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DESIGN, FABRICATION, AND FABRICATION EVALUATION OF HIGH TEMPERATURE FUEL PINS

by

R. L. Gulley

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3-7960

BATTELLE NORTHWEST
BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORY

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FINAL REPORT

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ABSTRACT

A total of twenty-seven molybdenum clad fuel pins were designed and fabricated by Battelle-Northwest for the Lewis Research Center of the National Aeronautics and Space Administration. The purpose of the pins is to provide irradiation data needed for the design of full-length reactor fuel pins. Six of the fuel pins contained depleted uranium dioxide (UO_2); fourteen contained fully enriched UO_2; one contained depleted uranium nitride (UN); and six contained fully enriched UN.

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INTRODUCTION

Battelle-Northwest has completed a program to design and fabricate high temperature fuel pins for the Lewis Research Center of the National Aeronautics and Space Administration.(1) This report, the fifth and final of a series(2,3,4,5) required in this contract, describes the design, fabrication, and fabrication evaluation of the fuel pins.

SUMMARY

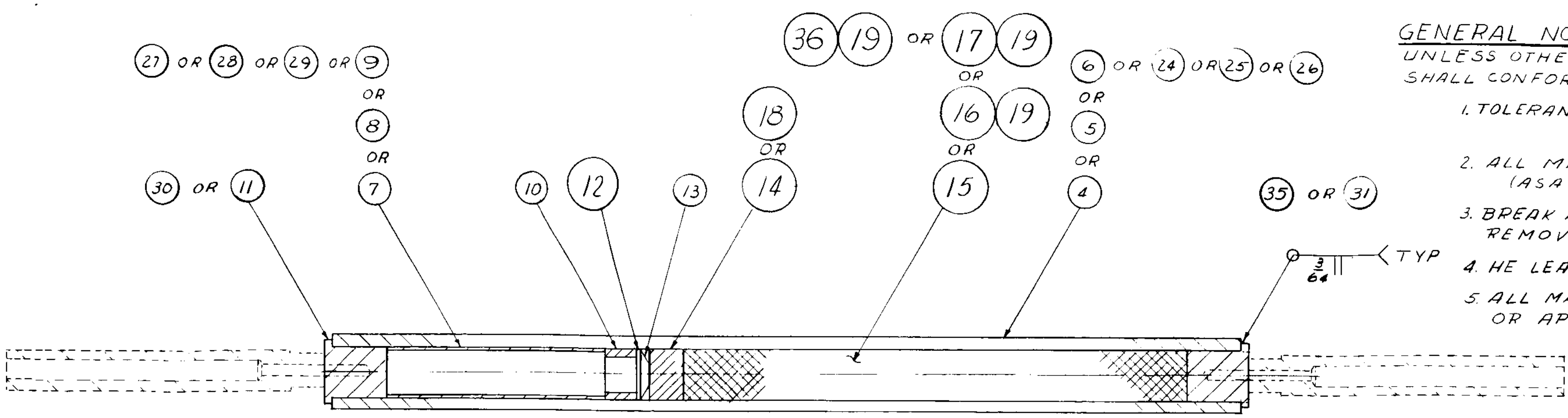
A total of twenty-seven molybdenum clad fuel pins were fabricated for tests and evaluation. Six of these fuel pins were prototypes and contained depleted uranium dioxide (UO_2); fourteen contained fully enriched UO_2; one contained depleted uranium nitride (UN); and six contained fully enriched UN. A number of short pellets were used to make up each UO_2 fuel column, and a single pellet was used for each UN fuel column. All of the pins met the required criteria and quality levels established for the design irradiation conditions. Pertinent data for each pin are presented in Table I. Design specifications for the fuel pins are presented in Drawing No. R-1008 (Figure 1).

The purpose of these pins is to provide irradiation data needed for the design of full-length reactor fuel pins. Primary factors considered in the design of these pins for high temperature service to high exposure include:

Table I
Fuel Pin Data

Pin No.	Fuel*	Pellet Type**	Fuel Weight (grams)	Plenum Length (inches)	Number†	End Cap Extensions
5	Dep. UO_2	S	9.6292	1	1P^	No
7	" "	S	9.6080	1	1P	No
10	" "	C	8.0267	7/8	2P	No
13	" "	C	8.0129	7/8	2P	No
16	" "	C	8.0568	7/8	2P	No
23	" "	C	8.0231	7/8	2P	No
29	En. UO_2	C	7.8620	1/2	23	Yes
33	" "	C	7.9126	1/2	23	Yes
38	" "	C	7.9282	1/2	23	Yes
36	" "	C	7.8658	1	22	Yes
39	" "	C	7.9465	1	22	Yes
37	" "	C	7.8766	1	22	Yes
26	" "	S	9.8407	1	21	Yes
30	" "	S	9.8760	1	21	Yes
34	" "	S	9.8559	1	21	Yes
25	" "	S	9.8545	1	21	Yes
28	" "	S	9.8977	1-1/2	20	Yes
31	" "	S	9.8518	1-1/2	20	Yes
35	" "	S	9.8970	1-1/2	20	Yes
27	" "	S	9.8426	1-1/2	20	Yes
9	Dep. UN	C	10.8680	1/2	34	No
11	En UN	C	10.5962	1/2	33	Yes
12	" "	C	10.7351	1/2	33	Yes
14	" "	C	10.8633	1/2	33	Yes
15	" "	C	10.8501	1	32	Yes
19	" "	C	10.5859	1	32	Yes
20	" "	C	10.6619	1	32	Yes

* Dep.-Depleted; En.-Fully Enriched
** C - Cored; S-Solid
† See Figure 1
^ P - Prototypic



GENERAL NOTES:

UNLESS OTHERWISE SPECIFIED ALL PARTS SHALL CONFORM TO THE FOLLOWING

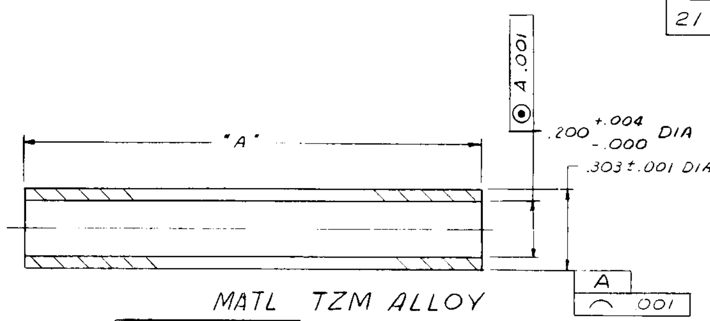
1. TOLERANCE: DECIMAL ±.005
   ANGULAR ± 0°30'
2. ALL MACHINED SURFACES 63 (ASA B46.1 1962)
3. BREAK ALL SHARP EDGES & CORNERS REMOVE ALL BURRS
4. HE LEAK CHECK ALL WELDS 7b
5. ALL MATERIAL TO BE AS SPECIFIED OR APPROVED EQUAL QUALITY

1	ASSEMBLY
2	ASSEMBLY
3	ASSEMBLY
20	ASSEMBLY
21	ASSEMBLY

22	ASSEMBLY
23	ASSEMBLY
32	ASSEMBLY
33	ASSEMBLY
34	ASSEMBLY

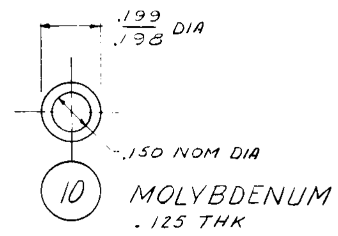
QTY.										PT. NO.	DESCRIPTION	MATL
									X	1	ASSEMBLY	
								X		2		
							X			3		
									1	4	TUBE (OUTER CLADDING)	
								1		5		
										6		
									1	7	TUBE (SPACER)	
								1		8		
										~~9~~		
1	1	1					1	1	1	10	SPACER	
1							2	2	2	11	END CAP	
1	1	1	1	1	1	1	1	1	1	12	WAFER .195 DIA x .005 THK	TUNGSTEN
1	1	1	1	1	1	1	1	1	1	13	SPRING	
			1	1	1	1		1	1	14	END PELLET $.190^{+.000}_{-.004}$ DIA x .125 THK	DEPLETED UO_2
					2"	2"			2"	15	FUEL PELLET .192±.002 DIA x AR THK	UO_2 95±1.5% TD
			2"	2"				2"		16	.195±.002 DIA x $.090^{+.004}_{-.000}$ ID x AR THK	
	2"	2"					2"			17	.195±.002 DIA x $.090^{+.004}_{-.000}$ ID x AR THK	UN
1	1	1					1	4a		18	END PELLET $.190^{+.000}_{-.004}$ DIA x .125 THK	DEPLETED UN
1	1	1	1	1			1	1		19	SUPPORT SLEEVE .090 DIA x $^{.002}_{.001}$ WALL x 2.000 LG	TUNGSTEN
						X				20	ASSEMBLY	
					X					21		
				X						22		
			X							23		
						1				24	TUBE (OUTER CLADDING)	
		1		1	1					25		
1	1		1				1			26		
						1				27	TUBE (SPACER)	
		1		1	1					28		
1	1		1				1			29		
	1	1	1	1	1	1				30	END CAP (TOP)	
	1	1	1	1	1	1				31	(BOTTOM)	
		X								32	ASSEMBLY	
	X									33		
X										34		
1										35	END CAP	
2"										36	FUEL PELLET .195±.002 DIA x $.090^{+.004}_{-.000}$ ID x AR THK	DEPLETED UN

6a

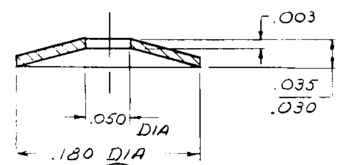


MATL TZM ALLOY

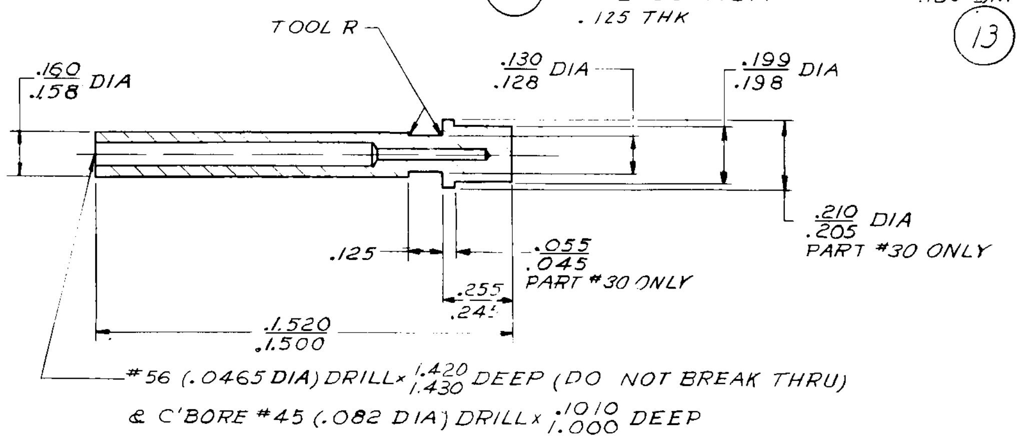
PART #	"A" LG
4	3.615±.010
5	3.465±.010
6	3.015±.010
24	4.025±.010
25	3.525±.010
26	3.025±.010



