube (30 cc). The second measurement method uses a metal bellows attached to the fuel tube inside the furnace; a pressure increase in the fuel rod is translated to linear motion of the bellows, which is registered by a dial indicator. The total bellows motion is of the order of 0.020 inch for 50 psi rise in the fuel tube. Initial tests showed that the bellows method was less subject to leaks than the electrical transducer method because of the differences in tube fittings.

Both the bellows-type pressure transducer and the strain gauge pressure transducer indicated an average of less than 25 microliters gas release per gram of fuel oxide. The series of measurements were performed on samples consisting of 700 to 800 grams of fuel pellets (approximately 14 pellets in a sealed tube) from batch 617. It is concluded from these and previous measurements on single pellets that no significant pressure due to pellet gas release will be generated in the SEFOR fuel rods during reactor operation.

8.2.3 Unidentified Inclusions

The unidentified inclusions (bright spots) present in pre-production pellets persisted during production. At the time the micro-probe became available for use on SEFOR fuel, pellet production was about half complete. The pellet analyzed by micro-probe was from batch 609. This particular batch was chosen because in addition to the bright spots noted in previous batches, pellets also contained inclusions of another type. Micro-probe work positively identified the bright spots as stainless steel, and the other inclusions as aluminum (probably picked up from the alumina used in the pellet sintering boats).

A typical bright spot is shown in Figure 8.2-4. (The white line on the particle is a scratch mark on the carbon coating). This particular particle ($\sim 25\mu$ wide) was investigated to determine its elemental constituents. Figure 8.2-5 is a current specimen photograph, which indicates the relative atomic number of the various constituents.

Figure 8.2-4 Typical Bright Inclusion

Figure 8.2-6 K α Scan of Typical Bright Inclusion

Figure 8.2-5 Typical Bright Inclusion

The particular mode under which Figure 8.2-5 was taken, shows elements with low atomic numbers as a light phase and vice versa. Therefore, the void above the particle shows up as the brightest area, while the particle is shown to be of a lighter element(s) than the $\text{UO}_2\text{-PuO}_2$ matrix. An elemental scan of this particle showed that it contained iron, nickel, and chromium. Figure 8.2-6 is a $\text{K}\alpha$ Nickel scan of the particle. The snow effect in the matrix is due to background noise, and the white areas around the voids to the right of the particle have been attributed to edge effects.

A rough point count of the elements in question, indicated a very high concentration of iron and much lower concentrations of nickel and chromium. The finding suggested that the particle was at one time a type of stainless steel (there was no evidence of molybdenum). At the high pellet sintering temperatures (4 hours at 1650°C), melting of the stainless would be expected. The preliminary micro-probe data suggested that the nickel, chromium and molybdenum preferentially diffused out of the pellet during sintering. Close examination of Figure 8.2-5 shows a lighter colored phase at the tip of the protrusion on the left-hand side of the particle, as well as at the top of the particle (just below the void). A horizontal scan across the particle and through the protrusion indicated: 1) the iron concentration drops off radically in the light area, and 2) the nickel and chromium concentrations correspondingly increase in this area. This may be taken as evidence of an interaction of the stainless steel with the fuel, with iron being dissolved in the oxide matrix.

The predominantly iron concentration accounts for the disappearance of the "shiny" particles observed when etched with HNO_3 , i.e. iron is soluble in nitric acid. Several other "shiny" particles were scanned and again similar concentrations of iron, nickel, and chromium were observed. The high knoop hardness number reported for the "shiny" phase suggests that it could be in the form of an iron (nickel and chromium) carbide. It is concluded that the "shiny" particles observed in the SEFOR fuel fabricated by NFS, is a reminiscence of stainless steel picked up somewhere during the fabrication

procedure, probably abraded particles from the type 304SS granulating screen. The problem was not corrected, but probably could be corrected by using 400-series stainless steel screens and removing the particles with a magnet.

The micro-probe results showed no significant plutonium or uranium concentration (resolution limited by 1 micron beam diameter).

8.2.4 Low Plutonium Content

Twelve days after the initial minimum critical core configuration was achieved with 550 fuel rods (May 3, 1969), and during preliminary material reactivity worth measurements, it was discovered that the standard fuel rod numbered 874 (loaded with pellets from Nuclear Fuel Services' pellet batch 626) was worth approximately 45% less than the reference rod (#781, Batch 611). Fuel rod reactivity worth and other out-of-pile measurements (at SEFOR, Vallecitos, Los Alamos and Brookhaven National Laboratories) were then begun by GE and the USAEC to determine the nature and extent of the apparent low plutonium content in the SEFOR fuel. [During the investigation, 18 rods measured to be 15% to 50% low in reactivity worth and 29 rods suspected of being deficient in plutonium (based on NFS' rod loading records retained by GE) were removed from the core. On June 1, 1969, a second minimum critical core configuration was achieved with 522 fuel rods, in good agreement with the predicted value of 519 fuel rods.]

This investigation had several objectives, which were to:

- A. Identify the plutonium-deficient fuel rods and fuel pellets (delivered by NFS for Instrumented Fuel Assemblies being fabricated by GE).
- B. Determine the approximate plutonium deficiency in the fuel.
- C. Investigate possible causes of the plutonium deficiency, with the intent of limiting the fuel measurements to certain suspect groups of fuel, and determining whether any fuel might contain excess plutonium.

- D. From the results of (A), (B), and (C) above, determine the number of rods which were not usable in the reactor and the number of usable rods.

The objectives of this investigation were accomplished with the following results.

8.2.4.1 IDENTIFICATION OF PLUTONIUM-DEFICIENT FUEL

Plutonium-Deficient Fuel Rods

The plutonium deficient fuel rods can be placed in 3 groups (all stated plutonium deficiencies are relative to a reference rod -- 717 for gamma scan measurements, and 781 for reactivity measurements; no correction between chemical analysis and the non-destructive methods was obtained for fuel rods).

Fuel Rods Loaded by NFS Prior to August 8, 1968

Batch 625 contains 40 rods, all of which were loaded by NFS prior to August 8, 1968, (one rod, 826, was reloaded after August 8). Measurements on 16 of these rods (8-reactivity, 8-gamma scan) show that Batch 625 is uniformly $4.1 \pm 0.8\%$ (90% confidence) low in plutonium content. All of these rods were accepted by GE - see Table 8.2-11.

Batch 626 contains 41 rods, of which 20 were loaded by NFS prior to August 8, 1968. Measurements on 9 of these 20 rods (9 reactivity, 1 gamma and neutron scan) show that the 20 are also uniformly $2.8 \pm 1.2\%$ (90% confidence) low in plutonium content. All of these rods were accepted by GE - see Table 8.2-11.

Fuel Rods Loaded by NFS on and after August 8, 1968

Twenty-one Batch 626 rods were loaded on and after August 8, 1968. Neutron and gamma scan, and reactivity measurements on 19 rods (rejected by GE - see Table 8.2-10) show that they contain both normal pellets (20.4% Pu/U+Pu) and plutonium-deficient pellets (from 13% to 19% Pu/U+Pu; 13.5% to 13.9% obtained by chemical analysis of

TABLE 8.2-10

LOW PLUTONIUM CONTENT - REJECTED

392	}	Reloaded After 8/8/68	885	}	Batch 626 Loaded After 8/8/68	
728			886			
870	}	Batch 626 Loaded After 8/8/68	887	}		
871			888			
872			889	}	Reloaded After 8/8/68	
873			890			
874			891	}		
875			896			
876			915	}		
877			917			
878			918			
881			919			
882			920			
883			921			
884			924			

TABLE 8.2-11

SLIGHTLY LOW PLUTONIUM CONTENT - RETAINED AT SEFOR

806		840		122	
807		841		916	
808		842		923	
809		843	Batch 625	144	
810		844	Loaded Prior to	894	
811		845	8/8/68	895	
813		846		880	
814		847		249	
815		848		257	
816		849		266	
817		850		277	
818		851		290	
819		852		304	
820		853		892	
821	Batch 625	854		893	
822	Loaded Prior to	855		321	Rods Reloaded
823	8/8/68	856		325	after 8/8/68
824		857		327	
825		858	Batch 626	333	
827		859	Loaded prior	334	
829		860	to 8/8/68	375	
830		861		359	
832		862		377	
833		863		623	
834		864		194	
835		865		173	
836		866		151	
837		867		152	
838		868		212	
839		869	Batch 626	826	
		879	Loaded after 8/8/68		

2 pellets from Rod 874 performed by NBL and GE), and are from 10% to $35 \pm 2\%$ (90% confidence) low in plutonium content. The other 2 rods of the 21 rods are approximately 4% low in reactivity worth per gram of fuel oxide, relative to a standard rod (Rod 871, Batch 611), and were accepted by GE - see Table 8.2-11. The plutonium deficiency in these 2 rods is uncertain because the plutonium distribution in the rods is unknown; however, the 2 rods are in the range of 2% to 4% deficient in plutonium.

Fuel Rods Reloaded by NFS After August 8, 1968

Forty-four rods (including 41 rods from Batches 601-608 and 623; one Batch 625 rod; one "post August 8" Batch 626; and one Batch 627 "guinea pig" rod) were reloaded by NFS after August 8, 1968. Gamma scan showed that the guinea pig rod (A19) is uniform and normal in plutonium content. The Batch 626 rod (873) was found to be low in plutonium content. Gamma scan and reactivity measurements on 41 of the remaining 42 rods (one rod was used by GE in other tests for specification compliance) show that 16 rods contain varying numbers of plutonium-deficient pellets; eleven of these 16 rods are from 4.5% to $17\% \pm 2\%$ (90% confidence) low in plutonium content (these 11 rods were returned to NFS - see Table 8.2-10; and the other 30 rods were accepted by GE - see Table 8.2-11), and the other 5 rods are from 1% to $4\% \pm 2\%$ low in plutonium content. Of the other 25 rods, gamma scans of 14 rods show that the axial plutonium distribution is apparently uniform and the rods are apparently 1% to $4\% \pm 2\%$ low in plutonium, reactivity measurements of 5 rods show that these rods are also apparently 1% to $4\% \pm 2\%$ low in plutonium, and a reactivity measurement on a group of 7 rods showed that the group was $2\% \pm 1\%$ low in enrichment (gamma scan of these 7 rods showed that each of 4 rods probably contained 3 to 4 plutonium-deficient pellets).

Rod with Fuel Loading Errors

One rod, 533 (Batch 617), was discovered to have the upper fuel-and-nickel reflector column inverted (i.e., the nickel reflector was placed towards the center of the rod, rather than at the upper end of the rod).

Fuel Pellets

At the end of fuel production (in September, 1968), NFS shipped 21.8 kg of fuel pellets to GE-Vallecitos for use in SEFOR Instrumented Fuel Assemblies (IFA's). Except for two pellets, labeled "625" and "626", these pellets were not identified by an NFS pellet batch number.

Gamma scan of all but 2 pellets (those labeled 625 and 625) and some scrap (5 broken 1-1/8" pellets), and chemical analysis of selected samples (to calibrate the gamma scan) show that these pellets fall into 3 groups of differing plutonium content:

- a. 19.5 kg of standard length (5/8 inch) pellets are 5% to 10% $\pm$ 3% low in plutonium content (approximately 6 kg of these pellets were sealed into 2 IFA fuel rods before the low plutonium pellets were discovered).
- b. 2.3 kg of special length (1-1/8 inch) pellets are 5% to 20% $\pm$ 3% low in plutonium content.
- c. 2 pellets, one labeled by NFS "625" and one labeled "626", are both 30% low in plutonium content (the "625" pellet is not representative of Batch 625, as demonstrated by the results of reactivity and gamma scan measurements of Batch 625 fuel rods mentioned above).

8.2.4.2 Within-Specification Fuel Rods

The methods used to obtain measurements of reactivity worth and plutonium content apparently have uncertainties (standard deviations) of $\pm$ 1% or greater in the measurement, or $\pm$ 0.2% Pu/U+Pu or greater. The fuel specification requires that the Pu/U+Pu ratio be $20.4 \pm 0.1\%$ (0.05% tolerance plus 0.05% uncertainty) Pu/U+Pu, as determined from the assays and weights of the plutonium and uranium nitrate solutions used in making the "master mix" (there were four standard, and one "guinea pig", master mixes in the SEFOR project). Thus, it is clear that the measurements used in this investigation cannot be used to demonstrate that the fuel meets specification.

Of the total number of rods (756 standard and 18 "guinea pig"), 650 (633 standard and 17 guinea pig) rods are not associated with the above 3 groups of plutonium-deficient fuel rods (the other guinea pig rod was reloaded after August 8, 1968, but was shown to be usable, see 8.2.4.1 above). Of the 650 rods, gamma activity measurements were made on 68 standard (Batches 600-602, 606, 609-612, 615-623, and CD) and 17 guinea pig rods, and reactivity measurements were made on 35 standard rods (from all pellet batches except Batch 604, which was indicated to be good by a reactivity measurement on Rod 880, reloaded after August 8, 1968, with Batch 604 pellets). These measurements show that:

- a. The plutonium distribution along the rods (inferred from gamma activity distribution) is uniform within the measurement uncertainty($\pm 3\%$), and
- b. The plutonium content per gram oxide weight in the rods (inferred from reactivity, total gamma and/or neutron emission, and plutonium content of the reference rod) is that specified (with an overall uncertainty of $\pm 2\%$).

Table 8.2-12 shows the summary of non-destructive measurements made on fuel rods to determine the extent of the plutonium content variation.

Brookhaven National Laboratory has responsibility for determining the plutonium deficiency; however, based upon the measurements described in this report, the total plutonium deficiency is estimated to be 5.6 ± 0.8 (90% confidence interval) kgs in Batch 625, Batch 626, rods reloaded after August 8, 1968, and the 21.8 kg of loose pellets. Measurements on rods at Los Alamos Scientific Laboratory (LASL), and measurements on pellets at New Brunswick Laboratory (NBL) and GE-Vallecitos (VNC) have shown that the missing plutonium is replaced by uranium.

TABLE 8.2-12

Summary of Measurements for Plutonium Content in SEFOR Fuel Rods

(Some rods have been examined by more than one technique.)

Population (Pellet Batch)	Number of Rods	Total Number Examined	Gamma Scan	Neutron Scan	Reactivity Measurement	Remarks
Batches 600-624 (Master Mixes No. 101-104) and reworked rods finished before Batch 626	615	95	68	4	34	No rods out-of-specification,*uniform Pu content in all rods.1 rod with fuel reflector column inverted.
Batch CD	19	8	7	1	1	No rods out-of-specification;* uniform Pu content in all rods.
Batch 625 (1 Batch 625 was re-loaded after 8/8/68 - see below)	39	16	8	1	8	Rods $4.1 \pm 0.8\%$ below specified Pu content; uniform Pu content in all gamma-scanned rods.
Batch 626(prior to August 8)	20	9	1**	1**	9	Rods $2.8 \pm 1.2\%$ below specified Pu content.
Batch 626(Post-August 8)	21	21	19	19	19	19 of 21 have significant number of pellets low in plutonium content. Axial gamma scans show low and non-uniform Pu content in 18 rods, and one rod is uniformly low.
Reloaded after August 8	42	41***	36	27	6	
a. Rods not renumbered (includes 1 Batch 625 rod)	26	25***	21	14	4	2 rods have significant number of pellets low in Pu content.
b. Rods renumbered	16	16	15	13	2	9 rods have significant number of pellets low in Pu content.
Batch 627(Master Mix No. 105) (Guinea Pig Rods)	18	18	18	2	1	Uniform Pu content in all rods.

- * Accuracy of non-destructive measurement techniques is not adequate to verify that fuel rods are actually in-spec, but will detect rods with Pu content out-of-spec by more than 2 or 3%.
- ** One of six with reactivity measurement removed from core and sent to GE-Vallecitos.
- *** The remaining rod was used for destructive QC work at GE-Vallecitos and was not gamma-scanned.

8.2.4.3 Investigation of Possible Causes of Plutonium Deficiency

Pellet batches CD (19 rods), 625 (40 rods), and 626 (41 rods) were made from re-dissolved scrap pellets obtained from the pellets produced prior to these batches (this procedure was permitted by the fuel production procedures). Of these three batches, 625 and 626 have various degrees of low-enrichment, while CD (the first re-dissolved scrap batch) apparently has the specification plutonium content. In contrast to the AEC and GE findings, NFS' in-production measurements of plutonium content in the samples taken from the 625 and 626 batches show that these fuel batches contain the plutonium content specified by GE. Two avenues have been identified by which plutonium-deficient fuel may have resulted from the re-dissolution process (and which are not present in the master mix make-up process used for the prior fuel); these are:

- (1). Addition of scrap UO_2 insulator pellets (4 such pellets are used in each SEFOR fuel rod, along with approximately 55 fuel pellets) as well as $(\text{Pu-U})\text{O}_2$ fuel pellets into the dissolver tank (1 kg, which is approximately 1/3 of a fuel rod, constituted one dissolver-load); and
- (2). Lack of complete dissolution of the plutonium (unfortunately, the filter residues from the dissolver effluent filtration are not separately identified in the waste material stored at NFS).

Examination of NFS' re-dissolution records do not indicate any differences in procedures between batches CD, 625 and 626; hence, it appears that hypothesis (1) above is more likely true than hypothesis (2).

No means of obtaining fuel pellets with higher-than-specification plutonium content have been identified in the scrap dissolution and subsequent co-precipitation process, assuming that only UO_2 of fuel pellets available to NFS were placed in the dissolver. (NFS' records show that the Batch 626 fuel was prepared prior to the "guinea pig" Batch 627 fuel.)

Alpha-autoradiographs of selected pellets provide additional confirmation that oxide powders of varying enrichments were mixed in

small batches in fabrication of the plutonium-deficient fuel.

Alpha-autoradiographs of the plutonium-deficient pellets listed below:

1 pellet from Rod 874 ($\sim 13.5\%$ Pu/U+Pu), Batch 626 loaded after August 8, 1968.

1 pellet alleged to be from Batch 626, sent to GE by NFS as a "QC" sample. ($\sim 14.5\%$ Pu/U+Pu)

1 pellet alleged to be from Batch 625, sent to GE by NFS as a "QC" sample. ($\sim 14.5\%$ Pu/U+Pu)

3 pellets from loose pellets shipped by NFS to GE for IFA rods (~ 17 to 19% Pu/U+Pu).

2 1-1/8 inch long pellets (~ 17 to 19% Pu/U+Pu).

showed that the plutonium distribution within these pellets was inhomogeneous. The most inhomogeneous distribution was observed in the pellets with the lowest plutonium content, and the plutonium distribution becomes more homogeneous as the plutonium content of the pellet approaches the specification value. Electron-microprobe analysis of the pellet alleged to be from Batch 626 showed the lowest, average, and highest plutonium enrichment zones to be 10% , 15% and 21% ($\pm 1\%$) Pu/U+Pu, respectively. The observed particle sizes of varying plutonium concentration ranged from 0.002 to 0.050 inches, which is consistent with the 10-mesh screen size which NFS used in screening the oxide powder.

Alpha-autoradiographs of the within-specification pellets listed below:

1 - Pre-production pellet (Master Mix 101)

1 - Batch 603 (Master Mix 102)

1 - Batch 611 pellet (Master Mix 103)

1 - Batch 621 (Master Mix 104)

1 - Batch 622 (Master Mix 104)

3 - Batch 625 pellets (Master Mix 104)

1 - Batch 627 pellet (Master Mix 105)

show that these pellets are homogeneous in plutonium content.

[A "calibration" test performed by NFS during pre-production work showed that particles 1% high in plutonium, which had been screened (-10 mesh) to provide particles of approximately 0.100-inch size could be observed in an alpha-autoradiograph of an otherwise normal fuel pellet. Similar particles 1% low in plutonium could not be observed.]

In summary, the GE and AEC investigation indicates that the plutonium-deficient pellets were fabricated by NFS at the end of production from re-dissolved scrap material (Batches 625 and 626). Batch 625 was properly cross-blended and appears to be uniformly low in plutonium content by $4.1 \pm 0.8\%$. Batch 626 was not completely cross-blended and thus pellets of varying enrichments were found in Batch 626. As indicated by the alpha-autoradiographs and electron-microprobe analysis, the plutonium-deficient pellets contained material of various low enrichments, which were obtained because of errors in the re-dissolution of small (1 kg oxide) groups of pellets. The subsequent processing of the re-dissolved plutonium-uranium nitrate material (co-precipitation in 4 kg lots, etc.) did not contribute to the plutonium-deficiency.

8.3 Fuel Rod Production Problems

8.3.1 Leaking Fuel Rods

A high percentage of the first production rods were found to leak when inspected by the helium mass spectrometer method. It was discovered by helium leak testing new end plugs that the bar stock contained porosity to the extent that helium leaked through the 40 mil thick conical section. A repair procedure was developed; leaking end plugs were then removed and new end plugs made from new bar stock lots were installed.

Although metallography did not reveal inclusions and porosity in the bar stock, it was evident that such did exist in some of the bars from a particular heat of steel. Severe leaks were occasionally revealed by bubble checks. All leaks were related to end plug

inclusions as a result of checking each end individually in order to isolate the leak. Only once has a leak been observed to occur in the tube wall, but never in a weld (blowouts excepted).

NFS reduced the incidence early in production by dye-penetrant checking all the plugs. Additional lots of plugs were subsequently required (as consumption was far greater than expected) but these were machined from different heats of material and the rods produced with this material were found to be virtually free of leaks.

In view of the early high incidence of leaks, a final leak check was instituted as the reactor site upon delivery of rods from the vendor. Approximately 3 to 4 percent of the early rods were found to leak even though all the rods had been checked twice by the vendor. This concern for future unpredictable leaks led to adding a second leak check at the site. This leak check required heating both end plugs to 800°F just prior to loading in the leak chamber. It was earlier demonstrated that heating known leakers increased the leak rate; therefore, it was suggested that heating may tend to open any incipient leak by thermal expansion and thus reveal defects which would pass normal tests.

One hundred two (102) early production rods, some of which were leakers, were returned to the vendor for pellet outgassing as described earlier. New end plugs were installed after outgassing. The rewelded rods and new rods, fabricated with plugs made from different heats of bar stock, showed no leaks on the first cold check at the site. The final hot leak check revealed 22 leakers, thus demonstrating the effectiveness of this technique and the importance of the quality of raw material.

Many rods completed but not yet shipped were also reworked by removing the end plugs, outgassing, and welding new end plugs. Rods reworked in this manner contained pellet batches 600 through 611 (Rod Serial Numbers 101 to 427, 623, 624, 625, 892, 893, 894). All subsequent pellet batches were outgassed prior to loading into tubes.

8.3.2 End Plug Welds

The problems with end plug welding are described in Section 7, Production Development. Bulging after closure, plutonium contamination, and end plug runout persisted as problems throughout production, however, the rework rate was acceptable. A few rods were delivered to the reactor site with excessive end plug runout. These were repaired by cold straightening. Some rework rods had misalignment between the hole in the top end plug and the slot in the bottom end plug. These were repaired at the site by filing the slot wider. It was verified by trial that the widened slot would provide adequate alignment in the fuel rod assembly-disassembly station.

8.3.3 Electron Beam Welds

About 60 percent of the first 102 fuel rods shipped to the site were rejected because of excessive diameter at the electron beam weld. These rods were repaired at the site by filing away weld metal that projected above the tube surface. NFS was permitted to remove the weld metal in a lathe on subsequent production rods after the electron beam weld inspection was complete.

8.4 Summary of SEFOR Rejects

The first shipment (102 fuel rods) were all returned to the vendor for vacuum outgassing, with the following defects noted:

Helium Leak - Rods 268, 215, 192, 248, 269

Weight Discrepancy - Rods 277, 213, 194, 163

EB Weld Diameter - About 60% of the EB Welds
exceeded the allowable diameter.

All defects were corrected by NFS prior to reshipping.

Subsequent shipments contained defects as tabulated in Tables 8.4-1 and 8.4-2.

TABLE 8.4-1

FUEL RECEIVING INSPECTION DISCREPANCIES

<u>Rod No.</u>	<u>Discrepancy</u>	<u>Status</u> (May 1971)
170	Top End Plug 0.030 TIR	Cold Straightened (serviceable)
197	Volatiles Destructive Examination	Destroyed
200	Dented Cladding, 0.009"	On Hand (serviceable)
258	Suspected Helium Leak (Cold)	On Hand (unserviceable)
265	Bow 0.050" TIR	Cold Straightened (serviceable)
298	Top TIR 0.010"	Cold Straightened (serviceable)
302	Top TIR 0.013"	Cold Straightened (serviceable)
321	Helium Leak (Hot)	On Hand (unserviceable)
324	Volatiles Destructive Examination	Destroyed
349	Volatiles Destructive Examination	Destroyed
359	Bottom TIR 0.012"	Cold Straightened (unserviceable, Low Pu)
374	Volatiles Destructive Examination	Destroyed
375	Top TIR 0.014"	Cold Straightened (unserviceable, Low Pu)
377	Bottom TIR 0.007"	Cold Straightened (unserviceable, Low Pu)
410	Volatiles Destructive Examination	Destroyed
432	Helium Leak (Cold Destructively Examined (volatiles)	Destroyed

TABLE 8.4-1
(continued)

<u>Rod No.</u>	<u>Discrepancy</u>	<u>Status</u> (May 1971)
444	Helium Leak (Hot) Destructively Examined (volatiles)	Destroyed
473	Helium Leak (Hot) Upper Pellet Stack Displaced After Repair	Leak Repaired Unserviceable
481	Helium Leak (Hot) Destructively Examined (volatiles)	Destroyed
483	Helium Leak (Hot)	Rejected (not repairable)
489	Helium Leak (Cold) Destructively Examined (volatiles)	Destroyed
495	Destructively Examined (volatiles)	Destroyed
497	Helium Leak (Hot) Upper Pellet Stack Displaced after Repair	Leak Repaired Unserviceable
499	Helium Leak (Hot)	Unserviceable
507	Helium Leak (Hot) Destructively Examined (volatiles)	Destroyed
509	Helium Leak (Hot) Helium Leak (Hot) after Repair	Repaired (unserviceable)
516	Helium Leak (Hot) Destructively Examined (volatiles)	Destroyed
517	Helium Leak (Cold)	Repaired (serviceable)
518	Helium Leak (Hot) Helium Leak (Hot) after Repair	Unserviceable
525	Upper Pellet Stack Displaced after Repair	Unserviceable

TABLE 8.4-1
(continued)

<u>Rod No.</u>	<u>Discrepancy</u>	<u>Status</u> (May 1971)
533	Reflector Mislocated	Unserviceable
537	Helium Leak (Hot) Helium Leak Cold Following Repair	Unserviceable
549	Helium Leak (Hot)	Repaired (serviceable)
522	Helium Leak (Hot) Helium Leak (Hot) after Repair Hole & Slot Misaligned after Repair	Unserviceable
557	Helium Leak (Hot) Helium Leak (Hot) after Repair	Unserviceable
559	Helium Leak (Hot)	Repaired (serviceable)
563	Helium Leak (Hot) Helium Leak (Hot) after Repair	Unserviceable
564	Helium Leak (Hot)	Repaired (serviceable)
569	Helium Leak (Hot) Helium Leak (Cold) after Repair	Unserviceable
591	Helium Leak (Cold)	Repaired (serviceable)
592	Helium Leak (Hot) Helium Leak (Hot) after Repair	Unserviceable
597	Helium Leak (Hot) GE Damaged during Handling	Unserviceable
624	Top TIR 0.020	Cold Straightened (serviceable)
625	Suspected Leak (Hot)	Unserviceable
679	Helium Leak (Hot)	Repaired (serviceable)
710	Helium Leak (Hot) Helium Leak (Cold) after Repair	Unserviceable

TABLE 8.4-1
(continued)

<u>Rod No.</u>	<u>Discrepancy</u>	<u>Status</u> (May 1971)
717	Helium Leak (Hot)	Repaired (serviceable)
728	Bottom TIR 0.008"	Cold Straightened (unserviceable, Low Pu)
742	Cladding Dent 0.006"	Serviceable
788	Top TIR 0.020"	Cold Straightened (serviceable)
A01	Top TIR 0.021"	Cold Straightened (serviceable)
A02	Top TIR 0.016"	Cold Straightened (serviceable)
A06	Top TIR 0.014"	Cold Straightened (serviceable)
A07	Top TIR 0.009"	Cold Straightened (serviceable)
A10	Top TIR 0.024 Hole & Slot Misaligned	Cold Straightened Slot Filed (serviceable)
A12	Top TIR 0.036	Cold Straightened (serviceable)
A13	Helium Leak (Hot) Helium Leak (Cold) after Repair	Unserviceable
A14	Top TIR 0.013" Hole & Slot Misaligned GE Damaged during Handling	Unserviceable
A17	Top TIR 0.013" Hole & Slot Misaligned	Cold Straightened (Serviceable) Slot Filed
A18	Top TIR 0.011"	Cold Straightened (serviceable)
A19	Hole & Slot Misaligned	Slot Filed (serviceable)

TABLE 8.4-2

RECEIVING INSPECTION DISCREPANCIES

SPECIAL CORE RODS

<u>Rod No.</u>	<u>Discrepancy</u>	<u>Status</u>
DD	Leak (Cold)	Unserviceable
DI	Leak (Cold)	Unserviceable
X22	Leak (Cold)	Unserviceable
X29	Leak (Hot)	Unserviceable
X37	Leak (Cold)	Unserviceable
X42	Leak (Hot)	Unserviceable
X48	Leak (Hot)	Unserviceable
X59	Top End Plug Wrong Size	Returned to NFS
SM	Leak (Hot)	Unserviceable

8.5 Summary of VNC Quality Control

8.5.1 General

This section summarizes the results of the various analyses obtained from selected pellets of mixed plutonium-uranium oxide fabricated for the Southwest Experimental Fast Oxide Reactor. In general, these results were meant to verify the results obtained by the fuel fabricator (Nuclear Fuel Services). No consideration was given to statistically sampling the fuel, as required of the fabricator, although sample pellets were obtained from every master mix, in some instances from every pellet batch of a master mix. The sampling frequency was intended to be as flexible as possible so that should problems arise, the frequency of GE samples could be increased accordingly. As a result, GE was able to adequately cover the problems of oxygen-to-metal ratio (O/M), total gas, and low plutonium.

The fabrication was planned for two phases: A pre-production run to verify the fabricator's capability, and the production run. All pre-production and production starting materials (plutonium nitrate and uranium nitrate) were blended in five master mixes (101 through 105). Table 8.5-1 shows the breakdown of the master mixes into pellet batches.

8.5.2 Pre-Production (Master Mix 101)

Table 8.5-2 contains the results of the analytical work performed on the pre-production pellets. It should be noted that the powder from which this group of pellets was fabricated was subsequently designated Master Mix 101 and Pellet batches 600 and 601 were fabricated from this Master Mix. Twenty-two of one group and four pellets of a second group were received for evaluation of the pre-production run. The 22-pellet group was designated GE batch B-277 and the 4-pellet group designated B-278. In Figures 8.5-1 and 8.5-2 are shown the pellets in an "as-received" condition. The only difference between the two groups was the powder pre-pressing and pressing conditions. The powder of the first group (GE B-277) had been pre-pressed at a pressure greater than the subsequent pellet pressing pressure. The powder

TABLE 8.5-1

MASTER MIX, PELLET BATCH IDENTIFICATION

Master Mix IdentificationPellet Batch Identification

101	601, 2/3 602
102	1/3 602, 603 through 609
103	609 through 612, 614 through 616
104	617 through 626
105	627

TABLE 8.5-2

PRE-PRODUCTION PELLETS

Master Mix 101 Analytical Results by G.E.

<u>Analysis</u>		<u>B-277(22 Pellet Lot)</u>	<u>B-278(4 Pellet Lot)</u>
Visual		Summarized in report.	
Dimensions	Dia. (Avg.)	0.8752	0.8750
		0.8753	0.8753
		0.8749	
		0.8749	
	Length (Avg.)	0.6123	0.6225
		0.6320	0.6128
		0.6388	
		0.6419	
	Dish Depth (Range)	0.0184-0.0235	0.0142-0.0170
		0.0160-0.0209	0.0142-0.0154
		0.0125-0.0192	
		0.0163-0.0166	
Density, % T.D. (Based on 11.06 g/cc T.D.)		91.9% T.D.	93.2
		91.7	93.9
		89.7	
		90.7	
Metallography		See Text	
Alpha Autoradiography		See Text	
O/M		2.0012 (Avg. 4 Det.)	1.999 (Avg. 2 Det.)
		2.0015 (Avg. 2 Det.)	

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TABLE 8.5-2 (Continued)

O/M		B-277		B-278
		2.0002		
		2.0018	2.0012	---
		2.0013		
		2.0016		
Dried in argon atmosphere		2.000	1.9837 ⁽¹⁾	1.9963
		1.9674		1.9994 1.9978
		2.0013	2.0015	1.9990
		2.0017		1.9989 1.9990
<hr/>				
Dried in helium atmosphere		1.9983		(2)
	40 x 60 M	1.9987		1.9979
	multiple Ox. and Red.	1.9973		1.9957
		1.9977		2.0107 ⁽¹⁾
X-ray diffraction	Lattice Parameter (Whole Pellet Face)	° A = 5.4561±0.0003 single phase, well crystallized, slight amount of un- identified second phase.		° A = 5.4557±0.0003 single phase, well crystallized.
	Inclusion and Oxide Matrix	Film indicated strong mixed oxide lines. Secondary Lines were weak although they could be interpreted as nitride or α iron if additional substanti- able evidence were available.		---
Gas Analysis (Lab. A)		29.6±6.0μ l/g ⁽³⁾		
		125.5±6.0μ l/g ⁽³⁾		
		123.0±6.0μ l/g ⁽⁴⁾		
		6.9±6.0μ l/g ⁽⁴⁾		

(1) Weighing errors caused erroneous results.

(2) Sample lost due to spillage.

(3) 1 erent pellets--same--batch--same firing.

(4) Repeat sample from pellet that yielded 125.5μ l/g
gas. Stepped temperature.

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TABLE 8.5-2 (Continued)

Gas Analysis (Lab. B)⁽⁵⁾

200μ l/g Reported Composition of Gas		
H ₂	-	54%
CO	-	43%
CH ₄	-	0.4%
CO ₂	-	0.4%
Other Hydrocarbons	-	0.3%
H ₂ O	-	0.9%

Thermogram

B-277B-278No indication of wt. loss
to 400°C

Pu/Pu+U

20.3%

20.7

20.4%

20.2%

Pu-239+241/Pu+U

18.6%

19.0

18.7

18.5

U-235

0.24%

0.25

0.23

0.23

⁽⁵⁾ Independently submitted by NFS to Lab. B

TABLE 8.5-2 (Continued)

B-277

Impurities (ppm) (BMI-ANL Results)

<u>Sample</u>	<u>A</u>	<u>B</u>
Ag	--	--
Al	20	20
B	--	--
Ba	--	--
Be	--	--
Bi	<.5	<.5
Ca	<1	<1
Cd	--	--
Cr	10	5
Cu	.5	.2
Fe	50	20
In	--	--
K	--	--
Mg	.2	.2
Ar	--	--
Mn	5	5
Mo	<5	<5
Na	-	--
Ni	5	5
P	<50	<50
Pb	--	--
Sb	--	--
Si	20	50
Sn	--	--

TABLE 8.5-2 (continued)

Impurities (ppm)	<u>Sample</u>	<u>A</u>	<u>B</u>
	Ti	<1	<1
	Tl	--	--
	V	--	--
	Zn	--	--
	Li	<5	<5
	Cl	<10	<10
	F	<5	<5

NOTE: The pre-production pellets were subsequently designated Master Mix 101 (Pellet Batch 600 and 601).

Photo No. 46225
Unground

Photo No. 46226
Unground

Photo No. 46227
Ground

FIGURE 8.5-1
"AS-RECEIVED" PRE-PRODUCTION
PELLETS GE B-277

Photo No. 46229
Poor Appearance
(B-277)

Photo No. 46231
Good Appearance
(B-277)

Photo No. 46235
(B-278)

FIGURE 8.5-2

CLOSE-UP OF PRE-PRODUCTION PELLETS

for the second group (GE B-278) had been pre-pressed at a pressure less than the pellet pressing pressure. The net result of these two pre-pressing conditions was that the first group of sintered pellets was composed of islands of higher density mixed oxide. In other words, the porosity was built into pellet. This granular character of group (GE B-277) is evident in the alpha-autoradiographs (Figures 8.5-3 and 8.5-4).

8.5.2.1 Alpha Autoradiography

The technique of alpha-autoradiography yields information on the relative degree of homogeneity of plutonium. Alpha particles (approximately 2,000,000:1, Pu:U) damage the bonding character of cellulose nitrate plastic. This damage is subsequently etched by a caustic solution. After washing and drying the plastic film, the damage is visible and can be projected onto a photosensitive paper. The dark areas indicated in Figures 8.5-3 and 8.5-4 result from a lack of plutonium in that area. This may be caused by a void or inclusion of some material other than a highly alpha active material. No evidence of non-homogeneity was detected in the pre-production pellets by this technique.

8.5.2.2 Metallography

Several inclusions were noted in the metallographic sections prepared. These were bright, metallic appearing particles that could not be readily identified by normal metallographic techniques. X-ray diffraction by a powder camera technique was attempted. Because of the small size of the inclusions (10 to 50 μm) identification in the oxide matrix was difficult and not conclusive, although some lines of α -iron, UC, UC₂, U₂C₃, and UN₂ were indicated. It should be noted that the total amount of the bright, metallic appearing particles was much less (by at least an order of magnitude) than the specifications called for and, in no instance, ever exceeded 0.5% for any surface examined. Subsequently, electron microprobe analysis was run on similar appearing particles and these

FIGURE 8.5-3
B-277 Alpha-Autoradiograph

FIGURE 8.5-4
B-278 Alpha-Autoradiograph

were identified as a 300 series stainless steel. The results are discussed in Section 8.2.

8.5.2.3 Oxygen to Metal Ratio (O/M)

The O/M technique described in GEAP-4271⁽⁵⁾ was used as a standard technique by both NFS and GE. The GE results were consistently at the stoichiometric value of 2.00 while the NFS results were consistently hypostoichiometric. This led to strict control of the sampling and analytical procedure. Several variations of the "standard" technique were attempted, always leading to the same result (GE stoichiometric, NFS hypostoichiometric). A detailed analysis of the NFS procedure and apparatus indicated the original procedure to be correct and the results obtained by GE to be correct. The problem was that water vapor was being introduced into the NFS system so that during the reduction step of the analysis, the material was never reduced to a stoichiometric condition. The net result being that the indicated weight gain was obtained by oxidation from a stoichiometric condition and reduction to a hyperstoichiometric $(2.00 + x)$ condition. In addition, analysis of the sintering furnace gas indicated the influent gas to be nominally 8% hydrogen, while the effluent was only about 4% hydrogen. Fifty percent of the reducing atmosphere was removed and the water-to-hydrogen ratio $[^P\text{H}_2\text{O}/\text{H}_2]$ far exceeded $(>10^{-3})$ that required to obtain hypostoichiometric fuel. With the correction of these two problems, (1) drying the gas used for O/M determination and (2) increasing the sintering gas flow so that the effluent sintering gas approached the influent gas value of 8% H_2 , the GE and NFS results converged to the required hypostoichiometric range of 1.98 - 1.99 O/M.

8.5.2.4 Total Gas

The indicated total gas of the sintered pellets was $>50\mu\text{l/g}$. At the time of pre-production, and early in the production, GE did not have total gas analytical capability for plutonium bearing samples. This analysis was initially contracted for through an independent laboratory. The disagreement between this laboratory subsequently led to a round-robin analysis with four laboratories participating. This is fully discussed in Section 8.2.2.

8.5.3 Master Mix 102

Two pellets and 50.4 grams of a third pellet from batch 603 were received in October, 1967. Samples from the same batch were sent to an independent laboratory for gas, carbon, and impurity analysis.

The material was out of specification on the basis of carbon content and gas release (volatile). Carbon analysis yielded results of 0.042 wt % and 0.043 wt % (2 grams each sample). The gas release was 880 $\mu\text{l/g}$ and 980 $\mu\text{l/g}$ (10 grams each sample).

The samples were prepared by crushing the total sample received and separating into 2-10 gram samples (gas analysis) and 2-2 gram samples (carbon analysis). Gas analysis samples were dried at approximately 120°C for 48 hours prior to running.

Carbon analysis was made by a combustometric technique in which oxygen is flowed into a furnace containing the sample, forming CO_2 . The effluent from the furnace was absorbed on ascarite contained in a tube. The tube is weighed and the carbon content is back calculated from the weight of CO_2 generated. The results appear to be consistent for both carbon and volatiles (see Table 8.5-3).

Table 8.5-3 shows the results obtained as compared to the specifications.

The pellets "as-received", metallography, and alpha autoradiography photos appear in Figures 8.5-5 through 8.5-9. Both "as-polished" and "as-etched" photos are shown. The "as-polished" metallographic photos did not indicate the numerous metallic appearing particles that had shown in the pre-production pellets; although to the naked eye there appeared to be several, but much smaller in size in the "as-polished" condition. The average grain size in the "as-etched" photos is about 7 μ .

In the alpha autoradiographs a "corona" around the pellet is noted. The pellet was not mounted in hysol, and therefore, the cellulose nitrate film was subjected to alpha bombardment from the wall of the pellet. This caused the "corona". In mounted pellets, the hysol mounting plastic completely stops or attenuates the alpha particles

TABLE 8.5-3

MASTER MIX 102

ANALYTICAL RESULTS BY GE

Characteristics	Specification	Results			
		0°	90°		
A. Diameter	0.875±0.001	0.8756	0.8756		Top
		0.8756	0.8754		Middle
		0.8754	0.8755		Bottom
B. Length	0.625±0.094	0.6017	0.6032	$\frac{180^\circ}{0.6051}$	$\frac{270^\circ}{0.6041}$
C. Dish Depth	0.015±0.003	0.014	0.019 ⁽¹⁾		
D. Shoulder	0.040±0.010	0.020		0.020	
E. Density	10.06/10.29 g/cc	10.18 g/cc			
F. Percent Second Phase	5% Max.	<2%			
G. Oxygen to Metal Ratio	1.98±0.01	1.993±0.004	95% confidence limit		
H. Pu-239 + 241/Pu+U	18.7±0.3%	Not available - to be forwarded			
I. Pu/Pu+U		20.29%			
J. Impurities:					
Hydrogen	5 ppm Max.	Not measured			
Boron	10 ppm Max.	Not detectable			
Nitrogen	200 ppm Max.	Not measured			
Carbon	250 ppm Max.	125 ppm			
Chloride	25 ppm Max.	<10 ppm ⁽²⁾			
Fluoride	25 ppm Max.	<5 ppm ⁽²⁾			
All others including Al, Ag, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Mo, Na, Ni, Pb, Si, Sn, Ti, V.	2500 ppm Max.	<300 ppm			
K. Volatiles	0.05 cc/g	0.880 cc/g ⁽³⁾			
L. Homogeneity	1% Deviation from Normal	XRD-Well Crystallized Solid Solution			
		Alpha Autoradiograph-meets specification ⁽³⁾			
M. Physical Appearance	Photos	Meets Specification			

(1) Due to Identification Mark on Pellet

(2) Results not valid - See Text

(3) See Text

TABLE 8.5-3

(ADDENDUM)

CONTRIBUTION OF CARBON TO GAS RELEASE

If the average value for carbon is taken and one assumes that all the carbon is removed as CO (reduces the mixed oxide fuel O/M) in the volatiles analysis or as CO₂ in the combustometric carbon analysis, the total gas release due to carbon can be calculated.

Average Carbon Value - 0.0425 wt %

1. Total Gas Release from Combustometric Carbon Analysis

$$4.25 \times 10^{-2} \text{ wt \%} = 4.25 \times 10^{-4} \text{ g C}$$

$$(4.25 \times 10^{-4} \text{ g}) \left[\frac{44}{12} \right] = 1.56 \times 10^{-3} \text{ g CO}_2$$

$$\left(\frac{1.56 \times 10^{-3} \text{ g}}{44 \text{ MW CO}_2} \right) (2.24 \times 10^4 \text{ ml/mole}) = .793 \text{ ml CO}_2$$

2. Total Gas Release from Volatiles Analysis (Reduction of Fuel)

$$(4.25 \times 10^{-4} \text{ g C}) \left[\frac{28}{12} \right] = 9.92 \times 10^{-4} \text{ g CO}$$

$$\left(\frac{9.92 \times 10^{-4} \text{ g}}{28 \text{ MW CO}} \right) (2.24 \times 10^4 \text{ ml/mole}) = .793 \text{ ml CO}$$

Figure 8.5-5 BATCH 603 PELLETS AS-RECEIVED

Outside Diameter As-Polished

400X

Center As-Polished

400X

Mid Radius As-Polished

400X

Figure 8.5-6

BATCH 603 PELLETS AS-POLISHED

Outside Diameter As-Etched

400X

Center As-Etched

400X

Mid Radius As-Etched

400X

Figure 8.5-7 BATCH 603 PELLETS AS-ETCHED

Figure 8.5-8 BATCH 603 PELLETS ALPHA AUTORADIOGRAPH AS POLISHED

Figure 8.5-9

BATCH 603 PELLETS ALPHA AUTORADIOGRAPH AS ETCHED

so they do not register on the film. The autoradiographs do not indicate any unusual high or low concentrations of plutonium.

The chlorine and fluorine numbers indicated in the impurity analysis are not reliable. These determinations were made after the mixed oxide power was oxidized at 700°C. These elements would probably be volatilized at this temperature. An error was made by not taking part of the sample for chlorine and fluorine analysis prior to oxidation.

8.5.4 Master Mix 103

The pellets submitted from NFS for analysis were from pellet batch 610 and 611, and met specification, except that the physical appearance was drastically different. Surface cracking and crazing predominated. Some cracks penetrated the surface up to 1/8 inch. The pellets seemed quite integral, even with the unusual surface appearance. No inhomogeneities were indicated by the alpha-autoradiographs or pellet metallography. Total gas content of the pellets continued to be a problem. This finally resulted in the vacuum outgassing of the fuel. The problems encountered and the solutions to these problems are discussed in Section 8.2. Analytical results appear in Table 8.5.4.

8.5.5 Master Mix 104

Some "barrelling" of the pellet was indicated by the top, mid, and bottom diameter measurements. This apparently resulted from the diameter grinding operations. If ring gauges were used, this may not be detected when density specification and column weight are met. The oxygen-to-metal ratio, while hypostoichiometric, was indicated to be high by an average of 0.003 O/M units. Only one pellet batch of eight indicated a high gas content. This was the first Pellet Batch 617. The remainder Batches 618 through 625, inclusive, indicated a maximum of 37 $\mu\text{l/g}$ total gas. Pellet Batches 625 and 626

TABLE 8.5-4

MASTER MIX 103 ANALYTICAL RESULTS BY G.E.

<u>Characteristic</u>	<u>Specifications</u>	<u>Batch</u>	<u>Top</u>	<u>Middle</u>	<u>Bottom</u>	
Diameter	0.875"±0.001	NFS 611 - 0°	0.8723"	0.8755"	0.8738"	
		NFS 611 - 90°	0.8730	0.8755	0.8742	
		NFS 610 - 0°	0.8735	0.8745	0.8735	
		NFS 610 - 90°	0.8745	0.8735	0.8745	
Length	5/8"±3/32"		<u>0°</u>	<u>90°</u>	<u>180°</u>	<u>270°</u>
		NFS 611	0.6009"	0.5995"	0.5995"	0.6008"
		NFS 610	0.5942	0.5948	0.5935	0.5935
Dish Depth	0.015"±0.003"		<u>Top</u>		<u>Bottom</u>	
		NFS 611	0.0154"		0.0133"	
		NFS 610	0.0125		0.0161	
Shoulder	0.040"±0.010"	NFS 611	0.033"			
		NFS 610	0.033"			
Density	9.993/10.401	NFS 611	10.36 g/cc			
		NFS 610	10.14 g/cc			
% Second Phase	< 5%	NFS 611	Meets Specification	}	As determined by metallographic preparation & x-ray diffraction	
		NFS 610	Meets specification			
Isotopic		NFS 610	<u>Center</u>		<u>Outer</u>	
		Pu-239	90.95 wt %		90.88 wt %	
		Pu-240	8.22		8.28	
		Pu-241	0.79		0.80	
		Pu-242	0.04		0.04	
		U-234	0.001		0.000	
		U-235	0.23		0.24	
		U-236	0.006		0.006	
		U-238	99.76		99.76	
		Pu/Pu-U	20.36		20.62	
	<u>Pu-239+241</u>	18.7±0.1				
	<u>Pu+U</u>					

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TABLE 8.5-4 (continued)

<u>Characteristic</u>	<u>Specifications</u>	<u>Batch</u>	<u>Volume Percent</u>				
Gas Analysis	50 $\mu\text{l/g}$	NFS 612	Total ($\mu\text{l/g} \pm 10\%$)	<u>H₂</u>	<u>N₂</u>	<u>CO</u>	<u>He</u>
		<u>Sample Point</u>					
	One Pellet	Peripheral	72.2	50.8	8.2	38.8	0.5
		Mid-Radius	48.0	43.5	35.7	20.2	0.6
	2nd Pellet	Random	13.8	52.1	22.6	22.3	1.2
Impurity		NFS 610	<u>General Electric Company-VNC Results, PPM</u>				
				<u>Cl</u>	<u>F</u>	<u>N</u>	
	One Pellet	Inner Sample	<1	<1	<1	<9	
		Peripheral Sample	<1	<1	<1	<1	

Independent Laboratory Results

All values are reported in parts per million. For the spectrographic analysis, a value preceded by a less than symbol (<) indicates the element was detected, but at a concentration less than the indicated value. A hyphen indicates the element was sought but not detected. Reported values are estimated to be within a factor of two of the actual concentration. The results for chloride and fluoride analyses were both less than the values indicated with no implication that chloride or fluoride was or was not detected. Carbon results are estimated to be within 10 percent of the actual concentration. There was no carbon analysis on Blend 609, as the sample was discarded before the carbon analyses were made.

	<u>Blend 609</u>	<u>Blend 610</u>		<u>Blend 609</u>	<u>Blend 610</u>		<u>Blend 609</u>	<u>Blend 610</u>
Ag	5	1	Fe	50	50	Pb	5	1
Al	100	200	In	-	-	Sb	-	-
As	-	-	K	-	-	Si	<10	20
B	<.2	-	Li	-	-	Sn	-	<5
Ba	-	-	Mg	<1	<1	Ti	<5	<5
Be	-	-	Mn	1	5	Tl	-	-
Bi	<.5	5	Mo	-	-	V	-	< 50
Ca	<2	50	Na	10	<2	Zn	-	-
Cd	-	-	Ni	<20	<20	C	-	50
Cr	<5	5	P	<50	<50	F	<10	<10
Cu	0.5	5				Cl	<5	<5

Table 8.5-4 (continued)

<u>Characteristic</u>	<u>Batch</u>	<u>Results</u>
Homogeneity		
Alpha Autoradiography	NFS 609	No indication of gross inhomogeneity.
	NFS 611	No indication of gross inhomogeneity.
Chemical	NFS 610	Note isotopic results No indication of gross inhomogeneity.
Physical Appearance		Poor -- cracking and crazing predominate. See Photos
Electron Microprobe	NFS 612	
<p>A "square" inclusion was located in a pellet from NFS batch 612. This inclusion was identified to be almost pure Al_2O_3. It contained no Pu or U. The inclusion was ~1 mil by 2 mils in size and located near the periphery. It appeared to have been in the green pellet. No Al_2O_3 containing compound was used in the sample preparation.</p>		
X-Ray Diffraction		Well crystallized, single phase mixed (Pu-U) oxide.

were the subject of questionable plutonium content and is fully discussed in Section 8.2. Figures 8.5-10 and 8.5-11 show alpha autoradiographs of pellet batch 620. Analytical results appear in Table 8.5-5.

8.5.6 Master Mix 105

Master Mix 105 was prepared for use in producing the pellet for the guinea pig rods (Pu-239 & 241/Pu+U+25%). No discrepancies were noted. Analytical results appear in Table 8.5-6. Alpha autoradiograph is shown in Figure 8.5-12.

Figure 8.5-10

Alpha-Autoradiograph MM104 (Batch 620)

Figure 8.5-11
Alpha-Autoradiograph MM104 (Batch 621)

TABLE 8.5-5

SUMMARY OF GE ANALYTICAL RESULTS FOR MASTER BLEND 104

<u>Characteristic</u>	<u>Specification</u>	<u>Batch</u>	<u>Top</u>	<u>Mid</u>	<u>Bottom</u>
Diameter	0.875"±0.001"	NFS 617 - 0°	<u>0.8703"</u>	<u>0.8734"</u>	<u>0.8691"</u>
		- 90°	<u>0.8710"</u>	0.8750"	<u>0.8702"</u>
		NFS 619 - 0°	<u>0.8705"</u>	0.8740"	<u>0.8716"</u>
		- 90°	<u>0.8726"</u>	0.8741"	<u>0.8700"</u>
		NFS 621 - 0°	0.8742"	0.8762"	0.8750"
		- 90°	0.8750"	0.8764"	0.8742"
		NFS 623 - 0°	<u>0.8734"</u>	0.8761"	0.8750"
		- 90°	0.8740"	0.8758"	0.8740"
Length	5/8"±3/32"		<u>0°</u>	<u>90°</u>	<u>180°</u>
		NFS 617	0.6222"	0.6260"	0.6224"
		NFS 619	0.6025"	0.5983"	0.5940"
		NFS 621	0.5842"	0.5841"	0.5833"
		NFS 623	0.6135"	0.6115"	0.6115"
				<u>270°</u>	

TABLE 8.5-5 (continued)

<u>Characteristic</u>	<u>Specification</u>	<u>Batch</u>	<u>Top</u>	<u>Bottom</u>
Dish Depth	0.015"±0.003"	NFS 617	0.0150"	0.0169"
			0.0167"	0.0141"
		NFS 619	0.0182"	0.0147"
			0.0158"	0.0137"
		NFS 621	<u>0.0123"</u>	<u>0.0089"</u>
			0.0129"	<u>0.0098"</u>
		NFS 623	0.0148"	0.0129"
			0.0148"	0.0145"
Shoulder	0.040"±0.010"	NFS 617	0.035"	0.040"
		NFS 619	0.040"	0.035"
		NFS 621	0.045"	0.040"
		NFS 623	0.040"	0.045"
Density	9.993/10.401 g/cc	NFS 617	10.05 g/cc	
		NFS 619	10.32 g/cc	
		NFS 621	10.18 g/cc	
		NFS 623	10.33 g/cc	

TABLE 8.5-5 (continued)

<u>Characteristic</u>	<u>Specification</u>	<u>Batch</u>				
% Second Phase	< 5%	NFS 621	Meets Specification	}	Metallographic and	
		NFS 621	Meets Specification		X-ray Diffraction	
Isotopic						
			<u>NFS 618</u>		<u>NFS 622</u>	
			Center	Outer	Center	Outer
	<u>Pu-239+241</u>		19.29	18.75	19.09	19.08
	Pu-239+241+U	Pu-239	90.94%	90.90%	90.88%	90.74%
	18.7±0.1%	240	8.24	8.27	8.27	8.37
		241	0.78	0.79	0.81	0.84
		242	0.04	0.04	0.04	0.05
		U-234	-	-	-	-
		235	0.23	0.23	0.50	0.24
		236	0.005	0.005	-	-
		238	99.76	99.77	99.5	99.76
		Pu/Pu+U	21.03	20.45	20.82	20.83
	O/M	1.98/1.99	NFS 618	<u>Inner</u> <u>1.998</u>	<u>Outer</u> <u>1.997</u>	
		NFS 622	<u>1.997</u>	<u>1.998</u>		

TABLE 8.5-5 (continued)

<u>Characteristic</u>	<u>Specification</u>	<u>Batch</u>	<u>Total</u> <u>($\mu\text{l/g}$)$\pm 10\%$</u>	<u>Volume Percent</u>				
				H_2	N_2	CO	CH_4	He
Gas Analysis	50 $\mu\text{l/g}$	NFS 617	90.2	45.0	21.7	23.7	0.3	0.1
		NFS 618	12.5	37.3	3.4	--	22.4	0.4
		NFS 619	14.8	15.0	2.2	9.7	0.2	0.1
		NFS 620	37.0	34.0	15.5	9.7	1.6	0.3
		NFS 621	25.7	17.5	1.1	--	2.0	0.1
		NFS 622	11.3	47.9	9.1	--	0.6	--
		NFS 623	19.9	34.4	5.0	22.7	0.6	0.3
		NFS 624	10.8	43.3	3.8	--	0.8	--

INDEPENDENT LABORATORY RESULTS (NFS 624)⁽³⁾

Impurity

Ag	<0.1 ⁽¹⁾	Ca	20	K	ND	Ni	20	Ti	ND
Al	100	Cd	ND	Li	ND	P	50	Tl	ND
As	ND ⁽²⁾	Cr	ND	Mg	5	Pb	5	V	<50
B	ND	Cu	5	Mn	5	Sb	ND	Zn	ND
Ba	ND	Fe	100	Mo	<5	Si	10	F	<5
Be	ND	In	<2	Na	1	Sn	<5	Cl	<10
BI	ND								

(1) < = Element detected but is less than indicated value

(2) ND = Not detected

(3) All results are in PPM.

TABLE 8.5-5 (continued)

Homogeneity

Alpha autoradiography

NFS 621

NFS 622

}

Meets specification - No indication
of gross inhomogeneity

Chemical

NFS

NFS

}

Meets specification - no indication
of gross inhomogeneity - note isotopic
results.

Physical Appearance

NFS 617/624

Generally better than previous, but
surface cracking and crazing still
predominates.

GEAP-137' 5

TABLE 8.5-6

GE ANALYTICAL RESULTS FOR MASTER MIX 105 (BATCH 627)

(G.E. I.D. B446)

<u>Characteristic</u>	<u>Specification</u>				
		<u>Top</u>		<u>Mid</u>	<u>Bottom</u>
Diameter	0.875"±0.001" - 0° - 90°	0.874"		0.874"	0.874"
		0.874"		0.874"	0.874"
		<u>0°</u>	<u>90°</u>	<u>180°</u>	<u>270°</u>
Length	5/8"±3/32"	0.637"	0.637"	0.635"	0.638"
Dish Depth	0.015"±0.003"	<u>Top</u>			<u>Bottom</u>
		Max - 0.0153"			0.0170"
		Min - 0.0131"			0.0128"
Shoulder	0.040"±0.010"	0.045"/0.055"			
Density	9.993/10.401 g/cc	10.28 g/cc			
% Second Phase	<5%	Alpha autoradiography indicates specification met - X-ray diffusion pending.			