(10) MOLYBDENUM
.125 THK

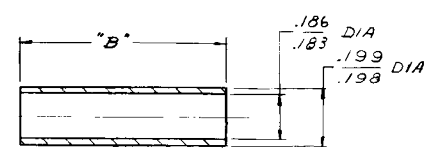


(13) TUNGSTEN



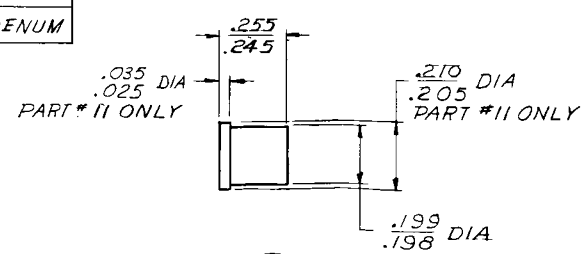
#56 (.0465 DIA) DRILL x 1.420/1.430 DEEP (DO NOT BREAK THRU)
& C'BORE #45 (.082 DIA) DRILL x 1.010/1.000 DEEP

PART #	NOTE	MATL
30	AS SHOWN	MOLYB
31	AS NOTED	DENUM



MATL MOLYBDENUM

PART #	"B" LG
7	.880/.870
8	.730/.720
~~9~~	~~.280/.270~~
27	1.340±.005
28	.840±.005
29	.340±.005



(11) MOLYBDENUM

(35) MOLYBDENUM 7c

	REVISIONS	BY	APP'D BY
7	PART #9 (c) WAS MISSPELLED a) WAS FIG 2 (b) DELETED		
6	(a) ADDED #32, 33, 34, 35, 36		
5	BLOCK ADDED "FIG 2" IN TITLE REMOVED "FIG 4" ZNG5		
4	28, 29, 30 & 31 & 23 PARTS # 24, 25, 26, 27, (b) ADDED ASSY # 20, 21, 22, (c) REMOVE QTY (1) PART 18		
3	REDRAWN - REDESIGN		

REFERENCE DRAWINGS

RESPONSIBLE ENGR. C.H. BLOOMSTER — APPROVED C H Bloomster
DRAWN BY BAUER — DATE 4-4-67 — CHECKED BY
SCALE NONE — CLASSIFICATION NONE

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P. O. BOX 999 • RICHLAND, WASHINGTON • 99352

HIGH TEMP. FUEL PIN FIGURE 1 7a

DWG. NO. R-1008 — SHEET NO. 1 — SHEETS 1 — REV. 7

FOLDOUT FRAME 1

FOLDOUT FRAME 2

- Maximum cladding and fuel temperatures
- Fuel expansion
- Internal pressures due to released fission gas
- Heat transfer from the fuel to the coolant
- Compatibility of the cladding with the fuel material and the coolant

Although it was necessary to develop techniques for fabricating the cored UN pellets, no significant problems were encountered in fabricating the pellets. Problems were encountered, however, with the cladding. Attempts to bore out stock molybdenum tubing to obtain a thin wall (0.025 in.) cladding failed to hold wall thickness and internal surface requirements. To eliminate the machining problems, a thick wall (0.050 in.) tubing was specified by NASA-Lewis. Adoption of the thick wall tubing introduced a weld penetration problem which was eventually corrected by altering the end cap design and developing a welding technique.

Significant aspects of the work performed under this contract were:

- A fuel pin design which met the criteria established by NASA-Lewis was developed.
- The fuel pins were fabricated to required criteria and quality levels.
- Cored UO_2 pellets with thin walls were fabricated to close tolerances.
- Solid and cored UN pellets were fabricated by hot isostatic compaction.
- A source of high quality TZM molybdenum alloy cladding tubes was established.
- A welding technique for making the fuel pin end closures was developed.

DESIGN OF THE FUEL PINS

The fuel pins described in this report were designed to provide irradiation data needed for the design of full-length reactor fuel pins. Primary factors considered in the design of these pins for high temperature service to high exposure include:

- Maximum cladding and fuel temperatures
- Fuel expansion
- Internal pressure due to released fission gas
- Heat transfer from the fuel to the coolant
- Compatibility of the cladding with the fuel material and the coolant.

Fuel Material and Form

Pelleted UO_2 was used in one of the basic fuel pin designs because of the large amount of experience and confidence that has been acquired with this type of fuel. The technology of this material is well advanced and its adequacy as a reactor fuel has been thoroughly demonstrated. Pelleted UN was used in one of the basic fuel pin designs because pelleted UN can be operated at higher powers without reaching excessive fuel temperatures than can pelleted UO_2. The thermal conductivity of UN is about six times that of UO_2.

Solid pellets and cored pellets were used in the fuel pin designs. Cored pellets allow for a shorter gas plenum than solid pellets because fuel temperatures are lower and fewer fission gases are released from the fuel. Solid pellets were used because of the large amount of experience with this form of fuel and the ease with which they can be fabricated.

Cladding Material

The operating conditions of these fuel pins required that a refractory metal be used for cladding. Tungsten, molybdenum, niobium, and tantalum were considered as candidate cladding materials. Based on neutronic, thermal, and strength properties, molybdenum was chosen to be the best suited cladding material. In addition, molybdenum is compatible with the fuel materials and coolant to which the cladding is to be exposed.

Fuel-to-Cladding Gap and Bond

The gap between the fuel and cladding was chosen so that differential expansion of the fuel and cladding would permit the pellets to contact the cladding but exert zero interface pressure at maximum operating conditions. The two components that comprise fuel expansion are thermal expansion and fission product swelling. Calculation of total fuel expansion was made on a conservative basis by using high values for thermal expansion and swelling rate.

One atmosphere of helium gas was used in these fuel pins to provide a heat transfer bond between the fuel and the cladding. Although experience has shown[6] that the generation and release of fission gases quickly provides a gaseous heat transfer bond and a corresponding reduction in fuel temperature, calculations show that almost all of the fuel in these pins would initially be molten if they were fabricated without a gas bond.

Helium gas, rather than nitrogen gas, was used in the fuel pins containing UN pellets because the thermal conductivity of helium is significantly ($\sim$5 times) higher than that of nitrogen. Consideration was given to the dependence of

UN decomposition on nitrogen pressure. Calculations, based upon experimental data[7], showed that for a fuel pin containing a 10.5 gram UN pellet and a 0.047 cu. in. (0.2 in. diameter by 1.5 in. long) gas plenum less than 0.0008% of the UN would decompose when at 2500°C and less than 0.08% would decompose when at 2850°C.

Cladding Thickness and Gas Plenum Length

Factors considered in arriving at a minimum cladding thickness included an estimate of the maximum internal pressure and an allowable cladding stress. The allowable stress was assumed to be equal to one-half the ultimate tensile strength reported by Brookes and Harris.[8] The maximum internal pressure was estimated by selecting a gas plenum length, based upon pin dimension limitations specified by NASA-Lewis[1], and assuming that all of the fission gases formed and the helium bond gas will be collected in the plenum. The average temperature of the gases was assumed to be the same as the maximum cladding temperature specified by NASA-Lewis.[1]

DESCRIPTION OF THE FABRICATION PROCESS

Flowsheets of the UO_2 and UN pellet preparation processes are presented in Figures 2 and 3, respectively. A flowsheet of the fuel pin fabrication process is presented in Figure 4.

Pellet Preparation

The UO_2 pellets were prepared by well-established cold pressing and sintering techniques. A detailed description of the basic process is presented in Special Report No. 2.[3] Ceramic grade UO_2 powder, which was purchased from a commercial vendor, was mixed with water and a binder