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TABLE B.5-6 (continued)

Characteristic	Specification		Center	Edge					
Isotopic	(Pu-239+Pu-241)/(Pu+U)	Pu-239	90.97%	90.97%					
		-240	8.18%	8.20%					
		-241	0.81%	0.79%					
		-242	0.04%	0.04%					
		U-235	0.24%	0.23%					
	Pu/(Pu+U)		28.02%	28.00%					
O/M	1.98/1.99		1.998	1.998					
Total Gas	50 µl/g		7.7 µl/g	10.1 µl/g					
Homogeneity	Alpha Autoradiography		Indicates specification met						
	Chemical		Meets specification - see Pu/(Pu+U) analysis						
Physical Appearance			Best appearing pellets received from NPS.						
<u>Impurities (PPM)</u>									
Ag	<.1	Ca	100	K	ND	Ni	<20	Ti	ND
Al	20	Cd	ND	Li	ND	P	<50	Tl	ND
As	ND	Cr	<5	Mg	5	Pb	1	V	ND
B	ND	Cu	2	Md	5	Sb	ND	Zn	50
Ba	ND	Fe	20	Mo	ND	Si	10	F	<5
Be	ND	In	ND	Na	2	Sn	10	Cl	<10
Bi	ND								
X-Ray Diffraction		Results show well crystallized, single phase, PuO ₂ -UO ₂ solid solutions.

REFERENCES

1. R. A. Meyer et al., "Design and Analysis of SEFOR Core I", GEAP-13598 (June, 1970).
2. SEFOR Facility Design and Safety Analysis Report, Supplement 5, "Additional Information on SEFOR Fuel Quality Control and Inspection".
3. C. N. Craig et al., "Plutonium-Uranium Mixed Oxide Fuel Pellet Fabrication Development for the Southwest Fast Oxide Reactor", GEAP-5285, October, 1966.
4. A. L. Schaeffler, Welding Journal, V. 26, n.10, Research Supplement, p. 601S-620S, October 1947, "Selection of Austenitic Electrodes for Welding Dissimilar Metals",

also

Metals Progress 56, p. 680, 949.
5. W. L. Lyon, "The Measurement of Oxygen to Metal Ratio in Solid Solution of Uranium and Plutonium Dioxides", GEAP-4271, May 1963.

APPENDIX A

Plutonium Nitrate Analyses from Atlantic Richfield
Hanford Co. (ARHCO).

TECHNICAL SERVICES SECTION
Z-PLANT
ANALYTICAL LABORATORY REPORT

IDENTIFICATION: Amended SEFOR ReportsMATERIAL: Plutonium
Nitrate

The analytical values reported on the following listed SEFOR lots should be amended as indicated:

<u>SEFOR Lot Identification</u>	<u>Amend reported chloride number to read</u>
26-11-1	<10 ppm
26-11-2	<10 ppm
26-12-1	<10 ppm
26-12-2	10

APPROVED:

J. H. Fillmore, Manager
Z-Plant Analytical Laboratory
Technical Services Section

DATE: March 1, 1967

**PLUTONIUM FINISHING SECTION
ANALYTICAL LABORATORY REPORT**

17m 101

IDENTIFICATION: SEFOR 26-11-1MATERIAL: Plutonium
Nitrate

< = Less Than

Plutonium Concentration *	0.1482 g Pu/g of solution
H ⁺	3.97 M
Specific Gravity	1.458
Fluoride	10 ppm
Chloride	140 ppm
Uranium	390 ppm
Sulfate	<1000 ppm
Carbon	130 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	<2	<20	1	<1	<1	2	<10	5	1	223	<5	<10

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<2	<2	<5	2	<5	<100	20	20	<1	<5	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
<u>91.006</u>	8.161	0.802	0.031

APPROVED:

W. L. Akers
W. L. Akers, Chemist
Analytical Laboratory
Quality Control, PFS

J. W. Fillmore
J. W. Fillmore, Manager
Quality Control
Plutonium Finishing Section

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PLUTONIUM FINISHING SECTION
ANALYTICAL LABORATORY REPORT

IDENTIFICATION: SEFOR 26-11-2MATERIAL: Plutonium Nitrate

< = Less Than

Plutonium Concentration *	0.1487 g Pu/g of solution
H ⁺	3.97 M
Specific Gravity	1.455
Fluoride	10 ppm
Chloride	160 ppm
Uranium	434 ppm
Sulfate	<1000 ppm
Carbon	180 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	100	<20	<1	<1	<1	2	<10	5	1	190	<5	20

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<2	1	<10	20	5	<100	2	146	1	10	<1	<100	5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
90.988	8.196	0.782	0.034

APPROVED:

W. L. Akers
W. L. Akers, Chemist
Analytical Laboratory
Quality Control, PFS

J. W. Fillmore
J. W. Fillmore, Manager
Quality Control
Plutonium Finishing Section

* Not to be used for official transfer quantities.

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ANALYTICAL LABORATORY REPORT

IDENTIFICATION: SEFOR 26-12-1MATERIAL: Plutonium Nitrate

< = Less Than

Plutonium Concentration *	0.1439 g Pu/g of Solution
H ⁺	3.98 M
Specific Gravity	1.449
Fluoride	11 ppm
Chloride	235 ppm
Uranium	607 ppm
Sulfate	<1000 ppm
Carbon	245 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	5	<20	<1	<1	<1	5	<10	5	<1	212	<5	20

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<2	10	<10	100	<5	<100	2	32	<1	<5	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
91.022	8.155	0.786	0.037

APPROVED: W. L. Akers
W. L. Akers, Chemist
Analytical Laboratory
Quality Control, PFS

J. W. Fillmore
J. W. Fillmore, Manager
Quality Control Subsection
Plutonium Finishing Section

* Not to be used for official transfer quantities.

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ANALYTICAL LABORATORY REPORT

IDENTIFICATION: SEFOR 26-12-2MATERIAL: Plutonium Nitrate

< = Less Than

Plutonium Concentration *	0.1474 g Pu/g of solution
H ⁺	3.86 M
Specific Gravity	1.468
Fluoride	18 ppm
Chloride	97 ppm
Uranium	645 ppm
Sulfate	<1000 ppm
Carbon	200 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K	
<1	<2	<20	<1	<1	<1	2	<10	5	2	240	<5	<10	
Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<2	<2	<10	50	<5	<100	<1	30	5	<5	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
90.943	8.210	0.809	0.038

APPROVED:

W. L. Akers

W. L. Akers, Chemist
Analytical Laboratory
Quality Control, PFS

J. W. Fillmore

J. W. Fillmore, Manager
Quality Control
Plutonium Finishing Section

*Not to be used for official transfer quantities.

PLUTONIUM FINISHING SECTION
ANALYTICAL LABORATORY REPORT

IDENTIFICATION: SEFOR 27-1-1MATERIAL: Plutonium
Nitrate

< = Less Than

Plutonium Concentration *	0.1481 g Pu/g of solution
H ⁺	3.81 M
Specific Gravity	1.471
Fluoride	<10 ppm
Chloride	<10 ppm
Uranium	468 ppm
Sulfate	<1000 ppm
Carbon	150

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	5	<20	<1	<1	<1	2	<10	5	2	280	<5	50

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	5	1	<10	200	<5	<100	<1	505	1	<5	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
90.978	8.188	0.791	0.043

APPROVED: W. L. Akers
W. L. Akers, Chemist
Analytical Laboratory
Quality Control, PFS

J. W. Fillmore
J. W. Fillmore, Manager
Quality Control
Plutonium Finishing Section

* Not to be used for official transfer quantities.

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ANALYTICAL LABORATORY REPORT**

IDENTIFICATION: SEFOR 27-1-2MATERIAL: Plutonium
Nitrate

< = Less Than

Plutonium Concentration *	0.1554 g Pu/g of solution
H ⁺	4.10 M
Specific Gravity	1.487
Fluoride	<10 ppm
Chloride	<10 ppm
Uranium	298 ppm
Sulfate	<1000 ppm
Carbon	155 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	2	<20	2	<1	<1	<2	<10	<5	<1	158	<5	<10

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	100	<2	<10	10	<5	<100	<1	40	<1	<5	<1	<100	<5

Isotopic Analysis - Weight PercentPu 239Pu 240Pu 241Pu 242

90.596

8.430

0.921

0.053

APPROVED:

W. L. Akers
W. L. Akers, Chemist
Analytical Laboratory
Quality Control, PFS

J. W. Fillmore
J. W. Fillmore, Manager
Quality Control
Plutonium Finishing Section

* Not to be used for official transfer quantities.

TECHNICAL SERVICES SECTION
Z-PLANT ANALYTICAL LABORATORY REPORT

IDENTIFICATION: SEFOR 27-1-3MATERIAL: Plutonium
Nitrate

< = Less Than

Plutonium Concentration *	0.1543 g Pu/g of solution
H ⁺	3.78 M
Specific Gravity	1.482
Fluoride	<10 ppm
Chloride	16 ppm
Uranium	180 ppm
Sulfate	<1000 ppm
Carbon	60 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	<2	<20	1	<1	<1	2	<10	5	2	512	<5	<10

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<1	1	<10	2	5	<100	<1	16	2	<5	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
90.742	8.329	0.881	0.048

APPROVED:

W. L. Akers
W. L. Akers, Chemist
Z-Plant Analytical Laboratory
Technical Services Section

J. W. Fillmore
J. W. Fillmore, Manager
Z-Plant Analytical Laboratory
Technical Services Section

* Not to be used for official transfer quantities.

TECHNICAL SERVICES SECTION
Z-PLANT ANALYTICAL LABORATORY REPORT

IDENTIFICATION: SEFOR 27-1-4MATERIAL: Plutonium Nitrate

< = Less Than

Plutonium Concentration*	0.1530 g Pu/g of solution
H ⁺	4.25 M
Specific Gravity	1.475
Fluoride	28 ppm
Chloride	<10 ppm
Uranium	215 ppm
Sulfate	2100 ppm
Carbon	195 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	<2	<20	<1	<1	<1	<2	<10	10	<1	415	<5	<10

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<2	<2	<10	20	<5	200	<1	50	10	<5	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
90.833	8.273	0.856	0.038

APPROVED:

W. L. Akers

W. L. Akers, Chemist
Z-Plant Analytical Laboratory
Technical Services Section

J. W. Fillmore

J. W. Fillmore, Manager
Z-Plant Analytical Laboratory
Technical Services Section

* Not to be used for official transfer quantities.

TECHNICAL SERVICES SECTION
Z-PLANT ANALYTICAL LABORATORY REPORT

IDENTIFICATION: SEFOR 27-2-1MATERIAL: Plutonium Nitrate

< = Less Than

Plutonium Concentration*	0.1592 g Pu/g of solution
H ⁺	3.92 M
Specific Gravity	1.493
Fluoride	115 ppm
Chloride	<10 ppm
Uranium	215 ppm
Sulfate	4000 ppm
Carbon	155 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	10	<20	<1	<1	<1	<2	<10	<5	1	550	<5	50

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<1	<1	<10	10	<5	<100	<1	340	1	<5	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
90.911	8.175	0.870	0.044

APPROVED:

W. L. Akers

W. L. Akers, Chemist
Z-Plant Analytical Laboratory
Technical Services Section

J. W. Fillmore

J. W. Fillmore, Manager
Z-Plant Analytical Laboratory
Technical Services Section

* Not to be used for official transfer quantities.

TECHNICAL SERVICES SECTION
Z-PLANT ANALYTICAL LABORATORY REPORT

IDENTIFICATION: SEFOR 27-3-1MATERIAL: Plutonium Nitrate

< = Less Than

Plutonium Concentration *	0.1549 g Pu/g of solution
H ⁺	3.87 M
Specific Gravity	1.481
Fluoride	13 ppm
Chloride	<10 ppm
Uranium	488 ppm
Sulfate	<1000 ppm
Carbon	100 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Ba	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	<2	<20	<1	<1	<1	<2	<10	5	<1	362	<5	<10

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<1	1	<10	10	5	<100	1	27	2	<5	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
90.854	8.274	0.831	0.041

APPROVED:

W. L. Akers

W. L. Akers, Chemist
Z-Plant Analytical Laboratory
Technical Services Section

J. W. Fillmore

J. W. Fillmore, Manager
Z-Plant Analytical Laboratory
Technical Services Section

* Not to be used for official transfer quantities.

TECHNICAL SERVICES SECTION
Z-PLANT ANALYTICAL LABORATORY REPORT

IDENTIFICATION: SEFOR 27-3-3MATERIAL: Plutonium Nitrate

< = Less Than

Plutonium Concentration *	0.1518 g Pu/g of solution
H ⁺	4.61 M
Specific Gravity	1.508
Fluoride	35 ppm
Chloride	<10 ppm
Uranium	310 ppm
Sulfate	<1000 ppm
Carbon	85 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
20	<2	<20	<1	<1	<1	2	<10	20	<1	480	<5	<10

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<1	<1	<10	50	<5	<100	<1	95	5	<5	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
90.624	8.432	0.902	0.042

APPROVED:

W. L. Akers
W. L. Akers, Chemist
Z-Plant Analytical Laboratory
Technical Services Section

J. W. Fillmore
J. W. Fillmore, Manager
Z-Plant Analytical Laboratory
Technical Services Section

* Not to be used for official transfer quantities.

ANALYTICAL LABORATORY

SAMPLE NO. SEFOR 27-8-1

< = Less Than

Plutonium Concentration*	0.1520 g/g
H ⁺	4.32 M
Specific Gravity	1.485
Fluoride	<10 ppm
Chloride	<20 ppm
Uranium	225 ppm
Sulfate	<1000 ppm
Carbon	110 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	5	<20	<1	<1	<1	10	<1	<10	1	540	<5	10

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<1	<1	<5	20	<5	<100	<2	76	2	<5	<1	<100	5

Isotopic Analysis - Weight Percent

<u>Pu 238</u>	<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
<50 ppm	90.627	8.421	0.899	0.053

*Not to be used for official AEC transfer form value.

APPROVED:

D. M. Creighton
 D. M. Creighton, Chemist
 Z-Plant Analytical Laboratory
 Technical Services Section

J. W. Fillmore
 J. W. Fillmore, Manager
 Z-Plant Analytical Laboratory
 Technical Services Section

TECHNICAL SERVICES SECTION
ANALYTICAL LABORATORY

SAMPLE NO. SEFOR 27-8-2

< = Less Than

Plutonium Concentration*	0.1535 g/g
H ⁺	3.89 M
Specific Gravity	1.480
Fluoride	<20 ppm
Chloride	<10 ppm
Uranium	278 ppm
Sulfate	<1000 ppm
Carbon	<50 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	≤5	<20	≤1	≤1	≤1	5	<1	<10	2	1005	<5	<5

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	1	<1	<5	10	<5	<100	<2	47	<2	<5	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
90.732	8.336	0.882	0.050

* Not to be used for official AEC transfer form value.

APPROVED:

W. R. Garity
W. R. Garity, Supervisor
Z-Plant Analytical Laboratory
Technical Services Section

J. W. Fillmore
J. W. Fillmore, Manager
Z-Plant Analytical Laboratory
Technical Services Section

8-21-67

TECHNICAL SERVICES SECTION
ANALYTICAL LABORATORY

SAMPLE NO. SEFOR 27-8-3

< = Less Than

Plutonium Concentration*	0.1575 g/g
H ⁺	4.48 M
Specific Gravity	1.504
Fluoride	<10 ppm
Chloride	<10 ppm
Uranium	190 ppm
Sulfate	<1000 ppm
Carbon	125 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	<5	<20	1	<1	<1	5	<1	<1	1	530	<5	10

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<1	<1	<5	50	<5	200	<2	65	2	<5	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
90.864	8.259	0.833	0.044

* Not to be used for official AEC transfer form value.

APPROVED:

W. L. Akers
W. L. Akers, Supervisor
Z-Plant Analytical Laboratory
Technical Services Section

J. H. Fillmore
J. H. Fillmore, Manager
Z-Plant Analytical Laboratory
Technical Services Section

TECHNICAL SERVICES SECTION
ANALYTICAL LABORATORY

SAMPLE NO. SEFOR 27-8-4

< = Less Than

Plutonium Concentration*	0.1574 g/g
H ⁺	4.75 M
Specific Gravity	1.509
Fluoride	<10 ppm
Chloride	<10 ppm
Uranium	84 ppm
Sulfate	<1000 ppm
Carbon	180 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	<5	<20	<1	<1	<1	<5	<1	10	1	270	<5	10

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<1	<1	<5	20	<5	200	<2	170	2	<5	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
90.510	8.560	0.886	0.044

* Not to be used for official AEC transfer form value.

APPROVED:

W. L. Akers
W. L. Akers, Supervisor
Z-Plant Analytical Laboratory
Technical Services Section

J. W. Fillmore
J. W. Fillmore, Manager
Z-Plant Analytical Laboratory
Technical Services Section

TECHNICAL SERVICES SECTION
ANALYTICAL LABORATORY

SAMPLE NO. SEFOR 27-8-5

< = Less Than

Plutonium Concentration*	0.1570 g/g
H ⁺	4.61 M
Specific Gravity	1.518
Fluoride	<10 ppm
Chloride	<10 ppm
Uranium	42 ppm
Sulfate	<1000 ppm
Carbon	80 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	<5	<2	<1	<1	<1	<5	<1	10	1	280	<5	<5

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<1	<1	<5	100	<5	200	<2	299	2	<5	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
90.797	8.307	0.854	0.042

* Not to be used for official AEC transfer form value.

APPROVED:

W. L. Akers

W. L. Akers, Supervisor
Z-Plant Analytical Laboratory
Technical Services Section

J. W. Fillmore

J. W. Fillmore, Manager
Z-Plant Analytical Laboratory
Technical Services Section

TECHNICAL SERVICES SECTION
ANALYTICAL LABORATORY

SAMPLE NO. SEFOR 27-8-6

< = Less Than

Plutonium Concentration*	0.1571 g/g
H ⁺	4.33 M
Specific Gravity	1.518
Fluoride	<10 ppm
Chloride	<10 ppm
Uranium	84 ppm
Sulfate	<1000 ppm
Carbon	240 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	20	<20	<1	<1	<1	10	<1	<10	1	1375	<5	10

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<1	<1	<5	50	<5	200	2	95	2	10	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
90.755	8.320	0.879	0.046

APPROVED:

W. L. Akers
W. L. Akers, Supervisor
Z-Plant Analytical Laboratory
Technical Services Section

J. W. Fillmore
J. W. Fillmore, Manager
Z-Plant Analytical Laboratory
Technical Services Section

8-25-67

* Not to be used for official AEC transfer form value.

TECHNICAL SERVICES SECTION
ANALYTICAL LABORATORY

SAMPLE NO. SEFOR 27-9-1

< = Less Than

Plutonium Concentration* 0.1562 g/g
H⁺ 4.71 M
Specific Gravity 1.501
Fluoride <10 ppm
Chloride <10 ppm
Uranium 1290 ppm
Sulfate <1000 ppm
Carbon 110 ppm

Metallic Impurities - Parts Per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	<5	<20	<1	<1	<1	<5	<1	<10	<1	895	<5	<5

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<1	<1	<5	2	<5	200	<2	200	2	<5	<1	<100	50

Isotopic Analysis - Weight Percent

<u>Pu 239</u>	<u>Pu 240</u>	<u>Pu 241</u>	<u>Pu 242</u>
90.667	8.405	0.882	0.046

* Not to be used for official AEC transfer form value.

APPROVED:

W. L. Akers
W. L. Akers, Supervisor
Z-Plant Analytical Laboratory
Technical Services Section

N. S. Wing
N. S. Wing, Manager
Z-Plant Analytical Laboratory
Technical Services Section

9-20-67

TECHNICAL SERVICES SECTION
PLUTONIUM FINISHING ANALYTICAL LABORATORY REPORT

CUSTOMER: SEFOR 28-6-1

MATERIAL Plutonium Nitrate

< = Less Than

Plutonium Concentration	0.1468 g/g*
H ⁺	4.91 M
Specific Gravity	1.502
Fluoride	<10 ppm
Chloride	<10 ppm
Uranium	127 ppm
Sulfate	<1000 ppm
Carbon	145 ppm

Metallic Impurities - Parts per Million

Ag	Al	As	B	Be	Bi	Ca	Cd	Cr	Cu	Fe	Ge	K
<1	<10	<20	1	<1	<1	<10	<1	10	2	240	<5	<5

Li	Mg	Mn	Mo	Na	Ni	P	Pb	Si	Sn	Ti	Tl	V	Zn
<5	<1	<1	<5	1	<5	<100	<1	45	<1	<10	<1	<100	<5

Isotopic Analysis - Weight Percent

<u>Pu-239</u>	<u>Pu-240</u>	<u>Pu-241</u>	<u>Pu-242</u>
90.972	8.157	0.831	0.040

* Pu assay not corrected for bias. Analyzed by chemical assay on 6-25-68.

APPROVED:

W. L. Akers
W. L. Akers, Supervisor
Pu Finishing Analytical Laboratory
Technical Services Section

N. S. Wing
N. S. Wing, Manager
Pu Finishing Analytical Laboratory
Technical Services Section

APPENDIX B

Uranyl Nitrate Certificate of Analysis
from NFS.

CERTIFICATE OF ANALYSIS

Material Uranyl Nitrate Solution

Date _____

Customer General Electric Company

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. _____

Sales Order No. 256-A

ELEMENT	ANALYSIS, ppm				
	Specification		A-62376		A-62377
Batch			256-A-01		256-A-02
Ag	500		< 0.1		< 0.1
Al	500		6		8
B	5		< 0.2		< 0.2
C	150		< 75		< 75
Ca	25		< 20		< 20
Cd	20		< 0.1		< 0.1
Cl	25		< 10		< 10
Cr	500		8		14
Cu	500		4		6
F	130		< 15		18
Fe	500		90		95
Mg	25		10		10
Na	500		10		10
Ni	500		26		32
Pb	500		< 1		< 1
Si	100		75		80
Sn	500		< 1		< 1
V	500		< 2.5		< 2.5
Zn	500		30		30
Other Impurities					
Mo			< 1		< 1
P			10		15
Th			< 100		< 100
Ti			1.5		1.5
Zr			5		5
g U/ g Solution			0.22716		0.22599
*% U-235			0.2294		

*This value was obtained by having AVCO/Tulsa analyze a composite sample of the uranyl nitrate solution.

Certified By: K.D. Hensley

Quality Control Department

K.D. Hensley

CERTIFICATE OF ANALYSIS

Material Uranyl Nitrate Solution

Date March 4, 1967

Customer General Electric Company

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. _____

Sales Order No. 256-A

ELEMENT	ANALYSIS, ppm				
	Specification		A-52563		A-52564
Batch			256-A-03		256-A-04
Ag	500		< 0.1		< 0.1
Al	500		3		2
B	5		< 0.2		< 0.2
C	150		< 75		< 75
Ca	25		< 20		< 20
Cd	20		< 0.1		< 0.1
Cl	25		< 10		< 10
Cr	500		7		5
Cu	500		1		1
F	130		< 15		16
Fe	500		32		26
Mg	25		6		4
Na	500		10		10
Ni	500		15		12
Pb	500		< 1		< 1
Si	100		90		75
Sn	500		< 1		< 1
V	500		< 2.5		< 2.5
Zn	500		30		25
Other Impurities					
Mo			< 1		< 1
P			10		10
Th			200		125
Ti			1.0		1.0
Zr			5		5
g U/ g S ₂ O ₈			0.22273		0.23161

Certified By: K.D. Hensley

Quality Control Department
K.D. Hensley

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material Uranyl Nitrate Solution

Date _____

Customer General Electric Company

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. _____

Sales Order No. 256-A

ELEMENT	ANALYSIS, ppm					
	Specification		A-52565	256-A-05		
Batch						
Ag	500		< 0.1			
Al	500		3			
B	5		< 0.2			
C	150		< 75			
Ca	25		< 20			
Cd	20		< 0.1			
Cl	25		< 10			
Cr	500		7			
Cu	500		2			
F	130		< 15			
Fe	500		36			
Mg	25		4			
Na	500		10			
Ni	500		15			
Pb	500		< 1			
Si	100		90			
Sn	500		< 1			
V	500		< 2.5			
Zn	500		30			
Other Impurities						
Mo			4			
P			15			
Ti			1.2			
Zr			5			
Th			< 100			
g U/g <u>U₂O₈</u>			0.22235			

Certified By: K.D. Hensley

Quality Control Department

K.D. Hensley

APPENDIX C

NFS Certificates of Analysis for Master Mix
Solutions.

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Lot 256-A-101		ANALYSIS, ppm		
	Specification: 22A1545				
3(a)	UNH Addition				
	Drum No.	UNH Lot No.	Net Weight (lbs.)		
	14	256-A-01	658.0		
	23	256-A-01	665.4		
	9	256-A-01	658.2		
	30	256-A-01	257.9		
			Total	2239.5	
3(b)	Pu (NO ₃) ₄ Addition				
	Lot No.	NFS net wt. grams			
	26-11-1	159,292			
	26-12-1	158,426			
	26-12-2	86,815			
		Total	404,006		
3(c)	gms Pu/gm (Pu + U) Solution				
	59.145 Kg. Pu/1,419.856 Kg. Sol. = 0.0416				
3(d)	gms. U/gm (Pu + U) Solution				
	230,760 Kg. U/1419,856 Kg. Sol. = 0.1625				
3(e)	Pu/(Pu + U) Ratio				
		59,145	=	20.40%	
	59,145 + 230,760				

Original Signed by
K. D. Hensley
 Certified By: _____
 Quality Control Department
 K. D. Hensley

GEAP-13760

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

Date Shipped

San Jose, California

Bill of Lading No.

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Lot 256-A-101	ANALYSIS, ppm
	Specification:	22A1545
3(f)	<u>Pu 239,241/(Pu + U) Ratio</u>	
		18.728%
3(g)	<u>Analytical Confirmation of Pu/(Pu + U) Ratio</u>	
		20.49%
		20.54%
		20.54%
3(h)	<u>Pu 239,241/(Pu + U) Ratio</u>	
		16.53%

Original Signed L

K. D. Hensley

Certified By:

Quality Control Department
K. D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Lot 256-A-102		ANALYSIS, ppm			
	Specification: 22A1545					
3(c)	gms. Pu/gm (Pu + U) Solution					
	146.729 Kg. Pu/3,519,804 Kg. Sol. = 0.0417					
3(d)	gms. U/gm (Pu + U) Solution					
	572.341 Kg. U/3,519,804 Kg. Sol. = 0.1626					
3(e)	Pu/(Pu + U) Ratio					
	$\frac{146.729}{146.729 + 572.341} = 20.40\%$					
3(f)	Pu 239.241/(Pu + U) Ratio					
	18.723%					
3(g)	Analytical Confirmation of Pu/(Pu + U) Ratio					
	20.42%					
	20.41%					
	20.41%					
3(h)	Pu 239.241/(Pu + U) Ratio					
	16.53%					

Certified By: _____

Original Signed by

 Quality Control Department
 K. D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Lot 256-A-102		ANALYSIS, ppm		
	Specification: 22A1545				
3(a)	UNH Addition				
	Drum No.		UNH Lot No.		Net Weight (lbs.)
	18		256-A-01		661.0
	31		256-A-01		392.2
	16		256-A-01		658.6
	32		256-A-01		662.6
	13		256-A-02		419.1
	28		256-A-02		664.8
	29		256-A-02		669.3
	22		256-A-02		663.8
	21		256-A-02		664.7
	12		256-A-02		120.6
				Total	5576.7
3(b)	Pu(NO ₃) ₃ Addition				
	Lot No.		NFS Net Wt.	grams	
	26-11-2		143,858		
	26-12-2		28,942		
	27-3-4		133,141		
	27-3-5		131,439		
	27-3-3		146,285		
	27-3-1		131,724		
	27-3-6		131,660		
	27-4-1		143,197		
		Total	990,246		

Original Signed by

K. D. Hensley

Certified By: _____

Quality Control Department

K. D. Hensley

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Lot 256-A-103		ANALYSIS, ppm		
	Specification: 22A1545				
3(a)	UNH Addition				
	Drum No.		UNH Lot No.		Net weight (lbs.)
	42		256-A-02		584.9
	7		256-A-02		656.3
	38		256-A-03		627.7
	41		256-A-03		659.8
	36		256-A-03		659.6
	43		256-A-03		642.2
	39		256-A-03		438.2
	33		256-A-03		642.7
	40		256-A-03		631.8
	35		256-A-03		648.6
	25		256-A-04		124.0
			Total		6,315.8
3(b)	Pu (NO ₃) ₄ Addition				
	Lot No.		NFS net weight grams.		
	27-7-1		146,583		
	27-7-2		158,703		
	27-5-3		132,960		
	27-4-2		124,661		
	27-4-3		130,284		
	27-4-4		131,620		
	27-5-1		145,665		
	27-5-2		117,930		
		Total	1,088,406		

Original signed by

K. D. Hensley

Certified By: _____

Quality Control Department

K. D. Hensley

GEAP-13760

Erwin, Tennessee

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped _____

Bill of Lading No.

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Original Sign

REDACTED

Quality Control Department
K. D. Hensley

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 5/8/68

Customer General Electric

P. O. Box 254

San Jose, California

Date Shipped _____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	ANALYSIS, ppm				
	Lot 256-A-104				
	Specification:	22A1545			
3(a)	UNH Addition				
	Drum No.	UNH Lot No.		Net Weight	(lbs.)
	26	256-A-04		657.5	
	11	256-A-04		662.8	
	20	256-A-04		655.0	
	27	256-A-04		650.9	
	5	256-A-04		657.3	
	10	256-A-04		651.4	
	19	256-A-04		652.6	
	25	256-A-04		278.5	
	4	256-A-05		619.8	
	17	256-A-05		332.6	
			Total	5,818.4	
3(b)	Pu (NO ₃) _x Addition				
	Lot No.	NFS Net Wt. (grams)			
	27-8-1	146,273			
	27-8-2	146,704			
	27-8-3	59,872			
	27-8-4	163,540			
	27-8-5	149,079			
	27-8-6	164,518			
	27-9-1	162,320			
		Total	992,306		

Certified By: K. D. Hensley

Quality Control Department
K. D. Hensley

Erwin, Tennessee

C-9

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date September 16, 1968

Customer General Electric Company

P. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Lot 256-A-105		ANALYSIS, ppm		
	Specification:	22A1545			
3(a)	<u>UNH Addition</u>				
	<u>Drum No.</u>		<u>UNH Lot No.</u>	<u>Net Weight (Lbs.)</u>	
	24		256-A-05	519.9	
	24		256-A-05	6.94	
			Total -	526.84	
3(b)	<u>Pu(NO₃)₄ Addition</u>				
	<u>Lot No.</u>		<u>NFS Net Wt. (grams)</u>		
	28-6-1		136,452		
3(c)	<u>gms. Pu/gm (Pu + U) Solution</u>				
	20.023 kg Pu/ 238.969 kg. sol. = 0.0838				
3(d)	<u>gms. U/gm (Pu + U) Solution</u>				
	53.505 kg U/238.969 kg. sol. = 0.2239				
3(e)	<u>Pu/(Pu + U) Ratio</u>				
	20,023				
	20,023 + 53,505 = 0.2723				

Certified By: _____

Quality Control Department

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Sales Order No. 256-A

C-11

APPENDIX D

NFS Certificates of Analysis for Pellet Batches

Erwin, Tennessee

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped _____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-600		ANALYSIS, ppm	
	Specification:	22A1545		
10(h)	Impurities			
		Maximum Individual		
	Impurity	Impurity Limit (ppm)		Found
	H	5		0.3
	B	10		< 0.20
	N	200		13
	C	250		72
	Cl	25		8
	F	25		< 1
		All Others 2500		
	Al			57
	Ag			< 0.10
	Ca			13
	Cd			< 20
	Cr			25
	Cu			10
	Fe			82
	Mg			5
	Mn			8
	Mo			7
	Na			55
	Ni			50
	Pb			< 1
	Si			40
	Sn			< 2
	Ti			< 250
	V			< 5
	Zn			41
			Total	< 671

Certified By: _____

Original Signed by _____

Quality Control Department
 K. D. Hensley

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Sales Order No. 256-A

D-5

GEAP-13760

Date 2/2/68

Sales Order No. 256-A

Original Signed by
K. D. Hensley

Certified By: _____
Quality Control Department
K. D. Hensley

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped _____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-601		ANALYSIS, ppm		
	Specification:	22A1545			
10(h)	<u>Impurities</u>				
			Maximum Individual		
	<u>Impurity</u>		<u>Impurity Limit (ppm)</u>		<u>Found</u>
	H		5		.46
	B		10		< 0.20
	N		200		3.5
	C		250		96
	Cl		25		13
	F		25		15
		All Others	2500		
	Al				45
	Ag				< 0.10
	Ca				18
	Cd				0.30
	Cr				30
	Cu				2
	Fe				160
	Mg				3
	Mn				7
	Mo				12
	Na				6
	Ni				38
	Pb				< 2
	Si				50
	Sn				< 2
	Ti				< 250
	V				< 5
	Zn				< 25
				Total	< 655

Certified By: _____

Original Signed by

K. D. Hensley

Quality Control Department

K. D. Hensley

GEAP-13760

Date 2/2/68

Date Shipped_____

Bill of Lading No. _____

Sales Order No. 256-A

Certified By: [Signature]

D-9

GEAP-13760

Material UO₂-PuO₂ Pellets

Date. 2/2/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Original Signed by
R. D. Hensley

Certified By:

Quality Control Department
K. D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 602 ANALYSIS, ppm				
	Specification: 22A1545				
10(d)	Pellets shall be single phase mixed oxide with not more than 5 per cent of material appearing as a second phase outside of solution.				
	Sample				
	1. Acceptable				
	2. Acceptable				
	3. Acceptable				
10(f)	The atom ratio of oxygen to heavy metal (Uranium plus Plutonium) shall be 1.97--1.99.				
	Center		Outer Diameter		
	1.988		1.990		
10(i)	Volatiles				
	Specification			Found	
	0.05 cc/gram (excluding water)			0.01 cc/gm.	
	30 ppm. total moisture			27	
10(i)	Homogeneity				
	Sample				
	1. Acceptable				
	2. Acceptable				
	3. Acceptable				

Original Signed by

K. D. Hensley

Certified By: _____

Quality Control Department
K. D. Hensley

GEAP-13760

Date February 2, 1968

Date Shipped _____

Bill of Lading No. _____

Sales Order No. 256-A

Original Signed by
K. D. Hensley
Certified By: _____
Quality Control Department
K. D. Hensley

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Date February 2, 1968.

Date Shipped_____

Bill of Lading No. _____

Sales Order No. 256-A

Sales Order No. 256-A

Certified By:

Quality Control Department
K. D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date February 2, 1968.

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-603		ANALYSIS, ppm		
	Specification:	22A1545			
10(h)	Impurities				
			Maximum Individual		
	Impurity		Impurity Limit (ppm)	Found	
	H		5	0.22	
	B		10	< 2	
	N		200	< 1	
	C		250	77	
	Cl		25	10	
	F		25	10	
			All Others	2500	
	Al			65	
	Ag			< 1	
	Ca			10	
	Cd			< 2	
	Cr			37	
	Cu			4	
	Fe			64	
	Mg			< 2	
	Mn			< 2	
	Mo			6	
	Na			4	
	Ni			92	
	Pb			< 1	
	Si			72	
	Sn			< 2	
	Ti			< 250	
	V			< 5	
	Zn			< 25	
			Total	< 644	

Certified By: _____

Original Signed by

K. D. Hensley

Quality Control Department

K. D. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets

Date February 2, 1968

Customer General Electric

P.O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department
K. D. Hensley

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Date February 2, 1968

Date Shipped

Bill of Lading No.

Sales Order No. 256-A

Purchase Order No. 205-58226-NG

Original Signed by
K. D. Hensley

Certified By: _____
Quality Control Department
K. D. Hensley

NUCLEAR FUEL SERVICES INC.

GEAP-13760

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date February 2, 1968

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-604					ANALYSIS, ppm	
	Specification: 22A1545						
10(d)	Pellets shall be single phase mixed oxide with not more than 5 per cent of material appearing as a second phase outside of solution.						
	<u>Sample</u>						
	1. Acceptable						
	2. Acceptable						
	3. Acceptable						
10(f)	The atom ratio of oxygen to heavy metal (Uranium plus Plutonium) shall be 1.97--1.99.						
	<u>Center</u>			<u>Outer Diameter</u>			
	1.990			1.988			
10(i)	<u>Volatiles</u>						
	<u>Specification</u>					<u>Found</u>	
	0.05 cc/gram (excluding water)					0.01 cc/gm.	
	30 ppm total moisture					28	
10(j)	<u>Homogeneity</u>						
	<u>Sample</u>						
	1. Acceptable						
	2. Acceptable						
	3. Acceptable						

Original Signed by

K. D. Hensley

Certified By: _____

Quality Control Department

K. D. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets

Date February 2, 1968

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped_____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Original Signed by
K. D. Hensley
Certified By: _____
Quality Control Department
K. D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date February 2, 1968

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-EG

Sales Order No. 256-A

ELEMENT	Blend 256-A-605 ANALYSIS, ppm				
	Specification: 22A1545				
10(d)	Pellets shall be single phase mixed oxide with not more than 5 per cent of material appearing as a second phase outside of solution.				
	<u>Sample</u>				
	1. Acceptable				
	2. Acceptable				
	3. Acceptable				
10(f)	The atom ratio of oxygen to heavy metal (Uranium plus Plutonium) shall be 1.97--1.99.				
	<u>Center</u>		<u>Outer Diameter</u>		
	1.987		1.986		
10(i)	<u>Volatiles</u>				
	<u>Specification</u>			<u>Found</u>	
	0.05 cc/gram (excluding water)			0.018	
	30 ppm total moisture			28	
10(j)	<u>Homogeneity</u>				
	<u>Sample</u>	<u>Center</u>	<u>Edge</u>	<u>mm/102</u>	
	1. Acceptable	2029	2027	20405	
	2. Acceptable				
	3. Acceptable				

Original Signed by
K. D. Hensley
Certified By: _____
Quality Control Department
K. D. Hensley

GEAP-13760

Erwin, Tennessee

Material UO₂-PuO₂ Pellets

Date February 2, 1968

Customer General Electric

P. O. Box 254

San Jose, California

Date Shipped_____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department

K. D. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets

Date February 2, 1968

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped

Bill of Lading No.

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Original Signed by

R. A. Henderson

Quality Control Department
K. D. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped

Bill of Lading No.

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Original Signed by
K. D. Hensley

Certified By: _____
Quality Control Department
K. D. Hensley

GEAP-13760

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-607	ANALYSIS, ppm			
	Specification: 22A1545				
10(d)	Pellets shall be single phase mixed oxide with not more than 5 per cent of material appearing as a second phase outside of solution.				
	<u>Sample</u>				
	1. Acceptable				
	2. Acceptable				
	3. Acceptable				
10(f)	The atom ratio of oxygen to heavy metal (Uranium plus Plutonium) shall be 1.97--1.99.				
		<u>Center</u>		<u>Outer Diameter</u>	
		1.983		1.984	
10(g)	<u>Verification of Pu/(Pu + U) Ratio</u>				
	20.28%				
	20.26%				

Original Signed by

K. D. Hersley

Certified By:

Quality Control Department

K. D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O., Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-607		ANALYSIS, ppm	
	Specification:	22A1545		
10(h)	<u>Impurities</u>			
	<u>Impurity</u>	<u>Maximum Individual Impurity Limit (ppm)</u>	<u>Found</u>	
	H	5	3	
	B	10	0.20	
	N	200	17	
	C	250	37	
	Cl	25	< 1	
	F	25	< 10	
	<u>All Others 2500</u>			
	Al		70	
	Ag		0.60	
	Ca		9	
	Cd		.20	
	Cr		38	
	Cu		< 2	
	Fe		118	
	Mg		< 2	
	Mn		< 2	
	Mo		7	
	Na		5	
	Ni		14	
	Pb		< 1	
	Si		99	
	Sn		< 2	
	Ti		< 250	
	V		< 5	
	Zn		< 25	
	<u>Total</u>		<u>< 541</u>	

Certified By: _____

Original Signed by:
K. D. Hensley

Quality Control Department
K. D. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets
Customer General Electric
P.O. Box 254
San Jose, California
Purchase Order No. 205-58226-NG

Date 2/2/68

Date Shipped_____

Bill of Lading No. _____

Sales Order No. 256-A

Certified By: John D. Bradley

Quality Control Department
K. D. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets
Customer General Electric
P.O. Box 254
San Jose, California
Purchase Order No. 205-58226-NG

Date 2/2/68

Date Shipped_____

Bill of Lading No. _____

Sales Order No. 256-A

Original Signed by
K. D. Hensley

Certified By:

Quality Control Department
K. D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
 Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped _____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-608		ANALYSIS, ppm	
	Specification: 22A1545			
10(d)	Pellets shall be single phase mixed oxide with not more than 5 per cent of material appearing as a second phase outside of solution.			
	<u>Sample</u>			
	1. Acceptable			
	2. Acceptable			
	3. Acceptable			
10(f)	The atom ratio of oxygen to heavy metal (Uranium plus Plutonium) shall be 1.97--1.99.			
	<u>Center</u>		<u>Outer Diameter</u>	
	1.988		1.986	
10(g)	Verification of Pu/(Pu + U) Ratio			
	20.22%			
	20.24%			
10(i)	<u>Volatiles</u>			
	<u>Specification</u>		<u>Found</u>	
	30 ppm total moisture		29	
10(j)	<u>Homogeneity</u> (Autoradiography)			
	<u>Sample</u>			
	1. Acceptable			
	2. Acceptable			
	3. Acceptable			

Certified By: _____

Quality Control Department
 K. D. Hensley

GEAP-13760

Erwin, Tennessee

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department

K. D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
 Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 5/23/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-609		ANALYSIS, ppm	
	Specification: 22A1545			
10(a)	Perpendicularity			
	Number Run	Number Rejected	Allowable Rejects	
	125	1	14	
	<u>End Flatness</u>			
	Number Run	Number Rejected	Allowable Rejects	
	125	0	14	
10(b)	Pellet density shall be 9.993 to 10.401 grams per cubic centimeter based on dimensions and weight. Density of the pellets from surface to center shall not vary more than ± 2 percent from the average density of the pellet.			
	<u>Geometric Density</u>			
	Number Run	Number Rejected	Allowable Rejects	
	125	6	7	
	<u>Immersion Density</u>			
	10.33 g/cc			
	10.24			
	10.21			

Certified By: K. D. Hensley

Quality Control Department
 K. D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 5/23/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-609 ANALYSIS, ppm				
	Specification: 22A1545				
10(d)	Pellets shall be single phase mixed oxide with not more than 5 per cent of material appearing as a second phase outside of solution.				
	Sample				
	1. Acceptable				
	2. Acceptable				
	3. Acceptable				
10(f)	The atom ratio of oxygen to heavy metal (Uranium plus Plutonium) shall be 1.97--1.99.				
	<u>Center</u>		<u>Outer Diameter</u>		
	1.985		1.989		
10(i)	Volatiles				
	Specification			<u>Found</u>	
	0.05 cc/gram (excluding water)			0.040 cc/gm.	
10(j)	<u>Homogeneity (Autoradiography)</u>				
	Sample				
	1. Acceptable				
	2. Acceptable				
	3. Acceptable				

Certified By: _____

Quality Control Department
K. D. Hensley

GEAP-13760

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-610		ANALYSIS, ppm	
	Specification:	22A1545		
10(a)	<u>Perpendicularity</u>			
	Number Run		Number Rejected	Allowable Rejects
	125		0	14
	<u>End Flatness</u>			
	Number Run		Number Rejected	Allowable Rejects
	125		0	14
10(b)	Pellet density shall be 9.993 to 10.401 grams per cubic centimeter, based on dimensions and weight. Density of the pellets from surface to center shall not vary more than + 2 per cent from the average density of the pellet.			
	<u>Geometric Density</u>			
	Number Run		Number Rejected	Allowable Rejects
	125		2	7
	<u>Immersion Density</u>			
	10.36	g/cc		
	10.33			
	10.36			

Original Signed by

E. B. Hensley

Certified By:

Quality Control Department
K. D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
 Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-610		ANALYSIS, ppm			
	Specification: 22A1545					
10(d)	Pellets shall be single phase mixed oxide with not more than 5 per cent of material appearing as a second phase outside of solution.					
	<u>Sample</u>					
	1. Acceptable					
	2. Acceptable					
	3. Acceptable					
10(f)	The atom ratio of oxygen to heavy metal (Uranium plus Plutonium) shall be 1.97--1.99.					
		<u>Center</u>		<u>Outer Diameter</u>		
		1.987		1.987		
10(i)	<u>Volatiles</u>					
	<u>Specification</u>				<u>Found</u>	
	30 ppm total moisture				24	
10(j)	<u>Homogeneity</u>					
	<u>Sample</u>					
	1. Acceptable					
	2. Acceptable					
	3. Acceptable					

Certified By: _____

Original Signed by
K. D. Hensley

Quality Control Department
 K. D. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets
Customer General Electric
P.O. Box 254
San Jose, California
Purchase Order No. 205-58226-NG

Date February 2, 1968

Date Shipped _____
Bill of Lading No. _____
Sales Order No. 256-A _____

Original Signed by
K. D. Hensley

Certified By: _____

Quality Control Department
K. D. Hensley

Erwin, Tennessee

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GEAP-13760

Erwin, Tennessee

Material UO₂-PuO₂ Pellets

Date 2/2/68

Customer General Electric

P.O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department

K. D. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets

Date 4/26/68

Customer General Electric

P. O. Box 254

San Jose, California

Date Shipped_____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

D-37

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 4/26/68

Customer General Electric

P. O. Box 254

San Jose, California

Date Shipped_____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

[illegible]

Certified By:..

Quality Control Department
K. D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
 Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 4/26/68

Customer General Electric

P. O. Box 254

San Jose, California

Date Shipped _____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-612		ANALYSIS, ppm		
	Specification:	22A1545			
10(h)	Impurities				
		Maximum Individual			
	Impurity	Impurity Limit (ppm)		Found	
	H	5		1.4	
	B	10		< 0.20	
	N	200		20	
	C	250		54	
	Cl	25		7	
	F	25		8	
		All Others 2500			
	Al			89	
	Ag			0.20	
	Ca			21	
	Cd			< 0.20	
	Cr			40	
	Cu			< 2.0	
	Fe			200	
	Mg			< 2	
	Mn			< 2	
	Mo			4	
	Na			20	
	Ni			29	
	Pb			5	
	Si			69	
	Sn			< 2	
	Ti			< 250	
	V			< 5	
	Zn			< 25	
			Total	< 856	

Certified By: K. D. Hensley

Quality Control Department
 K. D. Hensley

GEAP-13760

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 4/26/68

Customer General Electric

P. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

[illegible]

Certified By:.

Quality Control Department
K. D. Hensley

GEAP-13760

Erwin, Tennessee

Material UO₂-PuO₂ Pellets

Date 5/27/68

Customer General Electric

P. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department

K.D. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets

Date 5/27/68

Customer General Electric

P.O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department
K. D. Hensley

GEAP-13760

GEAP-13760

Erwin, Tennessee

Material UO₂-PuO₂ Pellets

Date 4/26/68

Customer General Electric

P. O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department

K. D. Hensley.

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ pelletsDate 4/26/68Customer General ElectricP. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NGSales Order No. 256-A

ELEMENT	Blend 256-A-615 ANALYSIS, ppm				
	Specification:	22A1545			
10(d)	Pellets shall be single phase mixed oxide with not more than 5 percent of material appearing as a second phase outside of solution.				
	Sample				
	1. Acceptable				
	2. Acceptable				
	3. Acceptable				
10(f)	The atom ratio of oxygen to heavy metal (Uranium plus Plutonium) shall be 1.97--1.99.				
		Center		Outer Diameter	
		1.985		1.986	
10(i)	Volatiles				
	Specification			Found	
	0.05 cc/gram (excluding water)			0.021	
				0.012	
10(j)	Homogeneity (Autoradiography)				
	Sample				
	1. Acceptable				
	2. Acceptable				
	3. Acceptable				

Certified By: K. D. Hensley

Quality Control Department

K. D. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets
Customer General Electric
P.O. Box 254
San Jose, California
Purchase Order No. 205-58226-NG

Date 5/13/68

Date Shipped_____

Bill of Lading No. _____

Sales Order No. 256-A

Certified By: K. D. Hensley
Quality Control Department
K. D. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets

Date 5/13/68

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped_____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department
K. D. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets

Date 5/13/68

Customer General Electric

P. O. Box 254

San Jose, California

Date Shipped_____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By: R. A. [Signature]

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GEAP-13760

CERTIFICATE OF ANALYSIS

Date 5/16/68

Date Shipped _____

Bill of Lading No. _____

Sales Order No. 256-A

Sales Order No. 256-A

Certified By: P. H. [Signature]

D-49.

GEAP-13760

Erwin, Tennessee

Material UO₂-PuO₂ Pellets

Date 5/16/68

Customer General Electric

P.O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department
K. D. Hensley

GEAP-13760

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 5/16/68

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped_____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-617		ANALYSIS, ppm	
	Specification:	22A1545		
10(h)	<u>Impurities</u>			
	<u>Impurity</u>	<u>Maximum Individual Impurity Limit (ppm)</u>	<u>Found</u>	
	H	5	0.04	
	B	10	< 0.20	
	N	200	10	
	C	250	46	
	Cl	25	9	
	F	25	5	
	All Others		2500	
	Al			20
	Ag			0.30
	Ca			13
	Cd			< 0.20
	Cr			34
	Cu			2
	Fe			160
	Mg			< 2
	Mn			< 2
	Mo			4
	Na			5
	Ni			40
	Pb			< 1
	Si			85
	Sn			< 2
	Ti			< 250
	V			< 5
	Zn			< 25
			Total	< 650

Certified By:

Quality Control Department
K. D. Hensley

GEAP-13760

Material $\text{UO}_2\text{-PuO}_2$ Pellets

Date 5/16/68

Customer General Electric

P.O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department
K. D. Hensley

CEAP-13760

Material UO₂-PuO₂ Pellets

Date 5/16/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California.

Bill of Lading No.

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

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NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
 Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 5/16/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-618		ANALYSIS, ppm			
	Specification:	22A1545				
10(d)	Pellets shall be single phase mixed oxide with not more than 5 per cent of material appearing as a second phase outside of solution.					
	Sample					
	1. Acceptable					
	2. Acceptable					
	3. Acceptable					
10(f)	The atom ratio of oxygen to heavy metal (Uranium plus Plutonium) shall be 1.97--1.99.					
	Sample					
	1.982					
10(i)	Volatiles					
	Specification				Found	
	0.05 cc/gram (excluding water)				0.005	
10(j)	Homogeneity (Autoradiography)					
	Sample					
	1. Acceptable					
	2. Acceptable					
	3. Acceptable					

Certified By: K. D. Hensley

Quality Control Department
 K. D. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets

Date 5/31/68

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped_____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department
K. D. Hensley

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Date 5/31/68

Date Shipped _____

Bill of Lading No. _____

Sales Order No. 256-A

Purchase Order No. 205-58226-NG

Certified By:

K. D. Hensley

GEAP-13760

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ pellets

Date July 11, 1968

Customer General Electric

P.O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading. No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-620		ANALYSIS, ppm	
	Specification: 22A1545			
10(a)	<u>Perpendicularity</u>			
	Number Run		Number Rejected	Allowable Rejects
	125		6	14
	<u>End Flatness</u>			
	Number Run		Number Rejected	Allowable Rejects
	125		0	14
10(b)	Pellet density shall be 9.993 to 10.401 grams per cubic centimeter, based on dimensions and weight. Density of the pellets from surface to center shall not vary more than ± 2 per cent from the average density of the pellet.			
	<u>Geometric Density</u>			
	Number Run		Number Rejected	Allowable Rejects
	125		5	7
	<u>Immersion Density</u>			
	10.23 g/cc			
	10.16			
	10.11			

Certified By: K. D. H. [Signature]

Quality Control Department

K. D. Hensly

GEAP-13760

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date July 11, 1968

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped_____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-620		ANALYSIS, ppm	
	Specification:	22A1545		
10(d)	Pellets shall be single phase mixed oxide with not more than 5 per cent of material appearing as a second phase outside of solution.			
	Sample			
	1. Acceptable			
	2. Acceptable			
	3. Acceptable			
10(f)	The atom ratio of oxygen to heavy metal (Uranium plus Plutonium) shall be 1.97--1.99.			
	Sample			
	1.985			
10(i)	Volatiles			
	Specification		Found	
	0.05 cc/gram (excluding water)		0.023 cc/gm.	
10(j)	Homogeneity (Autoradiography)			
	Sample			
	1. Acceptable			
	2. Acceptable			
	3. Acceptable			

Certified By:

Quality Control Department
K. D. Hensley

GEAP-13760

Erwin, Tennessee

Material: UO₂-PuO₂ Pellets

Date July 11, 1968

Customer General Electric Company

P.O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department

GEAP-13760

Erwin, Tennessee

Material $\text{UO}_2\text{-PuO}_2$ Pellets

Date 5/16/68

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped_____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department

K. D. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets

Date 5/16/68

Customer General Electric

P.O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

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CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ PelletsDate 5/16/68Customer General ElectricP.O.Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NGSales Order No. 256-A

ELEMENT	Blend CD		ANALYSIS, ppm		
	Specification: 22A1545				
10(h)	Impurities				
			Maximum Individual		
	Impurity		Impurity Limit (ppm)	Found	
	H		5	.06	
	B		10	< 0.20	
	N		200	10	
	C		250	188	
	Cl		25	< 1	
	F		25	3	
	All Others 2500				
	Al			< 5	
	Ag			.50	
	Ca			15	
	Cd			< .20	
	Cr			150	
	Cu			< 2	
	Fe			> 40	
	Mg			< 2	
	Mn			< 2	
	Mo			12	
	Na			7	
	Ni			19	
	Pb			< 1	
	Si			56	
	Sn			< 2	
	Ti			< 250	
	V			< 5	
	Zn			< 25	
			Total	< 1295	made

Certified By: K. S. HensleyQuality Control Department
K. S. Hensley

GEAP-13760

Material UO₂-PuO₂ Pellets

Date 5/16/68

Customer General Electric

P.O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By: K. D. Hensley
Quality Control Department
K. D. Hensley

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 6/12/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 621 ANALYSIS, ppm				
	Specification: 22A1545				
10(a)	<u>Perpendicularity</u>				
	Number Run		Number Rejected		Allowable Rejects
	125		3		14
	<u>End Flatness</u>				
	Number Run		Number Rejected		Allowable Rejects
	125		0		14
10(b)	Pellet density shall be 9.993 to 10.401 grams per cubic centimeter, based on dimensions and weight. Density of the pellets from surface to center shall not vary more than + 2 per cent from the average density of the pellet.				
	<u>Geometric Density</u>				
	Number Run		Number Rejected		Allowable Rejects
	125		3		7
	<u>Immersion Density</u>				
	10.11 g/cc				
	10.04				
	10.28				

Certified By: _____

Quality Control Department
K. D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
 Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 6/12/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 621					ANALYSIS, ppm	
	Specification: 22A1545						
10(d)	Pellets shall be single phase mixed oxide with not more than 5 per cent of material appearing as a second phase outside of solution.						
	Sample						
	1. Acceptable						
	2. Acceptable						
	3. Acceptable						
10(f)	The atom ratio of oxygen to heavy metal (Uranium plus Plutonium) shall be 1.97--1.99.						
	Sample						
	1.988						
10(i)	Volatiles						
	Specification					Found	
	0.05 cc/gram (excluding water)					0.012	
10(j)	<u>Homogeneity</u> (Autoradiography)						
	<u>Sample</u>						
	1. Acceptable						
	2. Acceptable						
	3. Acceptable						

Certified By: _____

Quality Control Department
 K. D. Hensley

A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Date 6/12/68

P.O. Box 254

Date Shipped_____

Bill of Lading No. _____

Sales Order No. 256-A

Certified By:

D-66

GEAP-13760

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 6/20/68

Customer General Electric

P.O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-622	ANALYSIS, ppm			
	Specification: 22A1545				
10(a)	<u>Perpendicularity</u>				
	Number Run		Number Rejected		Allowable Rejects
	125		4		14
	<u>End Flatness</u>				
	Number Run		Number Rejected		Allowable Rejects
	125		0		14
10(b)	Pellet density shall be 9.993 to 10.401 grams per cubic centimeter, bases on dimensions and weight. Density of the pellets from surface to center shall not vary more than + 2 percent from the average density of the pellet.				
	<u>Geometric Density</u>				
	Number Run		Number Rejected		Allowable Rejects
	125		5		7
	<u>Immersion Density</u>				
	10.48 g/cc				
	10.44				
	10.52				

Certified By:

Quality Control Department
K. D. Hensley

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date 6/20/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-622	ANALYSIS, ppm
	Specification: 22A1545	
10(i)	<u>Volatiles</u>	
	<u>Specification</u>	<u>Found</u>
	0.05 cc/gram (excluding water)	0.008 cc/gm.
10(i)	<u>Homogeneity (Autoradiography)</u>	
	<u>Sample</u>	
	1. Acceptable	
	2. Acceptable	
	3. Acceptable	

Certified By:

Quality Control Department
K. D. Hensley

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Date June 25, 1968

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No.

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department

K.D. Hensley

Material UO₂-PuO₂ Pellets

Date June 25, 1968

Customer General Electric

P.O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department
K.D. Hensley

GEAP-13760

A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date June 25, 1968

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped_____

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-623	ANALYSIS, pom			
	Specification: 22Al545				
10(d)	Pellets shall be single phase mixed oxide with not more than 5 percent of material appearing as a second phase outside of solution.				
	Sample				
	1. Acceptable				
	2. Acceptable				
	3. Acceptable				
10(f)	The atom ratio of oxygen to heavy metal (uranium plus plutonium) shall be 1.97--1.99.				
	Sample				
	1.983				
10(i)	Volatiles				
	Specification			Found	
	0.05 cc/gram (excluding water)			0.011 cc/gram	
10(j)	Homogeneity (Autoradiography)				
	Sample				
	1. Acceptable				
	2. Acceptable				
	3. Acceptable				

Certified By: K.P.H. Co.