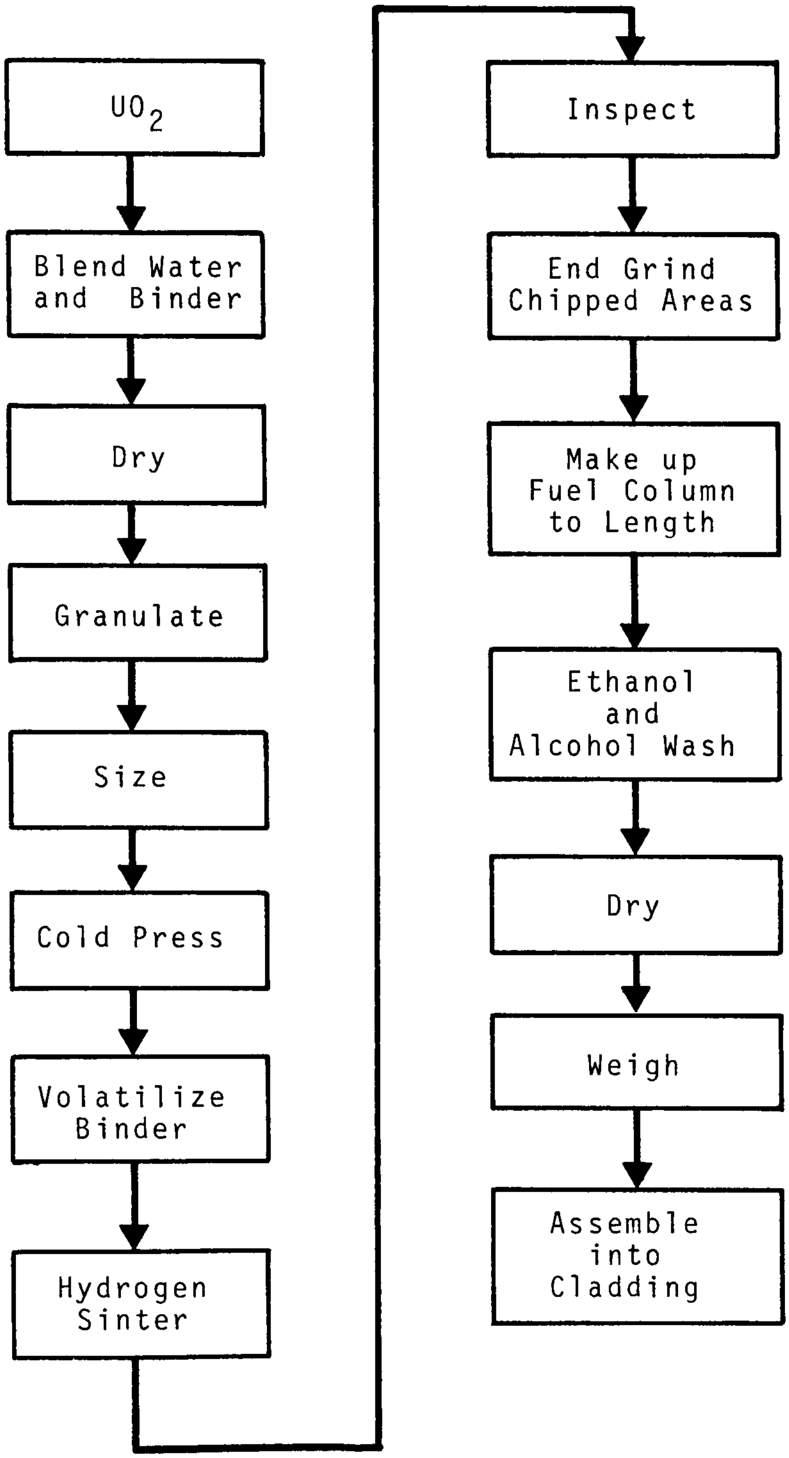


FIGURE 2. UO_2 Pellet Preparation Process

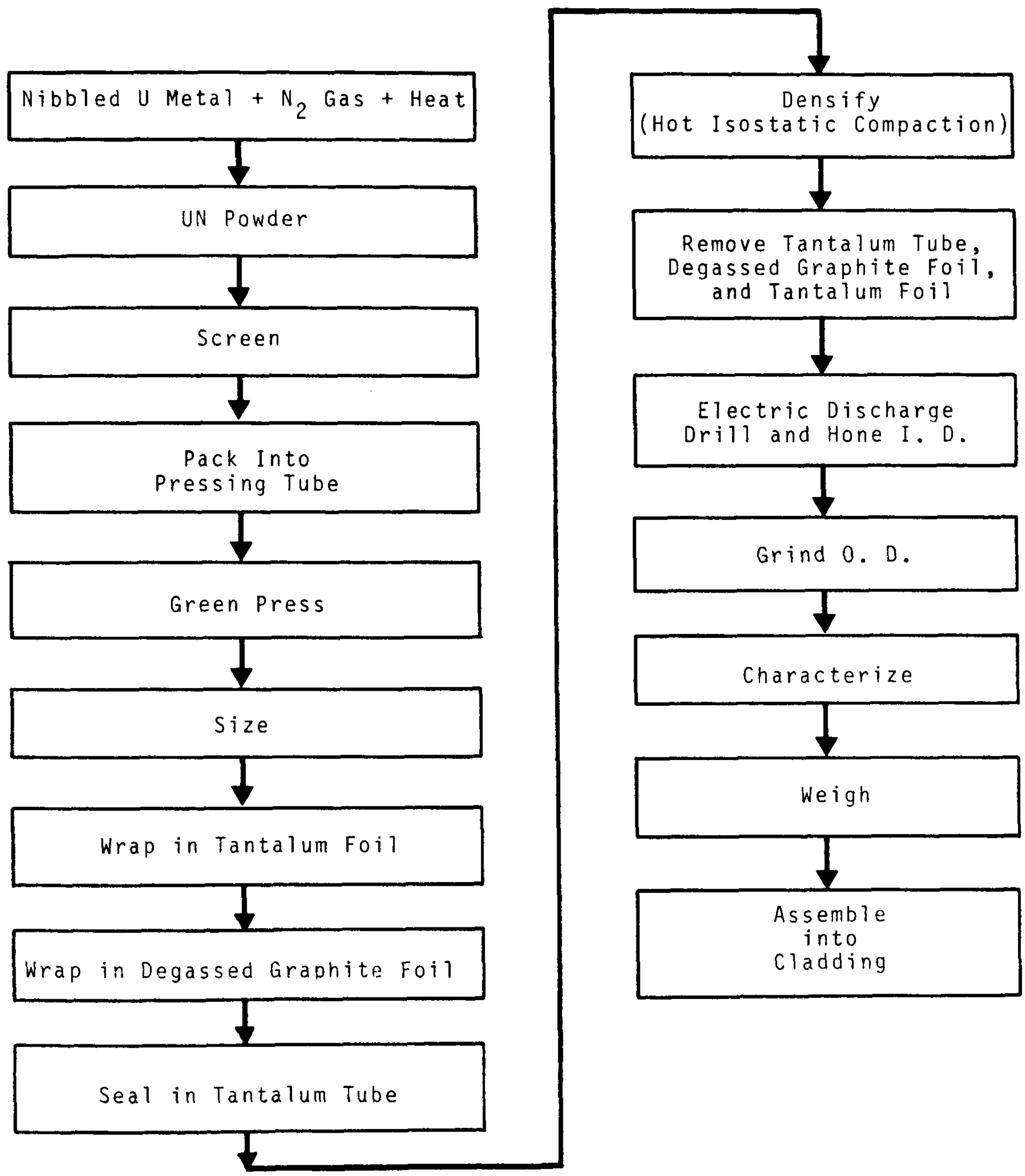


FIGURE 3. UN Pellet Preparation Process

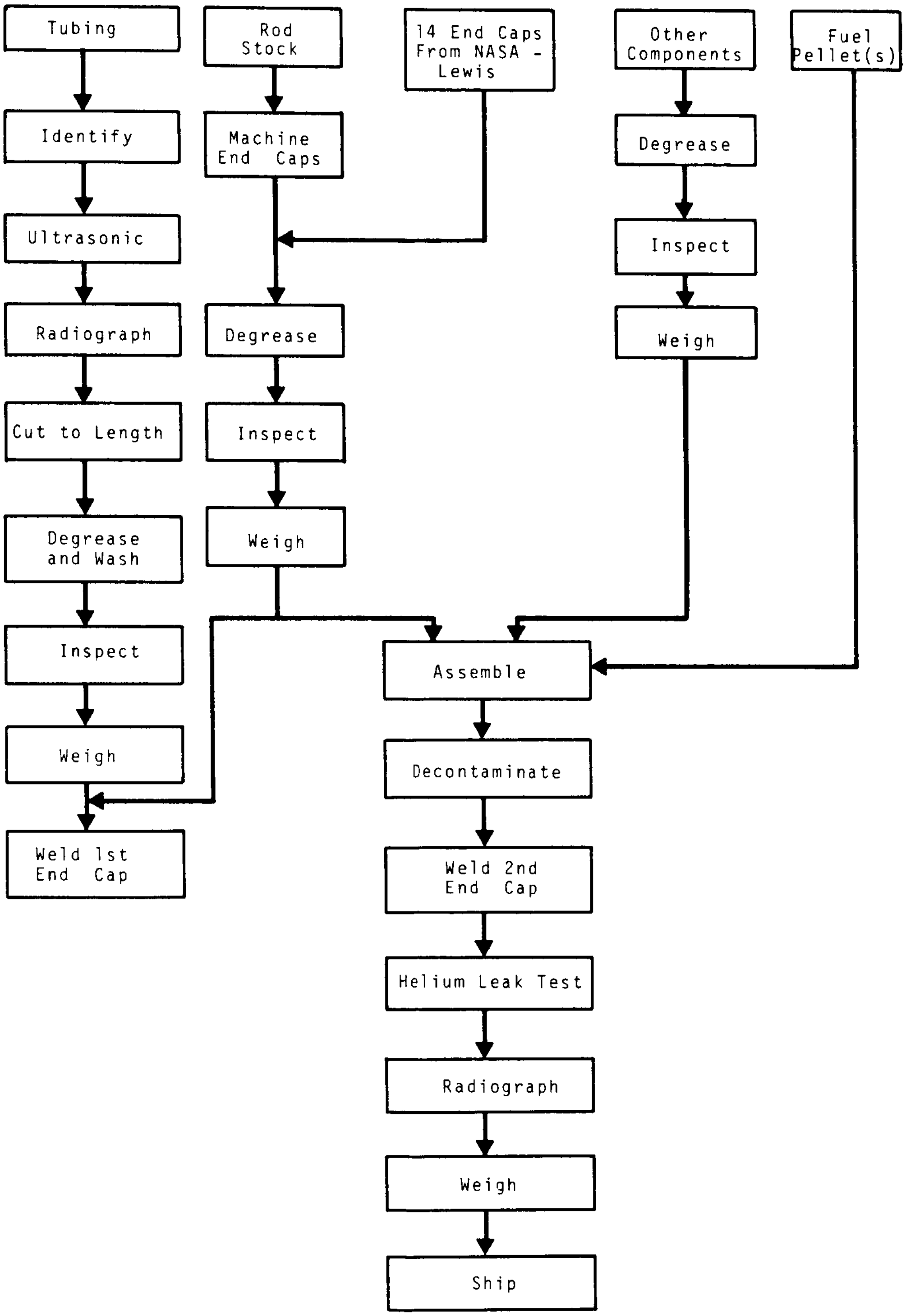


FIGURE 4. High Temperature Fuel Pin Fabrication Process

(Carbowax) to form a slurry. The slurry was dried, granulated, and sized. The pellets were cold pressed at 90,000 psi to a green density of 56-60% of theoretical and then sintered in hydrogen at 1680°C for eight hours. Because the sintering characteristics of the UO_2 powder had been determined and the pressing and sintering conditions carefully controlled, no grinding was necessary to obtain the desired diameter. The sintered pellets varied from 94-96% T.D. Pellets were end-ground, as necessary, to remove chipped areas. Fuel columns were fabricated to exact length by grinding the final pellet. After grinding, the pellets were washed in ethanol and dried.

The UN pellets were fabricated at the Battelle Memorial Institute Laboratories in Columbus, Ohio. Six cored pellets of polycrystalline UN were prepared from fully enriched uranium, and one cored pellet and ten wafer specimens of polycrystalline UN were prepared from depleted uranium. The UN powder was prepared by reacting nibbled* uranium metal with prepurified nitrogen gas in a reaction furnace that was evacuated to 1×10^{-6} torr before back filling with nitrogen. The reaction furnace contained tungsten heaters and shields and the nibbled uranium was contained in tungsten-lined molybdenum crucibles. To form the higher nitride powder, the nitrogen gas was maintained at 850°C and one atmosphere of pressure. When this reaction was completed, the temperature was slowly increased to 1400°C. The furnace was then evacuated to 1×10^{-5} torr to allow the powder to cool under a vacuum. Before removing the

---

* Uranium metal niblets are cubes ($\sim$1/8 in.) which contain a minimum amount of contaminants for their surface area.

UN-containing crucibles from the furnace, the furnace was back filled with argon gas. The UN powder was then placed in a dry box, screened through an 80 mesh seive, vibrationally packed into rubber hydrostatic pressing tubes, and green pressed into rods under a pressure of 100,000 psi. The rods were sized, wrapped in tantalum foil and degassed graphite foil, and inserted in tantalum tubes which were subsequently sealed by electron beam welding tantalum plugs in the ends of the tubes. Densification of the UN rods was accomplished by hot isostatic compaction at a temperature of 1650°C and a pressure of 15,000 psi for three hours. The pressure was released at temperature and the rods were furnace cooled. Final sizing of the densified pellets was accomplished by electrical discharge drilling to 0.084 in. diameter followed by honing of the I.D. to 0.090 in. and grinding of the O.D. to 0.195 in. To prevent extensive fracturing while cooling in the hot isostatic pressing autoclave, each rod was densified considerably oversize. Thus, approximately 0.25 in. was removed from the O.D. of each rod. The depleted UN pellets were prepared before the enriched pellets.