Quality Control Department
K.D. Hensley

GEAP-13760

Erwin, Tennessee

Material UO₂-PuO₂ Pellets

Date June 25, 1968

Customer General Electric

P.O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department

K.D. Hensley

Erwin, Tennessee

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CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date July 15, 1968

Customer General Electric Company

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-624		ANALYSIS, ppm	
	SPECIFICATION: 22A1545			
10(d)	Pellets shall be single phase mixed oxide with not more than 5 per cent of material appearing as a second phase outside of solution.			
	Sample			
	1. Acceptable			
	2. Acceptable			
	3. Acceptable			
10(f)	The atom ratio of oxygen to heavy metal (Uranium plus Plutonium) shall be 1.97--1.99.			
	Sample			
	1.982			
10(i)	Volatiles			
	Specification		Found	
	0.05 cc/gram (excluding water)		0.010 cc/gm.	
10(j)	Homogeneity (Autoradiography)			
	Sample			
	1. Acceptable			
	2. Acceptable			
	3. Acceptable			

Certified By: K. D. Hensley
Quality Control Department
K. D. Hensley

Erwin, Tennessee

AMENDED

CERTIFICATE OF ANALYSISMaterial UO₂-PuO₂ PelletsDate October 28, 1969Customer General Electric CompanyP.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NGSales Order No. 256-A

ELEMENT	Blend 256-A-625		ANALYSIS, ppm		
	Specifcation: 22A1545				
10(a)	<u>Perpendicularity</u>				
	Number Run		Number Rejected		Allowable Rejects
	125		1		14
	<u>End Flatness</u>				
	Number Run		Number Rejected		Allowable Rejects
	125		0		14
10(b)	Pellet density shall be 9.993 to 10.401 grams per cubic centimeter, based on dimensions and weight. Density of the pellets from surface to center shall not vary more than <u>+ 2</u> percent from the average density of the pellet.				
	<u>Geometric Density</u>				
	Number Run		Number Rejected		Allowable Rejects
	125		7		7
	<u>Immersion Density</u>				
	10.32 g/cc				
	10.21				
	10.21				

Erwin, Tennessee

AMENDED

CERTIFICATE OF ANALYSISMaterial UO₂-PuO₂ PelletsDate October 28, 1969Customer General Electric CompanyP.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NGSales Order No. 256-A

ELEMENT	Blend 256-A-625		ANALYSIS, ppm			
	Specification: 22A1545					
10(d)	Pellets shall be single phase mixed oxide with not more than 5 percent of material appearing as a second phase outside of solution.					
	<u>Sample</u>					
	1. Acceptable					
	2. Acceptable					
	3. Acceptable					
10(f)	The atom ratio of oxygen to heavy metal (uranium plus plutonium) shall be 1.97-1.99.					
	<u>Sample</u>					
	1.986					
10(i)	<u>Volatiles</u>					
	<u>Specification</u>			<u>Found</u>		
	0.05 cc/gram (excluding water)			0.009 cc/gm		
10(j)	<u>Homogeneity (Autoradiography)</u>					
	<u>Sample</u>					
	1. Acceptable					
	2. Acceptable					
	3. Acceptable					

Erwin, Tennessee

D-78

GEAP-13760

Date August 14, 1968

P. O. Box 254

Date Shipped

San Jose, California

Bill of Lading No.

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department.

K. D. Hensley

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Date August 14, 1968

P. O. Box 254

Date Shipped.

San Jose, California

Bill of Lading No.

Purchase Order No. 205-A-626

Sales Order No. 256-A

Certified By:

Quality Control Department

GEAP-13760

Material UO₂-PuO₂ Pellets

Date September 20, 1968

Customer. General Electric Company

P. O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By: K. D. Hensley
Quality Control Department
K. D. Hensley

GEAP-13760

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Pellets

Date September 20, 1968

Customer General Electric Company

P. O. Box 254

Date Shipped

San Jose, California

Bill of Lading No.

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	Blend 256-A-627		ANALYSIS, ppm	
	Specification: 22A1545			
10(c)	Density within Pellets			
	Surface	Center	Average	
	10.44 g/cc	10.26	10.35 g/cc	Acceptable within + 2%
	10.38	10.39	10.39	Acceptable within + 2%
	10.53	10.51	10.52	Acceptable within + 2%
	10.38	10.29	10.34	Acceptable within + 2%
	10.36	10.43	10.40	Acceptable within + 2%
	10.37	10.35	10.36	Acceptable within + 2%
10(d)	Pellets shall be single phase mixed oxide with not more than 5 per cent of material appearing as a second phase outside of solution.			
	1. Acceptable			
	2. Acceptable			
	3. Acceptable			
10(f)	The atom ratio of oxygen to heavy metal (Uranium plus Plutonium) shall be 1.97--1.99.			
	Center			
	1.984			
10(g)	Verification of Pu/ (Pu + U) Ratio			
	.2746			

Certified By:

Quality Control Department

K. D. Hensley..

NUCLEAR FUEL SERVICES, INC.

GEAP-13760

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ PelletsDate September 20, 1968Customer General Electric CompanyP. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NGSales Order No. 256-A

ELEMENT	Blend 256-A627		ANALYSIS, ppm		
	Specification:	22A1545			
10(h)	Impurities				
			Maximum Individual		
	Impurity		Impurity Limit (ppm)	Found	
	H		5	0.2	
	B		10	0.30	
	N		200	13	
	C		250	82	
	Cl		25	8	
	F		25	< 1	
			All Others	2500	
	Al			5	
	Ag			0.10	
	Ca			23	
	Cd			< 0.20	
	Cr			6	
	Cu			2	
	Fe			47	
	Mg			4	
	Mn			< 2	
	Mo			2	
	Na			23	
	Ni			11	
	Pb			< 1	
	Si			35	
	Sn			< 2	
	Ti			< 250	
	V			< 5	
	Zn			< 25	
			Total	< 548	

Certified By: K. D. HensleyQuality Control Department
K. D. Hensley

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Date September 20, 1968

P. O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department
K. D. Hensley

APPENDIX E

NFS Certificates of Analysis for Rod Shipments

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel RodsDate 2/2/68Customer General ElectricP.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NGSales Order No. 256-A

ELEMENT	First Shipment		ANALYSIS, ppm		
	Specification: 22A1548				
12(e)	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
	116	3270.2	589.0	540.6	
	121	3286.6	591.9	543.3	
	123	3278.2	590.4	541.9	
	124	3276.3	590.1	541.6	
	125	3274.1	589.7	541.2	
	127	3324.0	598.7	549.5	
	129	3275.0	589.8	541.4	
	131	3267.2	588.4	540.1	
	133	3270.5	589.0	540.6	
	134	3266.0	588.2	539.9	
	135	3266.6	588.3	540.0	
	138	3267.8	588.9	540.1	
	139	3277.8	590.7	541.9	
	143	3268.7	589.1	540.3	
	147	3288.1	592.5	543.5	
	148	3321.4	598.5	549.0	
	149	3292.1	593.3	544.2	
	150	3329.3	599.9	550.3	
	110	3273.8	589.6	541.2	
	152	3312.2	596.9	547.5	
	153	3304.0	595.3	546.1	
	154	3290.1	592.8	543.9	
	155	3280.2	591.2	542.2	
	157	3275.6	590.2	541.5	
	158	3273.3	589.8	541.1	
	159	3277.8	590.6	541.8	
	162	3277.6	590.6	541.8	
	171	3278.4	591.2	542.0	
	172	3282.8	591.5	542.6	
	173	3266.9	588.7	540.0	
	174	3265.1	588.4	539.7	

Original Signed by

K. D. Hensley

Certified By: _____

Quality Control Department

K. D. Hensley

GEAP-13760

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date 2/2/68

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped

Bill of Lading No..

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	First Shipment		ANALYSIS, ppm	
	Serial Number	Fuel Weight	Pu Weight	Pu 239 + 241 Weight
	Specification: 22A1548			
	175	3276.1	590.4	541.6
	176	3269.2	589.1	540.4
	177	3266.3	588.6	539.9
	178	3273.4	589.9	541.1
	264	3301.8	595.0	545.7
	163	3376.3	608.4	558.1
	165	3283.1	591.6	542.7
	166	3284.1	591.8	542.9
	167	3273.1	589.8	541.4
	168	3286.6	592.2	543.3
	169	3281.4	591.3	542.4
	170	3285.5	592.0	543.1
	179	3278.9	591.0	542.1
	180	3268.2	589.0	540.2
	181	3275.7	590.3	541.5
	183	3269.2	589.2	540.4
	185	3277.0	590.5	541.7
	186	3273.9	589.9	541.1
	189	3267.0	588.2	540.1
	192	3277.0	590.5	541.7
	200	3267.4	588.8	540.1
	244	3332.4	600.5	550.8
	245	3336.9	601.3	551.6
	247	3332.3	600.5	550.9
	248	3331.7	600.4	550.7
	253	3316.3	597.6	548.2
	254	3319.2	598.1	548.7
	255	3304.7	595.5	546.3
	256	3301.1	594.8	545.6
	258	3308.0	596.1	546.9
	259	3302.2	595.1	545.9

Original Signed by

K. D. Hensley.

Certified By:

Quality Control Department

K. D. Hensley

GEAP-13760

Erwin, Tennessee

Material UO₂-PuO₂ Fuel Rods

Date 2/2/68

Customer General Electric

P.O. Box 254

Date Shipped

San Jose, California

Bill of Lading No.

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Original Signed by
K. D. Hensley

Certified By: _____

Quality Control Department
K. D. Hensley

GEAP-13760

Date 2/2/68

Date Shipped _____

Bill of Lading No.

Sales Order No. 256-A

Original Signed by
K. D. Hensley
Certified By: _____
Quality Control Department
K. D. Hensley

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel RodsDate 5/21/68Customer General ElectricP. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NGSales Order No. 256-A

ELEMENT	5/21/68 Shipment		ANALYSIS, ppm		
	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
12(e)					
	429	3305.30	595.62	546.37	
	430	3317.30	597.78	548.35	
	431	3326.30	599.40	549.84	
	432	3353.27	604.26	554.30	
	433	3370.27	607.32	557.11	
	434	3350.90	603.83	553.90	
	435	3359.30	605.35	555.29	
	436	3336.60	601.26	551.54	
	437	3345.70	602.89	553.04	
	438	3341.30	602.10	552.32	
	439	3342.80	602.37	552.56	
	440	3318.10	597.92	548.48	
	441	3301.00	594.84	545.65	
	442	3315.10	597.38	547.99	
	444	3314.60	597.29	547.90	
	445	3297.00	594.12	544.99	
	447	3300.60	594.77	545.59	
	448	3315.80	597.51	548.10	
	450	3330.60	600.17	550.55	
	451	3323.30	598.86	549.34	
	452	3326.50	599.43	549.87	
	453	3306.50	595.83	546.56	
	454	3300.00	594.66	545.49	
	455	3309.70	596.41	547.09	
	456	3337.60	601.43	551.70	
	457	3329.60	599.99	550.38	
	460	3277.60	590.62	541.79	
	461	3338.70	601.63	551.89	
	462	3332.30	600.48	550.83	
	463	3331.80	600.39	550.75	
	464	3325.80	599.31	549.75	

Certified By: _____

K. D. Hensley
 Quality Control Department
 K. D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
 Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date 5/21/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. _____

Sales Order No. 256-A

ELEMENT	5/21/68 Shipment		ANALYSIS, ppm			
	Serial	Fuel	Pu	Pu 239+241		
	Number	Weight	Weight	Weight		
	465	3330.20	600.10	550.48		
	466	3325.70	599.29	549.74		
	467	3326.60	599.45	549.89		
	469	3335.70	601.09	551.39		
	470	3331.70	600.37	550.73		
	471	3320.80	598.41	548.93		
	472	3322.80	598.77	549.26		
	449	3303.60	595.31	546.08		
	473	3322.30	598.68	549.18		
	474	3329.60	599.99	550.38		
	477	3330.93	600.23	550.60		
	487	3330.27	600.11	550.49		
	479	3321.00	598.44	548.96		
	478	3333.73	600.74	551.06		
	480	3334.70	600.91	551.23		
	482	3327.20	599.56	549.99		
	483	3327.10	599.54	549.97		
	484	3338.70	601.63	551.89		
	498	3327.40	601.26	550.68		
	499	3321.70	600.23	549.74		
	500	3322.20	600.32	549.82		
	501	3337.20	603.03	552.31		
	504	3336.20	602.85	552.14		
	502	3320.20	599.96	549.49		
	506	3332.70	602.22	551.56		
	497	3323.90	600.63	550.10		
	494	3333.90	602.43	551.76		
	493	3331.30	601.96	551.33		
	492	3340.20	603.57	552.80		
	490	3333.90	602.43	551.76		
	489	3329.07	601.56	550.96		

Certified By: _____

K. D. Hensley
 Quality Control Department
 K. D. Hensley

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Date 5/21/68

P. O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. _____

Sales Order No. 256-A

Certified By:

Quality Control Department
K. D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
 Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date 5/28/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	5/26/68 Shipment		ANALYSIS, ppm		
	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
	481	3323.30	598.86	549.34	
	486	3339.80	601.83	552.07	
	491	3320.20	599.96	549.49	
	517	3322.20	600.32	549.82	
	518	3325.20	600.86	550.32	
	476	3320.10	598.28	548.81	
	519	3324.20	600.68	550.15	
	545	3357.37	606.68	555.64	
	495	3334.40	602.53	551.84	
	446	3286.60	592.24	543.27	
	526	3331.20	601.95	551.31	
	538	3325.20	600.86	550.32	
	570	3289.37	592.74	543.73	
	571	3288.27	592.55	543.55	
	574	3276.77	590.47	541.65	
	575	3296.27	593.99	544.87	
	576	3318.97	598.08	548.62	
	578	3329.10	601.57	550.97	
	579	3327.00	601.19	550.62	
	580	3328.67	601.49	550.89	
	581	3335.10	602.65	551.96	
	583	3323.40	600.54	550.02	
	584	3335.90	602.80	552.09	
	585	3341.80	603.86	553.07	
	586	3322.10	600.30	549.81	
	587	3325.93	600.99	550.44	
	588	3320.77	600.06	549.59	
	589	3328.27	601.42	550.83	
	590	3327.17	601.22	550.65	
	591	3321.90	600.27	549.77	
	592	3326.77	601.15	550.58	

Certified By: _____

Quality Control Department
 K. D. Hensley

Erwin, Tennessee

GEAP-13760

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date 5/28/68

Customer General Electric

P. O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

[illegible]

Certified By:

Quality Control Department
K. D. Hensley

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date 6/11/68

Customer General Electric

P.O. Box 254

San Jose, California

Date Shipped _____

Bill of Lading No. _____

Purchase Order No. _____

Sales Order No. 256-A

ELEMENT	6/7/68 Shipment		ANALYSIS, ppm		
	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
12(e)	633	3317.33	597.78	548.35	
	634	3319.30	598.14	548.68	
	635	3318.07	597.92	548.48	
	636	3317.77	597.86	548.43	
	637	3333.27	602.32	551.66	
	638	3331.27	601.96	551.33	
	639	3320.27	598.31	548.84	
	569	3289.30	592.73	543.72	
	620	3321.17	598.47	548.99	
	568	3313.30	597.06	547.69	
	619	3319.27	598.13	548.67	
	630	3318.30	597.96	548.51	
	629	3318.30	597.96	548.51	
	627	3334.27	602.50	551.82	
	621	3318.27	597.95	548.51	
	622	3318.57	598.01	548.56	
	628	3318.30	597.96	548.51	
	626	3323.17	598.83	549.32	
	582	3320.40	599.99	549.53	
	577	3299.27	594.53	545.37	
	564	3323.40	598.88	549.36	
	561	3349.43	603.57	553.66	
	552	3321.37	598.51	549.02	
	530	3331.20	601.95	551.31	
	496	3320.40	600.00	549.53	
	458	3335.80	601.11	551.41	
	618	3321.77	598.58	549.09	
	617	3318.90	598.06	548.61	
	616	3325.30	599.22	549.67	
	615	3320.10	598.28	548.81	
	614	3320.27	598.31	548.84	

Certified By: K.D. Hensley

Quality Control Department
K.D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
 Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date 6/11/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. _____

Sales Order No. 256-A

ELEMENT	6/7/68 Shipment		ANALYSIS, ppm			
	Serial	Fuel	Pu	Pu 239 + 241		
	Number	Weight	Weight	Weight		
	613	3320.93	598.43	548.95		
	612	3323.93	598.97	549.45		
	611	3325.63	599.28	549.73		
	609	3320.53	598.36	548.88		
	607	3320.33	599.98	549.51		
	632	3317.80	597.87	548.43		
	631	3318.80	598.05	548.60		
	645	3321.27	598.49	549.01		
	650	3319.27	598.13	548.68		
	644	3311.27	596.69	547.35		
	643	3320.60	598.37	548.90		
	648	3307.77	596.06	546.77		
	646	3305.77	595.70	546.44		
	642	3328.20	599.74	550.15		
	641	3317.27	597.77	548.34		
	640	3318.27	597.95	548.51		
	649	3321.27	598.49	549.01		
	660	3318.80	599.71	549.26		
	659	3319.80	599.89	549.43		
	658	3315.30	599.07	548.68		
	657	3317.30	599.44	549.01		
	656	3311.30	596.70	547.36		
	653	3325.93	599.33	549.78		
	651	3306.27	595.79	546.53		
	667	3316.40	599.27	548.86		
	661	3337.30	603.05	552.32		
	669	3322.90	600.45	549.94		
	668	3324.20	600.68	550.16		
	662	3323.40	600.54	550.02		
	670	3307.47	597.66	547.39		
	652	3307.77	596.06	546.77		

Certified By: _____

Quality Control Department
 K. D. Hensley

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Sales Order No. 256-A

E-14

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date 6/18/68

Customer General Electric

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. _____

Sales Order No. 256-A

ELEMENT	6/18/68 Shipment		ANALYSIS, ppm		
	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
	680	3332.40	602.16	551.51	
	671	3327.13	601.21	550.64	
	679	3329.43	601.63	551.02	
	672	3317.13	599.41	548.99	
	678	3322.93	600.45	549.94	
	673	3327.93	601.36	550.77	
	677	3331.93	602.08	551.43	
	674	3312.93	598.65	548.29	
	676	3323.93	600.63	550.11	
	675	3316.93	599.37	548.95	
	700	3331.90	602.07	551.43	
	699	3326.90	601.17	550.60	
	697	3331.90	602.07	551.43	
	696	3333.90	602.44	551.76	
	694	3349.60	605.27	554.36	
	698	3325.30	600.88	550.34	
	701	3338.93	603.34	552.59	
	691	3339.40	603.43	552.67	
	666	3315.90	599.18	548.78	
	608	3317.93	597.89	548.45	
	690	3348.40	605.06	554.16	
	605	3321.93	600.27	549.78	
	692	3345.40	604.51	553.66	
	664	3312.30	598.53	548.19	
	693	3349.40	605.24	554.33	
	689	3353.40	605.96	554.99	
	688	3350.40	605.42	554.49	
	654	3305.30	595.61	546.37	
	566	3334.13	600.81	551.13	
	647	3313.80	597.15	547.77	

Certified By: K. D. Hensley
 Quality Control Department
 K. D. Hensley

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Sales Order No. 256-A

E-16

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date June 28, 1968

Customer General Electric Company

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	6/28/68 Shipment		ANALYSIS, ppm		
	SPECIFICATION: 22A1548				
12(e)	Serial	Fuel	Pu	Pu 239+241	
	Number	Weight	Weight	Weight	
	710	3314.40	598.91	548.53	
	711	3311.90	598.46	548.12	
	712	3355.27	606.30	555.30	
	713	3384.27	611.54	560.10	
	714	3378.90	610.57	559.21	
	715	3377.90	610.39	559.04	
	717	3353.90	606.05	555.07	
	718	3377.90	610.39	559.04	
	719	3360.93	607.32	556.23	
	720	3357.90	606.77	555.73	
	721	3306.90	597.56	547.29	
	722	3304.90	597.20	546.96	
	723	3329.90	601.71	551.10	
	724	3322.90	600.45	549.94	
	725	3302.90	596.83	546.63	
	726	3327.90	601.35	550.77	
	727	3351.90	605.69	554.74	
	730	3343.50	604.17	553.35	
	731	3325.70	600.95	550.40	
	732	3321.70	600.23	549.74	
	733	3308.40	597.83	547.54	
	735	3300.90	596.47	546.30	
	737	3288.90	594.30	544.31	
	742	3395.30	613.53	561.92	
	743	3325.30	600.88	550.34	
	744	3349.39	605.23	554.32	
	747	3329.30	601.60	550.99	
	748	3339.30	603.41	552.65	
	749	3341.27	603.77	552.98	
	750	3350.77	605.48	554.55	
	751	3327.77	601.33	550.75	

Certified By: _____

Quality Control Department

Erwin, Tennessee

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date July 16, 1968

Customer General Electric Company

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	7/16/68 Shipment		ANALYSIS, ppm		
	SPECIFICATION: 22A1548				
12(e)	Serial	Fuel	Pu	Pu 239+241	
	Number	Weight	Weight	Weight	
	739	3292.93	595.03	544.98	
	752	3333.77	602.41	551.74	
	754	3310.93	598.29	547.96	
	756	3292.90	595.03	544.97	
	757	3326.90	601.17	550.60	
	758	3326.90	601.17	550.60	
	759	3327.90	601.35	550.77	
	762	3285.30	593.65	543.72	
	774	3312.90	598.64	548.28	
	773	3302.30	596.73	546.53	
	766	3322.27	600.33	549.84	
	767	3329.27	601.60	550.99	
	765	3334.27	602.50	551.82	
	761	3332.30	600.48	550.83	
	746	3338.27	603.23	552.48	
	709	3351.93	605.69	554.74	
	734	3321.90	600.27	549.77	
	738	3285.90	593.76	543.82	
	707	3354.93	606.24	555.24	
	706	3332.73	602.22	551.57	
	703	3332.30	602.15	551.50	
	704	3310.93	598.29	547.30	
	745	3328.43	601.45	550.86	
	789	3368.30	606.97	556.78	
	791	3390.17	612.60	561.07	
	790	3370.43	607.35	557.13	
	708	3356.93	606.60	555.57	
	695	3359.80	607.12	556.05	
	663	3346.30	604.68	553.81	
	783	3301.30	594.89	545.70	
	782	3289.30	592.40	543.72	

Certified By: K. H. G.
Quality Control Department

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date July 16, 1968

Customer General Electric Company

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	7/16/68 Shipment		ANALYSIS, ppm		
	SPECIFICATION: 22A1548				
12(e)	Serial	Fuel	Pu	Pu 239+241	
	Number	Weight	Weight	Weight	
	781	3362.30	605.89	555.79	
	780	3389.80	612.54	561.01	
	779	3394.30	613.35	561.76	
	777	3350.93	605.51	554.58	
	776	3380.30	610.82	559.44	
	393	3334.9	600.95	551.26	
	368	3335.7	601.09	551.40	
	395	3347.0	603.13	553.26	
	370	3351.9	604.01	554.07	
	426	3356.8	604.90	554.88	
	399	3365.7	606.50	556.35	
	397	3365.3	606.43	556.28	
	396	3342.0	602.23	552.43	
	391	3340.8	602.01	552.23	
	364	3351.9	604.01	554.07	
	365	3331.1	600.26	550.63	
	361	3365.6	606.48	556.33	
	367	3336.5	601.24	551.52	
	366	3318.7	598.03	548.58	
	382	3341.9	602.21	552.42	
	424	3345.8	602.91	553.06	
	383	3329.8	600.03	550.42	
	787	3393.30	613.17	561.59	
	786	3377.30	610.28	558.94	
	788	3390.30	612.63	561.09	
	785	3385.27	611.72	560.26	
	784	3384.30	611.54	560.10	
	753	3320.77	600.06	549.59	
	741	3304.30	595.43	546.20	
	740	3321.30	598.50	549.01	
	736	3271.30	591.12	541.40	

Certified By: _____

Quality Control Department

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Sales Order No. 256-A

Certified By: R. J. [Signature]
Quality Control Department

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
 Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date July 29, 1968

Customer General Electric Company

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	7/29/68 Shipment		ANALYSIS, ppm		
	SPECIFICATION: 22A1548				
12(e)	Serial	Fuel	Pu	Pu 239+241	
	Number	Weight	Weight	Weight	
	398	3362.60	605.94	555.84	
	419	3362.30	605.89	555.78	
	296	3322.40	598.70	549.19	
	403	3356.20	604.79	554.78	
	345	3297.30	594.17	545.04	
	402	3348.10	603.33	553.44	
	793	3360.30	607.21	556.13	
	794	3382.90	611.29	559.87	
	795	3364.90	608.04	556.89	
	796	3362.90	607.68	556.56	
	798	3335.90	602.80	552.09	
	797	3348.40	605.06	554.16	
	800	3291.90	594.85	544.81	
	802	3275.90	591.96	542.16	
	801	3295.90	595.57	545.47	
	806	3329.90	601.71	551.10	
	804	3293.40	595.12	545.06	
	807	3335.90	602.80	552.09	
	803	3302.90	596.83	546.63	
	805	3292.90	595.03	544.97	
	808	3334.90	602.62	551.93	
	811	3340.20	603.57	552.80	
	813	3337.40	603.07	552.34	
	810	3335.10	602.65	551.96	
	809	3338.90	603.34	552.59	
	819	3342.30	603.95	553.15	
	821	3332.70	602.22	551.56	
	818	3351.60	605.63	554.69	
	820	3334.70	602.58	551.89	
	404	3352.20	604.07	554.12	
	817	3320.83	600.07	549.60	

Certified By: K. D. Henderson
 Quality Control Department

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date July 29, 1968

Customer General Electric Company

P.O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	7/29/68 Shipment		ANALYSIS, ppm		
	SPECIFICATION: 22A1548				
12(e)	Serial	Fuel	Pu	Pu 239+241	
	Number	Weight	Weight	Weight	
	822	3341.30	603.77	552.99	
	815	3318.83	599.71	549.27	
	814	3329.40	601.62	551.02	
	816	3341.90	603.88	553.08	
	417	3374.90	608.16	557.87	
	197	3269.00	589.07	540.37	
	624	3328.27	599.75	550.16	
	223	3300.60	594.77	545.59	
	829	3332.90	602.26	551.59	
	828	3332.90	600.59	550.93	
	405	3361.20	605.69	555.61	
	410	3330.60	600.17	550.55	
	409	3330.80	600.21	550.58	
	416	3337.70	601.45	551.72	
	408	3347.20	603.17	553.29	
	407	3337.10	601.35	551.62	
	406	3354.10	604.41	554.43	
	411	3343.60	602.52	552.70	
	418	3362.50	605.92	555.82	
	827	3327.30	601.24	550.67	
	412	3363.00	606.01	555.90	
	414	3337.20	601.36	551.64	
	413	3346.60	603.06	553.19	
	420	3370.80	607.42	557.19	
	823	3337.30	603.05	552.32	
	415	3336.30	601.20	551.49	
	825	3327.30	601.24	550.67	
	824	3327.30	601.24	550.67	

Certified By: K. D. [Signature]

Quality Control Department

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel RodsDate August 10, 1968Customer General Electric CompanyP. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NGSales Order No. 256-A

ELEMENT	8/10/68 Shipment		ANALYSIS, ppm		
	Specification: 22A1548				
12(e)	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
	267	3310.90	596.62	547.29	
	299	3309.60	596.39	547.08	
	830	3318.90	599.73	549.28	
	832	3324.27	600.70	550.17	
	323	3306.40	595.81	546.55	
	240	3312.50	596.91	547.56	
	105	3274.50	589.74	541.27	
	205	3294.90	593.74	544.65	
	111	3268.90	588.73	540.35	
	373	3332.90	600.59	550.93	
	109	3273.60	589.58	541.13	
	102	3272.60	589.40	540.96	
	374	3347.00	603.13	553.26	
	235	3277.90	590.68	541.84	
	128	3292.20	592.93	544.20	
	295	3305.50	595.65	546.40	
	130	3266.80	588.35	540.00	
	103	3270.70	589.05	540.65	
	160	3276.90	590.50	541.67	
	117	3268.40	588.64	540.27	
	343	3299.10	594.50	545.34	
	337	3327.10	599.54	549.97	
	120	3283.20	591.30	542.71	
	312	3299.30	594.53	545.37	
	214	3280.70	591.18	542.30	
	350	3350.20	603.71	553.79	
	305	3326.80	599.49	549.92	
	836	3346.93	604.79	553.92	
	837	3341.93	603.89	553.09	
	834	3325.93	600.99	550.44	
	833	3331.93	602.08	551.43	

Certified By: KD. H. [Signature]

Quality Control Department

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date August 10, 1968

Customer General Electric Company

P. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	8/10/68 Shipment		ANALYSIS, ppm		
	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
	355	3319.40	598.16	548.70	
	838	3342.67	604.02	553.21	
	119	3265.20	588.06	539.74	
	263	3306.00	595.74	546.48	
	835	3336.93	602.98	552.26	
	279	3310.10	596.48	547.16	
	228	3294.40	593.65	544.56	
	342	3321.10	598.46	548.98	
	353	3342.40	602.30	552.50	
	840	3330.30	601.79	551.16	
	841	3334.90	602.62	551.93	
	842	3327.27	601.24	550.66	
	844	3348.43	605.06	554.17	
	845	3342.90	604.06	553.25	
	846	3328.93	601.54	550.94	
	847	3333.90	602.44	551.76	
	848	3321.30	600.16	549.68	
	849	3348.27	605.03	554.14	
	850	3341.93	603.89	553.09	
	851	3346.30	604.68	553.81	
	852	3350.40	605.42	554.49	
	853	3341.30	603.77	552.99	
	854	3334.90	602.62	551.93	
	855	3340.90	603.70	552.92	
	856	3318.30	599.62	549.18	
	858	3334.26	602.50	551.82	
	859	3330.27	601.78	551.16	
	860	3330.27	601.78	551.16	
	861	3340.20	603.57	552.80	
	862	3327.40	601.26	550.68	
	863	3354.40	606.14	555.15	

Certified By: K. D. H. G.

Quality Control Department

GEAP-13760

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date August 10, 1968

Customer General Electric Company

P. O. Box 254

Date Shipped_____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

[illegible]

Certified By:

Quality Control Department

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date August 16, 1968

Customer General Electric Company

P. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	8/16/68 Shipment		ANALYSIS, ppm		
	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
12(e)	360	3374.90	608.16	557.87	
	227	3286.30	592.19	543.22	
	324	3321.70	598.57	549.08	
	307	3314.50	597.27	547.89	
	126	3323.00	598.47	549.29	
	161	3278.10	590.71	541.87	
	351	3305.90	595.72	546.47	
	231	3266.60	588.64	539.97	
	226	3302.40	595.09	545.89	
	229	3284.30	591.83	542.89	
	251	3305.90	595.72	546.47	
	303	3305.20	595.60	546.35	
	237	3317.70	597.85	548.42	
	242	3336.10	601.17	551.46	
	306	3301.90	595.00	545.80	
	308	3301.80	594.98	545.79	
	788	3390.30	612.63	561.09	
	315	3298.20	594.34	545.19	
	197	3269.0	589.07	540.37	
	212	3345.20	602.81	552.96	
	151	3266.50	588.62	539.95	
	489	3329.07	601.56	550.96	
	865	3345.90	604.60	553.75	
	867	3341.20	603.75	552.97	
	868	3344.20	604.30	553.47	
	866	3342.90	604.06	553.25	
	207	3281.00	591.24	542.35	
	314	3306.30	595.80	546.53	
	206	3284.10	591.79	542.86	
	234	3287.00	592.32	543.34	
	313	3305.00	595.56	546.32	

Certified By: K. D. H. [Signature]

Quality Control Department

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date August 16, 1968

Customer General Electric Company

P. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	8/16/68 Shipment		ANALYSIS, ppm		
	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
	252	3305.30	595.62	546.37	
	316	3313.60	597.11	547.74	
	340	3325.40	599.24	549.69	
	309	3309.00	596.28	546.98	
	379	3320.90	598.43	548.94	
	246	3335.40	600.97	551.34	
	318	3307.20	595.96	546.68	
	310	3301.70	594.97	545.77	
	335	3285.90	592.12	543.16	
	872	3357.20	606.65	555.62	
	870	3332.10	602.11	551.46	
	869	3352.90	605.87	554.90	
	874	3311.20	598.33	548.00	
	875	3286.20	593.82	543.87	
	283	3296.3	593.99	544.88	
	294	3305.30	595.62	546.37	
	280	3301.90	595.00	545.80	
	285	3312.40	596.89	547.54	
	879	3324.30	600.70	550.17	
	881	3333.30	602.33	551.66	
	877	3318.90	599.73	549.28	
	878	3318.90	599.73	549.28	
	876	3313.34	598.72	548.36	
	293	3300.30	594.71	545.54	
	146	3281.70	591.36	542.47	
	286	3304.80	595.52	546.28	
	236	3275.90	590.32	541.51	
	301	3302.60	595.13	545.92	
	108	3276.60	590.12	541.62	
	322	3324.70	599.11	549.57	
	284	3306.00	595.74	546.48	

Certified By: _____

Quality Control Department

Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Sales Order No. 256-AE-29

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date August 23, 1968

Customer General Electric Company

P. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	8/23/68 Shipment		ANALYSIS, ppm	
	Serial	Fuel	Pu	Pu 239 + 241
	Number	Weight	Weight	Weight
	354	3344.3	602.65	552.81
	799	3325.2	600.86	550.32
	145	3286.4	592.21	543.24
	114	3274.8	589.79	541.32
	857	3340.60	603.65	552.87
	104	3275.3	589.88	541.41
	302	3301.1	594.86	545.67
	843	3325.43	600.91	550.36
	278	3306.2	595.78	546.51
	375	3331.9	600.41	550.76
	290	3325.3	599.22	549.67
	182	3267.0	588.71	540.03
	201	3276.2	590.37	541.56
	180	3268.2	588.93	540.23
	334	3324.3	599.04	549.51
	200	3267.4	588.79	540.10
	196	3269.0	589.07	540.37
	193	3273.9	589.96	541.18
	190	3268.2	588.93	540.23
	203	3287.4	592.39	543.41
	195	3291.0	593.04	544.00
	136	3284.1	591.47	542.86
	173	3266.9	588.70	540.02
	186	3273.9	589.96	541.18
	185	3277.0	590.52	541.69
	216	3305.4	595.63	546.38
	327	3337.70	601.45	551.72
	257	3298.93	594.47	545.31
	893	3272.93	589.78	541.02
	894	3272.93	589.78	541.02
	135	3266.6	588.31	539.97

Certified By: K. A. H. [Signature]

Quality Control Department

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date August 23, 1968

Customer General Electric Company

P. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	8/23/68 Shipment		ANALYSIS, ppm		
	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
	158	3273.3	589.85	541.08	
	356	3299.20	594.52	545.36	
	425	3352.70	604.16	554.20	
	291	3297.80	594.26	545.13	
	107	3270.60	589.04	540.63	
	380	3342.60	602.34	552.53	
	238	3299.60	594.59	545.42	
	198	3266.10	588.55	539.89	
	204	3287.50	592.41	543.42	
	376	3356.00	604.75	554.75	
	243	3334.00	600.79	551.11	
	888	3291.17	594.71	544.69	
	890	3285.27	593.65	543.71	
	886	3272.27	591.30	541.56	
	891	3265.30	590.04	540.41	
	889	3293.30	595.10	545.04	
	884	3273.27	591.48	541.73	
	885	3284.27	593.47	543.55	
	880	3325.57	599.27	549.72	
	882	3268.37	590.59	540.92	
	883	3273.80	591.58	541.81	
	764	3327.27	599.57	549.99	
	401	3389.20	610.73	560.23	
	768	3330.27	601.78	551.16	
	772	3330.43	601.81	551.19	
	769	3325.30	600.88	550.34	
	771	3356.30	606.48	555.47	
	344	3304.40	595.45	546.22	
	338	3324.50	599.07	549.54	
	224	3288.40	592.57	543.57	
	778	3389.30	612.45	560.93	

Certified By: _____

Quality Control Department

A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Date August 23, 1968

P. O. Box 254

Date Shipped

San Jose, California

Bill of Lading No.

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

Certified By:

Quality Control Department

Erwin, Tennessee

E-33

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date September 13, 1968

Customer General Electric Company

P. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	9/13/68 Shipment		ANALYSIS, ppm		
	Specification: 22A1548				
12(e)	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
	121	3286.6	588.96	543.27	
	169	3281.4	591.31	542.42	
	871	3358.20	606.83	555.78	
	148	3321.4	598.52	549.03	
	171	3278.4	590.77	541.92	
	221	3324.4	599.06	549.52	
	275	3317.6	597.83	548.40	
	260	3313.8	597.15	547.77	
	265	3302.4	595.09	545.89	
	392	3327.93	599.69	550.11	
	153	3304.0	595.38	546.15	
	124	3276.3	590.06	541.57	
	155	3280.2	591.09	542.22	
	125	3274.1	589.67	541.21	
	159	3277.8	590.66	541.82	
	149	3292.1	593.24	544.18	
	166	3284.1	591.79	542.86	
	133	3270.5	589.02	540.61	
	157	3275.6	590.26	541.46	
	873	3314.40	598.91	548.53	
	321	3294.0	593.58	544.50	
	266	3305.33	595.62	546.37	
	143	3268.7	588.69	540.32	
	325	3307.23	595.96	546.69	
	264	3301.8	594.98	545.79	
	245	3336.9	601.31	551.59	
	896	3312.93	596.99	547.63	
	253	3316.3	597.60	548.18	
	895	3321.93	598.61	549.12	
	273	3307.1	595.94	546.66	
	277	3281.2	591.27	542.38	

Certified By: _____

Quality Control Department

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date September 13, 1968

Customer General Electric Company

P. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	9/13/68 Shipment		ANALYSIS, ppm		
	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
	127	3324.0	598.65	549.46	
	181	3275.7	590.28	541.47	
	333	3326.6	599.45	549.89	
	359	3349.0	603.49	553.59	
	319	3280.2	591.09	542.22	
	261	3303.9	595.36	546.13	
	916	3269.90	589.24	540.51	
	256	3301.1	594.86	545.67	
	915	3268.30	588.62	540.25	
	826	3332.93	602.26	551.60	
	304	3319.70	598.21	548.75	
	194	3309.27	596.33	547.02	
	222	3294.0	593.58	544.50	
	192	3277.0	590.52	541.69	
	917	3291.50	593.13	544.08	
	271	3316.2	597.58	548.17	
	274	3307.0	595.92	546.65	
	163	3276.3	590.39	541.57	
	262	3308.5	596.19	546.90	
	259	3302.2	595.06	545.85	
	230	3279.5	590.97	542.10	
	377	3352.6	604.14	554.18	
	742	3395.30	613.53	561.92	
	432	3353.27	604.26	554.30	
	728	3311.93	598.47	548.12	
	918	3267.30	588.77	540.08	
	517	3322.20	600.32	549.82	
	591	3321.90	600.27	549.77	
	258	3308.0	596.10	546.81	
	919	3272.20	589.65	540.89	
	920	3269.27	589.12	540.41	

Certified By: _____

Quality Control Department

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date September 13, 1968

Customer General Electric Company

P. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	9/13/68 Shipment		ANALYSIS, ppm		
	Specification: 22A1548				
12(e)	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
	127	3324.0	598.65	549.46	
	181	3275.7	590.28	541.47	
	333	3326.6	599.45	549.89	
	359	3349.0	603.49	553.59	
	319	3280.2	591.09	542.22	
	261	3303.9	595.36	546.13	
	916	3269.90	589.24	540.51	
	256	3301.1	594.86	545.67	
	915	3268.30	588.62	540.25	
	826	3332.93	602.26	551.60	
	304	3319.70	598.21	548.75	
	194	3309.27	596.33	547.02	
	222	3294.0	593.58	544.50	
	192	3277.0	590.52	541.69	
	917	3291.50	593.13	544.08	
	271	3316.2	597.58	548.17	
	274	3307.0	595.92	546.65	
	163	3276.3	590.39	541.57	
	262	3308.5	596.19	546.90	
	259	3302.2	595.06	545.85	
	230	3279.5	590.97	542.10	
	377	3352.6	604.14	554.18	
	742	3395.30	613.53	561.92	
	432	3353.27	604.26	554.30	
	728	3311.93	598.47	548.12	
	918	3267.30	588.77	540.08	
	517	3322.20	600.32	549.82	
	591	3321.90	600.27	549.77	
	258	3308.0	596.10	546.81	
	919	3272.20	589.65	540.89	
	920	3269.27	589.12	540.41	

Certified By: K. A. H. P.

Quality Control Department

NUCLEAR FUEL SERVICES, INC.

A Subsidiary of W. R. Grace & Co.

Erwin, Tennessee

GEAP-13760

CERTIFICATE OF ANALYSIS

Material UO₂-PuO₂ Fuel Rods

Date September 13, 1968

Customer General Electric Company

P. O. Box 254

Date Shipped _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 25 A

ELEMENT	9/13/68 Shipment		ANALYSIS, ppm		
	Specification: 22A1548				
12(e)	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
	475	3326.10	599.36	549.80	
	624	3328.27	599.75	550.16	
	606	3321.73	600.24	549.75	
	357	3348.4	603.38	553.49	
	358	3349.3	603.54	553.64	
	250	3327.4	599.60	550.02	
	131	3267.2	588.42	540.07	
	255	3304.7	595.51	546.27	
	247	3332.3	600.48	550.83	
	254	3319.2	598.12	548.66	
	268	3301.2	594.88	545.69	
	276	3311.3	596.70	547.36	
	244	3332.4	600.50	550.85	
	270	3306.5	595.83	546.56	
	269	3319.0	598.08	548.63	
	215	3330.6	600.17	550.55	
	887	3297.08	595.78	545.67	
	248	3331.7	600.37	550.73	
	272	3309.2	596.32	547.01	
	218	3268.2	588.93	540.23	
	142	3273.3	589.52	541.08	
	220	3267.2	588.75	540.07	
	134	3266.0	588.21	539.87	
	150	3329.3	599.94	550.33	
	174	3265.1	588.37	539.72	
	175	3276.1	590.35	541.54	
	139	3277.8	590.33	541.82	
	138	3267.8	588.53	540.17	
	176	3269.2	589.11	540.40	
	140	3267.2	588.42	540.07	
	189	3267.0	588.71	540.04	

Certified By: K. D. H. [Signature]
Quality Control Department

CERTIFICATE OF ANALYSIS

Material: UO₂-PuO₂ Fuel Rods

Date: September 13, 1968

Customer: General Electric Company

P. O. Box 254

Date Shipped: _____

San Jose, California

Bill of Lading No. _____

Purchase Order No. 205-58226-NG

Sales Order No. 256-A

ELEMENT	9/13/68 Shipment		ANALYSIS, ppm		
	Serial	Fuel	Pu	Pu 239 + 241	
	Number	Weight	Weight	Weight	
12(e)					
	172	3282.8	591.56	542.65	
	170	3285.5	592.05	543.09	
	233	3316.8	597.69	548.27	
	921	3279.30	590.93	542.07	
	225	3323.1	598.82	549.31	
	372	3343.9	602.57	552.75	
	923	3265.50	588.44	539.79	
	924	3303.10	595.22	546.00	
	Item No. 2				
	A01	3353.30	806.80	740.41	
	A02	3359.30	808.25	741.73	
	A03	3365.30	809.69	743.06	
	A04	3354.30	807.04	740.63	
	A06	3375.30	812.10	745.27	
	A07	3380.47	813.34	746.41	
	A08	3369.30	810.65	743.94	
	A09	3368.25	810.40	743.71	
	A10	3379.30	813.06	746.15	
	A11	3352.30	806.56	740.19	
	A12	3358.40	808.03	741.53	
	A13	3343.70	804.49	738.29	
	A14	3337.20	802.93	736.85	
	A15	3348.20	805.58	739.28	
	A16	3338.23	803.18	737.08	
	A17	3358.23	807.99	741.50	
	A18	3338.93	803.35	737.24	
	A19	3334.27	802.23	736.21	

Certified By: _____

Quality Control Department

Erwin, Tennessee

E-39

APPENDIX F

**NFS Certifications of Analysis for Inert Materials for
Fuel Rods**

NUCLEAR FUEL SERVICES, INC.
ERWIN, TENNESSEE 37650 **NFS**

October 7, 1968

*TO Pfisterer
10-11-68*

Mr. James Behlen
APO - R & D Procurement
General Electric Company
175 Curtner Avenue
San Jose, California

Reference: Purchase Order 205-58226

Subject: Heat Numbers - Fuel Rod Components

Dear Mr. Behlen:

Fuel rod components were produced from materials having the heat numbers indicated below:

<u>Component</u>	<u>Heat Number</u>
End Fittings and Center Spaces	51323, 57186 and 57185
Springs	4305J21
Nickel Reflectors	N9420A

Supplier's certifications are attached for your information.

Very truly yours,

NUCLEAR FUEL SERVICES, INC.

Sherman Williams
Sherman Williams

SW/jd
Att.

GEAP-13760

035 12.23 01/20/57

IFSD COI 12. United States Steel Supply

HGGD

CH 14533

Division of

United States Steel Corporation

OPERATING COPY

DATE 1/20/67	SHIPPING PROMISE 1/23/67	GLASGOW/EP		COPIES 20	DATE SHIPPED JAN 24 1967
USD ORD. 14533	CUST. CODE 00000000	CUST. ORDER NO. 7864	CD 364		
CHARGE T	ACCURATE MACHINE PRODUCTS CORP		SHIP TO	RETURN TO TRAFFIC BY:	
	P O BOX 830			T M E 11:00 P.M.	
	JOHNSON CITY TENNESSEE			DATE 1/23 1-24	
		SAME	710 WEST WALNUT ST JOHNSON CITY TENNESSEE		

Description & Specification:

SS RD T304 A&CG

46 pcs. 1" 14'R ASTM A-276

END
P. H. H. H.
SPACER MTL

51323

Slab

Lot

Color Identification

Chemistry

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Other				G/S
.067	.97	.026	.018	.41	.08	9.07	18.62	.14					

Mechanical Properties

TENSILE STRENGTH PSI	YIELD POINT PSI	YIELD STRENGTH PSI	ELONG. %	PER CENT RED. AREA	HARDNESS	BEND TEST	HOMO- GENEITY
88,000		50,000	57.8	2	BHN 174		

End Quench Hardenability — 16ths Inches

1	2	3	4	5	6	8	10	12	14	16	18	20	24	28	32
Guaranteed Min- RC															
This Heat- RC															

SPECIAL TESTS

Corrosion

Macro

Hardenability —
Special

Decarb.

Other

UNLESS OTHERWISE INDICATED THE ABOVE TEST RESULTS CONFORM TO THE REQUIREMENTS OF THE LISTED SPECIFICATION.

WE HEREBY CERTIFY THAT THE ABOVE
DATA IS AS CONTAINED IN OUR RECORDS.
United States Steel Supply

P-3

By

1035 12.23 01/20/67

STANDARD 12. United States Steel Supply

CHGO

CH 14533

Division of

GEAP-13760

United States Steel Corporation

OPERATING COPY

DATE	SHIPPING PROMISE	GLASGOW/EP		COPIES	DATE SHIPPED
1/20/67	1/23/67	1-2	364	20	JAN 24 1967
USD ORD.	CUST. CODE	CUST. ORDER NO.	CD		
14533	00000000	7864			
CHARGE	ACCURATE MACHINE PRODUCTS CORP		SHIP TO	RETURN TO TRAFFIC BY:	
	P O BOX 830			TIME 1:00 P.M.	
	JOHNSON CITY TENNESSEE			DATE 1/23 1-24	

Description & Specification:

SS RD T304 A&CG

46 pcs. 1" 14'R ASTM A-276

END
P. H. H. H.
SPACE 114

Heat 51323 Slob Lot

Color Identification

Chemistry

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Other	G/S
.067	.97	.026	.018	.41	.08	9.07	18.62	.14		

Mechanical Properties

TENSILE STRENGTH PSI	YIELD POINT PSI	YIELD STRENGTH PSI	ELONG.		PER CENT RED. AREA	HARDNESS	BEND TEST	HOMO- GENEITY
			%	IN.				
88,000		50,000	57.8	2	76.0	BHN 174		

End Quench Hardenability — 16ths Inches

1	2	3	4	5	6	8	10	12	14	16	18	20	24	28	32
Guaranteed Min- RC															
This Heat- RC															

SPECIAL TESTS

Corrosion _____ Macro _____ Hardenability — _____
Decarb. _____ Other _____ Special _____

UNLESS OTHERWISE INDICATED THE ABOVE TEST RESULTS CONFORM TO THE REQUIREMENTS OF THE LISTED SPECIFICATION.

WE HEREBY CERTIFY THAT THE ABOVE
DATA IS AS CONTAINED IN OUR RECORDS.
United States Steel Supply

E-4

By _____

GEAP-13760

035 12.23 01/20/67

IFSD CO# 12.3
HOCO

United States Steel Supply

United States Steel Corporation

GN 14533

Division of

OPERATING COPY

DATE 1/20/67		SHIPPING PROMISE 1/23/67		GLASGOW/EP		DATE SHIPPED JAN 24 1967	
USD ORD. 14533	CUST. CODE 00000000	CUST. ORDER NO. 7864	CD 364	COPIES 20	RETURN TO TRAFFIC BY: T 1:00 P.M. DATE 1/23/67		
CHARGE TO ACCURATE MACHINE PRODUCTS CORP P O BOX 830 JOHNSON CITY TENNESSEE			SHIP TO SAME 710 WEST WALNUT ST JOHNSON CITY TENNESSEE		END P. H. H. + SPACER MTD		

Description & Specification:

SS RD T304 A&CG

46 pcs. 1" 14'R ASTM A-276

Lot 51323

Slob

Lot

Color Identification

Chemistry

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Other			G/S
.067	.97	.026	.018	.41	.08	9.07	18.62	.14				

Mechanical Properties

TENSILE STRENGTH PSI	YIELD POINT PSI	YIELD STRENGTH PSI	ELONG. %	PER CENT RED. AREA	HARDNESS	BEND TEST	HOMO- GENEITY
88,000		50,000	57.8	2	76.0	BHN 174	

End Quench Hardenability — 16ths Inches

1	2	3	4	5	6	8	10	12	14	16	18	20	24	28	32
Guaranteed Min- RC															
This Heat- RC															

SPECIAL TESTS

Corrosion	Macro	Hardenability — Special
Decarb	Other	

UNLESS OTHERWISE INDICATED THE ABOVE TEST RESULTS CONFORM TO THE REQUIREMENTS OF THE LISTED SPECIFICATION.

WE HEREBY CERTIFY THAT THE ABOVE
DATA IS AS CONTAINED IN OUR RECORDS.

United States Steel Supply

By

J. M. TULL METALS COMPANY, INC.

NUCLEAR FUEL SERVICES

GEAP-13760

Date JUNE 5 19 68

ERWIN, TENNESSEE

Date Shipped

Your Order No.

22918

Our Order No.

181510

MATERIAL

Manufactured By

Item 1 1" DIA. C6 T 304 STAINLESS ROUND ROD 160# 60 FT.

Item 2

Item 3

Item 4

CERTIFICATION OF MATERIALS

This will certify that the above described material was produced in accordance with the following specifications.

ASTM A276-65 COND A

Item 2

Item 3

Item 4

ATLANTA, GA.

Tull Warehouse Location

Signature

CERTIFICATE OF TESTS

CHEMICAL ANALYSIS

Item No.	Heat No.	Alloy No.	C	MN	PK P	S	SI	CR	NI	MO	CU	CO
1	57185		.062	.88	.029	.026	.56	18.70	8.94	.18	.18	.10
2												
3												
4												

HEAT NO.

MECHANICAL PROPERTIES

Item No.	HEAT NO.	Tensile Str.	Yield Str.	%Elong 2"	Hardness	Bend Test	Test Satis.	RED OFA AREA %
1	57185	85,000	38,000	59.0	XXXXX BHN 152			74.6
2								
3								
4								

We hereby certify that the above figures are correct as contained in the records of this company.

ATLANTA, GA.

Tull Warehouse Location

LEIGH PARHAM

Signature

J. M. TULL METALS COMPANY, INC.

NUCLEAR FUEL SERVICES

GEAP-13760

Date JUNE 5 19 68

ERWIN, TENNESSEE

Date Shipped

Your Order No. 22918

Our Order No. 181510

MATERIAL

Manufactured By

Item 1 1" DIA. C6 T 304 STAINLESS BOUND ROD 160# 60 FT.

Item 2

Item 3

Item 4

CERTIFICATION OF MATERIALS

This will certify that the above described material was produced in accordance with the following specifications.

ASTM A276-65 COND A

Item 2

Item 3

Item 4

ATLANTA, GA.

Tull Warehouse Location

Signature

CERTIFICATE OF TESTS

CHEMICAL ANALYSIS

Item No.	Heat No.	Alloy No.	C	MN	PK P	S	SI	CR	NI	MO	CU	CO
1	57185		.062	.88	.029	.026	.56	18.70	8.94	.18	.18	.10
2												
3												
4												

HEAT NO.

MECHANICAL PROPERTIES

Item No.	HEAT NO.	Tensile Str.	Yield Str.	%Elong 2"	Hardness	Bend Test	Test Satis.	RED OFA AREA %
1	57185	85,000	38,000	59.0	XXXXX BHN 152			74.6
2								
3								
4								

We hereby certify that the above figures are correct as contained in the records of this company.

ATLANTA, GA.

Tull Warehouse Location

F-7

Signature

Form 712

J. M. TULL METALS COMPANY, INC.

NUCLEAR FUEL SERVICES

GEAP-13760

Date JUNE 5 19 68

ERWIN, TENNESSEE

Date Shipped

Your Order No.

22918

Our Order No.

181510

MATERIAL

Manufactured By

Item 1 1" DIA. CG T 304 STAINLESS BOUND ROD 160# 60 FT.

Item 2

Item 3

Item 4

CERTIFICATION OF MATERIALS

This will certify that the above described material was produced in accordance with the following specifications.

ASTM A276-65 COND A

Item 2

Item 3

Item 4

ATLANTA, GA.

Tull Warehouse Location

Signature

CERTIFICATE OF TESTS**CHEMICAL ANALYSIS**

Item No.	Heat No.	Alloy No.	C	MN	XX P	S	SI	CR	NI	MO	CU	CO
1	57185		.062	.88	.029	.026	.56	18.70	8.94	.18	.18	.10
2												
3												
4												

HEAT NO.**MECHANICAL PROPERTIES**

Item No.	Heat No.	Tensile Str.	Yield Str.	%Elong 2"	Hardness	Bend Test	Test Satis.	RED OF A AREA %
1	57185	85,000	38,000	59.0	XXXXX BHN 152			74.6
2								
3								
4								

We hereby certify that the above figures are correct as contained in the records of this company.

ATLANTA, GA.

Tull Warehouse Location

LEIGH PARHAM

Signature

J. M. TULL METALS COMPANY, INC.

NUCLEAR FUEL SERVICES

GEAP-13760

Date MAY 10 19 68

ERWIN, TENNESSEE

Date Shipped _____

Your Order No. 22530

Our Order No. 143573

MATERIAL

Manufactured By _____

Item 1 170 FT. 1 CIG 034 STNLS. STEEL ROUND ROD 454#

Item 2 _____

Item 3 _____

Item 4 _____

CERTIFICATION OF MATERIALS

This will certify that the above described material was produced in accordance with the following specifications.

ASTM A276, 65 COND A

Item 2

Item 3

Item 4

ATLANTA, GA.

Tull Warehouse Location

Leigh Parkam
Signature

CERTIFICATE OF TESTS

CHEMICAL ANALYSIS

Item No.	Heat No.	Alloy No.	C	MN	P	S	SI	CR	NI	MO	CU	CO
1	57186		.053	.66	.023	.023	.43	18.22	8.66	.15	.12	.08
2												
3												
4												

MECHANICAL PROPERTIES

Item No.	Grain Size	Tensile Str.	Yield Str.	%Elong 2"	Hardness	Bend Test	Test Satis.	RED OF AREA
1		92,000	48,000	54.0	BHN 197			70.9
2								
3								
4								

We hereby certify that the above figures are correct as contained in the records of this company.

ATLANTA, GA.

Tull Warehouse Location

F-9

Leigh Parkam
Signature

Form 712

J. M. TULL METALS COMPANY, INC.

NUCLEAR FUEL SERVICES

GEAP-13760

Date MAY 10 19 68

ERWIN, TENNESSEE

Date Shipped

Your Order No. 22530

Our Order No. 143573

MATERIAL

Manufactured By

Item 1 170 FT. 1 CIG 034 STNLS. STEEL ROUND ROD 454#

Item 2

Item 3

Item 4

CERTIFICATION OF MATERIALS

This will certify that the above described material was produced in accordance with the following specifications.

Item 1 ASTM A276; 65 COND A

Item 2

Item 3

Item 4

ATLANTA, GA.

Tull Warehouse Location

Signature

CERTIFICATE OF TESTS

CHEMICAL ANALYSIS

Item No.	Heat No.	Alloy No.	C	MN	P	S	SI	CR	NI	MO	CU	CO
1	57186		.053	.66	.023	.023	.43	18.22	8.66	.15	.12	.08
2												
3												
4												

MECHANICAL PROPERTIES

Item No.	Grain Size	Tensile Str.	Yield Str.	%Elong 2"	Hardness	Bend Test	Test Satis.	RED OF AREAS
1		92,000	48,000	54.0	BHN 197			70.9
2								
3								
4								

We hereby certify that the above figures are correct as contained in the records of this company.

ATLANTA, GA.

Tull Warehouse Location

Signature

J. M. TULL METALS COMPANY, INC.

NUCLEAR FUEL SERVICE

GEAP-13760

Date MAY 10 19 68

Date Shipped _____

Your Order No. 22530Our Order No. 143573ERWIN, TENNESSEE

MATERIAL

Manufactured By _____

Item 1 170 FT. 1 CIG 034 STNLS. STEEL ROUND ROD 454#

Item 2 _____

Item 3 _____

Item 4 _____

CERTIFICATION OF MATERIALS

This will certify that the above described material was produced in accordance with the following specifications.

ASTM A276, 65 COND A

Item 2

Item 3

Item 4

ATLANTA, GA.

Tull Warehouse Location

Signature Leigh Parkam

CERTIFICATE OF TESTS

CHEMICAL ANALYSIS

Item No.	Heat No.	Alloy No.	C	MN	P	S	SI	CR	NI	MO	CU	CO
1	57186		.053	.66	.023	.023	.43	18.22	8.56	.16	.12	.08
2												
3												
4												

MECHANICAL PROPERTIES

Item No.	Grain Size	Tensile Str.	Yield Str.	%Elong 2"	Hardness	Bend Test	Test Satis.	RED OF AREA%
1		92,000	48,000	54.0	BHN 197			70.9
2								
3								
4								

We hereby certify that the above figures are correct as contained in the records of this company.

ATLANTA, GA.

Tull Warehouse Location

Signature Leigh Parkam

REPORT OF MATERIAL ANALYSIS

GEAP-13760

Associated Spring Corporation

Wallace Barnes Davis
Bristol, Conn. 06012

Customer

NUCLEAR FUEL SERVICES INC.
A Sub. of W.R. Grace & Co.
Erwin, Tennessee 37650

ART NO.	CUSTOMER ORDER NO.	OUR ORDER NO.	MATERIAL SPEC.
159A2752 Rev.4	13823	B35504	Inconel X-750

CHEMICAL ANALYSIS

ARBON .03	MANGANESE .49	PHOSPHORUS	SULPHUR .007
SILICON .30	CHROMIUM 15.34	VANADIUM	NICKEL 72.98
LEAD .04	COPPER	ZINC	IRON 6.65
NITROGEN	MOLYBDENUM	TUNGSTEN	COBALT
ALUMINUM .63	MAGNESIUM	BERYLLIUM	TITANIUM 2.68
NIOBIUM & tantalum .83			

PHYSICAL PROPERTIES

SIZE OF MATERIAL .062" Dia.		VENDOR OF RAW MATERIAL H.K. Porter	
TENSILE STRENGTH 138,500-141,000 PSI	REDUCTION OF AREA	ELONGATION	ROCKWELL
HEAT NUMBER 1305J21	BDLE., LOT, CODE NO.	BEND	KINK
WRAPPING	TWIST	COILING	ETCHING
Tensile: 194,000-201,000 PSI AFTER heat treating			

REMARKS
Parts heat treated and passivated.