Cladding and Hardware Preparation

Cladding tubes, which had been fabricated from solid TZM molybdenum alloy bar stock, were obtained from Thermo Electron Engineering Company, Woburn, Massachusetts. These tubes had been sized by grinding the O.D. and drilling the I.D. with a centercut gun drill.[9] Use of a special lubricant, developed by Thermo Electron Engineering Company, eliminated the need for honing the I.D. The cladding was nondestructively tested and then machined to length.

End caps were machined from solid molybdenum bar stock. The plenum sleeves and the support rings were machined from swaged molybdenum tubing having a 0.25 in. (outside) diameter and 0.050 in. wall thickness. Electrical discharge machining (EDM) was used to fabricate the tungsten wafers and springs from unalloyed tungsten foil.

Pin Assembly

All pin components (Figure 5 and 6) were thoroughly cleaned in acetone and ethanol and dried before assembly. The tungsten support sleeves were only used with cored pellets. Although not shown in Figure 5, plenum support rings and penum support sleeves of the type shown in Figure 6 were used in the pins containing UO_2 pellets as well as in the pins containing UN pellets. End caps without extensions, similar to those shown in Figure 5, were only used in fuel pins containing depleted fuel. End caps with extensions, similar to those shown in Figure 6, were used in fuel pins containing enriched fuel. The interior components, including the fuel pellets, were then inserted into the tubing. The assembly was placed in a welding box which was evacuated to 1×10^{-4} torr and backfilled with helium. The second end cap was welded into place, completing the fuel pin assembly (Figure 7).

EVALUATION OF THE FUEL PINS

Ceramic grade UO_2 was purchased to ASA N5.5 specification, issued September 20, 1965, by the American Standards Association, Inc. Analyses of the depleted and enriched UO_2 powder, as reported by the vendors, are shown in Table II. After processing the depleted and enriched UO_2 into pellets, the oxygen-uranium ratio (O/U), and flourine, chlorine, and water contents were determined (Table III).

The UN pellets were analyzed at the Battelle Memorial Institute Laboratories in Columbus, Ohio. Analyses of the UN pellets are shown in Table IV.

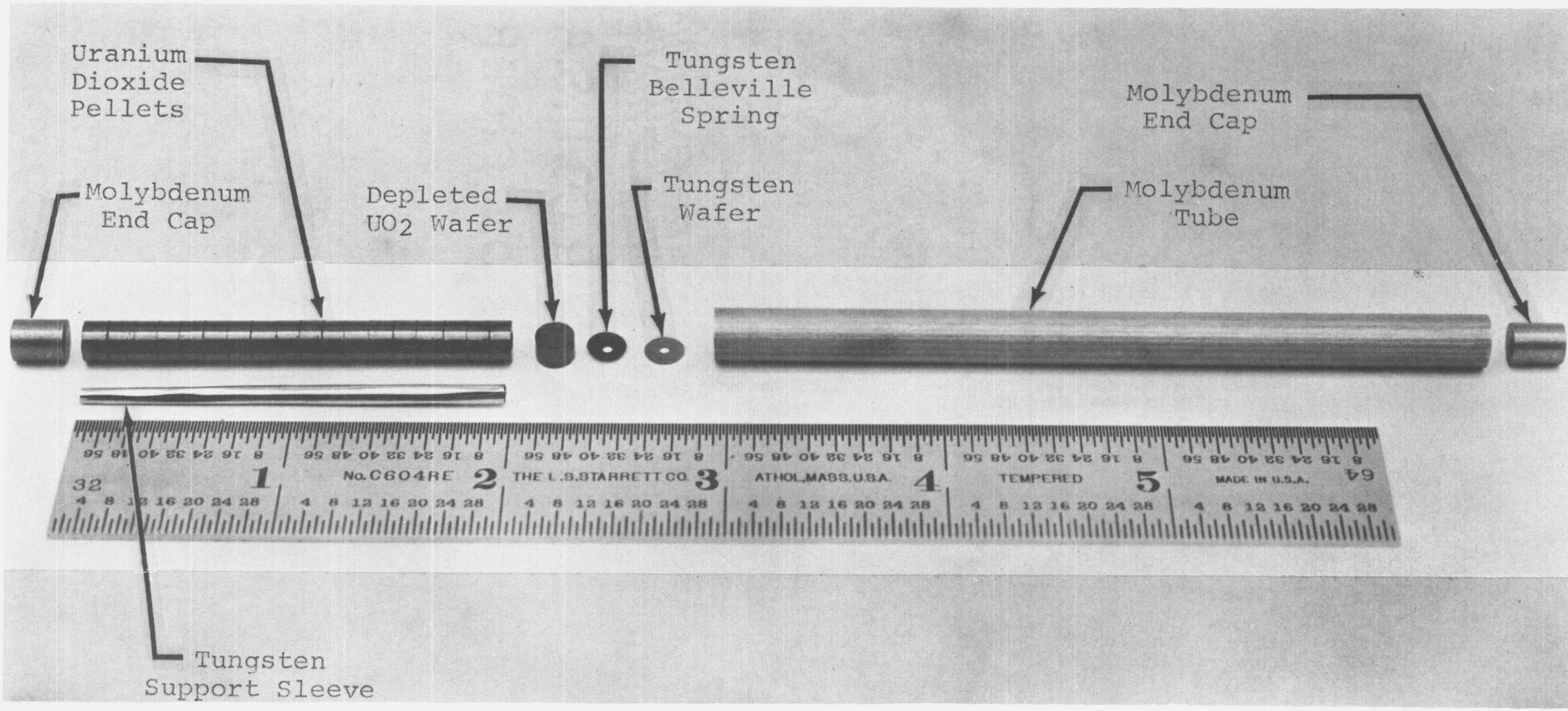


FIGURE 5. Components for High Temperature Fuel Pins Containing UO_2 Pellets. The Tungsten Support Sleeves Were Used With Cored Pellets.

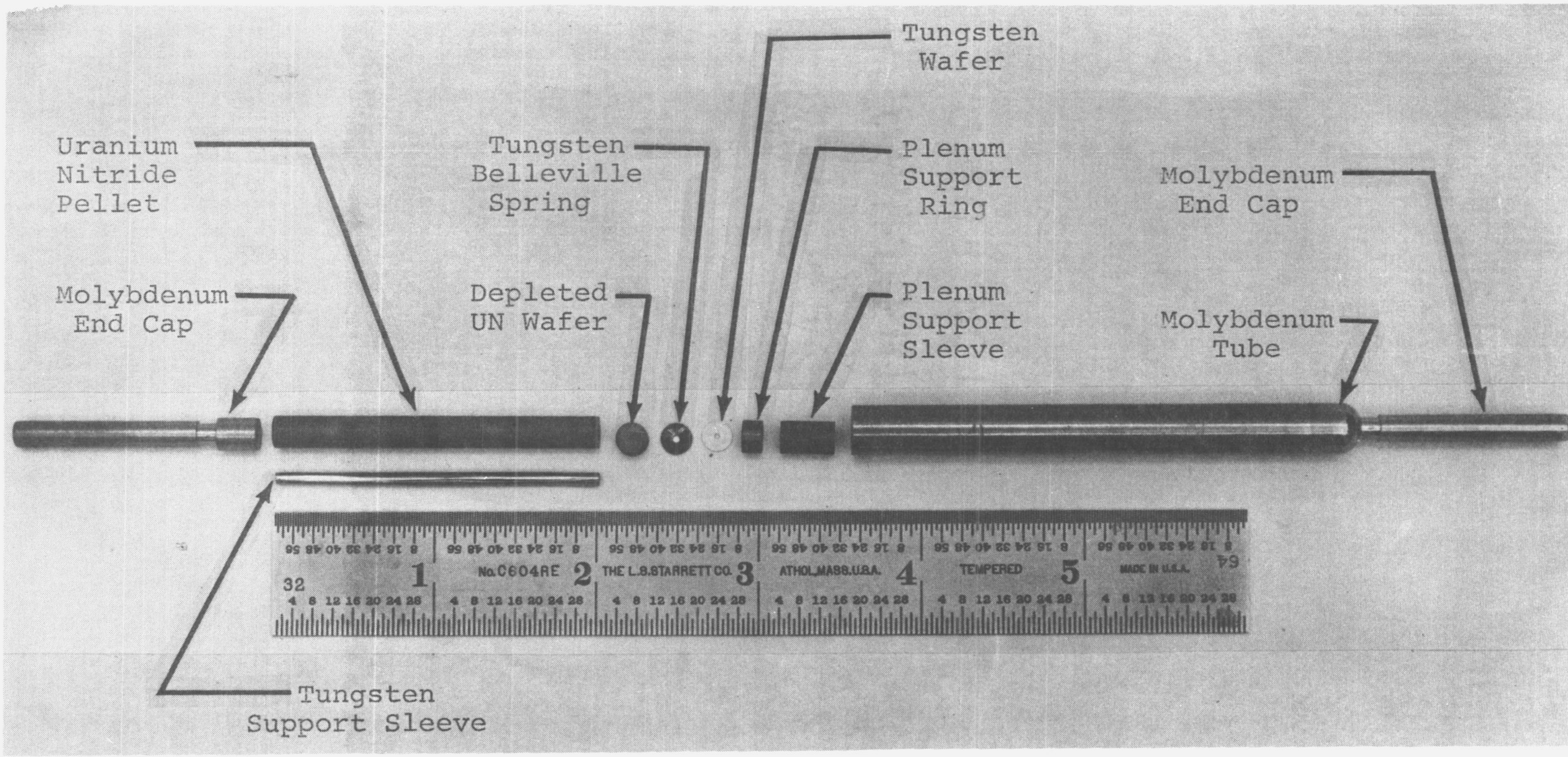


FIGURE 6. Components for High Temperature Fuel Pins Containing UN Pellets

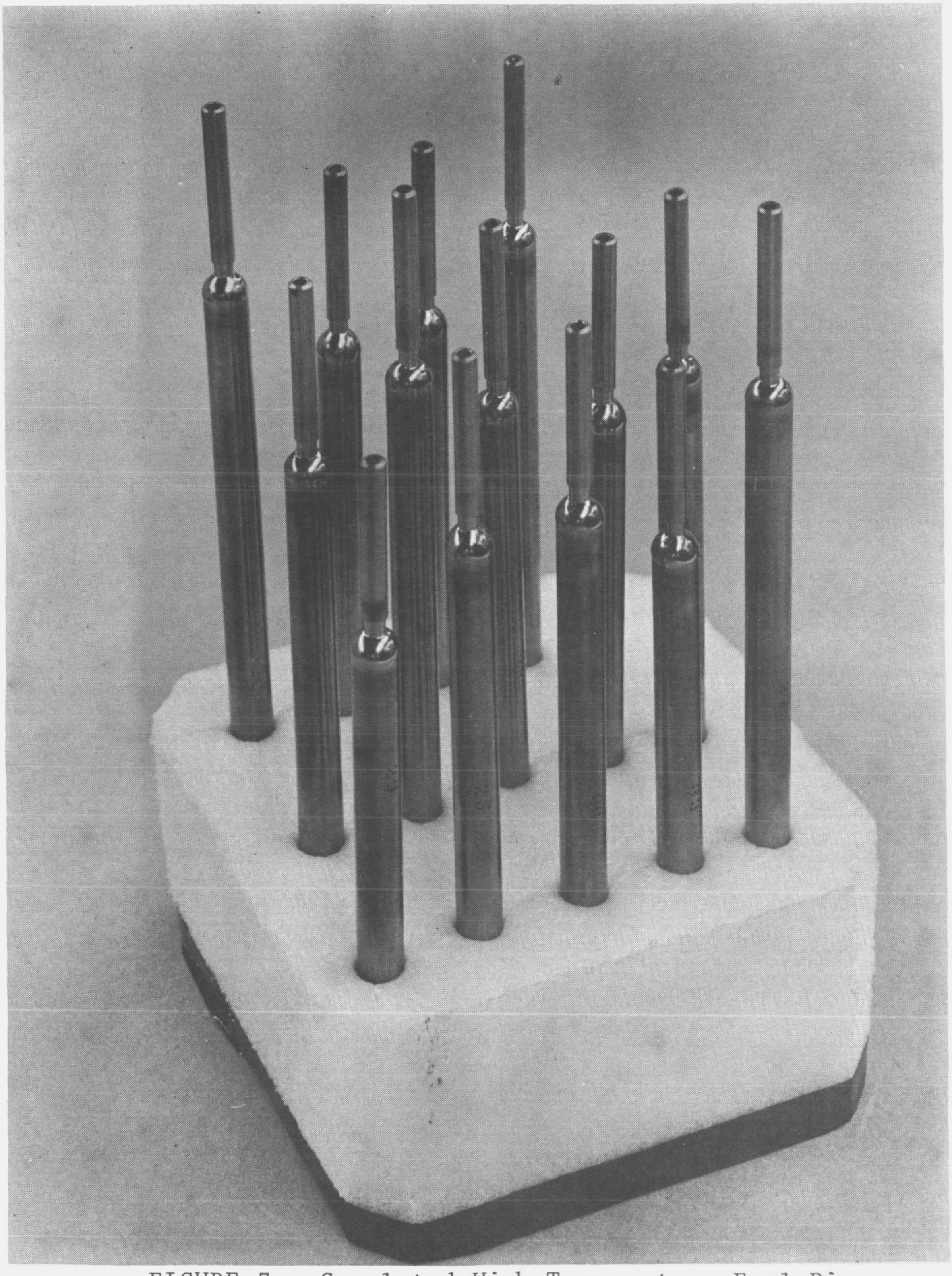


FIGURE 7. Completed High Temperature Fuel Pins

Table II
Analyses of Depleted and Enriched UO_2 Powder

Constituent	Analyses (ppm) Dep. UO_2	En UO_2	Constituent	Analyses (ppm) Dep. UO_2	En UO_2
Ag	< 0.1	0.1	Mn	< 5	< 5
Al	4	< 25	Mo	< 1	< 10
B	< 0.2	< 0.25	N	-	81
Ba	< 5	< 2.5	Na	< 40	< 10
Be	< 0.1	< 0.5	Ni	42	46
Bi	< 1	< 1	P	< 10	< 12.5
Ca	< 20	< 25	Pb	< 1	< 1
Cd	< 0.1	< 0.2	Rb	--	< 10
Cl	-	< 10	Sb	--	< 5
Co	< 5	< 2.5	Si	120	< 25
Cr	16	< 17	Sn	< 1	< 2.5
Cs	--	5	Sr	--	< 10
Cu	2	< 10	Th	--	< 8
F	136	10	Tl	--	< 10
Fe	48	40	Ti	1.2	< 25
In	--	< 2.5	V	< 2.5	< 25
K	--	< 10	Zn	30	< 25
Li	< 50	< 1	Zr	2	< 25
Mg	18	< 17			

Table III
Analyses of Depleted and Enriched UO_2 Pellets

Constituent	Analysis Depleted UO_2	Enriched UO_2
Oxygen	2.005 O/U ratio	2.019 O/U ratio
Water	15 ppm	27 ppm
Flourine	< 2 ppm	<2 ppm
Chlorine	<10 ppm	<5 ppm
Carbon	--	30 ppm

Table IV
Analyses of UN Pellets

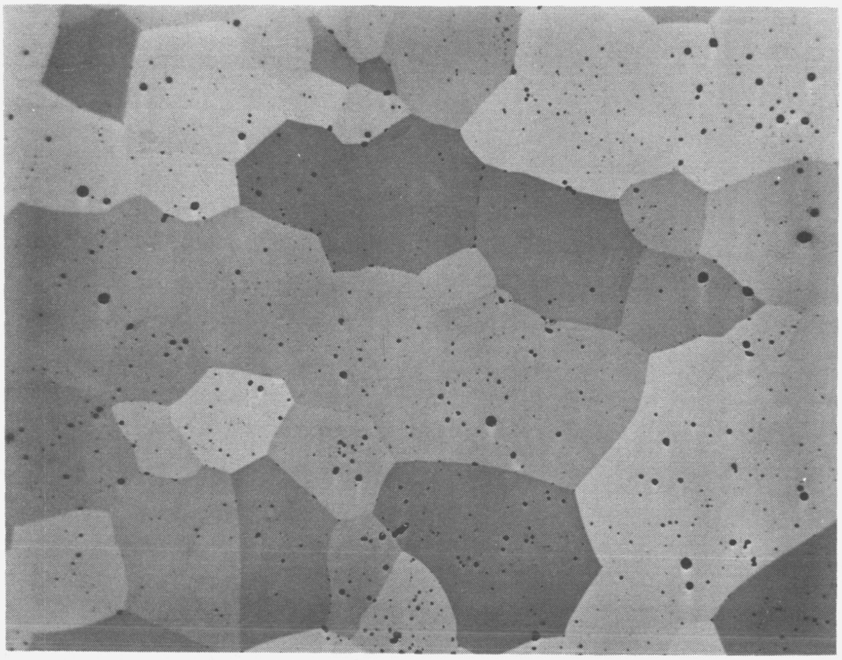
Pellet Number	N*	O	C	Fe	B	Si	Cr	Ca	Cu	Ni	Mg	Mo
Depleted	5.60	340	190	22	<0.3	35	<5	<1	20	20	<2	<3
Enriched 1-4	5.17	677	340	100	1	20	20	5	2	40	2	1
Enriched 5-6	5.14	875	470	200	0.5	50	15	30	5	50	10	50

* Wt%

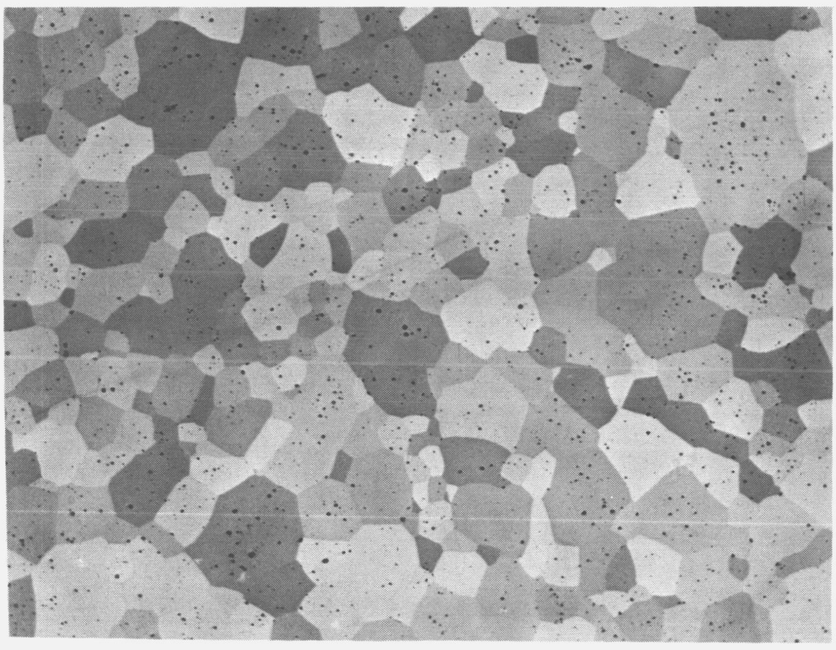
Metallographic samples of the UN pellet material were also taken at the Battelle Memorial Institute Laboratories in Columbus, Ohio. Typical microstructures of the depleted UN pellets are shown in Figure 8. Typical microstructures of the enriched UN pellets are shown in Figure 9 and 10. The white second phase visible in the microstructure, especially for pellets 5 and 6 (Figure 10), was not positively identified but has been occasionally observed in other uranium nitride specimens made from enriched uranium. The second phase is thought to be oxide, because the oxygen contents in pellets 5 and 6 are higher than in the other UN pellets (Table IV). However, this phase does not have the usual appearance of oxide inclusions. Recent irradiations by Battelle-Northwest with (U,Pu)N fuel containing 4000-5900 ppm oxygen indicates that the oxygen content in these fuel pins (340-875 ppm) should not adversely affect fuel performance (i.e., excessive grain growth or thermal decomposition at temperatures up to 2000°C).[10] The nitrogen contents of the enriched pellets, as shown by chemical analyses (Table IV), are lower than the microstructures would indicate. Pellets 1 through 4 were used in pins 11, 12, 14, and 15, respectively, and contained uranium enriched to 93.17 per cent ^{235}U. The uranium used for pellets 5 and 6 (pins 19 and 20) contained 93.10 per cent ^{235}U.

The dimensions of all fuel pellets were accurately measured and the densities determined. Fuel column weights, dimensions, and densities for all of the fuel pins are shown in Table V.