SPECIAL TESTS: Based on sample inspection, we certify that, this shipment is in compliance with blueprint specifications. This certification does not relieve buyer of his obligation to inspect shipment on receipt.

This report covers 947 pieces shipped Jan. 20, 67 Packing list B35504

I certify that the above information is correct

Authorized Agent

Subscribed and sworn to before me at Bristol, Conn. this 20th day of January 1967

Notary Pub

My Commission expires April 1, 1969

REPORT OF MATERIAL ANALYSIS

GEAP-13760
Associated Spring Corporation

Wallace Barnes Division
Bristol, Conn. 06012

Customer

NUCLEAR FUEL SERVICES INC.
A Sub. of W.R. Grace & Co.
Erwin, Tennessee 37650

ART NO.	CUSTOMER ORDER NO.	OUR ORDER NO.	MATERIAL SPEC.
159A2752 Rev.4	13823	B35504	Inconel X-750

CHEMICAL ANALYSIS

CARBON .03	MANGANESE .49	PHOSPHORUS	SULPHUR .007
SILICON .30	CHROMIUM 15.34	VANADIUM	NICKEL 72.98
ALUMINUM .63	COPPER .04	ZINC	IRON 6.65
NIOBIUM & tantalum .83	MOLYBDENUM	TUNGSTEN	COBALT
	MAGNESIUM	BERYLLIUM	TITANIUM 2.68

PHYSICAL PROPERTIES

SIZE OF MATERIAL 062" Dia.		VENDOR OF RAW MATERIAL H.K. Porter	
TENSILE STRENGTH 38,500-141,000 PSI	REDUCTION OF AREA	ELONGATION	ROCKWELL
HEAT NUMBER 305J21	SOLE, LOT, CODE NO.	BEND	KINK
WELDING	TWIST	COILING	ETCHING
Tensile: 194,000-201,000 PSI AFTER heat treating			

REMARKS

parts heat treated and passivated.

SPECIAL TESTS: Based on sample inspection, we certify that, this shipment is in compliance with blueprint specifications. This certification does not relieve buyer of his obligation to inspect shipment on receipt.

This report covers 947 pieces shipped Jan. 20, 67 Packing list B35504

I certify that the above information is correct

[Signature] Authorized Agent

Subscribed and sworn to before me at Bristol, Conn. this 28rd day of January 1967

[Signature] Notary Public

My Commission expires April 1, 1969

REPORT OF MATERIAL ANALYSIS

GEAP-13760

Associated Spring Corporation

Wallace Barnes Divis
Bristol, Conn. 06012

Customer

NUCLEAR FUEL SERVICES INC.
A Sub. of W.R. Grace & Co.
Erwin, Tennessee 37650.

ART NO.	CUSTOMER ORDER NO.	OUR ORDER NO.	MATERIAL SPEC.
159A2752 Rev.4	13823	B35504	Inconel X-750

CHEMICAL ANALYSIS

CARBON .03	MANGANESE .49	PHOSPHORUS	SULPHUR .007
SILICON .30	CHROMIUM 15.34	VANADIUM	NICKEL 72.98
LEAD	COPPER .04	ZINC	IRON 6.65
N	MOLYBDENUM	TUNGSTEN	COBALT
ALUMINUM .63	MAGNESIUM	BERYLLIUM	TITANIUM 2.68
NIOBIUM & tantalum .83			

PHYSICAL PROPERTIES

SIZE OF MATERIAL .062" Dia.		VENDOR OF RAW MATERIAL H.K. Porter	
TENSILE STRENGTH 138,500-141,000 PSI	REDUCTION OF AREA	ELONGATION	ROCKWELL
HEAT NUMBER 1305J21	BDLE., LOT, CODE NO.	BEND	KINK
DRAWING	TWIST	COILING	ETCHING
Tensile: 194,000-201,000 PSI AFTER heat treating			

Parts heat treated and passivated.

SPECIAL TESTS: Based on sample inspection, we certify that, this shipment is in compliance with blueprint specifications. This certification does not relieve buyer of his obligation to inspect shipment on receipt.

This report covers 947 pieces shipped Jan. 20, 67 Packing list B35504

I certify that the above information is correct

[Signature] Authorized Agent

Subscribed and sworn to before me at Bristol, Conn. this 28rd day of January 1967

[Signature] Notary Public

My Commission expires April 1, 1969

HUNTINGTON ALLOY PRODUCTS DIVISION
THE INTERNATIONAL NICKEL COMPANY, INC.
HUNTINGTON, WEST VIRGINIA 25720

M-1091 REV 5-61
GEAP-13760

12-05-65

PAGE 1 OF 1

J H TULL METALS CO INC
285 MARIETTA ST N W
ATLANTA 2 GA

AIR MAIL

30313

DE 01-136696

ACCURATE MACHINE PROD CORP
JOHNSON CITY TENN

AIR MAIL

EXPLANATION OF NOTES

- (1) IF THIS REPORT IS A "CERTIFICATE OF COMPLIANCE", THE MATERIAL FURNISHED ON THE ORDER SHOWN COMPLIES WITH THE SPECIFICATION SHOWN AS FOLLOWS:
(A) CHEMICALLY (BASED ON LADLE ANALYSIS) AS LISTED.
(B) MECHANICALLY (BASED ON AVAILABLE PRODUCTION DATA).
- (2) IF TEMPERATURE IS NOT SHOWN, MECHANICAL PROPERTIES WERE OBTAINED AT ROOM TEMPERATURE.
- (3) STRESS RUPTURE OR CREEP PROPERTIES LISTED IN TABLE WERE OBTAINED AFTER HEAT TREATMENT SHOWN IN REMARKS BELOW.
- (4) SYMBOLS IN REMARKS COLUMN OF STRESS RUPTURE OR CREEP PROPERTIES TABLE INDICATE FOLLOWING CONDITIONS REGARDING RUPTURE LIFE HOURS SHOWN:
"D"-TEST DISCONTINUED WITHOUT FRACTURE.
"S"-COMBINATION NOTCH AND SMOOTH BAR SPECIMEN FRACTURED IN SMOOTH GAUGE.
"X"-STRESS WAS INCREASED PER SPECIFICATION OPTION TO INDUCE EARLY FRACTURE.
- (5) UNLESS OTHERWISE SHOWN, %NI INCLUDES A SMALL AMOUNT OF COBALT.

ER 7481

IV INCO

CA1400

SPECIFICATION ASTM B-160-61

CERTIFICATE OF COMPLIANCE (1) ☐ CERTIFICATE OF CHEMICAL ANALYSIS ☐

QUANTITY	DESCRIPTION OF MATERIAL AS SHIPPED
90 PCS 1392 LBS	.875" DIA X 4.375" RULT NICKEL 200 CD RND CD

MECHANICAL PROPERTIES AS SHIPPED (2)															
QUANTITY	INGOT	HEAT NO.	PIECE NUMBERS	HARDNESS	AV. GRAIN DIAMETER IN INCHES	YIELD STRENGTH AT (P.S.I. X 100)				TENSILE STRENGTH P.S.I. X 100	% ELONGATION	% REDUCTION OF AREA	TEMPERATURE °F	STRAIN RATE	
						.2% OFFSET	.02% OFFSET	.01% OFFSET	EXTENSION UNDER LOAD					IN IN./MIN. TO .2% YIELD	IN IN./MIN. AFTER YIELD
		N2420A		RB 021	.	0025					0050	25	81		

STRESS RUPTURE OR CREEP PROPERTIES (3)												
QUANTITY	INGOT	HEAT NO.	PIECE NUMBERS	HARDNESS	TEMPERATURE °F	STRESS P.S.I. X 10	RUPTURE LIFE IN HOURS	RE-MARKS (4)	% ELONGATION	% REDUCTION OF AREA	% CREEP	AT HOURS

ANALYSES

% C	% MN	% FE	% S	% SI	% CU	% NI (5)	% CR	% AL	% TI	% MG	% CO	% MO	CB+TA	EL. %	EL. %
0.06	00.27	00.03	.005	00.02	00.01	99.58	.	.	.	.	.	.	.	.	.

F-15

THIS IS TO CERTIFY THAT ALL REQUIRED INSPECTIONS AND TESTS HAVE BEEN COMPLETED IN ACCORDANCE WITH THE ORDER REQUIREMENTS AND THAT THE VALUES SHOWN ARE CORRECT AND TRUE. BASED ON THESE TESTS THE MATERIAL COMPLIES WITH THE ORDER REQUIREMENTS.

(Signature)

HUNTINGTON ALLOY PRODUCTS DIVISION
THE INTERNATIONAL NICKEL COMPANY, INC.
HUNTINGTON, WEST VIRGINIA 25720

M-1091 REV. 3

GEAP-13760

12-05-66

PAGE 1 OF 1

J H TULL METALS CO INC
285 MARLETTA ST N W
ATLANTA 2 GA

AIR MAIL

30313

ED-136596

ACCURATE MACHINE PROD CORP
JOHNSON CITY TENN

AIR MAIL

EXPLANATION OF NOTES

- (1) IF THIS REPORT IS A "CERTIFICATE OF COMPLIANCE", THE MATERIAL FURNISHED ON THE ORDER SHOWN COMPLIES WITH THE SPECIFICATION SHOWN AS FOLLOWS:
(A) CHEMICALLY (BASED ON LADLE ANALYSIS) AS LISTED.
(B) MECHANICALLY (BASED ON AVAILABLE PRODUCTION DATA).
(2) IF TEMPERATURE IS NOT SHOWN, MECHANICAL PROPERTIES WERE OBTAINED AT ROOM TEMPERATURE.
(3) STRESS RUPTURE OR CREEP PROPERTIES LISTED IN TABLE WERE OBTAINED AFTER HEAT TREATMENT SHOWN IN REMARKS BELOW.
(4) SYMBOLS IN REMARKS COLUMN OF STRESS RUPTURE OR CREEP PROPERTIES TABLE INDICATE FOLLOWING CONDITIONS REGARDING RUPTURE LIFE HOURS SHOWN:
"D" - TEST DISCONTINUED WITHOUT FRACTURE.
"S" - COMBINATION NOTCH AND SMOOTH BAR SPECIMEN FRACTURED IN SMOOTH GAUGE.
"X" - STRESS WAS INCREASED PER SPECIFICATION OPTION TO INDUCE EARLY FRACTURE.
(5) UNLESS OTHERWISE SHOWN, %NI INCLUDES A SMALL AMOUNT OF COBALT.

ER 7481

Y INCO

CA1400

SPECIFICATION ASTM B-160-61

☒ CERTIFICATE OF COMPLIANCE (1)

☐ CERTIFICATE OF CHEMICAL ANALYSIS

QUANTITY	DESCRIPTION OF MATERIAL AS SHIPPED
30 PCS 1392 LBS	.875" DIA X 4.375" MULT NICKEL 200 CO RND CO

CAL PROPERTIES AS SHIPPED (2)															
QUANTITY	INGDT	HEAT NO.	PIECE NUMBERS	HARDNESS	AV. GRAIN DIAMETER IN INCHES	YIELD STRENGTH AT (P.S.I. X 100)			EXTENSION UNDER LOAD	TENSILE STRENGTH P.S.I. X 100	% ELONGATION	% REDUCTION OF AREA	TEMPERATURE OF	STRAIN RATE	
						.2% OFFSET	.02% OFFSET	.01% OFFSET						IN IN./IN. MIN. TO .2% YIELD	IN IN./IN. MIN. AFTER YIELD
		N9420A		RB 091		0025				0350	25	81			

RUPTURE OR CREEP PROPERTIES (3)												
QUANTITY	INGOT	HEAT NO.	PIECE NUMBERS	HARDNESS	TEMPERATURE OF	STRESS P.S.I. X 10	RUPTURE LIFE IN HOURS	REMARKS (4)	% ELONGATION	% REDUCTION OF AREA	% CREEP	AT HOURS

L ANALYSES																
% C	% MN	% FE	% S	% SI	% CU	% NI (5)	% CR	% AL	% TI	% MG	% CO	% MO	CB+TA	EL. %	EL. %	EL. %
0.05	00.27	00.03	.005	00.02	00.01	99.58	.	.	.	.	.	.	.	.	.	.

THIS IS TO CERTIFY THAT ALL REQUIRED INSPECTIONS AND TESTS HAVE BEEN COMPLETED IN ACCORDANCE WITH THE ORDER REQUIREMENTS AND THAT THE VALUES SHOWN ARE CORRECT AND TRUE. BASED ON THESE TESTS THE MATERIAL COMPLIES WITH THE ORDER REQUIREMENTS.

F-16

HUNTINGTON ALLOY PRODUCTS DIVISION

THE INTERNATIONAL NICKEL COMPANY, INC.

HUNTINGTON, WEST VIRGINIA 25720

GEAP-13760

M-1091 REV. 5

12-05-66

PAGE 1 OF 1

J M TULL METALS CO INC
285 HARIETTA ST N W
ATLANTA 2 GA

AIR MAIL

30313

ED1-136596

ACCURATE MACHINE PROD CORP
JOHNSON CITY TENN

AIR MAIL

EXPLANATION OF NOTES

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 - (A) CHEMICALLY (BASED ON LADLE ANALYSIS) AS LISTED.
 - (B) MECHANICALLY (BASED ON AVAILABLE PRODUCTION DATA).
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- (3) STRESS RUPTURE OR CREEP PROPERTIES LISTED IN TABLE WERE OBTAINED AFTER HEAT TREATMENT SHOWN IN REMARKS BELOW.
- (4) SYMBOLS IN REMARKS COLUMN OF STRESS RUPTURE OR CREEP PROPERTIES TABLE INDICATE FOLLOWING CONDITIONS REGARDING RUPTURE LIFE HOURS SHOWN:
 - "D"-TEST DISCONTINUED WITHOUT FRACTURE.
 - "S"-COMBINATION NOTCH AND SMOOTH BAR SPECIMEN FRACTURED IN SMOOTH GAUGE.
 - "X"-STRESS WAS INCREASED PER SPECIFICATION OPTION TO INDUCE EARLY FRACTURE.
- (5) UNLESS OTHERWISE SHOWN, ".NI" INCLUDES A SMALL AMOUNT OF COBALT.

ER 7481

Y INCO

CA1:00

SPECIFICATION ASTM B-160-61

☒ CERTIFICATE OF COMPLIANCE (1)

☐ CERTIFICATE OF CHEMICAL ANALYSIS

QUANTITY	DESCRIPTION OF MATERIAL AS SHIPPED
30 PCS 1392 LBS	.875" DIA X 4.375" MULT NICKEL 200 CD RND CD

MECHANICAL PROPERTIES AS SHIPPED (2)													
QUANTITY	INGOT	HEAT NO.	PIECE NUMBERS	HARDNESS	AV. GRAIN DIAMETER IN INCHES	.2% OFFSET	.02% OFFSET	.01% OFFSET	EXTENSION UNDER LOAD	TENSILE STRENGTH P.S.I. X 100	% ELONGATION	% REDUCTION OF AREA	TEMPERATURE °F
		N9420A		RB 091		0825				0850	25	81	

STRESS RUPTURE OR CREEP PROPERTIES (3)													
QUANTITY	INGOT	HEAT NO.	PIECE NUMBERS	HARDNESS	TEMPERATURE °F	STRESS P.S.I. X 10	RUPTURE LIFE IN HOURS	REMARKS (4)	% ELONGATION	% REDUCTION OF AREA	% CREEP	AT HOURS	

CHEMICAL ANALYSES																	
% C	% MN	% FE	% S	% SI	% CU	% NI (5)	% CR	% AL	% TI	% MG	% CO	% MO	CB+TA	EL.	%	EL.	%
0.03	00.27	00.03	.005	00.02	00.01	99.58	.	.	.	.	.	.	.	.	.	.	.

F-17

THIS IS TO CERTIFY THAT ALL REQUIRED INSPECTIONS AND TESTS HAVE BEEN COMPLETED IN ACCORDANCE WITH THE ORDER REQUIREMENTS AND THAT THE VALUES SHOWN ARE CORRECT AND TRUE. BASED ON THESE TESTS, THE MATERIAL COMPLIES WITH THE ORDER REQUIREMENTS.

NUCLEAR FUEL SERVICES, INC.
ERWIN, TENNESSEE 37650

NFS

October 4, 1968

Mr. James Behlen
 APO - R & D Procurement
 General Electric Company
 175 Curtner Avenue
 San Jose, California

*To Pflaster
 10-8-68*

B9.6

Reference: Purchase Order 205-58226

Subject: Heat Numbers - Fuel Rods

Dear Mr. Behlen:

The heat number associated with each group of SEFOR fuel rods is listed below:

<u>Rod Numbers</u>	<u>Heat Number</u>
101 - 137	W00949
138 - 281	W00949 and W91668
282 - 459	W00949
460 - 643	W91668
644 - 798	W01782
799 - 842	W03078
843 - 871	W01782
872 - 896	W03078
915 - 924	W03078
A01 - A19	W03078
B4C Rods	W00949

Tubing from Heats W00949 and W91668 were inadvertently intermingled at the Buehler Corporation. The resulting fuel rods were assigned identification numbers 138 through 218.

Tube Methods, Inc.'s test reports on the tubing are attached.

Very truly yours,

NUCLEAR FUEL SERVICES, INC.

Sherman Williams

Sherman Williams

SW/jd
 Attachment

The Methods Inc.

TWX 510-660-0140

		TWX 510-660-0140		TMI ORDER NO. 3817 1 - 2	
CUSTOMER'S ORDER NO. 14448		DATED 1/6/67		TMI ORDER DATE 1/18/67	
TERMS				TMI INVOICE DATE 5/2/67	

SHIP TO

Item 1 Nuclear Fuel Services, Inc.
A Subsidiary of W.R. Grace & Co.
Erwin, Tenn.

Item 2 Orbit Industries
Cleveland, Ohio

SHIP VIA: Truck Collect		(Check with off. before shipping)		F.O.B. Mill	
CUTTING INSTRUCTIONS approx. 45 - 48" Contact office before cutting		SPECIAL ☐ INSTRUCTIONS ☐ MARKINGS Req. No. 7708		SHIPPING PROMISE Wk. Feb. 27th or sooner	
Use Heat No. 00949				DATE SHIPPED	AMT. SHIPPED
TYPE 316	SPECIFICATION AND CONDITION B50-YP79A-2	Item 2		5/8/67	1110'4"
GRADE Seamless	Dwg. 159A2747	Item 1		5/8/67	95'0-5/8"
	U.T. test required				
QUANTITY ORDERED: 3940 ft.	SIZE: .0015"				
	.890" ID + or - .005" x				
	.040" Wall + or - .002"				
INSPECTION: General Electric	Ladle	Check			

TEST REPORT

FOR
CHEMICAL
PROPERTIES

HEAT NO.	W00949	W00949				
C	.041	0.053				
Mn	1.74	1.94				
P	.016	0.020				
S	.025	0.015				
Si	.50	0.524				
Cr	17.25	17.27				
Ni	13.66	13.93				
Mo	2.41	2.38				
Ti						
Cb/Ta						
Ta						
Co						
Cu	.12	--				
Al						
Sn						
Fe						
N						
V						
W						
B	.001	.001				
		F-19				

See Reverse Side for Physical Properties Test Report

PHYSICAL PROPERTIES—TEST REPORT

QUANTITY	LOT	HEAT NO.	AREA	YIELD PT. LBS.	YIELD PT. PSI	ULTIMATE LBS.	ULTIMATE PSI	ELONG. % 2"	ROCK. HARD.
9000	Lot	AWC0949	.117"	4800 5130	41000 43800	10130 10300	85600 88000	58 56	B78 B77 B79 B80 B79
<p>UT tested per TMI approved procedure and found satisfactory.</p> <p>Straightness OK</p> <p>Dimension OK</p> <p>Surface Condition of ID & OD 63 RMS or better.</p>									

RAW MATERIAL SOURCE
 Flange

Allegheny Ludlum Steel Corp.

CORROSION RATE	
GRAIN SIZE	6
CORROSION TEST	
CRUSH	
EMBRITTLMENT	
FLARING	OK
FLATTENING	OK
HUEY	
HYDROSTATIC	
BENDING	
MACRO ETCH	
MICRO ETCH	

CERTIFICATION
 I CERTIFY THIS REPORT TO BE CORRECT.
TUBE METHODS INC.

 SWORN AND SUBSCRIBED BEFORE ME
 THIS 2 DAY OF May 19 67

F-20

John C. McNamee
 Notary Public
 My Commission Expires 12/19/70

TUBING SPECIALISTS • MANUFACTURERS • METALLURGISTS • ENGINEERS

Tube Methods Inc.

GEAP-13760

Bridgeport • Montgomery County • Pennsylvania 19405 • Phone 215-279-7700

TVX 510-660-0140

CUSTOMER'S ORDER NO.	14448	DATED	1/6/67	TMI ORDER NO.	3817-2
TERMS		(C.O. 5/4/67)		TMI ORDER DATE	5/4/67
				TMI INVOICE DATE	6/30/67

SOLD TO

Nuclear Fuel Services, Inc.
A Subsidiary of W.R. Grace & Co.
Erwin, Tenn. 37650

SHIP TO

Orbit Industries
3841 Ridge Rd.
Cleveland, Ohio

SHIP VIA: Truck Prepaid & Add

F.O.B. Mill

CUTTING INSTRUCTIONS 26 Pcs. cut 48" + or - 1/32" Bal. cut 45-5/8" lg. + or - 1/64"	SPECIAL ☐ INSTRUCTIONS ☐ MARKINGS MARK: For Nuclear Fuel Services Order 15901	SHIPPING PROMISE		
TYPE 316	SPECIFICATION AND CONDITION B50-YP79A-2	DATE SHIPPED	AMT. SHIPPED	BALANCE
GRADE Seamless	Dwg. 159A2747 U.T. required	6/30/67	815'2"	1000'0"
QUANTITY ORDERED: 3755 ft.	SIZE: .890" ID + or - .0015" x .040" Wall + or - .002" .041			
INSPECTION: General Electric	Ladle Check			

TEST
REPORT

FOR
CHEMICAL
PROPERTIES

HEAT NO.	W00949	W00949				
C	.041	0.053				
Mn	1.74	1.84				
P	.018	0.020				
S	.025	0.015				
Si	.50	0.524				
Cr	17.25	17.27				
Ni	13.65	13.93				
Mo	2.41	2.38				
Ti						
Cb/Ta						
Ta						
Co						
Cu	.12	--				
Al						
Sn						
Fe						
N						
V						
W						
B	.001	.001				
			F-21			

See Reverse Side for Physical Properties Test Report

PHYSICAL PROPERTIES—TEST REPORT

QUANTITY	LOT	HEAT NO.	AREA	YIELD PT. LBS.	YIELD PT. PSI	ULTIMATE LBS.	ULTIMATE PSI	ELONG. % 2"	ROCK. HARD.
615'2"	Lot A	W00949	.117"	5130 4800	43000 41000	10300 10130	88000 86500	56 52	B79 B77 B78 B80 B79
	Lot B	W00949	.117"	4900	41900	10370	88600	56	B80 B81 B79 B82

UT tested per TMI approved procedure and found satisfactory.

Straightness OK

Dimensions OK

Surface Condition of ID & OD 63 RMS or better.

RAW MATERIAL SOURCE **Allegheny Ludlum Steel Corp.**

Flange	OK
CORROSION RATE	
GRAIN SIZE	6 6
CORROSION TEST	
CRUSH	
EMBRITTLEMENT	
FLARING	OK OK
FLATTENING	OK OK
HUEY	
HYDROSTATIC	
BENDING	
MACRO ETCH	
MICRO ETCH

F-22

CERTIFICATION

I CERTIFY THIS REPORT TO BE CORRECT.
TUBE METHODS INC.

SWORN AND SUBSCRIBED BEFORE ME
THIS 5 DAY OF July 19 67

Notary Public

My Commission Expires

See Reverse Side for Physical Properties Test Report

PHYSICAL PROPERTIES—TEST REPORT

QUANTITY	LOT	HEAT NO.	AREA	YIELD PT. LBS.	YIELD PT. PSI	ULTIMATE LBS.	ULTIMATE PSI	ELONG. % 2"	ROCK HARD
612'1"	Lot A	W00949	.117"	6130 4800	43800 41000	10300 10130	88000 86000	56 58	B79 B77 B78 B80 B79
	Lot B	W00949	.117"	4900	41900	10370	88600	56	B81 B79 B82 B80
	Lot	CW91668	.120"	5430 5040	45200 42000	10490 10310	87400 85900	56 58	B84 B86 B83 B80
Surface Condition of ID OD 63 RMS or better UT tested per TMI approved procedure and found satisfactory. Straightness OK Dimensions OK									

RAW MATERIAL SOURCE

Allegheny Ludlum Steel Corp.

Flange	OK
CORROSION RATE	
GRAIN SIZE	6 6 6
CORROSION TEST	
CRUSH	
EMBRITTELEMENT	
FLARING	OK OK OK
FLATTENING	OK OK OK
HUEY	
HYDROSTATIC	
BENDING	
MACRO ETCH	
MICRO ETCH

CERTIFICATION

I CERTIFY THIS REPORT TO BE CORRECT.
TUBE METHODS INC.

SWORN AND SUBSCRIBED BEFORE ME
THIS 18 DAY OF Sept. 19 67

F-24

Notary Public

My Commission Expires _____

Tube Methods Inc.^G

File sefor

TXW 510-660-0140

		TWX 510-660-0140		TMI ORDER NO. 3817-2	
CUSTOMER'S ORDER NO. 14448		DATED 1/6/67		TMI ORDER DATE 5/4/67	
TERMS		(C.O. 5/4/67)		TMI INVOICE DATE 10/27/67	

SOLD TO

Nuclear Fuel Services, Inc.
A Subsidiary of W.R. Grace & Co.
Erwin, Tenn. 37650

SHIP TO

Orbit Industries
3841 Ridge Rd.
Cleveland, Ohio

SHIP VIA: Truck Prepaid & Add

F.O.B. Mill

CUTTING INSTRUCTIONS 26 Pcs. cut 48" + or - 1/32" Bal. cut 45-5/8" lg. + or - 1/64"	SPECIAL ☐ INSTRUCTIONS ☐ MARKINGS MARK: For Nuclear Fuel Services Order 15901	SHIPPING PROMISE		
TYPE 316 GRADE Seamless	SPECIFICATION AND CONDITION B50-YP79A-2 Dwg. 159A2747 U.T. required	DATE SHIPPED 10/27/67	AMT. SHIPPED 589'	BALANCE
QUANTITY ORDERED: 3755 ft.	SIZE: .890" ID + or - .0015" x .040" Wall + or - .002"			
INSPECTION: General Electric	641 Ladle Check Ladle

TEST REPORT

FOR
CHEMICAL
PROPERTIES

HEAT NO.	W00949	W00949	W91668	W91668		
C	.041	0.053	.074	.070		
Mn	1.74	1.84	1.66	1.70		
P	.018	0.020	.026	.026		
S	.025	0.015	.021	.019		
Si	.50	0.524	.46	.46		
Cr	17.25	17.27	17.48	17.42		
Ni	13.66	13.93	13.58	13.48		
Mo	2.41	2.38	2.37	2.38		
Ti						
Cb/Ta						
Ta	10+4+B--		for C-			
Co						
Cu	.12	0	.20	.19		
Al						
Sn						
Fe						
N						
V						
W						
B	.001	.001	--	--		
		F-25				

See Reverse Side for Physical Properties Test Report

PHYSICAL PROPERTIES—TEST REPORT

QUANTITY	LOT	HEAT NO.	AREA	YIELD PT. LBS.	YIELD PT. PSI	ULTIMATE LBS.	ULTIMATE PSI	ELONG. % 2"	ROC HAR.
509'	Lot A	W00949	.117"	6130	43800	10300	88000	56	B79
				4800	41000	10130	86600	56	B77
									B78
									B80
									B79
	Lot B	W00949	.117"	4900	41900	10370	88600	56	B81
									B79
									B82
									B80
	Lot C	W91668	.120"	5430	45200	10490	87400	56	B84
				5040	42000	10310	85900	58	B86
									B83
									B80

Surface Condiiton of ID & OD 63 RMS or better
 UT tested per TMI approved procedure and found satisfactory.
 Straightness OK
 Dimensions OK

RAW MATERIAL SOURCE Allegheny Ludlum Steel Corp.

Flange	OK
CORROSION RATE	
GRAIN SIZE	6 6 6
CORROSION TEST	
CRUSH	"
EMBRITTLEMENT	"
FLARING	OK OK OK
FLATTENING	OK OK OK
HUEY	"
HYDROSTATIC	"
BENDING	"
MACRO ETCH	"
MICRO ETCH	"

CERTIFICATION

I CERTIFY THIS REPORT TO BE CORRECT.
 TUBE METHODS INC.

SWORN AND SUBSCRIBED BEFORE ME
 THIS 31 DAY OF Oct. 1967

F-26

Notary Public

My Commission Expires _____

TUBING SPECIALISTS • MANUFACTURERS • METALLURGISTS • ENGINEERS

Tube Methods Inc.