All of the components of each pin were accurately weighed (Table VI), and the total weight of the components cross-checked with the weight of the assembled fuel pin. The weights agreed to within 0.1% for the prototype fuel pins

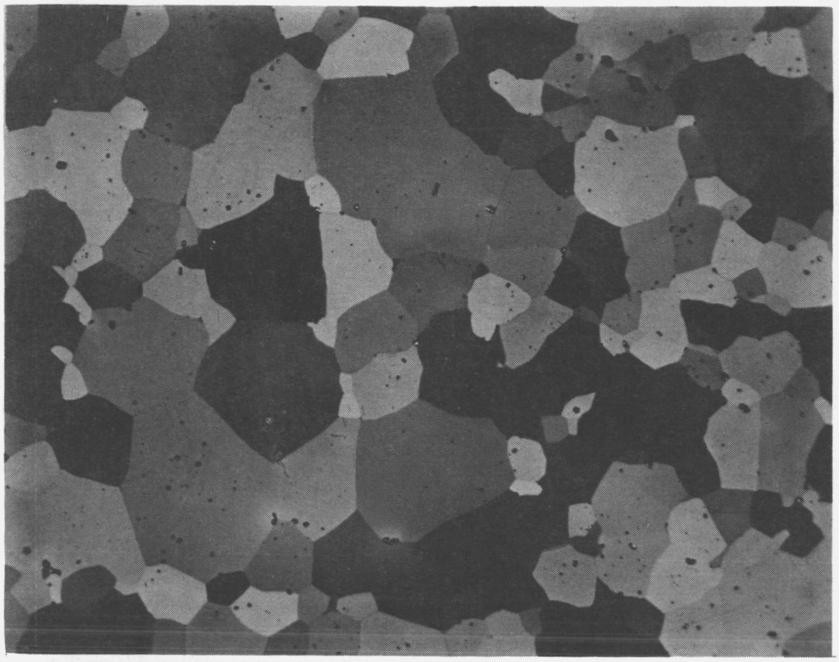


250X (Neg. No. BMI 7A433)

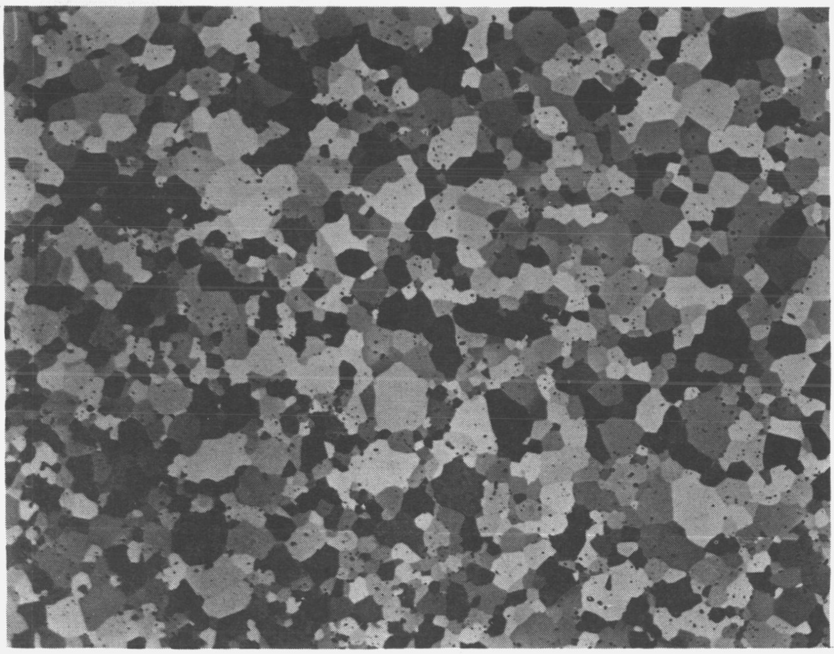


100X (Neg. No. BMI 7A432)

FIGURE 8. Microtstructures of Depleted UN Pellet

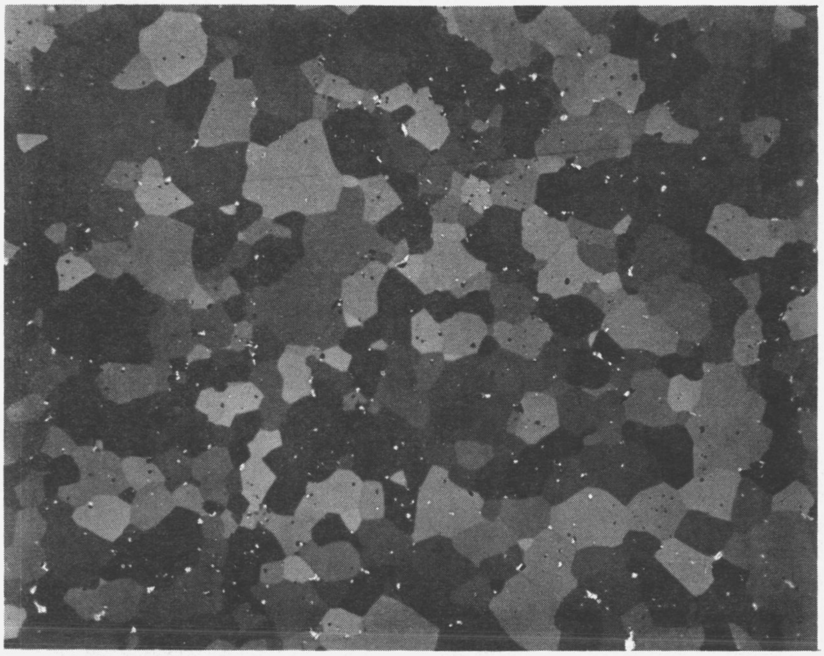


250X (Neg. No. BMI 0C672)

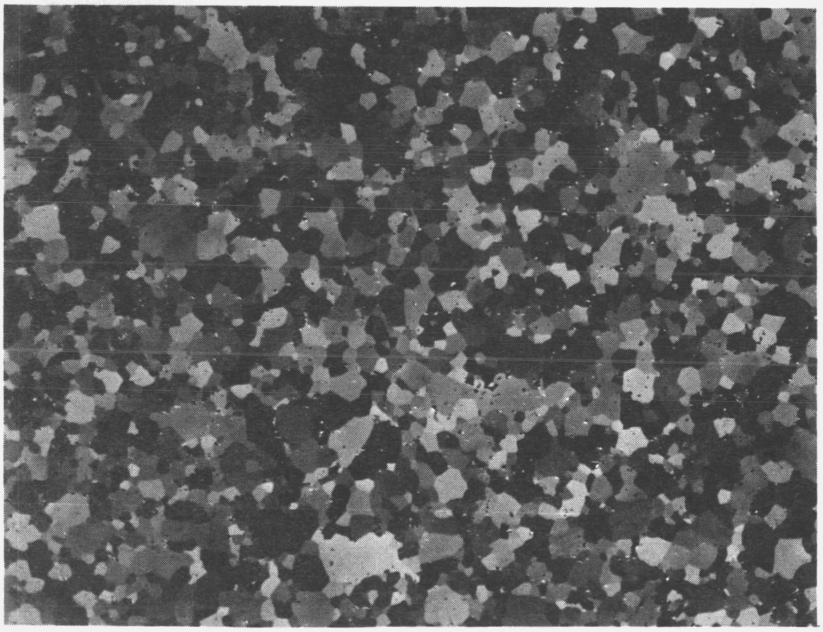


100X (Neg. No. BMI 0C670)

FIGURE 9. Microstructures of Enriched UN Pellets 1 through 4



250X (Neg. No. BMI 3C285)



100X (Neg. No. BMI 3C284)

FIGURE 10. Microstructures of Enriched UN Pellets 5 and 6

Table V
Weights, Dimensions, and Densities of Fuel Columns

Pin No.	Fuel*	Pellet Number	Column Length (inches)	Outside Diameter (inches)	Inside Diameter (inches)	Column Weight (grams)	Per Cent Theoretical Density
5	Dep. UO_2	NN**	2.001	0.188	None	9.6292	96.3
7	" "	NN	1.991	0.188	None	9.6080	96.1
10	" "	NN	1.993	0.193	0.086	8.0267	95.0
13	" "	NN	2.005	0.193	0.086	8.0129	94.8
16	" "	NN	1.999	0.193	0.086	8.0568	95.4
23	" "	NN	1.994	0.193	0.086	8.0231	95.0
25	En. UO_2	NN	1.995	0.192	None	9.8545	94.90
26	" "	NN	1.993	0.192	None	9.8407	94.87
27	" "	NN	2.001	0.192	None	9.8426	94.50
28	" "	NN	2.005	0.192	None	9.8977	94.85
30	" "	NN	2.002	0.192	None	9.8760	94.79
31	" "	NN	1.998	0.192	None	9.8518	94.74
34	" "	NN	1.997	0.192	None	9.8559	94.82
35	" "	NN	2.001	0.192	None	9.8970	95.03
29	" "	NN	1.991	0.195	0.094	7.8620	94.56
33	" "	NN	2.004	0.195	0.094	7.9126	95.81
36	" "	NN	1.995	0.195	0.094	7.8658	95.67
37	" "	NN	1.995	0.195	0.094	7.8766	95.81
38	" "	NN	2.010	0.195	0.094	7.9282	95.72
39	" "	NN	2.010	0.195	0.094	7.9465	95.93
9	Dep. UN	NN	2.002	0.195	0.093	10.8680	99.86
11	En. UN	1	2.000	0.196	0.092	10.5962	98.49
12	" "	2	2.003	0.196	0.092	10.7351	98.44
14	" "	3	2.003	0.196	0.091	10.8633	98.44
15	" "	4	1.996	0.197	0.092	10.8501	98.36
19	" "	5	1.990	0.194	0.091	10.5859	98.44
20	" "	6	2.001	0.195	0.091	10.6619	98.60

* Dep. - Depleted; En. - Fully Enriched
** NN - No Number Assigned

Table VI
Weight in Grams of Pin Components

Pin No.	Plenum Support Sleeve	Plenum Support Ring	Both End Caps	Tungsten Wafer	Spring	Tube	Pellet Support Sleeve	End Plug	Pellet Column	Total Weight by Summation	Weight Finished Element
5	0.5130	0.1974	2.6557	0.0386	0.0259	24.1605	--	0.6000	9.6292	37.8203	37.8194
7	0.5399	0.2146	2.6682	0.0362	0.0266	24.2189	--	0.5990	9.6080	37.9114	37.9106
10	0.4182	0.2030	2.6487	0.0360	0.0258	23.1718	0.2813	0.5940	8.0267	35.4055	35.4032
13	0.4104	0.2060	2.6654	0.0366	0.0266	23.1215	0.1888	0.5976	8.0129	35.2658	35.2633
16	0.4410	0.2182	1.3235*	0.0385	0.0274	24.4909**	0.2010	0.5942	8.0568	35.3915	35.3899
23	0.4445	0.1933	1.3030*	0.0361	0.0259	24.5560**	0.2654	0.6130	8.0231	35.4603	35.4629
25	0.4754	0.2456	8.4176	0.0370	0.0275	23.4003	--	0.6032	9.8545	43.0611	43.0591
26	0.4911	0.2122	8.4836	0.0367	0.0272	23.5782	--	0.6005	9.8407	43.2702	43.2626
27	0.8720	0.2477	8.4835	0.0354	0.0260	26.7345	--	0.5961	9.8426	46.8378	46.8395
28	0.9354	0.2178	8.4604	0.0355	0.0258	26.8367	--	0.6026	9.8977	47.0119	47.0164
29	0.2124	0.2145	8.6086	0.0359	0.0252	19.9405	0.2793	0.5963	7.8620	37.7747	37.7798
30	0.5138	0.2269	8.5239	0.0347	0.0252	23.4837	--	0.5975	9.8760	43.2817	43.2855
31	0.8166	0.2476	8.5886	0.0350	0.0260	26.6808	--	0.5966	9.8518	46.8430	46.8457
33	0.2116	0.2223	8.5376	0.0387	0.0266	19.9523	0.3196	0.6027	7.9126	37.8240	37.8263
34	0.4937	0.2065	8.5633	0.0368	0.0261	23.3903	--	0.6005	9.8559	43.1731	43.1736
35	0.8982	0.2226	8.4701	0.0365	0.0275	26.7417	--	0.5925	9.8970	46.8861	46.8867
36	0.4994	0.2375	8.4193	0.0360	0.0259	23.3208	0.2243	0.5935	7.8658	41.2225	41.2249
37	0.4565	0.2414	8.5125	0.0360	0.0257	23.5497	0.2934	0.5928	7.8766	41.5846	41.5882
38	0.2046	0.2188	8.5568	0.0350	0.0256	20.0383	0.2684	0.5944	7.9282	37.8701	37.8752
39	0.5056	0.2135	8.5588	0.0363	0.0252	23.4245	0.3051	0.5948	7.9465	41.6103	41.6156
9	0.1868	0.2200	1.1410*	0.0377	0.0250	21.5155**	0.2573	0.8759	10.8680	35.1272	35.1257
11	0.1932	0.1908	4.1713*	0.0394	0.0265	24.6032**	0.2290	0.8750	10.5962	40.9246	40.9315
12	0.1915	0.2235	4.1646*	0.0385	0.0269	24.5708**	0.2465	0.8579	10.7351	41.0553	41.0624
14	0.1806	0.2088	4.1835*	0.0365	0.0261	24.5536**	0.2714	0.8675	10.8633	41.1913	41.1970
15	0.5423	0.2214	4.3272*	0.0377	0.0267	27.8736**	0.2331	0.8706	10.8501	44.9827	44.9829
19	0.5249	0.2310	4.2638*	0.0365	0.0268	27.8985**	0.2510	0.8880	10.5859	44.7064	44.7050
20	0.4440	0.2238	4.2530*	0.0384	0.0275	27.8272**	0.2459	0.8640	10.6619	44.5857	44.5852

* Second end cap only
** Includes first end cap

containing depleted UO_2 pellets, and to within 0.02% for the remaining fuel pins.

Molybdenum tubing was purchased to the standard TZM alloy composition, i.e., 0.5% Ti, 0.08% Zr, and 0.02% C, bal.: molybdenum. Analysis of the TZM alloy is shown in Exhibit I. The cladding tubes were ultrasonically tested for internal defects using a 0.0026 in. deep by 0.015 in. long artificial defect as the reject level. Three of the original 20 pieces ordered were rejected. All pieces in a subsequent order were accepted. Wall thickness on all tubes, measured by micrometer at the tube ends and from radiographs, was uniform and within specifications. The dimensions of each component for each pin were checked. All dimensions conformed to the specifications shown on Drawings No. R-1008 (Figure 1) with the exception of the diameters of the solid depleted UO_2 pellets which were 0.188 in. and the inner diameters of the hollow depleted UO_2 pellets which were 0.086 in. These exceptions were inconsequential to the evaluation planned for the prototype pins and were accepted by NASA-Lewis.

The end caps were fabricated from unalloyed molybdenum. Fourteen end caps (Part 30, Figure 1) were supplied by NASA-Lewis for the fuel pins containing enriched UO_2 pellets. All other end caps were fabricated by Battelle-Northwest Laboratories from bar stock supplied by NASA-Lewis. No special significance is implied to either the part number, the supplier, or the fabricator; this point is documented only in the event that subsequent evaluation should detect a difference between the sources of material. An analysis which is representative of the unalloyed molybdenum used for the end caps is shown in Exhibit II.

SC 3245	SPECTROCHEMICAL ANALYSIS REPORT HAPO SPECTROCHEMICAL LABORATORY BUILDING 325	CCI SPEC. LAB.

MATERIAL: Mo Tubing

SUBMITTED BY	SUBMITTER'S NO.	ANALYZED BY	DATE REPORTED
C. H. Bloomster		R Ogden	4-27-67

ELEMENT		ELEMENT		ELEMENT		ELEMENT	
Ag	—	Hg	—	Re		Dy	
Al	* < M	In	—	Rh	—	Er	
As	—	Ir	—	Ru	—	Eu	
Au	—	K		Sb	—	Gd	
B	—	La	—	Sc		Ho	
Ba	—	Li		Si	T	Lu	
Be	—	Mg	—	Sn	—	Nd	
Bi	—	Mn	< T	Sr	—	Pr	
Ca		Mo	SS	Ta	—	Sm	
Cd	—	Na	—	Th	—	Tb	
Ce		Nb	—	Ti	M	Tm	
Co	—	Ni	—	Tl	—	Yb	
Cr	—	Os		U	—		
Cs		P	—	V	—		
Cu	< T	Pb	—	W	—		
Fe	M	Pd	—	Y	—		
Ga	—	Pt	—	Zn	—		
Ge		Pu		Zr	M		
Hf	—	Rb					

TYPE OF ANALYSIS

[X] QUALITATIVE

SYMBOL	MEANING	APP'X. CONC.
SS	MAJOR DETECTABLE CONSTITUENT	
S	STRONG	GREATER THAN 1 %
M	MODERATE	1 % TO 0.01 %
T	TRACE	LESS THAN 0.01 %
—	NOT DETECTED	
*	INTERFERENCE	
?	DETECTION UNCERTAIN. INTERFERENCE	

[ ] SEMIQUANTITATIVE

SYMBOL	MEANING
G	CONCENTRATION GREATER THAN
L	DETECTABLE CONCENTRATION LESS THAN
—	NOT DETECTED

NUMERICAL VALUES [ ] PARTS PER MILLION [ ] PERCENT [ ]

APPR'X. PRECISION ± FACTOR

[ ] QUANTITATIVE

SYMBOL	MEANING
GX (LX)	CONC. GREATER THAN (LESS THAN) CALIBRATED WORKING CURVE

NUMERICAL VALUES [ ] PARTS PER MILLION [ ] PERCENT [ ]

APPR'X. PRECISION ±

REMARKS:
Fe POSSIBLY CONTAMINATION FROM FILE. NONE DETECTED BY X-RAY FLOURECENSE.
Zr SHOWED AFTER LONGER THAN NORMAL BURNING TIME.

REPORT APPROVED: MCB

LABORATORY INFORMATION

SPECTROGRAPH AND SOURCE	SIZE OF SAMPLE	METHOD OF ANALYSIS	PLATE NO.
B+L Varisource DC Arc	10 mg	3 mm Crater	5830

BD-7600-057 (2-63) AEC-GE RICHLAND, WASH.

EXHIBIT I. Analysis of TZM Molybdenum Tubing

CCI SPEC. LAB.

SC 2858

SPECTROCHEMICAL ANALYSIS REPORT

HAPO SPECTROCHEMICAL LABORATORY
BUILDING 325

MATERIAL: Mo

SUBMITTED BY	SUBMITTER'S NO.	ANALYZED BY	DATE REPORTED
C. H. Bloomster		R. Ogden	1-12-67

ELEMENT		ELEMENT		ELEMENT		ELEMENT	
Ag	—	Hg	—	Re		Dy	
Al	M-S	In	*	Rh	—	Er	
As	—	Ir	*	Ru	—	Eu	
Au	—	K		Sb	—	Gd	
B	—	La	—	Sc		Ho	
Ba	—	Li		Si	T-M	Lu	
Be	—	Mg	T	Sn	—	Nd	
Bi	*	Mn	T-M	Sr	—	Pr	
Ca		Mo	S	Ta	—	Sm	
Cd	—	Na		Th	—	Tb	
Ce		Nb	—	Ti	—	Tm	
Co	—	Ni	—	Tl	—	Yb	
Cr	M	Os		U	—		
Cs		P	*	V	—		
Cu	T-M	Pb	—	W	—		
Fe	S	Pd	—	Y	—		
Ga	—	Pt	—	Zn	—		
Ge		Pu		Zr	—		
Hf	—	Rb					

TYPE OF ANALYSIS

[X] QUALITATIVE

SYMBOL	MEANING	APP'X. CONC.
SS	MAJOR DETECTABLE CONSTITUENT	
S	STRONG	GREATER THAN 1 %
M	MODERATE	1 % TO 0.01 %
T	TRACE	LESS THAN 0.01 %
—	NOT DETECTED	
*	INTERFERENCE	
?	DETECTION UNCERTAIN. INTERFERENCE	

[ ] SEMIQUANTITATIVE

SYMBOL	MEANING
G	CONCENTRATION GREATER THAN
L	DETECTABLE CONCENTRATION LESS THAN
—	NOT DETECTED

NUMERICAL VALUES: [ ] PARTS PER MILLION [ ] PERCENT [ ]

APPR'X. PRECISION ± FACTOR

[ ] QUANTITATIVE

SYMBOL	MEANING
GX (LX)	CONC. GREATER THAN (LESS THAN) CALIBRATED WORKING CURVE

NUMERICAL VALUES: [ ] PARTS PER MILLION [ ] PERCENT [ ]

APPR'X. PRECISION ±

REMARKS:

REPORT APPROVED: MCB

LABORATORY INFORMATION

SPECTROGRAPH AND SOURCE	SIZE OF SAMPLE	METHOD OF ANALYSIS	PLATE NO.
B&L Varisource DC Arc	100mg	3mm Crater	5830

BD-7600-057 (2-63) AEC-GE RICHLAND, WASH.

EXHIBIT II. Analysis of Molybdenum Bar Stock

All tungsten parts were fabricated from unalloyed tungsten foil.

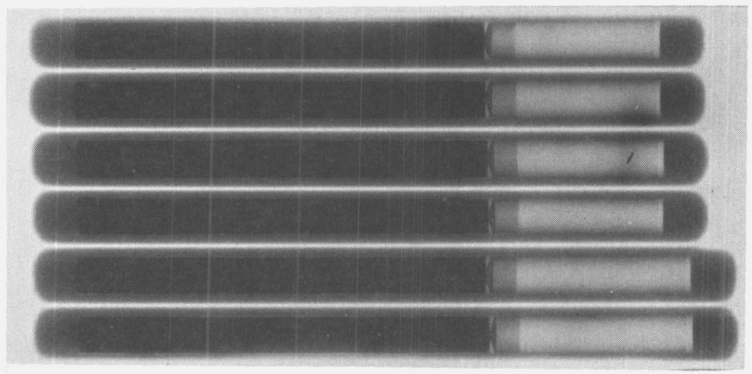
After final closure welding, the pins were checked for leaks with a helium leak detector. The pins were radiographed to determine weld penetration and fuel column integrity and location. Photographic prints made from radiographs of the fuel pins are shown in Figures 11, 12, and 13. Complete weld penetration was obtained on all pins. The minimum wall thickness in the weld regions was 75% of the specified tube wall thickness in all pins. Inversion of the tungsten Belleville spring was detected in fuel pin No. 39. Because the inverted spring will not affect the performance of the fuel pin, the pin was not disassembled.