GEAP-13760

Bridgeport • Montgomery County • Pennsylvania 19405 • Phone 215-279-7700

TWX 510-660-0140

CUSTOMER'S ORDER NO. 14448	DATED 1/6/67 (C.O. 5/4/67)	TMI ORDER NO. 3817-2
TERMS		TMI ORDER DATE 5/4/67
		TMI INVOICE DATE 12/12/67

SOLD TO

SHIP TO

Nuclear Fuel Services inc.
A Div. of W. R. Grace & Co.,
Erwin, Tenn. 37650

Orbit Industries
3841 Ridge Rd.
Cleveland, Ohio

SHIP VIA:

F.O.B.

CUTTING INSTRUCTIONS 26 Pcs. cut 48" + or - 1/32" Bal. cut 45-5/8" long + or - 1/64"	SPECIAL MARK: ☐ INSTRUCTIONS ☐ MARKINGS For Nuclear Fuel Services Order 15901	SHIPPING PROMISE		
TYPE 316	AND CONDITION 350-YD76A-2	DATE SHIPPED 12/12/67	AMT. SHIPPED 771.5"	BALANCE Open
GRADE Seamless	Dwg. 159A2747			
QUANTITY ORDERED: 3755 ft.	U. T. required			
INSPECTION: General Electric	SIZE: .890" ID + or - .0015" x .041" Wall + or - .0025" Ladle Check			

**TEST
REPORT**

**FOR
CHEMICAL
PROPERTIES**

HEAT NO.	W91568					
C	.074	.070				
Mn	1.66	1.70				
P	.025	.026				
S	.021	.019				
Si	.46	.46				
Cr	17.48	17.42				
Ni	13.58	13.43				
Mo	2.37	2.38				
Ti						
Cb/Ta						
Ta						
Co						
Cu	.20	.19				
Al						
Sn						
Fe						
N						
V						
W						
		F-27				

See Reverse Side for Physical Properties Test Report

PHYSICAL PROPERTIES—TEST REPORT

QUANTITY	LOT	HEAT NO.	AREA	YIELD PT. LBS.	YIELD PT. PSI	ULTIMATE LBS.	ULTIMATE PSI	ELONG. % 2"	ROCK. HARD.
771'9"		W91668	117"	5600	47900	10500	69700	59	B&4 B&5 B&2
Heat No. W91168 appearing on tally sheet is incorrect should read W91668.									
Surface Condition of ID & OD 63 RMS or better									
U. T. tested per TMI approved procedure and found satisfactory.									
Straightness OK									
Dimensions OK									

RAW MATERIAL SOURCE Allegheny Ludlum Steel Corp.

Flange	OK
CORROSION RATE	
GRAIN SIZE	6
CORROSION TEST	
CRUSH	"
EMBRIITLEMENT	OK
FLARING	OK
FLATTENING	"
HUEY	"
HYDROSTATIC	"
BENDING	"
MACRO ETCH	"
MICRO ETCH	"

F-28

CERTIFICATION

I CERTIFY THIS REPORT TO BE CORRECT.
TUBE METHODS INC.

SWORN AND SUBSCRIBED BEFORE ME
THIS 14 DAY OF Dec. 19 67

Notary Public

My Commission Expires

TWX 510-660-0140

TMI INVOICE DATE 1/19/68

Orbit Industries
3841 Ridge Rd.
Cleveland, Ohio

See Reverse Side for Physical Properties Test Report

PHYSICAL PROPERTIES—TEST REPORT

QUANTITY	LOT	HEAT NO.	AREA	YIELD PT. LBS.	YIELD PT. PSI	ULTIMATE LBS.	ULTIMATE PSI	ELONG. % 2"	ROCK. HARD.
790'10"	E	W91668	.120"	5680 5130	48800 42700	10570 10070	88100 83900	57 54	E84 E85
<p>Surface Condition of ID & OD 63 RMS or better.</p> <p>U.T. tested per TMI approved procedure and found satisfactory.</p> <p>Straightness OK</p> <p>Dimensions OK</p>									

RAW MATERIAL SOURCE
Flange

Allegheny Ludlum Steel Corp.

CORROSION RATE	
GRAIN SIZE	
CORROSION TEST	
CRUSH	"
EMBRITTLEMENT	" OK
FLARING	" OK
FLATTENING	"
HUEY	"
HYDROSTATIC	"
BENDING	"
MACRO ETCH	"
MICRO ETCH	"

F-30

CERTIFICATION

I CERTIFY THIS REPORT TO BE CORRECT.

TUBE METHODS INC.

Debra R. Lerner

SWORN AND SUBSCRIBED BEFORE ME

THIS 22 DAY OF Jan. 19 68

Notary Public

My Commission Expires

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TWX 510-662-0140

TMI INVOICE DATE 2/2/68

Cleveland, Ohio

TEST REPORT

FOR
CHEMICAL
OPERTIES

HEAT NO.	W01782	W01782				
C	.044	.042				
Mn	1.74	1.77				
P	.020	.020				
S	.018	.021				
Si	.55	.55				
Cr	17.40	17.47				
Ni	13.49	13.45				
Mo	2.32	2.34				
Ti						
Cb/Ta						
Ta						
Co						
Cu	.13	.13				
Al						
Sn						
Fe						
N						
V						
W						
		F-31				

See Reverse Side for Physical Properties Test Report

PHYSICAL PROPERTIES—TEST REPORT

QUANTITY	LOT	HEAT NO.	AREA	YIELD PT. LBS.	YIELD PT. PSI	ULTIMATE LBS.	ULTIMATE PSI	ELONG. % .2"	ROCK. HARD.
764'2"	F	W01782	.117"	5450	46600	10230	87400	54	B83 B85
<p>Surface Condition of ID & OD 63 RMS or better.</p> <p>U.T. tested per TMI approved procedure and found satisfactory.</p> <p>Straightness OK</p> <p>Dimensions OK</p>									

RAW MATERIAL SOURCE Allegheny Ludlum Steel Corp
 Flange OK

CORROSION RATE	
GRAIN SIZE	6
CORROSION TEST	
CRUSH	"
EMBRITTLEMENT	OK
FLARING	OK
FLATTENING	"
HUEY	"
HYDROSTATIC	"
BENDING	"
MACRO ETCH	"
MICRO ETCH	"

F-32

CERTIFICATION

I CERTIFY THIS REPORT TO BE CORRECT.

TUBE METHODS INC.

Harold W. Brown
 SWORN AND SUBSCRIBED BEFORE ME

THIS 5 DAY OF Feb. 19 68

Notary Public

My Commission Expires _____

PHYSICAL PROPERTIES—TEST REPORT

QUANTITY	LOT	HEAT NO.	AREA	YIELD PT. LBS.	YIELD PT. PSI	ULTIMATE LBS.	ULTIMATE PSI	ELONG. % 2"	ROCK. HARD.
117'10-3/8"		01782	.117"	4600	39300	10000	85500	54	B86 B84 B85
UT Tested per TMI approved procedure and found satisfactory Straightness OK Dimensions OK									

RAW MATERIAL SOURCE Allegheny Ludlum Steel Corp.

Slange	OK
CORROSION RATE	
GRAIN SIZE	6
CORROSION TEST	
CRUSH	
EMBRITTLMENT	
FLARING	OK
FLATTENING	OK
HUEY	
HYDROSTATIC	
BENDING	
MACRO ETCH	
MICRO ETCH

F-34

CERTIFICATION

I CERTIFY THIS REPORT TO BE CORRECT.
TUBE METHODS INC.

SWORN AND SUBSCRIBED BEFORE ME
THIS 26 DAY OF March 19 68

Notary Public

Mu Commission Expires

Tube Methods Inc.

TWX 510-660-0140

TERMS

TMI INVOICE DATE 5/31/68

SOLD TO

SHIP TO

Orbit Industries
3841 Ridge Rd.
Cleveland, Ohio

SHIP VIA: Truck Prepaid & Add

F.O.B. Mill

CUTTING INSTRUCTIONS

SPECIAL	☐	INSTRUCTIONS	☐	MARKINGS
----------------	--------------------------	---------------------	--------------------------	-----------------

45-5/8" long
+ or - 1/64"

Req. No. 17560

MARK: Order 21897 on Nuclear
Fuel Services, Inc.

(Same as P.O. 14448, M.O. 3817)

SHIPPING PROMISE

Wk. May 27th SURE

TYPE

SPECIFICATION AND CONDITION

316

B50YP79A-2

GRADE

Seamless

Dwg. 159A2747

U.T. required

QUANTITY ORDERED:

SIZE:

150 Pcs.

.890" ID + or - .0015" x

INSPECTION:

.041" Wall + or - .0025"

DATE SHIPPED

5/31/68

AMT. SHIPPED

166 pcs.

BALANCE

~~None~~

(631'1-3/4")

TEST

REPORT

FOR
CHEMICAL
OPERTIES

HEAT NO.	W01782	W03078
C	.044	.056
Mn	1.74	1.69
P	.020	.024
S	.018	.019
Si	.55	.39
Cr	17.40	17.32
Ni	13.49	13.38
Mo	2.32	2.33
Ti		
Cb/Ta		
Ta		
Co		
Cu	.13	.20
Al		
Sn		
Fe		
N		
V		
W		
		F-35

See Reverse Side for Physical Properties Test Report

PHYSICAL PROPERTIES—TEST REPORT

QUANTITY	LOT	HEAT NO.	AREA	YIELD PT. LBS.	YIELD PT. PSI	ULTIMATE LBS.	ULTIMATE PSI	ELONG. % 2"	ROCK. HARD.
631'1-3/4"	A2	W03078	.117"	5200 5150	44400 44020	10160 10050	86800 85900	53 55	B68 B70 B65 B69
	A1	W01782	.117"	4800 4850	41000 41450	10050 10160	85900 86800	51 56	B65 B62 B67 B64
<p>U.T. listed per TMI approved procedure and found satisfactory.</p> <p>Straightness OK</p> <p>Dimensions OK</p> <p>Surface Condition of ID & OD 63 RMS or better</p>									

RAW MATERIAL SOURCE Allegheny Ludlum Steel Corp.

CORROSION RATE	
GRAIN SIZE	6 6
CORROSION TEST	
CRUSH	
EMBRITTLMENT	
FLARING	OK OK
FLATTENING	OK OK
SOFTENING	OK OK
HYDROSTATIC	
BENDING	
MACRO ETCH	
MICRO ETCH

F-36

CERTIFICATION

I CERTIFY THIS REPORT TO BE CORRECT.

TUBE METHODS INC.

SWORN AND SUBSCRIBED BEFORE ME

THIS 3 DAY OF June 19 68

Notary Public

My Commission Expires

Tube Methods Inc.

TWX 510-660-9140

TMI ORDER NO.	5280-2
TMI ORDER DATE	4/16/68
TMI INVOICE DATE	5/31/68

• Nuclear Fuel Services, Inc.
A Sub. of W. R. Grace & Co.
Erwin, Tenn.

Orbit Industries
3841 Ridge Rd.
Cleveland, Ohio

F.O.B.

SPECIAL ☐ INSTRUCTIONS ☐ MARKINGS
 Req. No. 18560
 MARK: Order 21897 on Nuclear
 Fuel Services, Inc.

SHIPPING PROMISE

SPECIFICATION AND CONDITION
B50Y79A-2
Dwg. 159A2747
U.T. Required

DATE SHIPPED	AMT. SHIPPED	BALANCE
5/31/68	55'7"	None

SIZE:
.890" ID + or - .0015" x
.041" Wall + or - .0025"

INSPECTION:

TEST REPORT

FOR
CHEMICAL
PROPERTIES

HEAT NO.	W03078
C	.056
Mn	1.69
P	.024
S	.019
Si	.39
Cr	17.32
Ni	13.38
Mo	2.33
Ti	
Cb/Ta	
Ta	
Co	
Cu	.20
Al	
Sn	
Fe	
N	
V	
W	

~~F-37~~

See Reverse Side for Physical Properties Test Report

PHYSICAL PROPERTIES—TEST REPORT

QUANTITY	LOT	HEAT NO.	AREA	YIELD PT. LBS.	YIELD PT. PSI	ULTIMATE LBS.	ULTIMATE PSI	ELONG. % 2"	ROCK. HARD.
55'7"	A2	W03078	.117"	5200 5150	44400 44020	10160 10050	86800 85900	53 55	B68 B70 BX B65 B69
<p>U.T. Listed per TMI approved procedure and found satisfactory.</p> <p>Straightness OK Dimensions OK Surface Condition of ID & OD 63 RMS or better</p>									

RAW MATERIAL SOURCE

Allegheny Ludlum Steel Corp.

CORROSION RATE	
GRAIN SIZE	6
CORROSION TEST	
CRUSH	
EMBRITTLEMENT	
FLARING	OK
FLATTENING	OK
Flange	OK
HYDROSTATIC	
BENDING	
MACRO ETCH	
MICRO ETCH

F-38

CERTIFICATION

I CERTIFY THIS REPORT TO BE CORRECT.
TUBE METHODS INC.

SWORN AND SUBSCRIBED BEFORE ME
THIS 3 DAY OF June 19 68

Notary Public

My Commission Expires _____

ENGINEER
File Se for

GEAP-13760

TWX 510-660-0140

SOLD TO

SHIP TO

Orbit Industries
3841 Ridge Rd.
Cleveland, Ohio

SHIP VIA: Truck Prepaid & Add		F.O.B. Mill		
CUTTING INSTRUCTIONS 45-5/8" long + or - 1/64"	SPECIAL ☐ INSTRUCTIONS ☐ MARKINGS MARK: Replacement on P.O. 2189 M.O. 5280, Item 1 Rej. reason: Material did not meet spec. requirements	SHIPPING PROMISE June 21st		
		DATE SHIPPED	AMT. SHIPPED	BALANCE
TYPE 316	SPECIFICATION AND CONDITION B50YP79A-2 Dwg. 159A2747 U.T. required	6/21/68	33 pcs.	None
GRADE Seamless			(125'5-5/8")	
QUANTITY ORDERED: 35 Pcs.	SIZE: .890" ID + or - .0015" x .041" Wall + or - .0025"			
INSPECTION:				

TEST REPORT

FOR
CHEMICAL
PROPERTIES

HEAT NO.	W03078					
C	.056					
Mn	1.69					
P	.024					
S	.019					
Si	.39					
Cr	17.32					
Ni	13.38					
Mo	2.33					
Ti						
Cb/Ta						
Ta						
Co						
Cu	.20					
Al						
Sn						
Fe						
N						
V						
W						
		F-39				

See Reverse Side for Physical Properties Test Report

PHYSICAL PROPERTIES—TEST REPORT

QUANTITY	LOT	HEAT NO.	AREA	YIELD PT. LBS.	YIELD PT. PSI	ULTIMATE LBS.	ULTIMATE PSI	ELONG. % 2"	ROCK. HARD.
125' 5-5/8"	A2	W03078	117"	5200 5150	44400 44020	10160 10050	86800 85900	53 55	B68 B70 B65 B69
<p>U.T. listed per TMI approved procedure and found satisfactory.</p> <p>Straightness OK</p> <p>Dimensions OK</p> <p>Surface Condition of ID & OD 63 RMS or better.</p>									

RAW MATERIAL SOURCE: Allegheny Ludlum Steel Corp.

CORROSION RATE	
GRAIN SIZE	6
CORROSION TEST	
CRUSH	"
EMBRITTLEMENT	"
FLARING	OK
FLATTENING	OK
WUEY Flange	OK
HYDROSTATIC	"
BENDING	"
MACRO ETCH	"
MICRO ETCH	"

F-40

CERTIFICATION

I CERTIFY THIS REPORT TO BE CORRECT.
TUBE METHODS INC.

SWORN AND SUBSCRIBED BEFORE ME
24 June 68

THIS DAY OF 19

Notary Public

My Commission Expires

APPENDIX G

NFS Calculations of Uncertainty on Pu/U+Pu
Ratio of Plutonium-Uranium Nitrate Master
Mixes.

GE Specifications 22A1545 and FP-136 require that the following uncertainty limits be demonstrated by calculation:

<u>Quantity</u>	<u>Maximum Uncertainty</u>
Master Mix $\frac{\text{Pu-239+241}}{\text{U+Pu}}$	$\pm 0.10\%$ Absolute
Project Grand Average $\frac{\text{Pu-239+241}}{\text{U+Pu}}$	$\pm 0.05\%$ Absolute

NFS-Q-18, the procedure established by NFS to meet these requirements, is included in this appendix with the numerical calculations for each Master Mix.

GEAP-13760

NUCLEAR FUEL SERVICES, INC.
ERWIN, TENNESSEE

NFS-Q-18, Revision 1

QUALITY CONTROL

CALCULATIONS FOR PLUTONIUM CONTENT IN SEFOR FUEL RODS

Procedure NFS-Q-18, Revision 1

Written by

W.R. Housholder

October 23, 1967

APPROVED:

DATE:

K. D. Hensley 10/23/67
Quality Control Supervisor
W. R. Housholder 10/23/67
Technical Director

Calculations for Plutonium Content in SEFOR Fuel Rods1.0 Scope

This procedure is to be used to calculate the tolerances within which the plutonium and the plutonium -239+241 contents in each fuel rod are known with 95% confidence as required by NFS Quality Control Plan--NFS-M-10, Revision 1, Section 3.1.4, Q.C. Point 12(e).

2.0 Summary

The weight of plutonium and the weight of Pu-239+241 in each fuel rod can be calculated from the weight of each fuel rod stack of fuel pellets, the Pu/Pu+U and the $Pu_f/Pu+U$ ratios of the fuel pellets, and from the O/metal ratio of the fuel pellets. The tolerances on these weights of Pu and Pu-239+241 at 95% confidence can be calculated from the standard deviations on the stack weights, on the Pu/Pu+U and $Pu_f/Pu+U$ ratios, and on the O/metal ratio. All fuel pellets in each rod will come from the same pellet batch and, hence, from the same Master-Mix solution lot except for the few rods which will be made up of leftover pellets from more than one pellet batch. This means that the Pu/Pu+U and the $Pu_f/Pu+U$ ratios and corresponding standard deviations will be the same for all rods derived from the same Master-Mix solution lot, and the O/metal ratio and its standard deviation will remain the same for all rods derived from the same pellet batch.

3.0 Calculations

See Section 4.0 for legend and index to calculations.

3.1 Weight of Total Pu in Each Fuel Rod

With 95% confidence the weight of total Pu in each fuel rod is calculated from the equation:

$$\begin{aligned} \text{Pu} &= \frac{R W}{1 + Z (O/M)} \pm 2 S_{\text{Pu}} \\ &= \frac{R W}{1 + Z (O/M)} [1 \pm 2 \left(\frac{S_{\text{Pu}}}{\text{Pu}} \right)] \end{aligned}$$

3.2 With 95% confidence the weight of Pu-239+241 in each fuel rod is calculated from the equation:

$$\begin{aligned} \text{Pu}_f &= \frac{R_f W}{1 + Z (O/M)} \pm 2 S_{\text{Pu}_f} \\ &= \frac{R_f W}{1 + Z (O/M)} [1 \pm 2 \left(\frac{S_{\text{Pu}_f}}{\text{Pu}_f} \right)] \end{aligned}$$

3.3 The relative standard deviation on the total Pu weight in each fuel rod ($\frac{S_{\text{Pu}}}{\text{Pu}}$) is calculated from the equation:

$$\left(\frac{S_{\text{Pu}}}{\text{Pu}} \right)^2 = \left(\frac{S_R}{R} \right)^2 + \left(\frac{S_W}{W} \right)^2 + \left(\frac{Z (O/M)}{1 + Z (O/M)} \right)^2 \left(\frac{S_{O/M}}{O/M} \right)^2$$

3.4 The relative standard deviation on the Pu-239+241 weight in each fuel rod ($\frac{S_{\text{Pu}_f}}{\text{Pu}_f}$) is calculated from the equation:

$$\left(\frac{S_{\text{Pu}_f}}{\text{Pu}_f} \right)^2 = \left(\frac{S_{R_f}}{R_f} \right)^2 + \left(\frac{S_W}{W} \right)^2 + \left(\frac{Z (O/M)}{1 + Z (O/M)} \right)^2 \left(\frac{S_{O/M}}{O/M} \right)^2$$

3.5 The overall Pu/Pu+U ratio (R) for each Master-Mix lot is calculated from the equation:

$$R = \frac{\sum_i (A_i B_i)}{\sum_i (A_i B_i) + DE}$$

3.6 The overall Pu_f/Pu+U ratio (R_f) for each Master-Mix lot is calculated from the equation:

$$R_f = \frac{\sum_i (A_i B_i C_i)}{\sum_i (A_i B_i) + DE}$$

3.7 The relative standard deviation on the overall Pu/Pu+U ratios ($\frac{S_R}{R}$) for each Master-Mix lot is calculated from the equation:

$$\left(\frac{S_R}{R}\right)^2 = \left(\frac{DE}{\sum_i A_i B_i + DE}\right)^2 \left[\frac{1}{N} \left(\frac{S_B}{B}\right)^2 + \frac{1}{N} \left(\frac{S_A}{A}\right)^2 + \left(\frac{S_E}{E}\right)^2 + \left(\frac{S_D}{D}\right)^2\right]$$

3.8 The relative standard deviation on the overall $Pu_f/Pu+U$ ratio $(\frac{S_{R_f}}{R_f})$ for each Master-Mix lot is calculated from the equation:

$$\left(\frac{S_{R_f}}{R_f}\right)^2 = \frac{1}{N} \left(\frac{S_C}{C}\right)^2 + \left(\frac{DE}{\sum_i A_i B_i + DE}\right)^2 \left[\frac{1}{N} \left(\frac{S_B}{B}\right)^2 + \frac{1}{N} \left(\frac{S_A}{A}\right)^2 + \left(\frac{S_E}{E}\right)^2 + \left(\frac{S_D}{D}\right)^2\right]$$

3.9 The ratio (Z) of the atomic weight of oxygen to the average atomic weight of Pu + U for each Master-Mix lot is calculated by the equation:

$$Z = \frac{16.000}{\bar{F}R + G(1-R)}$$

3.10 The average atomic weight ($\bar{F}$) of the plutonium in each Master-Mix lot is calculated from the equation:

$$\bar{F} = \frac{\sum_i (A_i B_i F_i)}{\sum_i (A_i D_i)}$$

4.0 Legend and Index to Calculations

A_i = Weight of Pu-solution in ith Pu-solution lot added to master-mix lot.

B_i = Assay (g Pu/gram solution) of ith Pu-solution lot.

C_i = Weight fraction of Pu-239+241 to total Pu for the ith Pu-solution lot.

D = Weight of U-solution added to master-mix lot.*

E = Assay (g U/g solution) of U-solution lot.*

$\bar{F}$ = Average atomic weight of Pu in a master-mix lot (see Section 3.10).

F_i = Atomic weight of Pu in the ith Pu-solution lot.

G = Atomic weight of U in U-solution lot.

$\sum_i$ = Sum overall Pu-solution lots.

i = Individual Pu-solution lot designation.

O/M = Oxygen to metal (Pu+U) atomic ratio.

N = Pu-solution lots in each master mix.

Pu = Weight of total Pu in each fuel rod (see Section 3.1).

Pu_f = Weight of Pu-239+241 in each fuel rod (see Section 3.2).

R = Ratio of the weight of total Pu to the weight of total Pu+U in each master-mix lot (see Section 3.5).

R_f = Ratio of the weight of Pu-239+241 to the weight of total Pu+U in each master-mix lot (see Section 3.6).

S_x = Standard deviation on X.

$\frac{S_x}{X}$ = Relative standard deviation on X.

$\frac{S_A}{A}$ = Relative standard deviation on the weighing of a Pu-solution lot.

$\frac{S_B}{B}$ = Relative standard deviation on the assaying of a Pu-solution lot.

*Assume only one U-solution lot required per master-mix lot.

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4.9 Legend and Index to Calculations (continued)

$\frac{S_c}{C}$ = Relative standard deviation of the isotopic evaluation of a Pu-solution lot.

$\frac{S_D}{D}$ = Relative standard deviation on the weighing of a uranium-solution lot.

$\frac{S_E}{E}$ = Relative standard deviation on the assaying of a uranium-solution lot.

$\frac{S_{O/M}}{O/M}$ = Relative standard deviation on the evaluation of oxygen to metal atomic ratio (O/M).

$\frac{S_{Pu}}{Pu}$ = Relative standard deviation on the weight of total Pu in each fuel rod (see Section 3.3).

$\frac{S_{Pu_f}}{Pu_f}$ = Relative standard deviation on the weight of Pu-239+241 in each fuel rod (see Section 3.4).

$\frac{S_R}{R}$ = Relative standard deviation on the ratio of total Pu weight to total Pu+U weight in each master-mix lot (see section 3.7).

$\frac{S_{R_f}}{R_f}$ = Relative standard deviation on the ratio of Pu-239+241 weight to total Pu+U weight in each master-mix lot (see Section 3.8).

$\frac{S_W}{W}$ = Relative standard deviation on the weighing of fuel rod pellet stacks.

W = Weight of fuel pellets in a fuel rod.

Z = Ratio of the atomic weight of oxygen to the average atomic weight of the Pu+U in each master lot (see Section 3.9).

Table I shows a summary of the uncertainty and average values which are used in the calculation of the uncertainty in $\frac{\text{Pu-239+241}}{\text{U+Pu}} (S_{R_f})$. The values shown for $S_{\frac{A}{A}}$, $S_{\frac{B}{B}}$, and $S_{\frac{E}{E}}$ were obtained from observation of the spread of repeated (2 or 3) measurements of Pu-nitrate weight, Pu-nitrate assay ($\frac{\text{gm Pu}}{\text{gm solution}}$), and U-nitrate assay. The $\frac{S_{O/M}}{O/M}$ values were obtained from O/M measurements on several pellet batches within each master mix.

Table II shows the values of S_{R_f} for each master mix and the values of uncertainty contributions from the major sources.

Table III shows the calculation of the uncertainty on the project grand average $\frac{\text{Pu-239+241}}{\text{U+Pu}} (S_{R_f})$, and that it meets the specification value of 0.05% (absolute).

TABLE I

Name	Designation	Master Mix Lot Number				Category
		256-A-101	256-A-102	256-A-103	256-A-104	
Fissionable Pu Fraction	S_{R_f}	Required	Required	Required	Required	Absolute Error
Fissionable Pu Fraction	R_f	0.1870	0.1870	0.1870	0.1870	Mean
Pu Enrichment	S_c	0.0015	0.0015	0.0015	0.0015	Absolute Error
Pu Enrichment	C	0.9180	0.9167	0.9171	0.9158	Mean
U-nitrate Assay	E	0.2272	0.2253	0.2220	0.2288	Mean
Weight of U-nitrate	D	1,016	2,540	2,876	2,630	Mean
Pu-nitrate Assay	B	0.1465	0.1482	0.1500	0.1557	Mean
Weight of Pu-nitrate	A	404	990	1,089	992	Mean
Pu-nitrate Assay	$\frac{S_B}{B}$	0.00385	0.00459	0.00338	0.00185	Relative Error
Weight of Pu-nitrate	$\frac{S_A}{A}$	0.000829	0.00210	0.00330	0.00413	Relative Error
U-nitrate Assay	$\frac{S_E}{E}$	0	0.00278	0	0	Relative Error
Weight of U-nitrate	$\frac{S_D}{D}$	0	0	0	0	Relative Error
Oxygen/Metal Ratio	$\frac{S_{O/M}}{O/M}$	0.00147	0.00108	0.00126	0.00190	Relative Error
Pu-nitrate lots/Pu master mix	N	3	8	8	7	---

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TABLE II

Contributions to S_{Rf}^2 , (Dispersion)² on Pu-239, 241/[Pu+U], for SEFOR

Master Mix Lot Number	Wi	N	Contributions to S_{Rf}^2					S_{Rf}^2
			Pu Enr. C	Pu Assay B	Wt. Pu Nitrate A	U Assay E	Wt. U Nitrate D	
256-A-101	0.113	3	3.10×10^{-8}	11.10×10^{-8}	0.65×10^{-8}	0	0	14.75×10^{-8}
256-A-102	0.281	8	1.18×10^{-8}	5.84×10^{-8}	1.22×10^{-8}	17.15×10^{-8}	0	25.39×10^{-8}
256-A-103	0.312	8	1.18×10^{-8}	3.18×10^{-8}	3.02×10^{-8}	0	0	7.38×10^{-8}
256-A-104	0.294	7	1.34×10^{-8}	1.09×10^{-8}	5.41×10^{-8}	0	0	7.84×10^{-8}

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TABLE III

Project Grand Overall $\frac{\text{Pu-239, 241}}{\text{Pu+U}}$ Ratio

	$s_{R_f}^2$	w_i
Master Mix 101	14.75×10^{-8}	0.113
Master Mix 102	25.39×10^{-8}	0.281
Master Mix 103	7.38×10^{-8}	0.312
Master Mix 104	7.84×10^{-8}	0.294

$$s_{R_f}^2 = [(14.75 \times 10^{-8})(0.113)^2 + (25.39 \times 10^{-8})(0.281)^2 + (7.38 \times 10^{-8})(0.312)^2 + (7.84 \times 10^{-8})(0.294)^2]$$

$$s_{R_f}^2 = [(14.75 \times 10^{-8})(1.28 \times 10^{-2}) + (25.39 \times 10^{-8})(7.90 \times 10^{-2}) + (7.33 \times 10^{-8})(9.73 \times 10^{-2}) + (7.84 \times 10^{-8})(8.64 \times 10^{-2})]$$

$$s_{R_f}^2 = 1.888 \times 10^{-8} + 2.006 \times 10^{-8} + 0.718 \times 10^{-8} + 0.677 \times 10^{-8}$$

$$s_{R_f}^2 = 5.289 \times 10^{-8}$$

$$s_{R_f}^2 = \underline{\underline{2.30 \times 10^{-4}}} < 5 \times 10^{-4} \quad \underline{\underline{\text{Acceptable}}}$$

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