PROBLEMS ENCOUNTERED DURING FABRICATION

Several difficult and time consuming problems were encountered in fabricating these fuel pins. The experience gained in solving these problems may be of value in fabricating other types of high temperature fuel pins or related fuel assembly components. For this reason, a brief discussion of these problems and their solution is presented. It will be of interest to note that the problems described were all associated with the cladding or end caps. No significant problems were encountered in fabricating the fuel pellets.

Considerable effort was expended in attempting to obtain the thin wall (0.025 in.) molybdenum cladding originally specified for the fuel pins. Stock molybdenum tubing, made by powder metallurgy, was available in the proper outside diameter, but the wall thickness was 0.050 in. Attempts to bore out this tubing met with many difficulties. The as-fabricated tubing cracked during machining; annealing

Pin No.



23

16

13

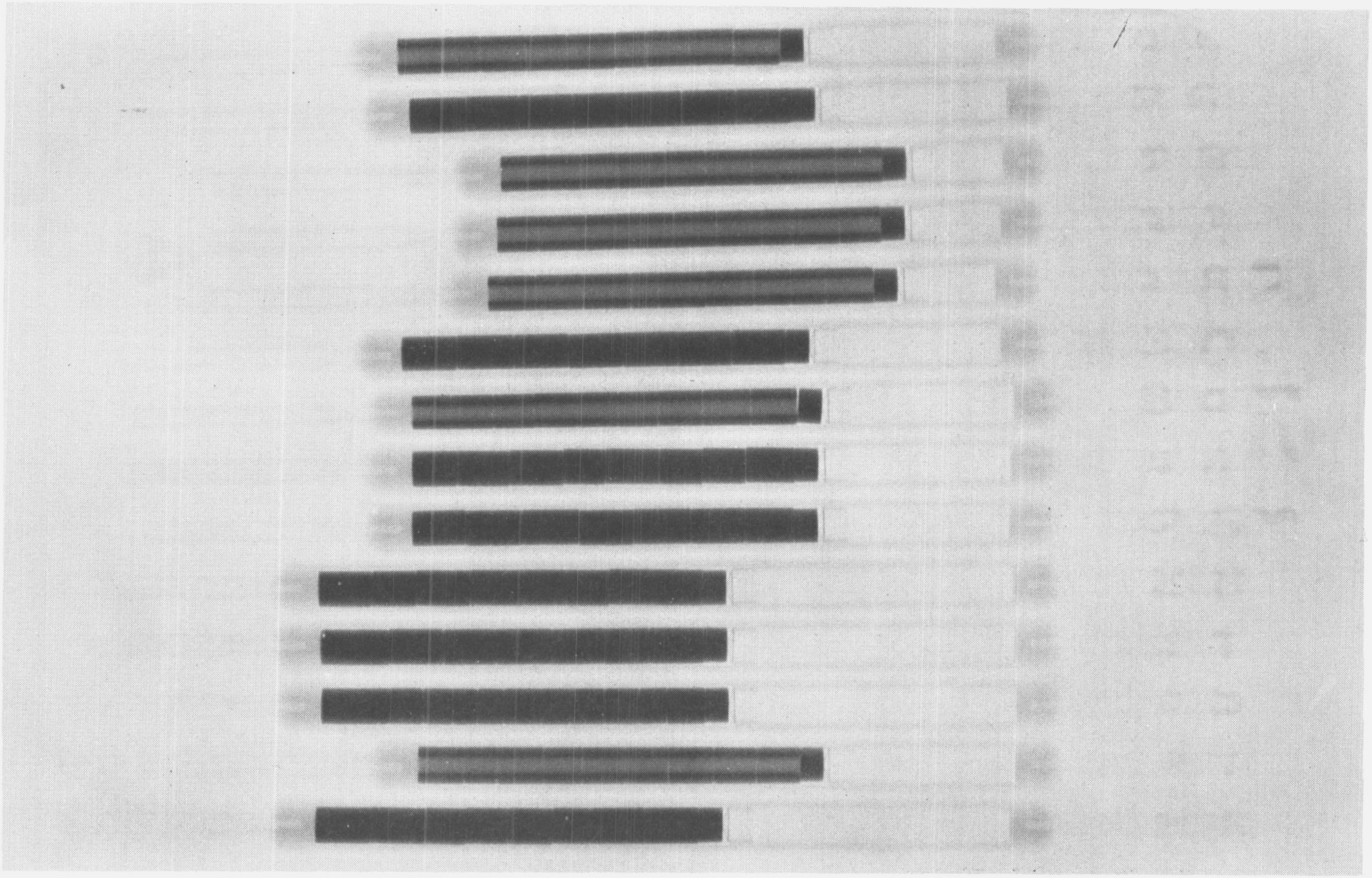
10

7

5

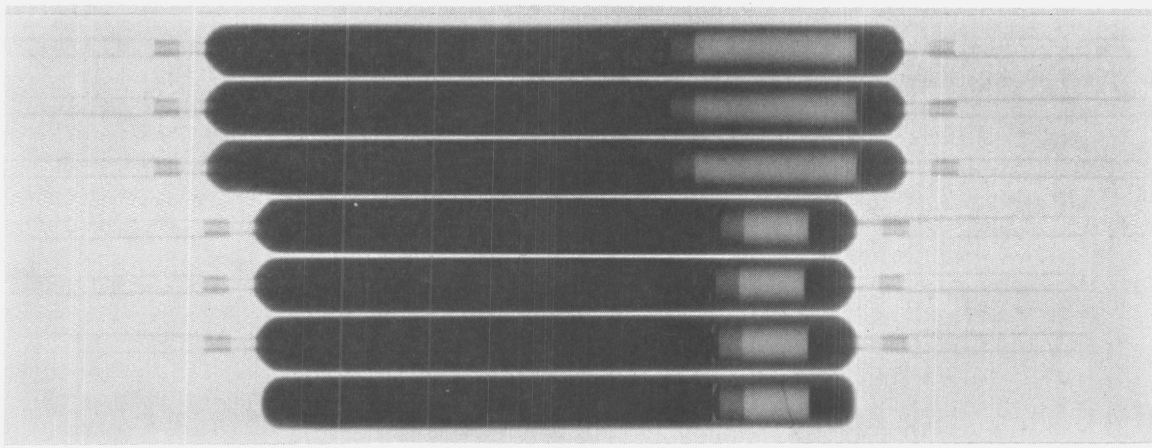
(Radiograph 4-17-67)

FIGURE 11. Radiograph of Assembled Fuel Pins Containing Depleted UO_2 Pellets



(Radiograph 6-23-67)

FIGURE 12. Radiograph of Assembled Fuel Pins Containing Enriched UO_2 Pellets



(Radiograph 10-25-67)

FIGURE 13. Radiograph of Assembled Fuel Pins Containing UN Pellets

alleviated this problem. Early machining attempts failed to hold wall thickness requirements, and although steady progress was made, the starting variation in wall thickness was too large to overcome by machining and the wall thickness reject rate remained high. In addition, a large percentage of the tubes were rejected for internal defects.

One lot of stock molybdenum tubing having a 0.250 in. (outside) diameter and 0.030 in. wall thickness, also a powder metallurgy product, was obtained and evaluated. Excessive cracking was detected in the tubing with the ultrasonic test, and no further work with this tubing was attempted.

These two types of tubing had not been fabricated by the vendors for nuclear fuel cladding. Consequently, they were not subjected to the strict quality control required for such use.

In view of these problems, NASA-Lewis specified that the wall thickness be increased to 0.050 in. With the adoption of the thick wall (0.050 in.) tubing, weld penetration became a problem. With the 0.025 in. wall tubing, 100% weld penetration was achieved, but with the 0.050 in. wall tubing, penetration in the test welds was between 50 and 60 per cent. Welding techniques were developed for the enriched UO_2 fuel pins with the goal of 80 per cent minimum penetration. The problem centered around the end cap design. The end cap contained a stem which restricted the electrode position. This restriction, in turn, limited the ability to apply to the proper location the amount of heat required to simultaneously melt approximately equal volumes of the end cap and can wall.

By relieving the diameter of the stem 0.015 in. and positioning the 1/16 in. diameter tungsten electrode at a 45° angle to the outer edge of the cladding, 80% penetration was achieved using 85 amperes and a welding speed of 7 rpm. Weld penetration varied between 50 and 60 per cent by the other technique investigated. By increasing the current to 90 amperes, complete penetration (100 per cent) was obtained on the fuel pins, themselves.

During final weld closure of the enriched UN fuel pins, the angle of the electrode was less than 45° and molten metal relocated to the small diameter region of the end caps. The unacceptable pins were reclad with new cladding and end caps.

The welding problem was corrected by increasing the angle of the tungsten electrode, thereby directing more heat into the weld region. Complete penetration was obtained on the acceptable enriched UN fuel pins. The minimum wall thickness in the weld regions of all pins was 75% of the tube wall thickness.

REFERENCES

1. Fuel Pin Design, Evaluation and Fabrication, NASA Contract No. NAS3-7960, June 29, 1966, (Classified).

2. Proposed Designs for High Temperature Fuel Pins, Y-49006-1, Battelle-Northwest to Lewis Research Center, August 3, 1966. (Confidential).

3. Proposed Fabrication Processes and Evaluation Techniques for High Temperature Fuel Pins, Y-49006-3, Battelle-Northwest to Lewis Research Center, August 11, 1966.

4. Fabrication and Evaluation of Prototype High Temperature Fuel Pins, Y-49006-12, Battelle-Northwest to Lewis Research Center, May 1, 1967, (Confidential).

5. Fabrication of High Temperature Enriched UO_2 Fuel Pins, Y-49006-15, Battelle-Northwest to Lewis Research Center, July 10, 1967, (Confidential).

6. Ceramics Research and Development Operation, Quarterly Report, January-March, 1964, HW-81600. General Electric Company, Richland, Washington.

7. J. Bugl and A. A. Bauer. Phase, Thermodynamic, Oxidation, and Corrosion Studies of the Systems Uranium-Nitrogen, BMI-1692, Battelle Memorial Institute, Columbus, Ohio, September, 1964. p. 6.

8. C. A. Brooker and B. Harris, "Tensile Properties of Refractory Metals at High Temperature," Powder Metallurgy in the Nuclear Age, Plansec Proceedings 1961, edited by F. Benesovsky, Metallwerk Plansec AG., Reutte/ Tyrol, pp. 712-722. 1962.

9. M. L. Begeman. Manufacturing Processes, John Wiley and Sons, Inc., New York, N. Y., 1957. 4th ed., pp. 465-467.

10. G. R. Horn, "Mixed Nitrides Irradiations," Quarterly Progress Report, April, May, June, 1967, Reactor Fuels and Materials Development Programs for Fuels and Materials Branch of USAEC Division of Reactor Development and Technology, BNWL-473, pp. 3.8-3.10, September, 1960.

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